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Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm^2, Cusco, 2021

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RESUMEN

Esta tesis pretende determinar cuál es el efecto de interacción entre un aditivo plastificante y la materia orgánica contaminante que puede traer el agregado; utilizando una herramienta estadística moderna y potente; de manera tal que, se amplíe el conocimiento acerca de este tema con la utilidad posterior de poder optimizar la producción del concreto, reduciendo el efecto de los contaminantes orgánicos que deterioran su resistencia; y por lo tanto, reduciendo a través de los plastificantes el consumo de cemento en las obras.

EL objetivo general es, por tanto: Analizar la medida en la cual se da el efecto de la contaminación orgánica del agregado, en la resistencia a la compresión de un concreto plastificado, aplicando un análisis Bootstrap.

Este trabajo persigue una utilidad metodológica, dado que la relación entre los contaminantes orgánicos y el plastificante permitirá exponer y explicar su comportamiento a través de un modelo matemático, y con esto un diseño y control de calidad más eficiente durante la producción de los concretos.

La hipótesis general que plantea esta tesis es que la contaminación orgánica del agregado reduce la resistencia superficial de un concreto plastificado 210 kg/cm2 en por lo menos un 10%, según lo determina el análisis Bootstrap.

Palabras clave: resistencia, concreto, materia orgánica

ABSTRACT

The present thesis tries to determine what is the interaction effect between a plasticizer additive and the contaminating organic matter that the aggregate can bring; especially using a modern and powerful statistical tool; in such a way that knowledge about this topic is expanded with the subsequent utility of being able to optimize the production of concrete, reducing the effect of organic pollutants that deteriorate its resistance; and therefore, effectively reducing the consumption of cement in the works through plasticizers.

The general objective is, therefore: To analyze the extent to which the effect of organic contamination of the Huambutío aggregate occurs on the surface resistance of 210 kg / cm2 plasticized concrete, applying a Bootstrap analysis.

For the execution of this investigation, a detailed and in-depth review of the state of the art will be made on the following topics:

Concrete technology, Materials for concrete production Coarse aggregate requirements for producing concrete, Fine aggregate requirements for producing concrete, Water requirements for producing concrete, Types of cement for producing concrete, Plasticizers and superplasticizers for concrete. Contaminants from concrete aggregates. Organic matter or compost. Strength of hardened concrete.

With this work, a methodological utility is pursued with the present work since the relationship between organic pollutants and the chosen plasticizer expose and explain their behavior through a mathematical model, and with this a more efficient design and quality control during production. of the concrete.

The general hypothesis that this thesis raises is the organic contamination of the Huambutío aggregate, reduces the surface resistance of a plasticized concrete 210 kg / cm^2 by at least 10%, as determined by the Bootstrap analysis.

The population for the present investigation is the laminated concrete prepared with the stone aggregate of the Huambutío quarry in the city of Cusco.

Keywords: resistance, concret, organic matter.

I. INTRODUCCIÓN.

Gracias a los beneficios mecánicos en estado endurecido y fresco, y al escaso cuidado que demanda en el tiempo, el concreto ha sido uno de los materiales que más se ha empleado alrededor de todo el mundo para la realización de diversas obras.

Es por este motivo que en el mercado cusqueño aparecieron diversas empresas, las cuales brindan este material, generalizando de esta manera consumo.

A pesar de la evidente importancia del concreto, existen factores que contaminan los materiales con que se fabrica, y siendo los agregados el elemento más abundante en todos los tipos de concreto es importante conocer y controlar las características de estos. En la Ciudad de Cusco los agregados se vinieron obteniendo de aproximadamente 20 canteras, sin contar las nuevas canteras que se van aperturando, siendo la cantera de Huambutío una de las más utilizadas, sin embargo, no existe ningún registro o base de datos que contenga información como las propiedades físicas, características litológicas, pureza u otros que permitan una evaluación "a priori" del agregado obtenido de estas canteras.

Y siendo uno de los principales factores contaminantes de los agregados la presencia de materia orgánica, pudiendo provocar problemas en la fabricación de concreto, también afectando la acción plastificante de un aditivo, que puede verse seriamente comprometida a raíz de la inclusión excesiva de materia orgánica que llega al concreto junto con los materiales pétreos, incluso lograr anular dicho efecto plastificante, resultó de vital importancia estudiar los efectos de la contaminación orgánica en la resistencia del concreto plastificado.

Por todo lo expuesto se planteó, ¿En qué medida se da el efecto de la contaminación orgánica del agregado de Huambutío, en la resistencia a la compresión de concreto plastificado 210 kg/cm^2, aplicando un análisis bootstrap.?

De éste, también se enunciaron los siguientes problemas específicos, ¿En qué medida la cantidad de contaminante orgánico afecta la resistencia a la compresión del concreto?, ¿En qué medida se da el efecto combinado del agregado pétreo y del contaminante orgánico en la resistencia a la compresión del concreto?, ¿En qué medida el cementante mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto?, ¿En qué medida se da el efecto combinado del agua de mezcla y del contaminante orgánico en la resistencia a la compresión del concreto?, ¿En qué medida el aditivo mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto?

Con esta investigación se buscó determinar, cuál es el efecto de la interacción entre un aditivo plastificante y la materia orgánica contaminante que puede traer el agregado, permitiendo exponer y explicar su comportamiento a través de un modelo matemático, y con esto un diseño y control de calidad más eficiente durante la producción de los concretos; utilizándose para esto un instrumento estadístico adecuado, para poder establecer intervalos de confianza en los que la cantidad de presencia de materia orgánica no sea perjudicial; de tal forma que, se pueda optimizar la producción del concreto, reduciendo el efecto de los contaminantes orgánicos que deterioran su resistencia; y por lo tanto, reducir efectivamente a través de los plastificantes el consumo de cemento en las obras.

Para este estudio, la estadística y en especial las técnicas de remuestreo representaron una herramienta poderosa para analizar la interacción entre factores de un fenómeno, el bootstrap constituye la técnica más versátil y conocida dentro del método de remuestreo, ya que es un método para estimar la distribución de una estadística con muestras finitas.

Según lo expuesto, el objetivo general fue analizar la medida en la cual se da el efecto de la contaminación orgánica del agregado en la resistencia a la compresión de un concreto plastificado 210 kg/cm^2 aplicando un análisis bootstrap. Así mismo, se planteó como objetivos específicos, determinar en qué medida la cantidad de contaminante orgánico afecta a la resistencia a la compresión del concreto; también, determinar en qué medida se da el efecto combinado del agregado pétreo y del contaminante orgánico en la resistencia a la compresión del concreto; del mismo modo, determinar en qué medida el cementante mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto, también determinar en qué medida se da el efecto combinado del agua de mezcla y del contaminante orgánico en la resistencia a la compresión del concreto, y por ultimo; determinar en qué medida el aditivo mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto.

De acuerdo con lo anteriormente expresado, la hipótesis que se planteó en la investigación fue que: La contaminación orgánica del agregado, reduce la resistencia a la compresión de un concreto plastificado 210 kg/cm^2 en por lo menos un 10%, según lo determina el análisis bootstrap. De esta se tiene las siguientes hipótesis secundarias; la resistencia a la compresión del concreto se reduce en por lo menos 1% por cada 1% de aumento en el contenido de contaminante orgánico, un incremento de 10% en la arena junto a un incremento de 1% en el en el contaminante orgánico producen cuando menos un 2% de pérdida en la resistencia superficial del concreto, un incremento de 10% en el cementante reduce el efecto del contaminante orgánico en por lo menos 5%, un incremento de 10% en el agua de mezcla junto a un incremento de 1% en el en el contaminante orgánico producen cuando menos un 5% de pérdida en la resistencia superficial del concreto, un incremento de 1% en el aditivo reduce el efecto del contaminante orgánico en por lo menos 2%.

II. MARCO TEÓRICO

Antecedentes Internacionales.

Tenemos que cuando se utilizan agregados gruesos de diferente origen, la resistencia del concreto se ve afectada, es decir; usar grava extraída de un depósito aluvial en el concreto contribuye a que soporte cargas superiores a 3115 psi, a la del diseño inicia la diferencia del material de origen montañoso que demostró ser menos resistente con 2652 psi, es decir no cumplió con el diseño de la mezcla. También se evidencio que el aumento de la resistencia del concreto con grava procedente de Villavicencio fue por el aspecto físico de sus partículas, las cuales era redondeadas incluso siendo trituradas a comparación de las de los agregados obtenidos de la cantera de Mosquera que eran partículas semiangulares con superficies más opacas y muy porosas. (Abril y Ramos, 2017, p. 77).

En otro estudio se descubrió que la mezcla con un aditivo plastificante (Acrilcor -50) vs con la mezcla con agregados saturados, al ser sometidos a una carga última a los 28 días, en un ensayo de compresión, la diferencia entre los resultados es de 20% respecto a la resistencia esperada de diseño, obteniendo así que la resistencia a la compresión en la mezcla con el aditivo plastificante Acrilcor, se halla 15.9 MPa por encima de la resistencia de diseño esperada, así se proyecta un 190% superior a la proyectada. La mezcla con material saturado no logro tener un proceder de un 100% de la resistencia de diseño prevista, logrando tan solo un 83%, ya que la carga máxima soportada no alcanzo a los 17.5MPa. (López y Bocanegra, 2017, p. 65).

Con la siguiente investigación se pudo concluir que n siempre a mayor cantidad de cemento mayor será la resistencia, ya que los agregados pétreos poseen ciertas características que hacen que las partículas de cemento las compacte mejor, también se pudo concluir que la relación agua – cemento, determina el asentamiento del concreto así como también la manejabilidad de la mezcla. Otro hallazgo importante fue que el proyecto que presento mayor resistencia a la compresión fue el que menor cantidad de cemento requirió en el diseño de mezclas, por último se observó que en relación al agua, en los dos casos donde la resistencia a la compresión fue baja se utilizó un nivel de agua 30ml por debajo de la constante para todos los dos proyectos y 10 ml por encima de la constante, donde la falta de agua podría presentar una incidencia sobre la resistencia. (Ortiz, 2015, p. 67).

Según los resultados obtenidos de la siguiente investigación, se concluyó que al aplicar MCF, a un concreto a la edad de 28 días, es viable, para que el concreto adquiera una mayor resistencia, ya que se observó en los resultados que a los especímenes modificados con MCF superaron la resistencia de los cilindros convencionales, siendo el porcentaje óptimo de PCM que se le debe aplicar al concreto es del 5% y el porcentaje menos favorable es cuando se aplicó 10% de PCM. Así se determinó que los materiales de cambio de fase orgánico (MCF), no afectan de una manera negativa al concreto en la ganancia de su resistencia máxima, al contrario lo potencializa, logrando ganar hasta un 17,88% adicional de resistencia con respecto a la resistencia esperada del diseño. (Tangarife y Silva, 2019, p. 73).

Antecedentes Nacionales.

En este estudio se pudo determinar lo importante que es saber la calidad de los agregados de tres diferentes canteras de la ciudad de Abancay, para poder conocer si los agregados cumplen con los límites permisibles que dicta la norma, se realizaron diferentes ensayos como los de granulometría, ensayo de peso unitario, peso específico y ensayo de abrasión. De los cuales se obtuvo que el agregado grueso de la cantera de Santa Lucia y la cantera Espinoza, la proporción de sus partículas se encuentran aproximadamente fuera del rango establecido por los límites, ya que presentan un tamaño nominal máximo de ¾” al igual que la cantera

Altamirano, que presenta en sus partículas tamaño nominal máximo de 1”. Y el agregado fino de la cantera Altamirano si cumplen con los límites establecidos, al igual que la cantera de Santa Lucia y la cantera Espinoza, ya que todas estas canteras obtuvieron un módulo de finura de 2.95 y 3.03 respectivamente. (Olarte, 2017, p. 328).

En otro antecedente donde se alcanzó a analizar un vínculo entre el grado de la fluidez y la cantidad del aditivo; en otras palabras, a más cantidad de aditivo, el mortero será más fluido; así mismo, se percibió un descenso en la fluidez con transcurso del tiempo, se determinó, que el resultado en todos los aditivos decrece, a medida que reduce su densidad, en la interfaz aguada del mortero, llegando a que la fortaleza de este se consuma (la gradiente de caída dependerá del tipo de aditivo, es decir, según la tecnología de cada aditivo), también mientras más finos tenía la arena, absorbía mayor cantidad de agua, y generaba morteros más secos; y además, luego de 7 y 28 días, los morteros diseñados con estas arenas, obtenían las menores resistencias a compresión, en semejanza con los otros tipos de morteros. (Samaniego, 2018, p. 127-128).

Así también luego de comparar las propiedades del concreto, usando diferentes proporciones de aditivos Chema plast y Sika Plastiment HE-98, se observó que el aditivo plastificante marca Sika Plastiment HE-98 brindo mejores resultados que el aditivo Chema Plast. Demostrándose así que en estado freso del concreto, el mejor proceder fue cuando se utilizó el porcentaje de aditivo intermedio de Sika Plastiment HE-98, así como también en estado endurecido del concreto, tanto en la resistencia a la compresión, como en la tracción del concreto. Se obtuvo mejores resultados usando el aditivo Sika Plastiment® HE-98. Se observó que el mejor comportamiento fue con este aditivo, donde se logró mejorar la resistencia a la compresión, tracción y módulo de elasticidad hasta de un 10% más que el concreto patrón y para la resistencia a la flexión se logró una variación mínima de la resistencia usando los dos aditivos. (Chero y Seclén, 2018, p. 111-112).

Se estudió la influencia de las características de los agregados de las canteras del sector El Milagro –Huanchaco, donde los resultados obtenidos fueron desfavorables en todas las canteras estudiadas, ya que no cumplían con algunos requisitos establecidos por la NTP 400.037:2014 para poder elaborar un diseño de mezcla. Por lo cual se realizaron modificaciones con la intención de optimizar los agregados. Para lograr mejorar las propiedades indispensables y requeridas según el diseño de mezcla, se deben optimizar la proporción de cada material, así como también los agregados deberán cumplir con los límites establecidos por la norma NTP 400.037, siendo estos agregados partículas durables, limpias, resistentes y libres de productos químicos, recubrimientos de arcilla y otros materiales u otros materiales finos que puedan perjudicar la mezcla del concreto, donde se encontró que en el estudio realizado, el contenido de finos de todas las canteras no cumplieron con los límites establecidos por la norma. (Castro y Vera, 2017, p. 125).

Bases Teóricas.

1.- Diseño de Mezclas.

La elaboración del concreto nos asegura, Durabilidad, Economía, Trabajabilidad y Resistencia Mecánica; además es el producto de juntar gradual, sistemática y económicamente, elementos inertes (arena – grava) junto con el cemento portland y agua como medio del aglomerante para el desarrollo del fraguado. (Díaz, 2012, p. 3).

El concreto está compuesto de agregados pétreos, agua, aire y cemento Portland en magnitudes apropiadas, para así poder conseguir propiedades determinadas, principalmente la resistencia. (Abanto, 2009, p. 11).

La tecnología del concreto está compuesta por los siguientes elementos que son: agregados pétreos, agua, cemento y aditivos como componentes eficaces y el aire como componente neutral. Antiguamente se consideraba a los aditivos como un componente facultativo, hoy en día forman un componente habitual. (Pasquel, 1993, p. 13).

Dentro de los materiales para la producción del concreto tenemos al Cemento portland, un producto con propiedades hidráulicas, proveniente del desmenuzamiento conjunta de yeso y Clinker; el Clinker es el resultado de la cocedura hasta fusión inicialmente de materiales calizos en una alta cuantía, que adjuntos con sílice y arcillas y verificadores como el mineral de hierro. El cual junto con el yeso dan un producto resultante con propiedades hidráulicas, que es el concreto. (Salamanca, 2000, p.78).

Así mismo tenemos a los agregados que son elementos secos, inactivos de forma granular, naturales o artificiales que en conjunto con el cemento portland y el agua conforman todo un sólido compacto o también llamado concreto. (Rivera, 2015, p. 41).

Estos agregados, se dividen en dos. Los agregados finos deben basarse en partículas duras, limpias y libres de elementos químicos, arcillas o de elementos más finos que puedan perjudicar la adherencia al cemento, si estas se encontraran dentro del agregado fino se desecharían. Habitualmente consisten en arenas naturales o piedras trituradas siendo la mayor parte menores que 5 mm. (Polanco, s.f., p. 11).

El agregado grueso resulta de la descomposición de las rocas, pudiéndose clasificarse en grava y en piedra chancada, también debe quedar retenido en el tamiz N° 4. (Torres, 2004, p. 44).

Los aditivos reductores de agua posibilitan reducir la cantidad de agua de una mezcla de concreto fresco, sin modificar su trabajabilidad o que también sin modificar su contenido de agua aumentan la trabajabilidad. (Gaspar-Tébar, 1994, p. 51).

Estos aditivos pueden ser orgánicos o inorgánicos, reducen el contenido de agua ya que trabajan en base al llamado efecto de superficie, donde crean una interface entre el cemento y el agua en la mezcla, disminuyendo así fuerzas de atracción entre las partículas, mejorando así el proceso de hidratación, también producen mejores características de trabajabilidad, impermeabilidad y de resistencia al reducirse la relación agua/cemento. (Pasquel, 1993, p. 119).

Existen varios contaminantes del concreto, pero para en el presente estudio nos orientamos en la materia orgánica.

Gracias a las lombrices, escarabajos o por pequeños animales detritívoros y a los organismos descomponedores como las bacterias y hongos, se logra obtener el compost, el cual es la descomposición de la materia orgánica. (Manual Básico para hacer Compost, 2004, p. 3).

También llamado comúnmente como abono, es un tipo de arreglo orgánico, producto inocuo, establecido principalmente por materia orgánica estable y madura, restos de animales, restos minerales, libre de patógenos o cualquier elemento que pueda dañar al suelo o a las plantas. (Silbert, 2018, p. 7).

Cuando existe una elevada cantidad de materia orgánica, el fraguado del cemento se ve impedido por esta, ya sea de manera parcial o total, la resistencia del concreto también puede verse restada o en peligro por otro tipo de partículas como la arcilla, carbón, madera, etc. (Gutiérrez, 2003, p. 27).

Las proporciones en la mezcla que cumpla con las especificaciones de los materiales disponibles, para la siguiente investigación se utilizaran el Método ACI, para este cálculo.

Expresión matemática del diseño de mezclas

$$Concreto = Cemento + Agua + Grava + Arena + Aditivos$$

Para el proceso de diseño de mezclas mediante este método se necesita saber; el estudio detallado de los planos y especificaciones técnicas de obra, así como también:

1.1 Cálculo de la Resistencia Promedio.

Se empleará la siguiente tabla para el cálculo de la resistencia promedio requerida cuando no hay datos disponibles para establecer una desviación estándar.

Tabla 1. *Resistencia promedio a la compresión.*

f'c *Kg/cm²*	***f'c*** ***(promedio)*** *Kg/cm²*
Menos de 210	**f'c** + 70
210 A 350	**f'c** + 84
Sobre 350	**f'c** + 98

Fuente: American Concrete Institute ACI 211

1.1.1. Cálculo del asentamiento o slump.

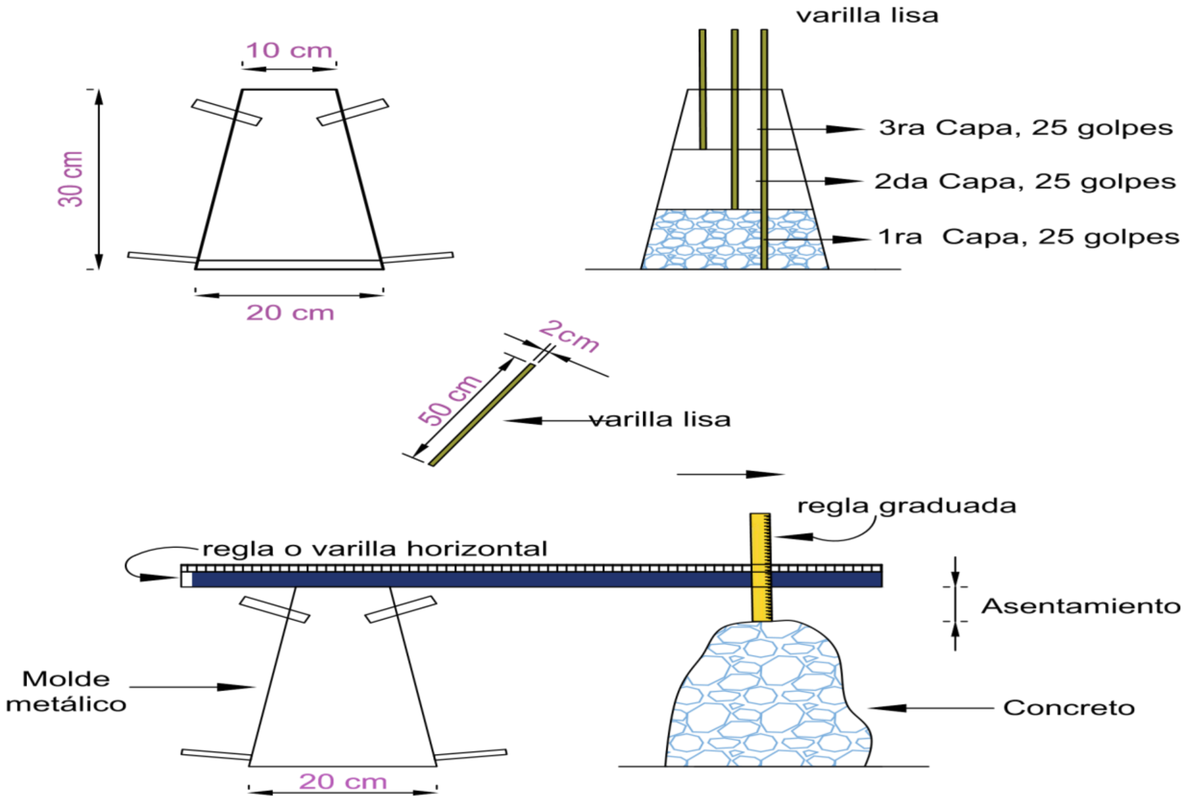
Según a lo que las especificaciones técnicas de obra requieran una consistencia establecida del concreto, en la siguiente tabla, podremos elegir el asentamiento:

Tabla 2. *Consistencia y asentamientos*

Consistencia	Asentamiento (mm)
Seca	0" (0mm) a 2" (50mm)
Plástica	3" (75mm) a 4" (100mm)
Fluida	≥ 5" (125mm)

Fuente: American Concrete Institute ACI 211

Figura 1. Prueba de revenimiento – Cono de Abrams.



Fuente: Elaboración propia

En caso no se tenga especificaciones de la consistencia requerida, se puede utilizar la siguiente tabla para elegir un valor adecuado según el trabajo a realizar.

Tabla 3. *Asentamientos recomendados para varios tipos de construcción.*

Tipos de Construcción	Revenimiento (cm)	
	MAXIMO	MINIMO
Zapatas y Muros de cimentación reforzados	8 cm	2 cm
Zapatas Simples, cajones y muros de subestructura	8 cm	2 cm
Vigas y Muros reforzados	10 cm	2 cm
Columnas	10 cm	2 cm
Pavimentos y losas	8 cm	2 cm
Concreto Ciclópeo y masivo	5 cm	2 cm

Fuente: American Concrete Institute ACI 211

1.2 Estimación del agua.

La siguiente tabla se usa para computar la cantidad de agua de mezcla tomando en consideración además de la consistencia y tamaño máximo del agregado, el perfil del mismo, estos mismos valores corresponden a mezclas sin aire incorporado.

Tabla 4. *Contenido de agua de mezcla*

Tamaño máximo nominal del agregado grueso		**Contenido de agua en el concreto, expresado en lt/m³, para los asentamientos y perfiles de agregado grueso indicados**					
		25mm a 50mm (1"-2")		**75mm a 10mm (3"-4")**		**150mm a 175mm (6" a 7")**	
mm.	pulg.	Agregado redondeado	Agregado anguloso	Agregado redondeado	Agregado anguloso	Agregado redondeado	Agregado anguloso
9.5	3/8"	185	212	201	227	230	250
12.7	1/2"	182	201	197	216	219	238
19.1	3/4"	710	189	185	204	208	227
25.4	1"	163	182	178	197	197	216
38.1	1 1/2"	155	170	170	185	185	204
50.8	2"	148	163	163	178	178	197
76.2	3"	136	151	151	167	163	182

Fuente: American Concrete Institute ACI 211

Tabla 5. *Limite permisibles para el agua de mezcla y curado*

DESCRIPCCION	LIMITE PERMISISBLE		
SOLIDOS EN SUSPENSION (RESIDUO INSOLUBLE)	5,000	ppm	máximo
MATERIA ORGANICA	3	ppm	máximo
ALCALINIDAD (NaCHCO3)	1,000	ppm	máximo
SULFATOS (ión SO4)	600	ppm	máximo
CLORUROS (ión Cl-)	1,000	ppm	máximo
pH	5 a 8	ppm	máximo

Fuente: NTP 339.088

1.3 Elección de la relación agua - cemento (a/c)

Si se toma en consideración la resistencia, para concretos preparados con cemento Portland tipo 1 o cementos comunes, puede tomarse la relación agua / cemento de la siguiente tabla.

Tabla 6. *Relación agua/cemento y resistencia a la compresión del concreto.*

RESISTENCIA A LA COMPRESION A LOS 28 DIAS (f'cr) (kg/cm^2)*	RELACION AGUA/CEMENTO DE DISEÑO EN PESO	
	CONCRETO SIN AIRE INCORPORADO	CONCRETO CON AIRE INCORPORADO
450	0.38	---
400	0.43	---
350	0.48	0.4
300	0.55	0.46
250	0.62	0.53
200	0.70	0.61
150	0.80	0.71

Fuente: American Concrete Institute ACI, 211

1.4 Cálculo del contenido del cemento

La cantidad de cemento por unidad de volumen del concreto es determinada dividiendo la cantidad de agua por la relación agua / cemento.

$$Contenido\ de\ cemento\ (Kg\ /\ cm3)\ = \frac{Contenido\ de\ agua\ de\ mezcla\ (lts/cm3)/}{Relación\ a/c\ (para\ f'cr\ )}$$

$$Volumen\ de\ cemento\ (m3)\ = \frac{\text{Contenido de cemento (Kg)}}{\text{Peso específico del cemento (Kg / cm3)}}$$

1.5 Estimación del contenido de agregado fino y grueso.

Para la estimación del contenido de agregado grueso mediante la siguiente tabla, en función del tamaño máximo nominal del agregado grueso y del módulo de fineza del agregado fino, nos permite obtener un coeficiente b / b_0 resultante de la división del peso seco del agregado grueso entre el peso unitario seco y compactado del agregado grueso expresado en Kg / cm^3.

Tabla 7. *Módulo de fineza de la combinación de los agregados*

TAMAÑO MAXIMO DEL AGREGADO GRUESO		Volumen del agregado grueso, seco y compactado por unidad de volumen de concreto, para diferentes módulos de fineza del agregado fino			
		MODULO DE FINEZA DEL AGEGADO FINO			
mm.	pulg.	2.40	2.60	2.80	3.00
10	3/8"	0.50	0.48	0.46	0.44
12.5	1/2"	0.59	0.57	0.55	0.53
20	3/4"	0.66	0.64	0.62	0.60
25	1"	0.71	0.69	0.67	0.65
40	1 1/2"	0.76	0.47	0.72	0.70
50	2"	0.76	0.76	0.74	0.72
70	3"	0.81	0.79	0.77	0.75
150	6"	0.87	0.85	0.83	0.81

Fuente: American Concrete Institute ACI 211

Obtenido b/b_0 comenzamos a calcular la cantidad de agregado grueso necesario para un m^3 de concreto, de la siguiente manera:

$$Peso\ seco\ del\ A.\ grueso\ (kg/m^3) = \frac{b}{b_0} x(Peso\ unitario\ {\scriptstyle compactado}\ del\ A.\ grueso)$$

Entonces los volúmenes de los agregados grueso y fino serán:

$$Vol. Agregado\ grueso\ (m3)\ = \frac{Peso\ seco\ del\ A. grueso}{Peso\ especifico\ del\ A. grueso}$$

$$Vol. Agregado\ _{fino}\ (m3) = 1 - (Vol. Agua + Vol. Aire + Vol. Cemento + Vol. Agregado\ grueso)$$

Por consiguiente, el peso seco del agregado fino será:

$$Peso\ agregado\ fino\ (kg/m3) = (Vol. Agregado\ fino)(Peso\ específico\ del\ agregado\ fino)$$

1.6 Ajustes por humedad y absorción

La proporción de agua incorporada para formar la pasta será afectada por el contenido de humedad de los agregados. Si ellos están secos al aire absorberán agua. Así mismo si los agregados están mojados, aportarán algo de esta agua a la pasta aumentando la relación a/c, la trabajabilidad y disminuirán la resistencia a compresión.

Por consiguiente:

Agregado Grueso
- *Humedad = % W_g*
- *% Absorción = % a_g*

Agregado Fino
- *Humedad = % W_f*
- *% Absorción = % a_f*

Pesos de agregados húmedos:

$$Peso\ de\ A.grueso\ húmedo\ (Kg)\ = (Peso\ de\ A.grueso\ seco)(1 + \frac{\%W_g}{100})$$

$$Peso\ de\ A.fino\ húmedo\ (Kg) = (Peso\ de\ A.fino\ seco)(1 + \frac{\%W_f}{100})$$

1.7 Cálculo de proporciones en peso

Cemento : Agregado fino : Agregado grueso / Agua (Lts/Bls)

$$\frac{Peso\ cemento}{Peso\ cemento} : \frac{Vol\ A.fino\ huemedo}{Peso\ cemento} : \frac{Vol.A.grueso\ huemedo}{Peso\ cemento} / \frac{agua\ efectiva}{agua\ efectiva}$$

1.8 Cálculo de proporciones en volumen

Volúmenes en estado suelto:

- Cemento : $Vol.Cemento\ (m^3) = \frac{Peso\ cemento\ (kg)}{P.U.cemento\ (1500\ kg/m^3)}$
- Agregado fino : $Vol.A.fino\ (m^3) = \frac{Peso\ A.fino\ humedo\ (kg)}{P.U.A.fino\ humedo\ (kg/m^3)}$
- Agregado grueso : $Vol.Agrueso\ (m^3) = \frac{Peso\ A.Grueso\ humego\ (kg)}{P.U.A.grueso\ humedo\ (kg/m^3)}$

En el caso del agua, este se calculará en litros por bolsa de cemento (lts/bls), de la siguiente manera:

$$Agua\ (lts/bls) = \frac{Cantidad\ de\ agua\ por\ m^3\ de\ C^o}{(\frac{Peso\ cemento\ por\ m^3 de\ C^o}{Peso\ cemento\ por\ bolsa\ (42.5)})}$$

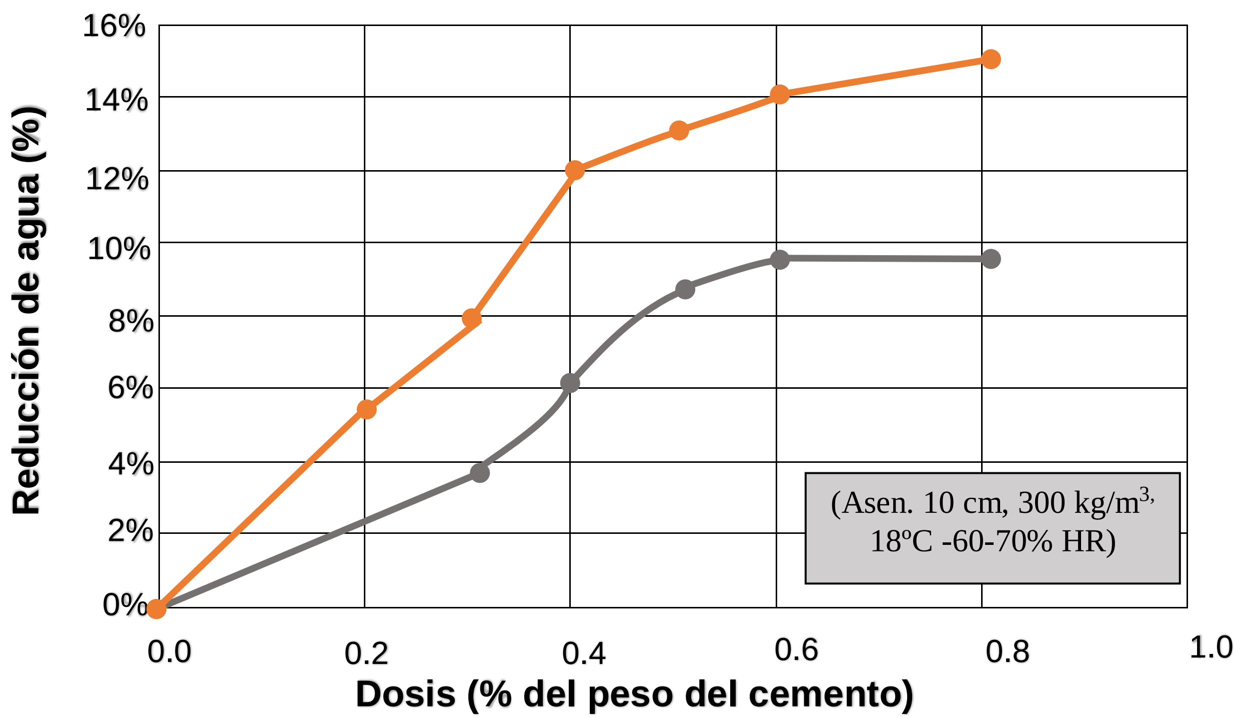
Proporciones en volumen:

Cemento	:	Agregado fino	:	Agregado grueso	/	Agua (Lts/Bls)
$\frac{Vol.cemento}{Vol.cemento}$	:	$\frac{Vol\ A.fino}{Vol.cemento}$	:	$\frac{Vol.A.grueso}{Vol.cemento}$	/	$Agua\ (Lts/Bls)$
C	**:**	**F**	**:**	**G**	**/**	**A**

6.- Aditivos.

El plastificante retardador disminuye la cantidad de agua que se utiliza para lograr una mezcla de una determinada consistencia, también retarda su fraguado, también acelera su fraguado y la resistencia de la mezcla a temprana edad. (Rivera, 2015, p. 151).

Figura 2. Curva de eficiencia de dos Plastiment.

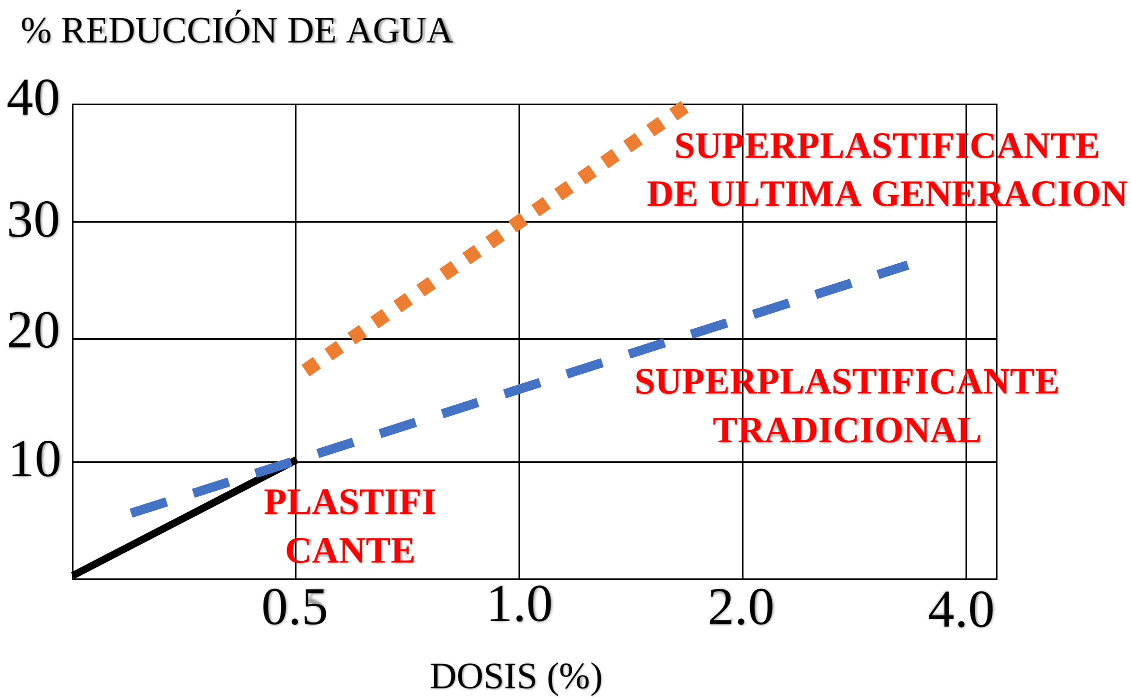


Fuente: SIKA (2013)

7.- Aditivos Superplastificantes.

Aparte de ser reductores de agua en la mezcla de concreto son ideales para vaciados en donde haya mucha congestión de armadura, la dosificación que mayormente se utiliza son del 0.2% al 2% del peso de cemento. (Pasquel, 1993, p. 120).

Figura 3. Efecto de los plastificantes y superplastificantes en el porcentaje de reducción de agua.



Fuente: Velandia, D. (2020)

III. METODOLOGÍA

3.1 Tipo y diseño de investigación

3.1.1 Tipo de investigación: El presente estudio es una investigación, descriptiva, explicativa, y cuantitativa, ya que está dirigida a determinar a través del conocimiento científico, los medios (metodologías, protocolos y tecnologías) por los cuales se puede cubrir una necesidad reconocida y específica.

3.1.2 Diseño de investigación: Este informe de investigación es del tipo diseño experimental porque la variable independiente se manipula deliberadamente y luego analizar las variaciones que puedan generar en las variables dependientes. Además, es un proyecto cuasi experimental porque trabaja con grupos de especímenes o probetas para ser ensayados y que son elegidos al azar.

3.2 Variables y Operacionalización:

3.2.1 Variables Dependientes: F'c del concreto

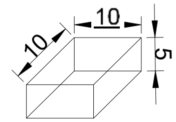
3.2.2 Variables Independientes: Contaminación orgánica del agregado

3.2.3 Variable Interviniente: Concreto plastificado

3.2.4 Operacionalización de variables:

Tabla 8 .*Matriz de operacionalización de las variables*

Var	Tipo	Definición conceptual	Definición operacional	Dimensiones	Sub dimensiones	Indicador	Técnica	Instrumento metodológico	Validación	Instrumento y/o equipo de ingeniería	Calibración del equipo de ingeniería	Escala	Valores esperados
Contaminación orgánica del agregado	Independiente	Se produce por la presencia en los agregados de elementos vegetales descompuestos que afectan la hidratación, el fraguado y la resistencia del concreto. El agua también puede proveer de contaminantes orgánicos al concreto (Torre, 2004).	Se define como la cantidad de materia orgánica como porcentaje en peso seco de los agregados finos. Se toma como agregado tanto grueso como fino al material procesado proveniente de la cantera de Huambutío. Se toma como material orgánico al compost industrial.	Contaminante orgánico	Cantidad de materia orgánica	WC %MO = ---------x100 % WAFS MO: materia orgánica en reemplazo del agregado fino WC: peso del compost seco WAFS: peso del agregado fino seco	Observación estructurada	Contenido de humedad del suelo conforme lo determina la norma ASTM D 2216 Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada. Cápsulas impermeables.	Fabricante o vendedor	Razón	0.0% 0.5%, 3% y 9%
Concreto plastificado de resistencia promedio f´c = 210 kg/cm2	Interviniente	Es el material resultante de la mezcla de los siguientes ingredientes: Agregado pétreo. Cementante Agua de mezcla Aditivo para concreto (Neville, 1987).	Se define en cada caso como: Porcentaje de agregado grueso que interviene en la mezcla del concreto. Porcentaje de agregado fino que interviene en la mezcla del concreto. Porcentaje de cementante que interviene en la mezcla del concreto. Cantidad de agua en la mezcla. Cantidad de plastificante en la mezcla.	Agregado pétreo	Agregado grueso	WAG %AG = --------x100 W Total %AG: porcentaje de agregado grueso seco para la mezcla WAG: peso del agregado grueso seco W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	30%, 35% y 40%
					Agregado fino	WAF %AF = --------x100 W Total %AF: porcentaje de agregado fino seco para la mezcla WAF: peso del agregado fino seco W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	25%, 15% y 35%
				Cementante	Cemento portland tipo IP	WC %C = --------x100 W Total %C: porcentaje de cemento para la mezcla WC: Peso del cemento W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	20%, 25% y 30%
				Agua	Agua destilada	WA %C = --------x100 W Total %A: porcentaje de agua para la mezcla WC: Peso del agua destilada W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	8%, 10% y 12%

Var	Tipo	Definición conceptual	Definición operacional	Dimensiones	Sub dimensiones	Indicador	Técnica	Instrumento metodológico	Validación	Instrumento y/o equipo de ingeniería	Calibración del equipo de ingeniería	Escala	Valores esperados
				Aditivo	Aditivo plastificante	$\%AP = \frac{WAP}{W\ Total} x100$ %AP: porcentaje de aditivo plastificante para la mezcla WAP: Peso del aditivo plastificante W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	0.5% a 2.5%
Resistencia del concreto	Dependiente	La resistencia máxima de los paralelepípedos experimentales de 10x10x5 cm, probados en compresión axial no confinada, después de curarlos en condiciones estándar de humedad en el laboratorio durante 28 días, se define como la resistencia a la compresión del concreto.	Explica la medición de la carga máxima soportada por la probeta para producir la fractura entre el área promedio de la sección de las muestras paralelepípedos de 10x10x5 cm curadas en condiciones estándar durante 28 días.	Resistencia a la compresión del concreto		Dimensiones de la muestra 	Observación estructurada	Analógico	Por juicio de expertos	Máquina de ensayo de compresión	Vendedor	Intervalo	10 Kg/cm^2 y 180 Kg/cm^2

Fuente: Elaboración propia

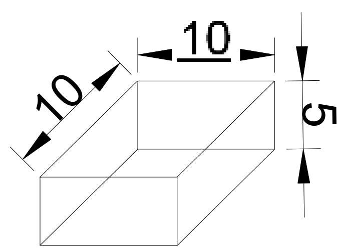
3.3 Población, muestra y muestreo

3.3.1 Población: La población para la presente investigación es el concreto plastificado preparado con el agregado pétreo de la cantera de Huambutío en la ciudad del Cusco.

3.3.2 Muestra: Cada muestra cuadrada ensayada tendrá las dimensiones y proporciones que se muestran en el siguiente esquema, y serán evaluadas a la edad de 28 días:

Figura 4. Dimensión y peso de la muestra paralelepípedo de concreto.

10 cm x 10 cm x 5 cm.

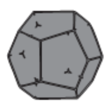


Fuente: Elaboración propia

En cuanto a la justificación del uso de un tamaño menor de especímenes de concreto se debe tener en cuenta lo siguiente:

Primero, lo que se busca en la investigación son las diferencias relativas de resistencia, es decir cuánto difiere el concreto preparado que incluye contaminantes en comparación al concreto normal y esto se verificará, no importa en que tamaño o forma de muestra se pruebe, por ejemplo:

Figura 5. Efecto de la forma de la muestra en el cambio en la resistencia

Forma y resistencia	Cambio neto	Cambio porcentual
Briqueta estándar de la norma  Sin materia orgánica fc = 150 — Briqueta estándar de la norma  Con materia orgánica fc = 100	$\text{Cambio} = \frac{150-100}{150} x100 = 33\%$	33%
Briqueta distinta de la norma  Sin materia orgánica fc = 180 — Briqueta distinta de la norma  Con materia orgánica fc = 120	$\text{Cambio} = \frac{180-120}{180} x100 = 33\%$	33%

Fuente: Elaboración Propia

Conforme se aprecia, lo que interesa para la investigación es el cambio porcentual que hay en la resistencia de un concreto contaminado comparado con otro concreto no contaminado, sin importar la forma o tamaño del espécimen que se haya ensayado. En este caso lo que interesa es encontrar que el concreto disminuye su resistencia en 33% debido a la contaminación, esto se puede probar incluso en columnas hechas a escala real donde probablemente el 33% también pueda ser hallado.

Dicho esto, hay que tener en cuenta que, las comparaciones sólo son posibles entre especímenes similares, es decir si se hacen 50 ensayos todos los ensayos deben tener el mismo tamaño y la misma forma para que puedan ser comparables, si se elige hacer muestras cilíndricas de 6“, todas las muestras cilíndricas deberían ser de 6”, por el contrario, si se elige una muestra de paralelepípedo de 10 × 10 × 5 todas las muestras deberían ser de este tipo para que haya posibilidad de compararlas.

Se hace énfasis en que lo que interesa es evidenciar el comportamiento de la sustancia, además se han empleado especímenes más pequeños para ahorrar costos de concreto y laboratorio, de manera que, no es importante el tamaño sino el cambio en la resistencia o en otras palabras cuanto pierde de resistencia el concreto por estar contaminado.

Hay que señalar, asimismo, que tanto las normas peruanas de estructuras como las normas del ACI, son aplicables a trabajos tanto de investigación como oficiales, la diferencia es que cuando se hacen ensayos con valor oficial para terceros como por ejemplo auditorías, supervisión de obras y otros hay que seguir la norma para que los ensayos puedan ser trazados y en ocasiones vayan al ámbito judicial. Sin embargo, en las investigaciones no necesariamente se sigue normas dado que las pruebas se pueden validar por la opinión de expertos y adaptar de otras investigaciones.

Tal es el caso de Hamad (2017) en su artículo titulado "*Size and shape effect of specimen on the compressive strength of HPLWFC reinforced with glass fibres*", quien estudió la influencia que tienen la forma y el tamaño de las muestras en la resistencia a la compresión, encontró que las muestras mas pequeñas ya sea de forma cubica o cilíndrica, presentaban una mayor resistencia a la compresión, sin embargo, la disparidad en la resistencia a la compresión para ambos tamaños y formas se eliminaban con un aumento de volumen en la fracción de fibras de vidrio utilizadas en la mezcla del concreto, demostrando de esta manera que la resistencia a la compresión en las muestras se daba principalmente por las variaciones en la mezcla mas que por el tamaño o la forma de las muestras. (p. 380).

Y ya que investigaciones suelen tener un enfoque mucho más amplio que sólo basarse en normas, cabe mencionar que las investigaciones sirven para perfeccionar las normas y no al contrario, por este motivo para la presente investigación se decidió emplear muestras de tamaño 10x10x5 cm. A efectos de tener una mayor practicidad y economicidad en su elaboración y manipulación.

Finalmente, hay que aclarar que las comparaciones en los diseños experimentales se realizan entre especímenes similares:

El número total de nuestras ensayadas será igual a 60, con distintas dosificaciones de materia orgánica, aditivo plastificante, agregado fino, agregado grueso, cemento y agua.

3.4 Técnicas e instrumentos de recolección de datos

- Extracción de los agregados finos y gruesos se seleccionó la cantera de Huambutío, del departamento del Cusco.
- Técnica de la observación del material registrado, todo lo observado se puso por escrito.
- Elaboración de especímenes en laboratorio de suelos.
- En la fase de trabajos de laboratorio la técnica de recolección de información será en forma manuscrita y analógica. Igualmente, se hará uso de técnicas mixtas de recolección de información entre analógicas y digitales.
- Ensayo de resistencia a la compresión.
- Guía de observación resumen porque nos permitirá elaborar sistemas de organización y clasificación de la información del ensayo de la resistencia a la compresión.
- Software BOOTSTRAP y ELISTAT (Método estadístico de remuestreo)

Diseño Estadístico Experimental (DOE):
Proporciona una metodología eficiente, basándose en estructurar y ejecutar un conjunto de pruebas y experimentos con el fin de generar datos que, al ser analizados estadísticamente, provean evidencias objetivas que permitan responder las preguntas planteadas en un proceso de investigación, así como también estudia, como modificar las condiciones ordinarias de un proceso de producción para poder incrementar la probabilidad de descubrir cambios significativos en la variable de respuesta, logrando así un mayor conocimiento del comportamiento del proceso de interés. Su objetivo es el de obtener el máximo de información requerida por el experimento con el mínimo coste y la máxima eficiencia.

DISEÑOS EXPERIMENTAL FACTORIAL FRACCIONADO

Este el tipo de diseño en los que el número de experimentos es una fracción del número de experimentos para el mismo diseño factorial completo. En otras palabras el diseño factorial fraccionado 2^{k-p} es una fracción del diseño factorial 2k, ya que existe exceso de información que acumulan los diseños factoriales completos cuando hay muchos factores, lo cual nos permiten sacrificar información poco importante reduciendo el número de experimentos a realizar.

DISEÑOS EXPERIMENTAL FACTORIAL FRACCIONADO D-OPTIMIZADO

La optimización, es el método más usado para encontrar muchas aplicaciones con varias respuestas cuya finalidad es alcanzar una calidad total de un resultado por lo que es necesario optimizar de manera simultánea las respuestas de interés.
La Función de Deseabilidad, mide la deseabilidad promedio de todas las variables de respuestas en cada combinación de factores. Consiste en definir una función en el espacio de factores que estima la deseabilidad global (D) del producto en cada punto. Basta maximizar D para obtener el punto óptimo buscado; para esto se requiere que todas las “Y” estén en la misma escala.

Los datos medidos provienen de un diseño fraccional factorial D – optimizado, no son datos paramétricos, por lo tanto no cumplen con los criterios de normalidad ni homoestaticidad, pues es el investigador el que manipula los niveles para medir la respuesta.

En esta investigación se planteó un diseño factorial fraccionado, para determinar cómo influyen los factores operacionales: materia orgánica, aditivo plastificante, agregado grueso, agregado fino, cemento, agua, en la variable de respuesta resistencia a la compresión del concreto (F’c). En otras palabras se medirá el efecto de varios factores sobre una respuesta.

3.5 Procedimientos

3.5.1 En campo:

- Extracción de los agregados de la cantera de Huambutío del departamento del cusco.
- Adquisición de los demás materiales como cemento, aditivo plastificante.

3.5.2 En Laboratorio:

- Elaboración de las muestras, haciendo uso de los equipos necesarios para la correcta elaboración, después de dosificar los materiales y realizar la mezcla, se funde en los moldes, al momento.
- Ensayo de resistencia a la compresión.

3.5.2 En Gabinete:

- Diseño del modelo experimental, para las diferentes dosificaciones.
- Análisis de resultados mediante software mediante Boostrap, y ELISTAT.

Resumen del diseño experimental

Total n° de ensayos: 60

D- eficiencia: 87%

Numero de réplicas: 2

Modelo no lineal con interacción

Tabla 9. *Diseño de muestras*

N	Run Order	Materia Orgánica (%)	Aditivo Plastificante (%)	Agregado Fino (%)	Agregado Grueso (%)	Cemento (%)	Agua (%)
N 1	50	0	0.5	0.32	0.4	0.2	0.08
N 2	28	0	0.5	0.35	0.3	0.27	0.08
N 3	48	0	0.5	0.25	0.37	0.3	0.08
N 4	9	0	0.5	0.35	0.33	0.2	0.12
N 5	45	0	0.5	0.25	0.4	0.23	0.12
N 6	44	0	0.5	0.28	0.3	0.3	0.12
N 7	46	0	2.5	0.32	0.3	0.3	0.08
N 8	13	0	2.5	0.25	0.4	0.27	0.08
N 9	25	0	2.5	0.35	0.3	0.23	0.12
N 10	33	0	2.5	0.28	0.4	0.2	0.12
N 11	53	0	2.5	0.25	0.33	0.3	0.12
N 12	30	0	2.5	0.325	0.375	0.2	0.10
N 13	6	9	0.5	0.35	0.37	0.2	0.08
N 14	54	9	0.5	0.32	0.3	0.3	0.10
N 15	8	9	0.5	0.25	0.4	0.27	0.08
N 16	16	9	0.5	0.35	0.3	0.23	0.12
N 17	3	9	0.5	0.28	0.4	0.2	0.12
N 18	4	9	0.5	0.25	0.33	0.3	0.12
N 19	15	9	2.5	0.32	0.4	0.2	0.08
N 20	5	9	2.5	0.35	0.3	0.27	0.08
N 21	24	9	2.5	0.25	0.37	0.3	0.08
N 22	58	9	2.5	0.35	0.33	0.2	0.12
N 23	51	9	2.5	0.25	0.4	0.23	0.12
N 24	31	9	2.5	0.28	0.3	0.3	0.12
N 25	49	3	2.5	0.35	0.37	0.2	0.08
N 26	2	3	1.5	0.3	0.35	0.25	0.10
N 27	59	3	1.5	0.3	0.35	0.25	0.10
N 28	37	3	1.5	0.3	0.35	0.25	0.10
N 29	36	3	1.5	0.3	0.35	0.25	0.10
N 30	52	3	1.5	0.3	0.35	0.25	0.10

N 31	26	0	0.5	0.32	0.4	0.2	0.08
N 32	34	0	0.5	0.35	0.3	0.27	0.08
N 33	18	0	0.5	0.25	0.37	0.3	0.08
N 34	57	0	0.5	0.35	0.33	0.2	0.12
N 35	55	0	0.5	0.25	0.4	0.23	0.12
N 36	35	0	0.5	0.28	0.3	0.3	0.12
N 37	43	0	2.5	0.32	0.3	0.3	0.08
N 38	29	0	2.5	0.25	0.4	0.27	0.08
N 39	38	0	2.5	0.35	0.3	0.23	0.12
N 40	20	0	2.5	0.28	0.4	0.2	0.12
N 41	42	0	2.5	0.25	0.33	0.3	0.12
N 42	40	0	2.5	0.325	0.375	0.2	0.10
N 43	22	9	0.5	0.35	0.37	0.2	0.08
N 44	7	9	0.5	0.32	0.3	0.3	0.08
N 45	12	9	0.5	0.25	0.4	0.27	0.08
N 46	14	9	0.5	0.35	0.3	0.23	0.12
N 47	41	9	0.5	0.28	0.4	0.2	0.12
N 48	56	9	0.5	0.25	0.33	0.3	0.12
N 49	23	9	2.5	0.32	0.4	0.2	0.08
N 50	21	9	2.5	0.35	0.3	0.27	0.08
N 51	27	9	2.5	0.25	0.37	0.3	0.08
N 52	47	9	2.5	0.35	0.33	0.2	0.12
N 53	32	9	2.5	0.25	0.4	0.23	0.12
N 54	19	9	2.5	0.28	0.3	0.3	0.12
N 55	60	3	2.5	0.35	0.37	0.2	0.08
N 56	10	3	1.5	0.3	0.35	0.25	0.10
N 57	39	3	1.5	0.3	0.35	0.25	0.10
N 58	17	3	1.5	0.3	0.35	0.25	0.10
N 59	11	3	1.5	0.3	0.35	0.25	0.10
N 60	1	3	1.5	0.3	0.35	0.25	0.10

Fuente: Elaboración propia

3.6 Método de análisis de datos

El tratamiento de la información obtenida durante los trabajos de laboratorio se hará mediante hojas de cálculo electrónicas. Seguidamente, se hará uso de la técnica estadística denominada Bootstrap, la cual se basa exactamente en la idea de producir un gran número de muestras a partir de la muestra original (población Boostrap) y calcular el valor de la estadística deseado para cada una de ellas, y así estimar la distribución muestral del estadístico.

La metodología bootstrap tiene sus bases en el muestreo aleatorio, definido como un método en el cual las pruebas sucesivas del experimento son independientes y la función de frecuencias permanece invariable de prueba a prueba. Tales propiedades se expresan matemáticamente de la siguiente manera:

$$f(x_1, x_2, \dots x_n) = f(x_1)f(x_2) \dots f(x_n)$$

Dónde: $f(x)$: es la función de frecuencia de la población que se muestrea
$x_1, x_2, \dots x_n$: son las variables correspondientes a n pruebas de la muestra.
Esta metodología radica en formar un tamaño n de muestras, para que a partir de las medias de todas las muestras generadas, conseguir la función de distribución. B muestras se generan a partir de un conjunto de datos de n elementos para la estimación de la desviación típica $s(X)$ de la media. Las muestras logradas se llaman muestras Bootstrap. (Hernández y Martínez, 2012, p.8)

Una muestra bootstrap de n elementos puede contener elementos repetidos. Se puede tener una muestra bootstrap con k conjuntos de números iguales. Como cada elemento del conjunto de los n datos puede encontrase en cualquier posición de la muestra; sucederá que la probabilidad de obtener determinada muestra bootstrap X^j con sus elementos prefijados es: (Hoel, 1980, p. 211)

$$P(X^j) = \frac{n!}{n_1!\ n_2! \dots n_k!}\left(\frac{1}{n}\right)^n$$

La ecuación anterior impone a las muestras bootstrap X^j de que ninguna de ellas sea construida como permutación de otra. A modo de ejemplo seleccionemos un conjunto de datos de cinco elementos, $x_1, x_2, x_3, x_4, y\ x_5$, con el cual el conjunto de las muestras bootstrap será:

$$\{x_1,x_1,x_1,x_1,x_1\}\{x_1,x_1,x_1,x_1,x_2\}\{x_1,x_1,x_1,x_1,x_3\}\{x_1,x_1,x_1,x_1,x_4\}\{x_1,x_1,x_1,x_1,x_5\}$$
$$\{x_1,x_1,x_1,x_2,x_2\}\{x_1,x_1,x_1,x_2,x_3\}\{x_1,x_1,x_1,x_2,x_4\}\{x_1,x_1,x_1,x_2,x_5\}\{x_1,x_1,x_1,x_3,x_3\}$$
$$\{x_1,x_1,x_1,x_3,x_4\}\{x_1,x_1,x_1,x_3,x_5\}\{x_1,x_1,x_1,x_4,x_4\}\{x_1,x_1,x_1,x_4,x_5\}\{x_1,x_1,x_1,x_5,x_5\}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\{x_4,x_4,x_4,x_4,x_5\}\{x_4,x_4,x_4,x_5,x_5\}\{x_4,x_4,x_5,x_5,x_5\}\{x_4,x_5,x_5,x_5,x_5\}\{x_5,x_5,x_5,x_5,x_5\}$$

El conjunto de las muestras bootstrap permite obtener la siguiente tabla:

Tabla 10. *Conjunto de muestras bootstrap*

j	**1**	**2**	**3**	**…**	$\boldsymbol{B}$
X^j	$\{x_1,x_1,x_1,x_1,x_1\}$	$\{x_1,x_1,x_1,x_1,x_2\}$	$\{x_1,x_1,x_1,x_1,x_3\}$	…	$\{x_5,x_5,x_5,x_5,x_5\}$
$P(X^j)$	$\frac{5!}{5!\,0!\,0!\,0!\,0!}\left(\frac{1}{5}\right)^5$	$\frac{5!}{4!\,1!\,0!\,0!\,0!}\left(\frac{1}{5}\right)^5$	$\frac{5!}{4!\,0!\,1!\,0!\,0!}\left(\frac{1}{5}\right)^5$	…	$\frac{5!}{0!\ 0!\ 1!\ 0!\ 5!}\left(\frac{1}{5}\right)^5$

Fuente: Hernández y Martínez (2012)

3.7 Aspectos éticos

La presente investigación es un trabajo de autoría propia, inédito, motivado por mis deseos de profundizar mis conocimientos en el tema tratado; por el cual, declaro que no es copia de otro trabajo similar y me someto en cualquier momento a la verificación por medio del software anti plagio TURNITIN para la verificación de la similitud; asimismo declaro conocer y cumplir con lo emanado en la RCUN 0262-2020/UCV del

28 de agosto del 2020 en la que se aprueba el Código de Ética en Investigación de la UCV.

IV. RESULTADOS

El objetivo general propuesto en la investigación fue; ¿En qué medida, la cantidad de contaminante orgánico afecta a la resistencia a la compresión del concreto?

Con la finalidad de determinar el efecto del contaminante orgánico y la resistencia compresiva del concreto y con base en el marco teórico y la sugerencia de expertos, se planteó el diseño experimental que se muestra a continuación

Tabla 11. *Diseño de mezclas, Factores y sus niveles.*

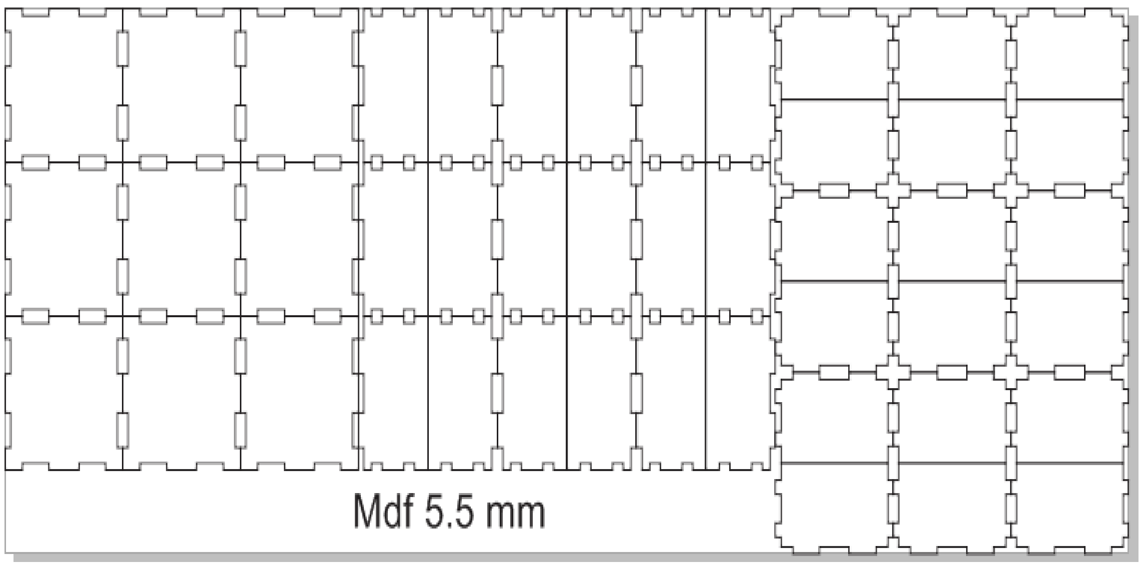
Nombre	Orden de ejecución	Materia Orgánica (%)	Aditivo Plastificante (%)	Agregado Fino (%)	Agregado Grueso (%)	Cemento (%)	Agua (%)
N 1	50	0	0.5	0.32	0.4	0.2	0.08
N 2	28	0	0.5	0.35	0.3	0.27	0.08
N 3	48	0	0.5	0.25	0.37	0.3	0.08
N 4	9	0	0.5	0.35	0.33	0.2	0.12
N 5	45	0	0.5	0.25	0.4	0.23	0.12
N 6	44	0	0.5	0.28	0.3	0.3	0.12
N 7	46	0	2.5	0.32	0.3	0.3	0.08
N 8	13	0	2.5	0.25	0.4	0.27	0.08
N 9	25	0	2.5	0.35	0.3	0.23	0.12
N 10	33	0	2.5	0.28	0.4	0.2	0.12
N 11	53	0	2.5	0.25	0.33	0.3	0.12
N 12	30	0	2.5	0.325	0.375	0.2	0.10
N 13	6	9	0.5	0.35	0.37	0.2	0.08
N 14	54	9	0.5	0.32	0.3	0.3	0.10
N 15	8	9	0.5	0.25	0.4	0.27	0.08
N 16	16	9	0.5	0.35	0.3	0.23	0.12
N 17	3	9	0.5	0.28	0.4	0.2	0.12
N 18	4	9	0.5	0.25	0.33	0.3	0.12
N 19	15	9	2.5	0.32	0.4	0.2	0.08
N 20	5	9	2.5	0.35	0.3	0.27	0.08
N 21	24	9	2.5	0.25	0.37	0.3	0.08
N 22	58	9	2.5	0.35	0.33	0.2	0.12
N 23	51	9	2.5	0.25	0.4	0.23	0.12
N 24	31	9	2.5	0.28	0.3	0.3	0.12
N 25	49	3	2.5	0.35	0.37	0.2	0.08
N 26	2	3	1.5	0.3	0.35	0.25	0.10
N 27	59	3	1.5	0.3	0.35	0.25	0.10
N 28	37	3	1.5	0.3	0.35	0.25	0.10
N 29	36	3	1.5	0.3	0.35	0.25	0.10
N 30	52	3	1.5	0.3	0.35	0.25	0.10
N 31	26	0	0.5	0.32	0.4	0.2	0.08
N 32	34	0	0.5	0.35	0.3	0.27	0.08
N 33	18	0	0.5	0.25	0.37	0.3	0.08
N 34	57	0	0.5	0.35	0.33	0.2	0.12
N 35	55	0	0.5	0.25	0.4	0.23	0.12
N 36	35	0	0.5	0.28	0.3	0.3	0.12
N 37	43	0	2.5	0.32	0.3	0.3	0.08
N 38	29	0	2.5	0.25	0.4	0.27	0.08
N 39	38	0	2.5	0.35	0.3	0.23	0.12
N 40	20	0	2.5	0.28	0.4	0.2	0.12
N 41	42	0	2.5	0.25	0.33	0.3	0.12
N 42	40	0	2.5	0.325	0.375	0.2	0.10
N 43	22	9	0.5	0.35	0.37	0.2	0.08
N 44	7	9	0.5	0.32	0.3	0.3	0.08
N 45	12	9	0.5	0.25	0.4	0.27	0.08
N 46	14	9	0.5	0.35	0.3	0.23	0.12
N 47	41	9	0.5	0.28	0.4	0.2	0.12
N 48	56	9	0.5	0.25	0.33	0.3	0.12
N 49	23	9	2.5	0.32	0.4	0.2	0.08
N 50	21	9	2.5	0.35	0.3	0.27	0.08
N 51	27	9	2.5	0.25	0.37	0.3	0.08
N 52	47	9	2.5	0.35	0.33	0.2	0.12
N 53	32	9	2.5	0.25	0.4	0.23	0.12
N 54	19	9	2.5	0.28	0.3	0.3	0.12
N 55	60	3	2.5	0.35	0.37	0.2	0.08
N 56	10	3	1.5	0.3	0.35	0.25	0.10
N 57	39	3	1.5	0.3	0.35	0.25	0.10
N 58	17	3	1.5	0.3	0.35	0.25	0.10
N 59	11	3	1.5	0.3	0.35	0.25	0.10
N 60	1	3	1.5	0.3	0.35	0.25	0.10

Fuente: Elaboración propia

Una vez definidos estos factores se empezó con la preparación de las muestras respetando las proporciones. Una descripción de los pasos seguidos para la preparación se muestra a continuación:

Para la elaboración de la mezcla se utilizaron los siguientes materiales:

Figura 6. Moldes de mdf de espesor de 5.5 mm

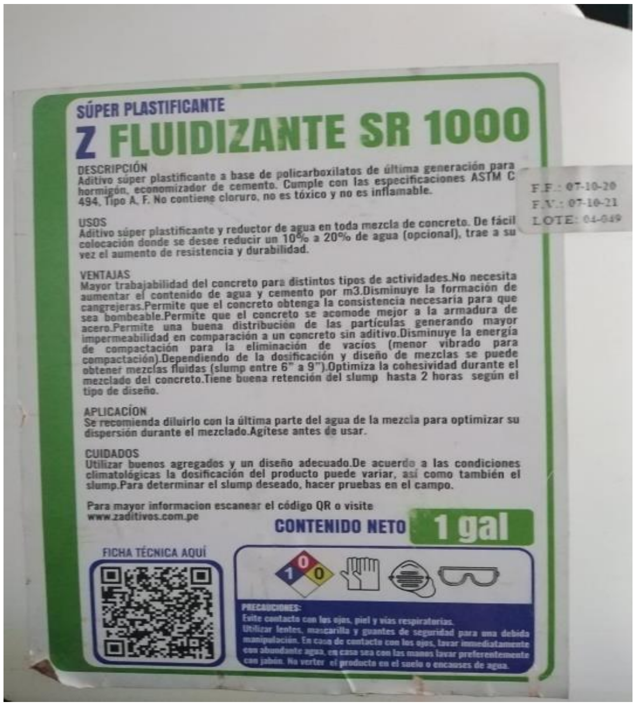


Fuente: Elaboración propia.

Figura 7. Materia orgánica

Fuente: Elaboración propia.

Figura 8. Aditivo plastificante “Z”



Fuente: Elaboración propia.

Figura 9. Primero se realizó el pesaje de todos los materiales, según la dosificación del diseño de mezclas.

Fuente: Elaboración propia.

Figura 10.- pesaje de materiales

Fuente: Elaboración propia.

Seguidamente se procedió con las mezclas para cada espécimen, esta se realizó el orden y proporciones indicados en el diseño de mezclas.

Figura 11. Se vierte materia orgánica

Fuente: Elaboración propia.

Figura 12. Se vierte agregado fino.

Fuente: Elaboración propia.

Figura 13. Se vierte cemento

Fuente: Elaboración propia.

Figura 14. Se vierte agregado grueso

Fuente: Elaboración propia.

Figura 15. Se dosifica el agua

Fuente: Elaboración propia.

Figura 16. Se dosifica el aditivo plastificante

Fuente: Elaboración propia.

Figura 17. Se agrega el agua junto al aditivo

Fuente: Elaboración propia.

Figura 18. Se mezcla todos los materiales

Fuente: Elaboración propia.

Figura 19. Se hizo la enumeración de cada espécimen

Fuente: Elaboración propia.

Figura 20. Especímenes terminados

Fuente: Elaboración propia.

Figura 21. Especímenes después de los 28 días de curado

Fuente: Elaboración propia.

Figura 22. Luego se hizo la medición de los especímenes y del peso de estos.

Fuente: Elaboración propia.

Figura 23. Seguidamente se realizó el ensayo simple a la compresión

Fuente: Elaboración propia.

Figura 24. Prensa compresión hidráulica para prueba a la compresión.

Fuente: Elaboración propia.

Figura 25. Acción de la prensa

Fuente: Elaboración propia.

Figura 26. Falla del espécimen después del ensayo simple a la compresión.

Fuente: Elaboración propia.

Resultados obtenidos:

Objetivo General: Una vez culminado el periodo de fraguado de las muestras, se procedió a la ejecución del ensayo de compresión simple y medición de la densidad de cada una, los resultados se muestran en la siguiente tabla:

Tabla 12. *Resultados de los ensayos de compresión y de densidad*

Nombre	Ancho (mm)	Profundidad (mm)	Altura (mm)	Volumen cm3	Peso (g)	Densidad	Carga (kg)	f´c (28 días)
N 1	101.11	100.78	59.84	609.8	1195.8	1.96	2470	40.89
N 2	100.96	100.53	57.9	587.7	1282.9	2.18	3480	59.66
N 3	100.85	101.91	59.3	609.5	1326.3	2.18	3500	58.22
N 4	101.48	100.64	55	561.7	1111.3	1.98	1510	27.17
N 5	101.33	99.43	53.95	543.6	1010.1	1.86	3230	59.64
N 6	101.24	101.88	48.83	503.6	1099.9	2.18	6110	123.21
N 7	101.54	103.13	54.94	575.3	1223.8	2.13	10040	178.58
N 8	100.75	101.02	54.92	559.0	1138.1	2.04	2640	47.65
N 9	100.73	101.16	54.4	554.3	1198.1	2.16	3060	55.72
N 10	100.92	101.25	53.93	551.1	1125.5	2.04	5590	102.54
N 11	100.55	101.01	49.73	505.1	1043.9	2.07	4660	92.98
N 12	100.89	100.67	57.81	587.2	1206.3	2.05	4920	84.45
N 13	100.16	99.82	61.51	615.0	1209	1.97	980	15.93
N 14	100.84	99.98	65.28	658.2	1283.1	1.95	2740	41.80
N 15	100.22	100.6	62.27	627.8	1253.5	2.00	2120	33.91
N 16	100.19	100.88	60.25	609.0	1199.9	1.97	2000	33.02
N 17	102.15	104.02	58.99	626.8	1123.9	1.79	830	13.65
N 18	100.44	100.25	61.87	623.0	1152.4	1.85	2380	38.34
N 19	101.79	102.5	59.46	620.4	1168.1	1.88	580	9.55
N 20	111.76	115.63	46.47	600.5	1088.7	1.81	790	14.95
N 21	100.33	100.43	63.21	636.9	1216.2	1.91	2060	32.47
N 22	100.54	101.41	57.6	587.3	1138.8	1.94	700	12.04
N 23	101.32	105.43	56.42	602.7	1179.8	1.96	1210	20.75
N 24	100.62	100.42	57.99	585.9	1125.9	1.92	2700	46.32
N 25	101.07	100.78	59.94	610.5	1241.1	2.03	3110	51.41
N 26	101.41	100.58	58.67	598.4	1272.4	2.13	5480	92.48
N 27	101.61	101.57	59.39	612.9	1257.2	2.05	4050	67.13
N 28	100.35	100.35	57.46	578.6	1269.8	2.19	8520	147.76
N 29	100.48	100.88	59.17	599.8	1255.8	2.09	4520	75.87
N 30	100.47	102.15	57.66	591.8	1216.3	2.06	5670	97.06
N 31	100.95	101.29	57.43	587.2	1138.3	1.94	2070	35.64
N 32	101.54	102.25	54.39	564.7	1157.1	2.05	3960	71.45
N 33	100.79	100.45	58.98	597.1	1267.3	2.12	2370	39.94
N 34	101.4	100.93	55.21	565.0	1062.3	1.88	2090	37.42
N 35	101.14	102.83	53.3	554.3	1075.1	1.94	2300	42.31
N 36	101.14	101.05	50.21	513.2	1088.9	2.12	5320	104.81
N 37	101.75	100.71	53.42	547.4	1155.1	2.11	6670	123.34
N 38	100.5	100.4	58.79	593.2	1259.2	2.12	7820	132.42
N 39	100.6	100.96	50.6	513.9	1079.2	2.10	4220	82.75
N 40	104.57	105.01	57.87	635.5	848.1	1.33	760	12.53
N 41	101.07	101.29	51.62	528.5	1103.9	2.09	9560	183.04
N 42	102.22	102.25	57.51	601.1	1182.2	1.97	1520	25.85
N 43	100.15	100.53	62.01	624.3	1207.3	1.93	1400	22.50
N 44	100.91	99.97	65.5	660.8	1236.8	1.87	2150	32.68
N 45	100.47	100.41	63.44	640.0	1237.6	1.93	1890	29.66
N 46	102.08	100.15	60	613.4	1193.1	1.95	3080	50.77
N 47	101.18	100.39	61.34	623.1	1193.2	1.92	970	15.69
N 48	102.6	101.86	66	689.8	1223.4	1.77	1910	28.31
N 49	100.51	100.73	61.17	619.3	1182.1	1.91	2060	33.47
N 50	101.54	103.22	57.38	601.4	1168.7	1.94	1700	28.94
N 51	100.28	100.31	59.94	602.9	1126.7	1.87	1210	20.13
N 52	101.38	101.03	57.32	587.1	1177.3	2.01	1290	22.24
N 53	100.63	100.77	60.9	617.6	1151	1.86	1470	23.97
N 54	103.79	102.13	54.84	581.3	1091.5	1.88	1810	32.06
N 55	101.03	100.3	60.05	608.5	1255.9	2.06	5020	83.04
N 56	101.31	101.50	57.70	593.3	1172.3	1.98	5290	90.41
N 57	101.28	101.59	62.03	638.2	1328.4	2.08	5460	86.78
N 58	100.2	100.66	57.69	581.9	1257.8	2.16	5290	91.30
N 59	101.2	101.17	58.93	603.3	1272.3	2.11	6960	116.72
N 60	100.3	100.57	59.76	602.8	1262.1	2.09	4710	78.47

Fuente: Elaboración propia

Estadística descriptiva de los resultados mediante el análisis estadístico Boostrap, el cual consiste en una técnica de remuestreo a partir de las 60 muestras el Boostrap realiza un remuestreo una 100 veces para poder así tener una media mucho más confiable, que solo promediando 60 muestras.

Tabla 13. *Datos estadísticos de remuestreo mediante análisis boostrap*

Estadístico	Media	Desviación típica (n-1)	Coeficiente de variación
Muestra 1	51.943	34.383	0.656
Muestra 2	50.916	32.394	0.631
Muestra 3	55.608	36.802	0.656
Muestra 4	61.298	32.473	0.525
Muestra 5	64.840	47.604	0.728
Muestra 6	56.114	42.324	0.748
Muestra 7	62.838	44.350	0.700
Muestra 8	61.977	39.840	0.637
Muestra 9	66.722	42.446	0.631
Muestra 10	56.744	41.627	0.727
Muestra 11	65.498	44.769	0.678
Muestra 12	63.804	44.574	0.693
Muestra 13	61.143	38.012	0.616
Muestra 14	56.253	38.535	0.679
Muestra 15	61.685	38.329	0.616
Muestra 16	62.162	50.414	0.804
Muestra 17	64.156	43.259	0.669
Muestra 18	56.981	43.285	0.753
Muestra 19	59.459	41.135	0.686
Muestra 20	56.267	39.366	0.694
Muestra 21	63.215	38.999	0.612
Muestra 22	57.000	42.429	0.738
Muestra 23	60.523	43.204	0.708
Muestra 24	59.802	38.312	0.635
Muestra 25	67.220	46.005	0.679

Muestra 26	64.437	47.891	0.737
Muestra 27	62.476	39.835	0.632
Muestra 28	59.431	40.105	0.669
Muestra 29	54.596	35.346	0.642
Muestra 30	52.928	32.859	0.616
Muestra 31	60.504	39.836	0.653
Muestra 32	62.879	44.102	0.696
Muestra 33	56.828	39.982	0.698
Muestra 34	51.356	33.664	0.650
Muestra 35	55.186	39.263	0.706
Muestra 36	57.358	35.523	0.614
Muestra 37	62.612	43.004	0.681
Muestra 38	58.380	44.531	0.756
Muestra 39	58.577	40.683	0.689
Muestra 40	51.198	33.871	0.656
Muestra 41	58.199	37.527	0.639
Muestra 42	67.351	43.435	0.640
Muestra 43	59.278	42.355	0.709
Muestra 44	73.129	46.531	0.631
Muestra 45	51.659	40.562	0.779
Muestra 46	55.540	37.705	0.673
Muestra 47	63.208	46.250	0.726
Muestra 48	62.012	46.934	0.751
Muestra 49	56.919	45.775	0.797
Muestra 50	58.115	39.303	0.671
Muestra 51	58.208	39.601	0.675
Muestra 52	68.513	44.735	0.647
Muestra 53	55.179	37.635	0.676
Muestra 54	55.342	41.572	0.745
Muestra 55	61.088	46.405	0.753
Muestra 56	63.327	49.156	0.770
Muestra 57	61.965	48.665	0.779
Muestra 58	57.502	44.468	0.767

Muestra 59	57.654	36.328	0.625
Muestra 60	59.530	38.937	0.649
Muestra 61	60.135	44.865	0.740
Muestra 62	57.313	36.060	0.624
Muestra 63	53.484	34.869	0.646
Muestra 64	54.553	35.295	0.642
Muestra 65	59.234	44.788	0.750
Muestra 66	53.044	39.626	0.741
Muestra 67	55.875	35.502	0.630
Muestra 68	52.638	39.415	0.743
Muestra 69	67.984	40.815	0.595
Muestra 70	45.835	27.609	0.597
Muestra 71	65.933	44.698	0.672
Muestra 72	61.783	37.058	0.595
Muestra 73	69.478	38.861	0.555
Muestra 74	63.089	48.765	0.766
Muestra 75	58.649	43.904	0.742
Muestra 76	66.894	47.264	0.701
Muestra 77	58.826	40.426	0.681
Muestra 78	67.181	37.470	0.553
Muestra 79	56.849	38.946	0.679
Muestra 80	57.754	31.921	0.548
Muestra 81	52.239	34.539	0.656
Muestra 82	58.954	38.935	0.655
Muestra 83	63.691	41.145	0.641
Muestra 84	47.358	34.145	0.715
Muestra 85	60.509	38.066	0.624
Muestra 86	68.070	45.549	0.664
Muestra 87	62.271	39.319	0.626
Muestra 88	60.808	41.104	0.670
Muestra 89	57.043	42.513	0.739
Muestra 90	65.644	46.214	0.698
Muestra 91	54.485	40.629	0.739

Muestra 92	57.086	39.537	0.687
Muestra 93	55.677	43.706	0.778
Muestra 94	58.691	47.551	0.803
Muestra 95	44.345	25.423	0.569
Muestra 96	54.745	37.454	0.678
Muestra 97	59.546	43.702	0.728
Muestra 98	67.630	42.228	0.619
Muestra 99	60.654	36.816	0.602
Muestra 100	59.300	40.071	0.670

Fuente: Elaboración Propia

La estadística descriptiva de los resultados obtenidos se muestra en la siguiente tabla:

Tabla 14. *Estadística descriptiva Bootstrap de los resultados*

Parámetros	Estimador	Estimador (Bootstrap)	Desviación típica (Bootstrap)	Límite inferior (Intervalo estándar bootstrap)
Media	59.230	59.319	5.202	48.821
Desviación típica (n-1)	41.414	40.560	4.710	31.990
Coeficiente de variación	0.693	0.679	0.060	0.573

Fuente: Elaboración propia

Tabla 15. *Promedios de resistencia*

	f´c (28días)	*Densidad cm^3/g*
Media	59.23	1.99
Error estándar	5.34651033	0.017832163
Mediana	44.32	1.98
Desviaciones estándar	41.4138909	0.138127339
Rango	173.49005	0.859882353
Máximo	183.04	2.19
Mínimo	9.55	1.33

Fuentes: Elaboración propia

Conforme se aprecia, el promedio de las resistencias obtenidas en las muestras desde 59.23 kilogramos por centímetro cuadrado.
Siendo el mayor valor encontrado el de 183.0 4 kg/cm^2 y el mínimo de 9.55 kg/cm^2.

Análisis del efecto de la cantidad de contaminante en el concreto.

Para dar respuesta este objetivo se hizo un análisis de regresión múltiple lineal, los resultados se aprecian a continuación.

Tabla 16. *Análisis de Regresión Múltiple lineal ANOVA*

ANOVA				Alpha
	df	*SS*	*MS*	*F*
Regresión	6	51127.7164	8521.28607	9.02105328
Residuo	53	50063.795	944.599905	
Total	59	101191.511		
	Coeficiente	*Error*	*t*	*p-value*
Intercepto	212.403093	1308.59306	0.16231409	0.87167577
Materia Orgánica (%)	**-5.8591666**	0.98698605	-5.9364229	2.2851E-07
Aditivo Plastificante (%)	7.9827062	4.40103216	1.81382592	0.07536742
Agregado Fino (%)	-186.97728	1304.95478	-0.1432826	0.88661039
Agregado Grueso (%)	-306.42498	1322.59395	-0.2316848	0.817675
Cemento (%)	145.751579	1298.23741	0.11226882	0.9110344
Agua (%)	-131.92311	1320.9504	-0.0998698	0.92082447

Fuente: Elaboración propia

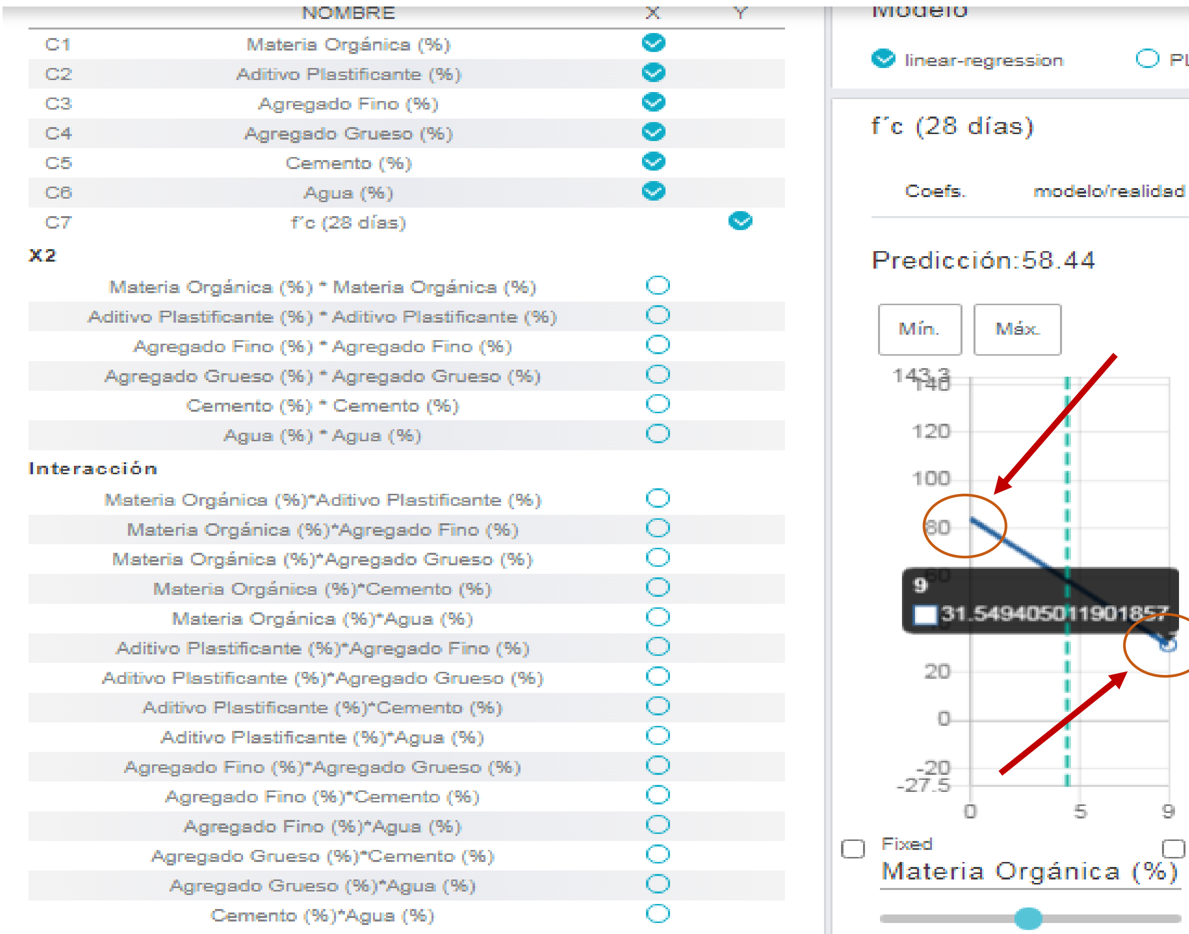
Conforme se aprecia se han logrado determinar los coeficientes de cada uno de los factores analizados en la experimentación, la materia orgánica tiene un coeficiente de menos 5.86, el aditivo plastificante alcanza un coeficiente de 7.98, asimismo, el agregado fino alcanza -186.98, el agregado grueso 306.42; por otro lado el cemento asciende a 145.75 y finalmente el agua a -131.92. Ahora bien para que estos coeficientes sean válidos sólo se toman en cuenta aquellos cuyo p-value sea menor o igual al nivel de significancia de 0.05 (esta es una cifra utilizada usualmente en experimentos estadísticos y recomendada por expertos), de esto último se desprende que sólo son significativos los efectos de: la materia orgánica y el aditivo plastificante. De estos últimos y a partir de sus coeficientes se puede inferir lo siguiente: por cada 1% de materia orgánica que se aumenta la masa de concreto, la resistencia se disminuye en 5.86 Kg/cm^2 asimismo, por cada 1% de plastificante que se aumenta el concreto, la resistencia sube en 7.98 Kg/cm^2. Con esto último se tiene determinada la medida en que la cantidad de contaminante orgánico afecta a la resistencia compresiva del concreto.

Para determinar los objetivos secundarios se hizo uso del software en línea ELLISTAT

Como objetivos secundarios determinamos:

OS1: ¿En qué medida el contaminante orgánico afecta la resistencia a la compresión del concreto? A través del análisis de datos de todos los ensayos se puede ver lo siguiente:
Que el porcentaje de materia orgánica reduce la resistencia a la compresión del concreto, mientras más porcentaje de materia orgánica mayor es la reducción de la resistencia, la resistencia se reduce desde 84.28 kg/cm^2 cuando no existe materia orgánica y hasta 31.55 kg/cm^2 cuando se aumenta 9 % de materia orgánica, como se observa en la figura N.º 27

Figura 27. Efecto del contaminante orgánico en la resistencia a la compresión



Fuente Ellistat

OS 2: ¿En qué medida se da el efecto combinado del agregado pétreo y del contaminante orgánico en la resistencia a la compresión del concreto?

Para poder determinar el efecto combinado, dentro del modelo estadístico, hay que tener en cuenta el efecto combinado de la materia orgánica por el agregado fino y de la materia orgánica por el agregado grueso, solo así se ha podido verificar lo siguiente:

1.-cuando no exista materia orgánica en el concreto, el agregado fino no tiene ninguna variación puesto que la recta de la resistencia se mantiene prácticamente horizontal, no existe variación, como se observa en la figura n°28.

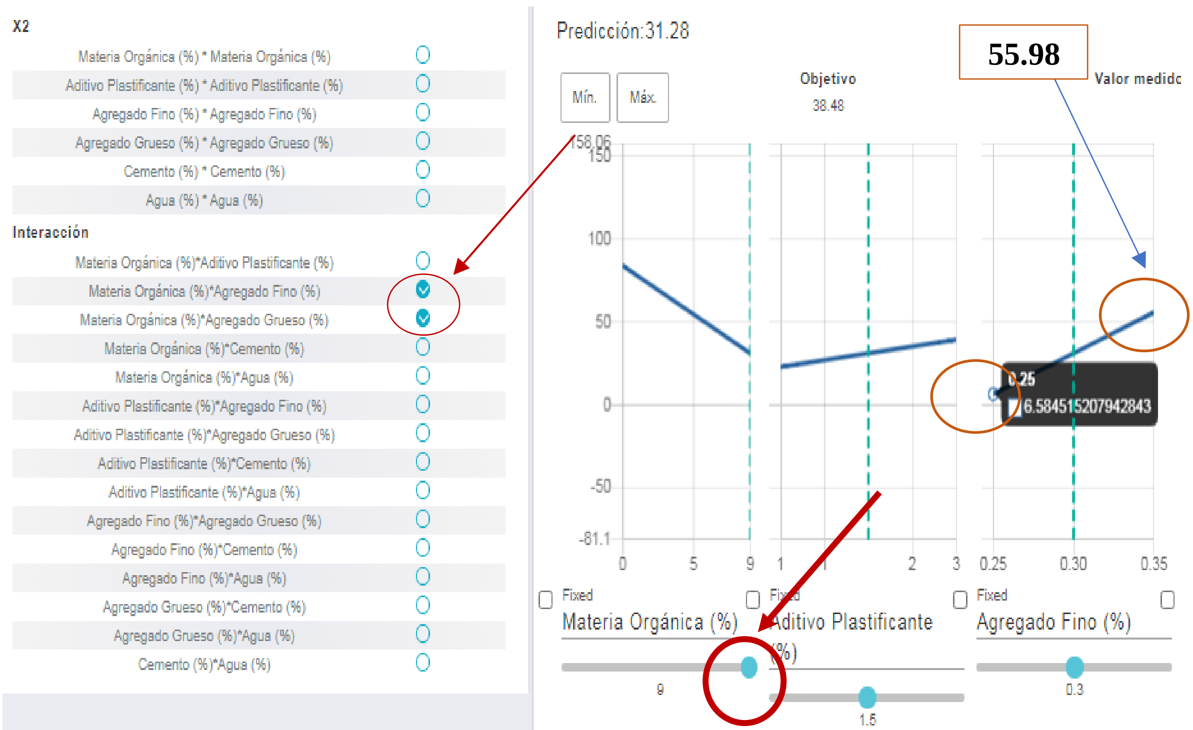
2.- cuando no exista materia orgánica el agregado grueso tiende a reducir muy ligeramente la resistencia a la compresión, como se observa en la figura n°28.

Figura 28. Efecto combinado del agregado pétreo y del contaminante orgánico sin materia orgánica

Fuente Ellistat

Mientras la materia orgánica aumenta, la función del agregado fino y del agregado grueso se convierte en mejorar la resistencia a la compresión, es decir hace un efecto contrario al aumento de la materia orgánica de 0 el efecto es casi nulo, pero cuanta más materia orgánica hay, el efecto del agregado fino y grueso es mejorar la resistencia, en el caso del agregado fino se mejora desde un 6.5 Kg/cm^2 hasta un 55.9 Kg/cm^2, ósea podría mejorar 9 veces su resistencia, como se observa en la figura 29.

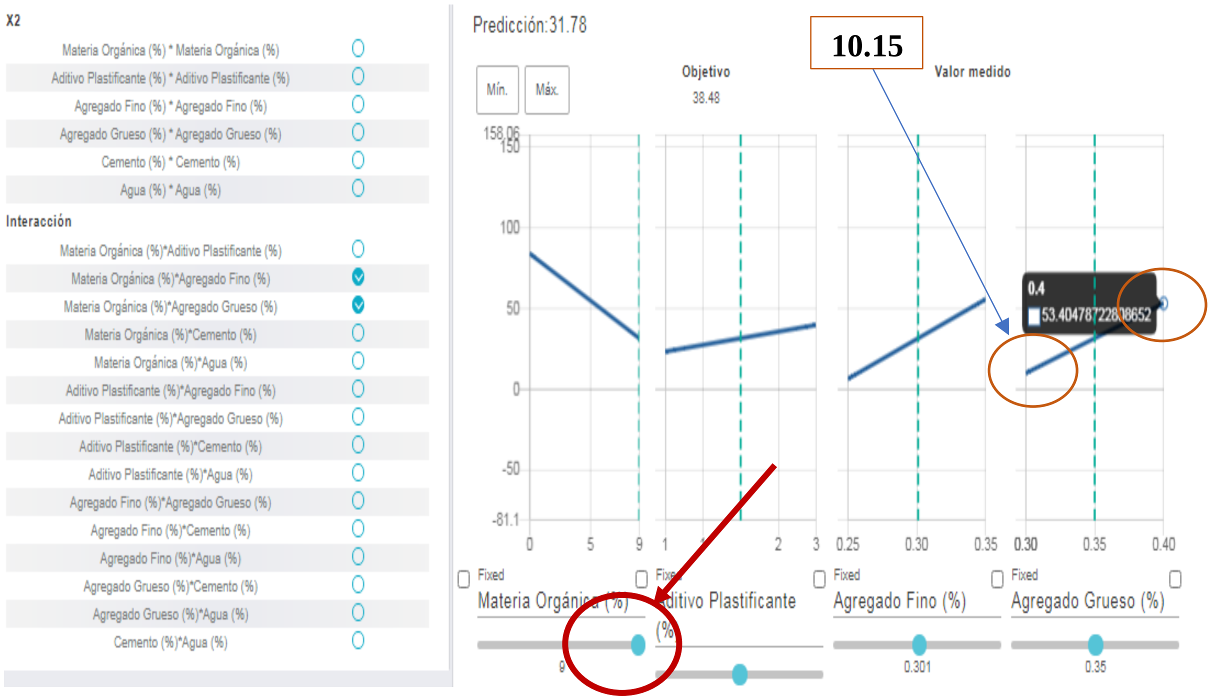
Figura 29. Efecto combinado del agregado fino y del contaminante orgánico



Fuente Ellistat

Igualmente el agregado grueso lo mejora desde 10.15 Kg/cm^2 hasta 53.40 Kg/cm^2; como se observa en la figura 30, en conclusión cuanto más agregado orgánico entra en el concreto la función de los agregados pétreos es mejorar la resistencia del concreto hace un efecto contrario al de la materia orgánica.

Figura 30. Efecto combinado del agregado grueso y del contaminante orgánico



Fuente Ellistat

OS 3: ¿En qué medida el cementante mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto? Para determinar este objetivo se ha procedido a maximizar la cantidad de materia orgánica hasta 9%, luego el cementante se reduce hasta 0.20% y se observa donde arranca la resistencia mínima de la materia orgánica como se observa en la figura 31.

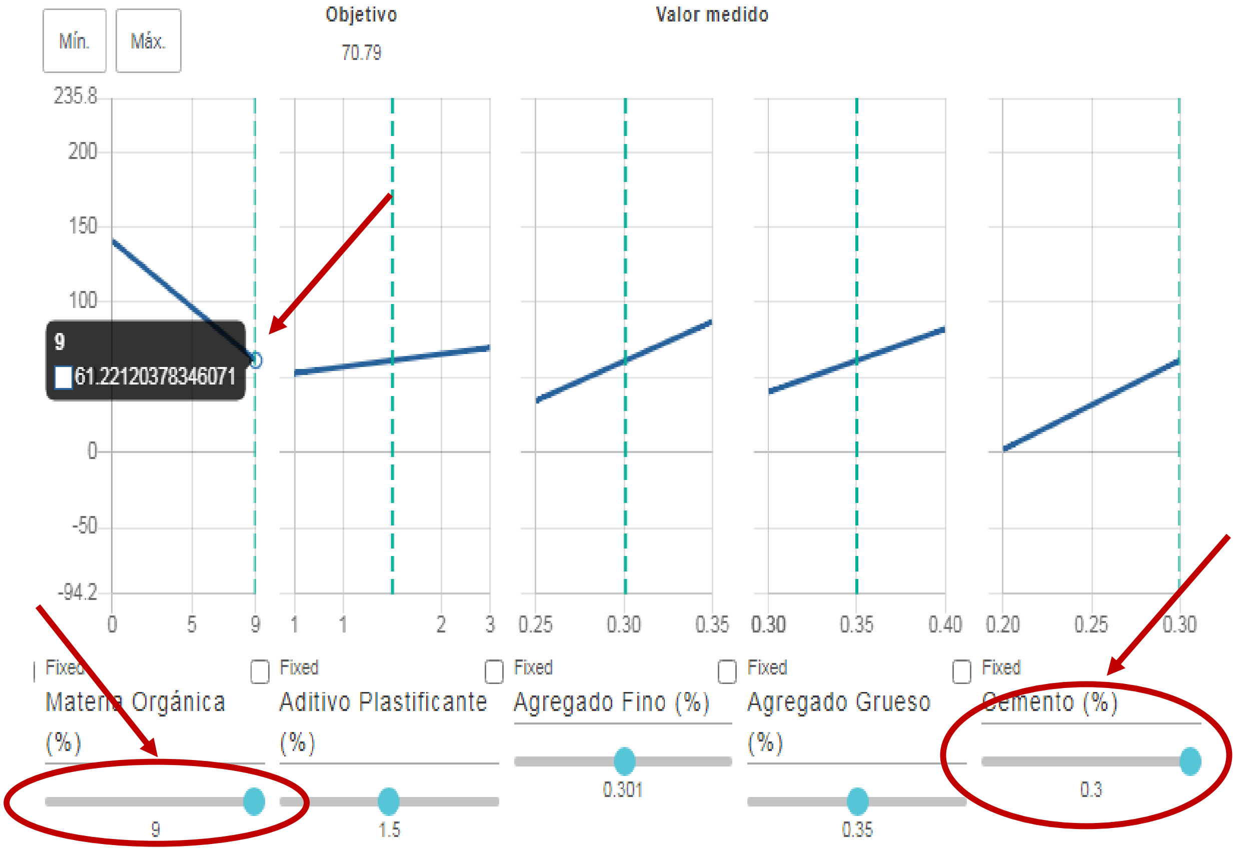
Figura 31. Cemento como mitigador de los efectos del contaminante orgánico

Fuente Ellistat

Aumentarle cemento a la mezcla del concreto, hace que la pérdida de resistencia por la materia orgánica se mitigue de un valor de 1.88 Kg/cm^2 hasta 61 Kg/cm^2, quiere decir que aumentarle el cemento desde 20% hasta 30% hace que la perdida de la resistencia del concreto debido a la materia orgánica sea mucho menor, en otras palabras el cementante contrarresta el efecto de la materia orgánica, como se observa en la figura 32.

Sin embargo hay que mencionar que esto tiene un costo, es decir si hay materia orgánica en el concreto, para mitigar esa materia orgánica necesitamos aumentarle más cemento, costando mucho más el m^3 de cemento.

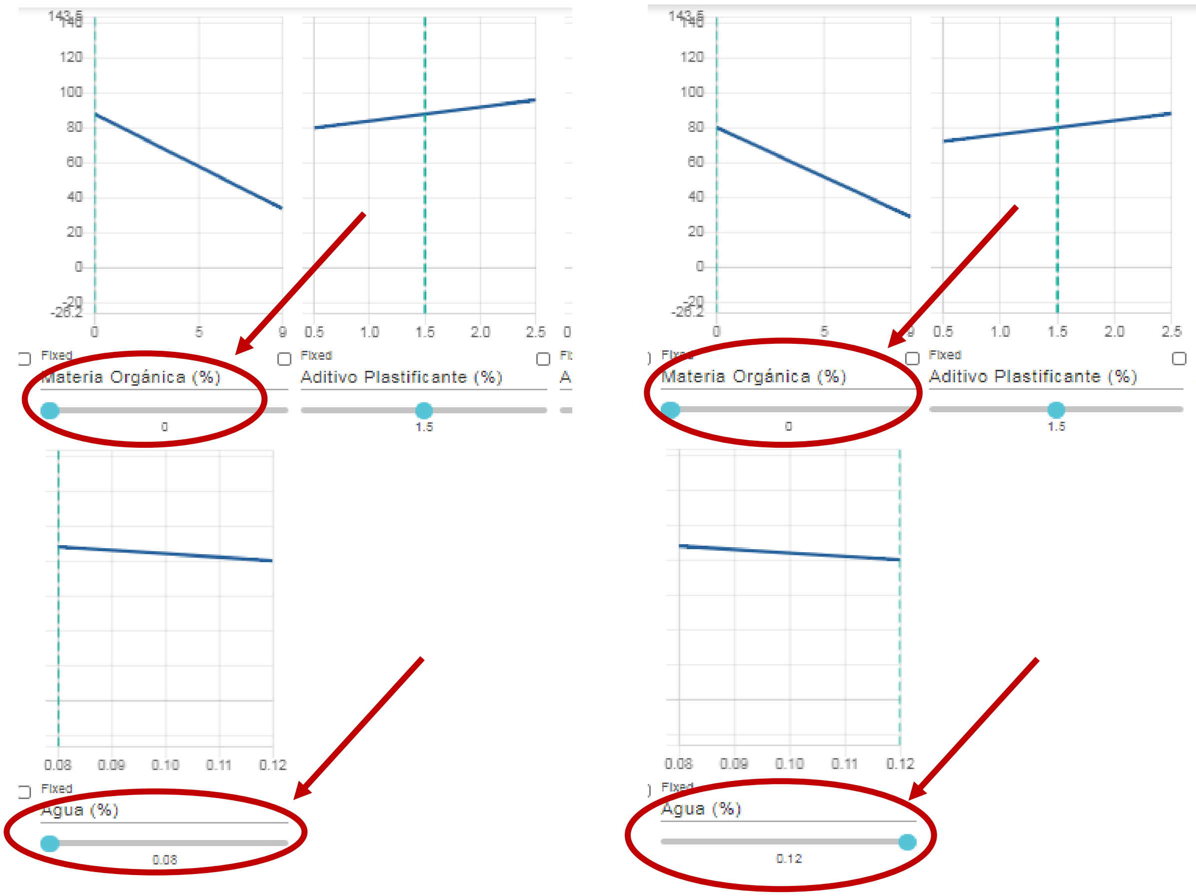
Figura 32. Optimización de la resistencia gracias al cementante



Fuente Ellistat

OS 4: ¿En qué medida se da el efecto combinado del agua de mezcla y del contaminante orgánico en la resistencia a la compresión del concreto, para llegar a la conclusión se apeló al modelo y se combinó estos dos factores; cuando la materia orgánica no está presente en el concreto, el incremento de agua de 0.08% a 0.12% no tiene un efecto muy grande, siendo prácticamente imperceptible, como se observa en la figura 33.

Figura 33. Efecto combinado del agua de mezcla y contaminante orgánico



Fuente Ellistat

Al aumentar el contenido de materia orgánica hasta un 9%, se ve que el contenido de agua en el concreto disminuye la resistencia, probablemente porque la materia orgánica tienda a sustraerle el agua al cementante, y si el cementante se queda sin agua no reacciona químicamente, sino reacciona la resistencia se ve perjudicada, como se observa en la figura 34.

Figura 34. Disminución de la resistencia por interacción de agua y materia orgánica

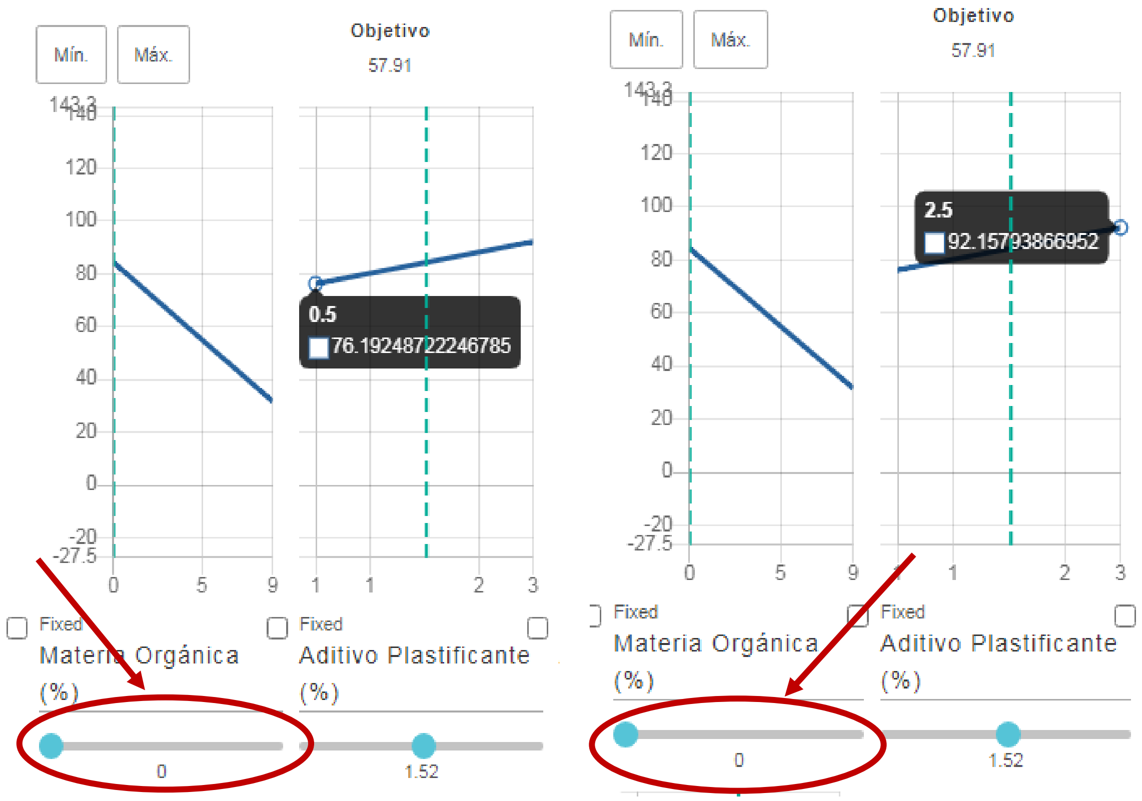
Fuente Ellistat

En conclusión, como se parecía en los gráficos, tanto con o sin la presencia de materia orgánica, aumentarle agua al concreto, disminuirá ligeramente la resistencia. Por ende, no existe una interacción significativa entre la materia orgánica y el agua de mezcla

OS 5: ¿En qué medida el aditivo mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto?

Cuando no existe materia orgánica dentro de la masa del concreto, el aditivo plastificante puede hacer que la resistencia se incremente desde 76.19 kg/cm^2 hasta 92.16 kg/cm^2. Como se observa en la figura 35.

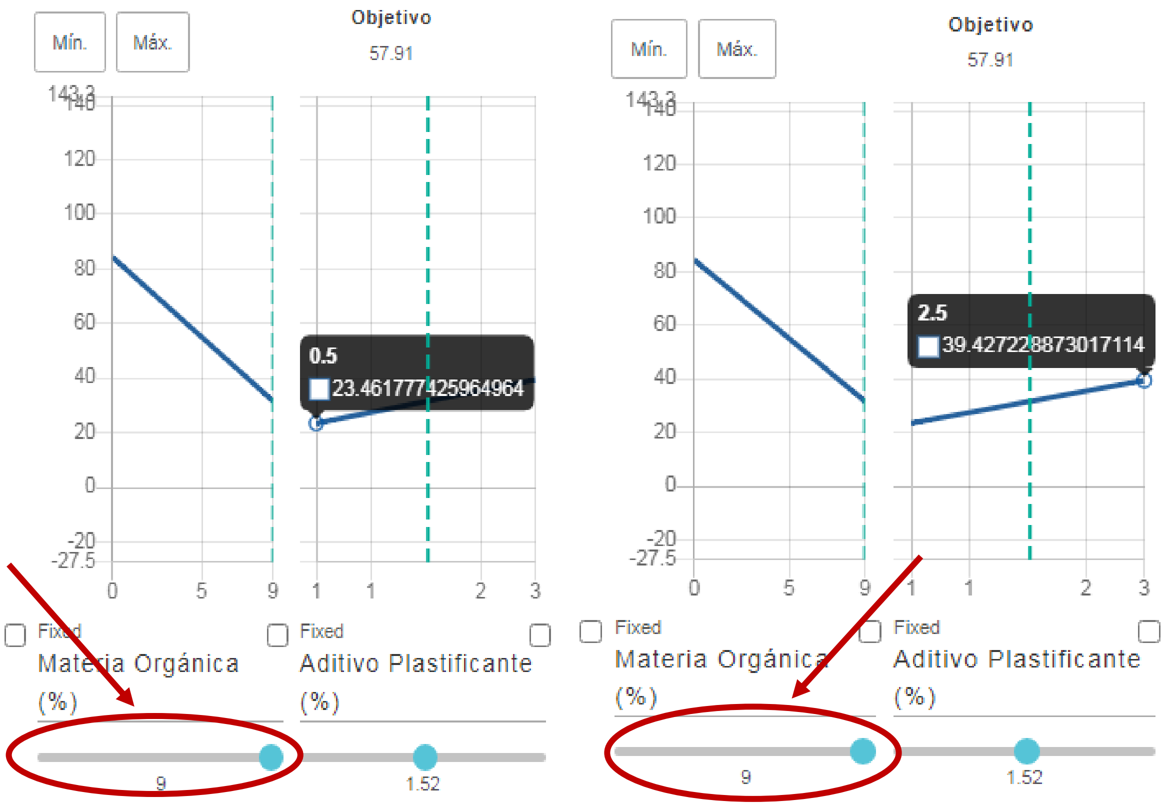
Figura 35. Optimización de la resistencia gracias al aditivo plastificante sin materia orgánica



Fuente Ellistat

Cuando la materia orgánica está presente se puede apreciar que la curva de resistencia del plastificante baja. Entonces, en conclusión la presencia de materia orgánica en el concreto reduce el efecto del aditivo plastificante, con un máximo de 9% de materia orgánica, el aditivo plastificante puede elevar la resistencia desde 23.46 kg/cm^2 hasta 39.43 kg/cm^2. Como se observa en la figura 36.

Figura 36. Optimización de la resistencia gracias al aditivo plastificante con materia orgánica



Fuente Ellistat

Por consiguiente la acción del plastificante se ve afectado con la presencia de materia orgánica. Cuando no hay materia orgánica en la mezcla, el plastificante cumple con su trabajo, con un incremento de materia orgánica, el aditivo plastificante reduce su potencia, quiere decir; que se obtiene menor resistencia por la misma dosis de plastificante, en otras palabras si los agregados pétreos estuviesen limpios el aprovechamiento del aditivo plastificante es el máximo, cuanto más contaminados estén, se pierde ese efecto del aditivo plastificante.

Para mejor entendimiento se presenta la siguiente tabla de resultados:

Tabla 17. *Resumen de resultados*

INTERACCION DE ELEMENTOS		CANTIDAD	RESISTENCIA A LA COMPRESION
Materia Organica		a mayor porcentaje	mayor es la reduccion de la resistencia
		al 9%	la resitencia se reduce hasta un 31.55 kg/cm^2
		0%	la resitencia se reduce desde 84.28 kg/cm^2
Agregado grueso	materia organica	0%	tiende a reducir muy ligeramente
	materia organica	a mayor porcentaje	mejora la resistencia desde un 10.15kg/cm^2 hasta un 53.40 kg/cm^2, mejorandolo en un 9%
Agregado fino	materia organica	0%	no tiene ninguna variacion
	materia organica	a mayor porcentaje	mejora la resistencia desde un 6.5kg/cm^2 hasta un 55.9 kg/cm^2, mejorandolo en un 9%
Cemento	materia organica	al 9%	pero aumentando cemento desde un 20% a 30% mitiga los efectos de la materia organica
Aditivo	materia organica	0%	hace que la resistencia se incremente desde 76.19 kg/cm^2 hasta 92.16 kg/cm^2
	materia organica	a mayor porcentaje	reduce el efecto del aditivo
Agua	materia organica	0%	no tiene un efecto muy grande
	materia organica	al 9%	disminuye la resistencia, ya que la materia organcia tiende a sustraerle el agua al cementante

Elaboración propia

V. DISCUSIÓN

D1: López y Bocanegra (2017) obtuvo en sus resultados, que la resistencia a la compresión en la mezcla del concreto con el aditivo plastificante Acrilcor, se halla 15.9 MPa por encima de la resistencia de diseño esperada, proyectándose así se un 190% superior a lo previsto, en cambio mezcla con material saturado no logro tener un proceder de un 100% de la resistencia de diseño prevista, logrando tan solo un 83% ya que la carga máxima soportada no alcanzo a los 17.5MPa (p.65).

Para el caso de esta investigación, la adición de aditivos plastificantes mejora la resistencia a la compresión del concreto, cuando no hay materia orgánica en la mezcla, el plastificante cumple con su trabajo, con un incremento de materia orgánica, el aditivo plastificante reduce su potencia, quiere decir; que se obtiene menor resistencia por la misma dosis de plastificante en la mezcla de concreto, en otras palabras si los agregados pétreos estuviesen limpios el aprovechamiento del aditivo plastificante es el máximo, cuanto más contaminados estén, se pierde ese efecto del aditivo plastificante.

D2: Ortiz (2015) En sus resultados concluyo que no siempre a mayor cantidad de cemento mayor será la resistencia, también se pudo concluir que la relación agua – cemento, determina el asentamiento del concreto así como también la manejabilidad de la mezcla (p. 67).

Así mismo en el presente estudio se demostró que aumentarle cemento, hace que la pérdida de resistencia por la materia orgánica se mitigue de un valor de 1.88 Kg/cm^2 hasta 61 Kg/cm^2, quiere decir que aumentarle el cemento desde 20% hasta 30% hace que la perdida de la resistencia del concreto debido a la materia orgánica sea mucho menor, en otras palabras el cementante contrarresta el efecto de la materia orgánica. Sin embargo hay que mencionar que esto tiene un costo, es decir si hay materia orgánica en el concreto, para mitigar esa materia orgánica necesitamos aumentarle más cemento, costando mucho más el m^3 de cemento.

D3: Samaniego (2018) Obtuvo en los resultados de su investigación que a mayor volumen del aditivo, tendrá mayor fluidez el mortero También demostró que, mientras más finos tenía la arena, mayor absorbía la cantidad de agua y generaba morteros más secos, y estos a su vez daban como resultado morteros con menor resistencia a la compresión Para el caso de la presente investigación, la adición de aditivo plastificante Z, nos demostró que si mejora la resistencia a la compresión del concreto, siempre y cuando no exista la presencia de materia orgánica (p. 127-128).

VI. CONCLUSIONES

CG: Se ha llegado analizar la medida en la cual se da el efecto de la contaminación orgánica del agregado en la resistencia a la compresión de un concreto plastificado 210kg/cm^2. Se determinó los coeficientes de cada uno de los factores analizados en la experimentación, donde se vio que sólo son significativos los efectos de: la materia orgánica y el aditivo plastificante. De estos últimos y a partir de sus coeficientes se puede inferir lo siguiente: por cada 1% de materia orgánica que se aumenta la masa de concreto, la resistencia se disminuye en 5.86 Kg/cm2 asimismo, por cada 1% de plastificante que se aumenta el concreto, la resistencia sube en 7.98 Kg/cm2.

Con esto último se tiene determinada la medida en que la cantidad de contaminante orgánico afecta a la resistencia compresiva del concreto.

C1: Se determino en que medida la cantidad de contaminante orgánico afecta la resistencia a la compresión del concreto. Que el porcentaje de materia orgánica reduce la resistencia a la compresión del concreto, mientras más porcentaje de materia orgánica mayor es la reducción de la resistencia, la resistencia se reduce desde 84.28 kg/cm2 cuando no hay materia orgánica y hasta 31.55 kg/cm2 cuando se aumenta 9 % de materia orgánica.

C2: Se llego a la conclusión de en que medida se da el efecto combinado del agregado pétreo y del contaminante orgánico en la resistencia a la compresión del concreto. Cuando no exista materia orgánica en el concreto, el agregado fino no tiene ninguna variación puesto que la recta del grafico se mantiene prácticamente horizontal, no existe variación, y cuando no exista materia orgánica el agregado grueso tiende a reducir muy ligeramente la resistencia a la compresión.

Mientras la materia orgánica aumenta, la función del agregado fino y del agregado grueso se convierte en mejorar la resistencia a la compresión, es decir hace un efecto contrario al aumento de la materia orgánica de 0 el efecto es casi nulo, pero cuanta más materia orgánica hay el efecto del agregado fino y grueso es mejorar la

resistencia, en el caso del agregado fino se mejora desde un 6.5 Kg/cm2 hasta un 55.9 Kg/cm2, ósea podría mejorarlo 9 veces su resistencia.
Cuanta más materia orgánica entra en el concreto, la función de los agregados pétreos es mejorar la resistencia del concreto hace un efecto contrario al de la materia orgánica.

C3: Se logro determinar en que medida el cementante mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto. Aumentarle cemento, hace que la pérdida de resistencia por la materia orgánica se mitigue de una resistencia de 1.88 Kg/cm2 incrementa a 61 Kg/cm2, quiere decir que aumentarle el cemento desde 20% hasta 30% hace que la perdida de la resistencia del concreto debido a la materia orgánica sea mucho menor, en otras palabras el cementante contrarresta el efecto de la materia orgánica.

C4: Se pudo especificar en que medida se da el efecto combinado del agua de mezcla y del contaminante orgánico en la resistencia a la compresión del concreto. Cuando la materia orgánica no está presente en el concreto, el incremento de agua de 0.08% a 0.12% no tiene un efecto muy grande, siendo prácticamente imperceptible.
Tanto con o sin la presencia de materia orgánica, aumentarle agua al concreto, disminuirá ligeramente la resistencia. Por ende, no existe una interacción significativa entre la materia orgánica y el agua de mezcla.

C5: Por último se logró establecer en qué medida el aditivo mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto. Cuando no existe materia orgánica dentro de la masa del concreto, el aditivo plastificante puede hacer que la resistencia se incremente desde 76.19 kg/cm^2 hasta 92.16 kg/cm^2.
La presencia de materia orgánica en el concreto reduce el efecto del aditivo plastificante, con un máximo de 9% de materia orgánica, el aditivo plastificante puede elevar la resistencia desde 23.46 kg/cm2 hasta 39.43 kg/cm2.

Si los agregados pétreos estuviesen limpios el aprovechamiento del aditivo plastificante es el máximo, cuanto más contaminados estén, se pierde ese efecto del aditivo plastificante

VII. RECOMENDACIONES

1. Se recomienda utilizar agregados pétreos limpios, que estén libres de impurezas orgánicas, para así evitar disminuciones de la resistencia a la compresión del concreto.

2. Se recomienda realizar estudios con la adición de otros tipos de aditivos, como acelerantes, para ver su comportamiento interactuando con la materia orgánica.

3. Se recomienda realizar estudios de costos acerca de si es conveniente lavar los agregados antes de su utilización o incrementar el cemento para mitigar los efectos de la materia orgánica.

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ANEXOS.

Anexo 01. *Matriz de consistencia*

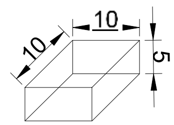
"Análisis Bootstrap del efecto de la contaminación orgánica del agregado de Huambutío, en la resistencia a la compresión de concreto plastificado 210 kg/cm^2."

PROBLEMA	OBJETIVOS	HIPÓTESIS	VARIABLES E INDICADORES	METODOLOGÍA
PROBLEMA GENERAL ¿En qué medida se da el efecto de la contaminación orgánica del agregado de Huambutío, en la resistencia a la compresión de concreto plastificado 210 kg/cm2, aplicando un análisis Bootstrap? **PROBLEMAS ESPECÍFICOS** A. ¿En qué medida la cantidad de contaminante orgánico afecta la resistencia a la compresión del concreto? B. ¿En qué medida se da el efecto combinado del agregado pétreo y del contaminante orgánico en la resistencia a la compresión del concreto? C. ¿En qué medida el cementante mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto? D. ¿En qué medida se da el efecto combinado del agua de mezcla y del contaminante orgánico en la resistencia a la compresión del concreto?	**OBJETIVO GENERAL** Analizar la medida en la cual se da el efecto de la contaminación orgánica del agregado de Huambutío, en la resistencia a la compresión de un concreto plastificado 210 kg/cm2, aplicando un análisis Bootstrap. **OBJETIVOS ESPECÍFICOS** A. Determinar en qué medida, la cantidad de contaminante orgánico afecta a la resistencia a la compresión del concreto. B. Determinar en qué medida se da el efecto combinado del agregado pétreo y del contaminante orgánico en la resistencia a la compresión del concreto. C. Determinar en qué medida el cementante mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto. D. Determinar en qué medida se da el efecto combinado del agua de mezcla y del contaminante orgánico en la resistencia a la compresión del concreto.	**HIPÓTESIS GENERAL** La contaminación orgánica del agregado de Huambutío, reduce la resistencia a la compresión de un concreto plastificado 210 kg/cm2 en por lo menos un 10%, según lo determina el análisis Bootstrap. **HIPÓTESIS ESPECÍFICAS** A. La resistencia a la compresión del concreto se reduce en por lo menos 1% por cada 1% de aumento en el contenido de contaminante orgánico. B. Un incremento de 10% en la arena junto a un incremento de 1% en el en el contaminante orgánico producen cuando menos un 2% de pérdida en la resistencia a la compresión del concreto. C. Un incremento de 10% en el cementante reduce el efecto del contaminante orgánico en por lo menos 5%. D. Un incremento de 10% en el agua de mezcla junto a un incremento de 1% en el en el contaminante orgánico producen cuando menos un 5% de pérdida en la resistencia a la compresión del concreto.	**VARIABLES E INDICADORES** **VARIABLE INDEPENDIENTE** Contaminación orgánica del agregado. Indicadores: • Contaminante orgánico • Cantidad de materia orgánica. **VARIABLE INTERVINIENTE** Concreto plastificado de resistencia promedio f´c = 210 kg/cm2. Indicadores: • Agregado Grueso • Agregado Fino • Cemento Portland tipo IP • Agua destilada • Aditivo plastificante **VARIABLE DEPENDIENTE** Resistencia del concreto.	**Tipo de investigación:** Aplicada **Diseño de investigación:** Experimental. Se realizará la prueba a compresión simple en muestras paralelepípedos de 10x10x5 cm curadas en condiciones estándar durante 28 días. Total, ensayos: 60. D-eficiencia: 87% Número de réplicas: 2. Modelo no lineal con interacción **Población y Muestra** • **Población:** Concreto plastificado preparado con el agregado pétreo de la cantera de Huambutío en la ciudad del Cusco. • **Muestra:** 60 muestras, con distintas dosificaciones de materia orgánica, aditivo plastificante, agregado fino, agregado grueso, cemento y agua.

E. ¿En qué medida el aditivo mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto?	E. Determinar en qué medida el aditivo mitiga los efectos del contaminante orgánico en la resistencia a la compresión del concreto.	E. Un incremento de 1% en el aditivo reduce el efecto del contaminante orgánico en por lo menos 2%.	Indicadores: • Resistencia a la compresión del concreto.	

ANEXO 2. Matriz de operacionalización de las variables

Var	Tipo	Definición conceptual	Definición operacional	Dimensiones	Sub dimensiones	Indicador	Técnica	Instrumento metodológico	Validación	Instrumento y/o equipo de ingeniería	Calibración del equipo de ingeniería	Escala	Valores esperados
Contaminación orgánica del agregado	Independiente	Se produce por la presencia en los agregados de elementos vegetales descompuestos que afectan la hidratación, el fraguado y la resistencia del concreto. El agua también puede proveer de contaminantes orgánicos al concreto (Torre, 2004).	Se define como la cantidad de materia orgánica como porcentaje en peso seco de los agregados finos. Se toma como agregado tanto grueso como fino al material procesado proveniente de la cantera de Huambutío. Se toma como material orgánico al compost industrial.	Contaminante orgánico	Cantidad de materia orgánica	$\%MO = \frac{WC}{\% WAFS} x100$ MO: materia orgánica en reemplazo del agregado fino WC: peso del compost seco WAFS: peso del agregado fino seco	Observación estructurada	Contenido de humedad del suelo conforme lo determina la norma ASTM D 2216 Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada. Cápsulas impermeables.	Fabricante o vendedor	Razón	0.0% 0.5%, 3% y 9%
Concreto plastificado de resistencia promedio f´c = 210 kg/cm2	Interviniente	Es el material resultante de la mezcla de los siguientes ingredientes: Agregado pétreo. Cementante Agua de mezcla Aditivo para concreto (Neville, 1987).	Se define en cada caso como: Porcentaje de agregado grueso que interviene en la mezcla del concreto. Porcentaje de agregado fino que interviene en la mezcla del concreto. Porcentaje de cementante que interviene en la mezcla del concreto. Cantidad de agua en la mezcla. Cantidad de plastificante en la mezcla.	Agregado pétreo	Agregado grueso	$\%AG = \frac{WAG}{W\ Total} x100$ %AG: porcentaje de agregado grueso seco para la mezcla WAG: peso del agregado grueso seco W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	30%, 35% y 40%
					Agregado fino	$\%AF = \frac{WAF}{W\ Total} x100$ %AF: porcentaje de agregado fino seco para la mezcla WAF: peso del agregado fino seco W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	25%, 15% y 35%
				Cementante	Cemento portland tipo IP	$\%C = \frac{WC}{W\ Total} x100$ %C: porcentaje de cemento para la mezcla WC: Peso del cemento W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	20%, 25% y 30%
				Agua	Agua destilada	$\%C = \frac{WA}{W\ Total} x100$ %A: porcentaje de agua para la mezcla WC: Peso del agua destilada W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Horno estufa de tiro forzado con termostato controlado de precisión +/- 5°C, calibrado Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	8%, 10% y 12%

Var	Tipo	Definición conceptual	Definición operacional	Dimensiones	Sub dimensiones	Indicador	Técnica	Instrumento metodológico	Validación	Instrumento y/o equipo de ingeniería	Calibración del equipo de ingeniería	Escala	Valores esperados
				Aditivo	Aditivo plastificante	$\%AP = \frac{WAP}{W\ Total} x100$ %AP: porcentaje de aditivo plastificante para la mezcla WAP: Peso del aditivo plastificante W Total: Peso total de los componentes del concreto fresco	Observación estructurada	Peso de las sustancias según el Manual de procedimientos Analíticos para suelos y agregados de construcción de la Universidad de Piura.	Norma técnica	Balanza de precisión con capacidad de 2000 g y lectura mínima de 0,1 gramo, calibrada.	Fabricante o vendedor	Razón	0.5% a 2.5%
Resistencia del concreto	Dependiente	La resistencia máxima de los paralelepípedos experimentales de 10x10x5 cm, probados en compresión axial no confinada, después de curarlos en condiciones estándar de humedad en el laboratorio durante 28 días, se define como la resistencia a la compresión del concreto.	Explica la medición de la carga máxima soportada por la probeta para producir la fractura entre el área promedio de la sección de las muestras paralelepípedos de 10x10x5 cm curadas en condiciones estándar durante 28 días.	Resistencia a la compresión del concreto		Dimensiones de la muestra 	Observación estructurada	Analógico	Por juicio de expertos	Máquina de ensayo de compresión	Vendedor	Intervalo	10 Kg/cm^2 y 180 Kg/cm^2

Anexo 3. *Efecto del tamaño y la forma de la muestra sobre la resistencia a la compresión*

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ORIGINAL ARTICLES

Size and shape effect of specimen on the compressive strength of HPLWFC reinforced with glass fibres

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KEYWORDS

Compressive strength;
Size effect;
Shape effect;
Lightweight concrete;
Foamed concrete;
Glass fibres

Abstract High performance lightweight foamed concrete (HPLWFC) have a structural strength with low density and high flowability. HPLWFC is used in modern concrete technology and extensively in the construction applications of high-rise buildings, long-span concrete structures and road sub-bases among others. This present work investigated the effect of size and shape specimen on the compressive strength of HPLWFC reinforced with glass fibres. Foam agent (organic material) was used to obtain lightweight concrete. The volume fractions of the glass fibres used were: 0.0%, 0.06%, 0.2%, 0.4%, and 0.6% by total volume of concrete. The fresh properties of HPLWFC were measured by flowability and fresh density tests. In this study, the size and shape of specimens used for compressive strength were cubes by size (150 × 150 × 150, 100 × 100 × 100 and 50 × 50 × 50 mm) and cylinders by size (150 × 300 and 100 × 200 mm). The results of HPLWFC mixes showed the increase in the compressive strength for all sizes of specimens with glass fibre content. The small size of specimens gave higher compressive strength in comparison with other sizes. The disparity in the compressive strength for two sizes and shapes (cubes and cylinders) were reduced with a rise in the volume fraction of the glass fibres.

1. Introduction

Lightweight concrete (LWC) is a versatile material that has created a great interest and large industrial demand in recent years in a wide range of construction projects, despite its known use dated back to 2000 years. LWC is a concrete, which by one means or another has been made lighter than conventional (normal weight aggregate) concrete (El-Zareef, 2010; Babu, 2008). LWC has an oven dry density range of about 300 to not exceed 2000 kg/m^3, with a compressive strength of a cube about 1 to more than 60 MPa. Lightweight foamed concrete has high flowability, low self-weight, minimum consumption of aggregate, controlled low strength, and excellent thermal insulation properties (Neville and Brooks, 2010). Lightweight foamed concrete (LWFC) is a cellular material composed of cement–sand matrix enclosing a large number of small pores roughly (0.1–1.0) mm size, uniformly distributed

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in a matrix. The LWFC consists of Portland cement paste or cement filler matrix (mortar) with a homogeneous void or the pore structure created by introducing air in the form of small bubbles (Mydin and Wang, 2011, 2012).

The concrete is considered as a brittle material and has some disadvantages such as poor fracture toughness, poor resistance to crack propagation and low impact strength. The function of using fibres in concrete is to enhance the mechanical properties of concrete. Fibres are used to modify the tensile strength, flexural strengths, toughness, impact resistance, fracture energy, arrest cracks formation and propagation and improve strength and ductility (Nahhas, 2013; Bagherzadeh et al., 2012; Dawood and Ramli, 2011; Mehta and Monteiro, 2006).

The cylinder specimen of concrete (150 diameter and 300 height) is a standard specimen to test the compressive strength in United States. While in Britain and Europe, the standard specimen for testing the compressive strength is a cube specimen of concrete by size 150 × 150 × 150 mm (Kim and Seong-Tae, 2002). The cubes are smaller compared with the cylinder specimen of concrete, and the advantages of cylinders do not depend on the quality and condition of the moulds and that their density can be more readily and accurately established by weighing and measuring (Day, 2006).

The main difference between cylinder and cube specimens is that the cylinder specimens need capping before loading because the top surface of the cylinder finished by the trowel causes no plane for testing. Two methods are used to obtain the plane surface of the cylinder. (i) Capping method: sulphur mortar, high strength gypsum plaster and cement paste in order to have plain loading surfaces, the thickness of the capping should be 1.5–3 mm and have the same strength of the concrete. (ii) Grinding method: is satisfactory but expensive (Al-Sahawneh, 2013; Neville and Brooks, 2010; Kim and Seong-Tae, 2002). Cubes do not require capping as they are turned over on their sides, when being loaded. The height/diameter ratio equal to 2, the compressive strength of cylinder specimens with varying diameter, the larger the diameter, the lower will be the strength (Kim and Seong-Tae, 2002). The cylinders are cast and tested in the same position, but the cubes are cast in one direction and tested at right angles to the position cast and thus no need of capping or grinding. In actual structures in the field, the casting and loading are similar to those of the cylinder and not like the cube (Shetty, 2005). The comparison between the compressive strength of cube and compressive strength of cylinder, a factor of 0.8 to the cube strength is often applied for normal strength concrete (Al-Sahawneh, 2013). Fig. 1 shows the influence of the aspect ratio of the compressive stress assuming that the value of the slope, was approximately selected as 45° since the confinement effects of frictional force would be negligible if the aspect ratio h/d becomes very large. Therefore, a cylinder with an aspect ratio $h/d = 1$ will be able to resist higher loads than a cylinder with an aspect ratio of 2 (Al-Sahawneh, 2013; Kim and Seong-Tae, 2002).

The usual fracture of cylinder specimens is cone and there are other types of concrete cylinders specimens fracture as shown in Fig. 2(a) (ASTM C 39). Fig. 2 (b) shows the typical failure modes of test cubes (Neville and Brooks, 2010; BS EN 12390-3, 2002). This paper was conducted to study the size and shape effect on the high performance lightweight foamed concrete with the addition of glass fibres. The shapes used were the cubes and cylinders. The size of specimen's cubes was 150 × 150 × 150 mm, 100 × 100 × 100 mm and 50 × 50 × 50 mm against the size of specimen's cylinders which was 150 × 300 mm and 100 × 200 mm. These sizes were chosen because it represented the sizes that are most commonly used locally and universally in the construction research. Additionally, glass fibres were added to high performance lightweight foamed concrete with different ratios and study the effect of glass fibres on compressive strength.

2. Materials and mix proportions

2.1. Materials

Ordinary Portland Cement (OPC) was used in different lightweight foamed concrete mixes. Such cement was taken from Badoosh Cement Factory in the Nineveh Province – Iraq. The physical characteristics are shown in Table 1. Besides, the chemical compositions of cement are shown in Table 2. Both physical and chemical characteristics are in compliance with the standard specification ASTM C 150. The natural river sand used as fine aggregate was supplied from the Kanhash Region – Mosul City. The specific gravity and fineness modulus of sand are 2.63 and 2.69, respectively. The grading limits are according to ASTM C 33 as given in Table 3. Normal tap water was used in this study for mixing and curing.

Foam agent was used to obtain lightweight foamed concrete. The type of foam agent (NEOPOR) (leycoChem LEYDE GmbH Germany) is an organic material, which has no chemical reaction but serves solely as wrapping material for the air to be induced in the concrete. The foaming agent has to be diluted in 40 parts of water before using it according to the manufacturer.

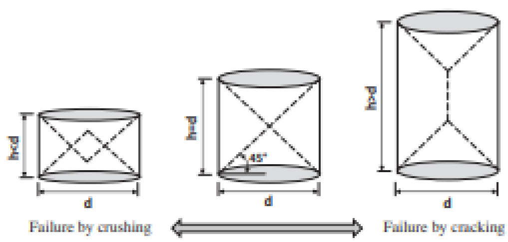

Figure 1 Effect of the specimen size and failure modes.

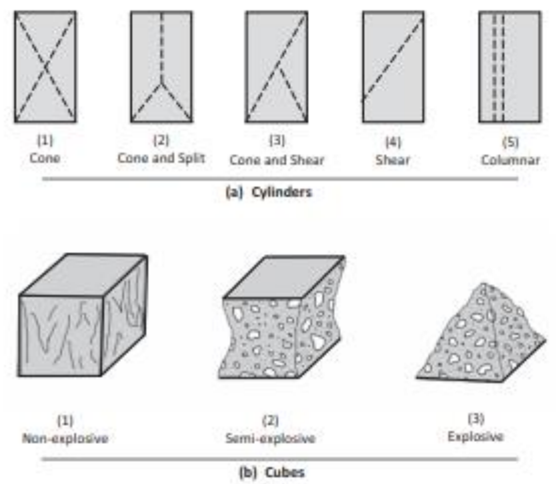

Figure 2 (a) Sketches of types of cylinders fracture (ASTM C 39) and (b) typical failure mode of test specimen cube according to (BS EN 12390-3, 2002; Neville and Brooks, 2010).

Table 1 Physical characteristics of cement used.

Test	Results	ASTM C 150 limits
Initial setting time (minutes)	220	Not less than 45 min. Not more than 375 min.
Fineness (Blaine m^2/kg)	300	Min. 280 m^2/kg
Compressive strength of 50 mm cubic mortar specimen (MPa)		
3 days	21	Min. 12 MPa
7 days	29	Min. 19 MPa

Glass fibres (GF) were used in the lightweight foamed concrete, the properties of the glass fibres are listed in Table 4.

Table 2 Chemical properties of cement used.

Constituent	Component of use cement (%)	ASTM C 150 limits
SiO_2	21.31	–
Al_2O_3	5.89	–
Fe_2O_3	2.67	–
CaO	62.2	–
MgO	3.62	⩽6%
SO_3	2.6	⩽3.5%
Loss of ignition	1.59	⩽3%
Insoluble residue	0.24	⩽0.75%
Free CaO	1.74	–
L.S.F.	0.8818	0.66–1.02
C_3S	33.37	–
C_2S	35.92	–
C_3A	11.09	–
C_4AF	8.12	–

2.2. Mix proportions

The mix proportion by volume used in this study was 1:2.25 cement: sand, respectively (ACI 211-2, 2002; Ramamurthy et al., 2009). The water requirement for a mix depends upon the composition and the amount of foam agent which is governed by the consistency and stability of the mix (Ramamurthy et al., 2009). The selection of water cement ratio in this study depended on three parameters: the optimum oven dry density (less than 1850 kg/m^3), flowability (equal or more than 110% flow) and compressive strength (equal or more than 17 MPa). This mix proportion is considered as shown in Table 5. Furthermore, fibres were incorporated in the lightweight foamed concrete mixes to produce different mixes. Different volume fractions of glass fibres were used as presented in Table 6.

3. Specimens

Different specimen shapes (i.e., cubes and cylinders) with different sizes for cubes and cylinder specimens were used. Three different cube specimens in size were used for each mix as shown in Table 6. Two different cylinder specimens in size were used for each mix as shown in Table 6.

4. Experimental work

4.1. Mix procedure

The procedure of mixing was achieved by blending the cement with sand according to the mix proportion as shown in Table 5, and then water was added to prepare the mortar. After that, the foam was added to the mortar to obtain lightweight foamed concrete. It should be mentioned that the preparation

Table 3 Grading of fine aggregate.

Sieve No. (mm)	Passing (%)	ASTM C 33 limits
No.4 (4.75)	100	95–100
No.8 (2.36)	81	80–100
No.16 (1.18)	66	50–85
No.30 (0.6)	52	25–60
No.50 (0.3)	25	5–30
No.100 (0.15)	7	0–10

Table 4 Properties of glass fibres.

Fibre properties	Quantity
Fibre length	12 mm
Aspect ratio	857
Specific gravity	2.68 g/cm^3
Modulus of elasticity	72 GPa
Tensile strength	1700 MPa
Chemical resistance	Very high
Electrical conductivity	Very low
Softening point	860 °C
Material	Alkali Resistant Glass
Shape	Straight

of the foam was done using the foam agent which was diluted in 40 parts of water according to the manufacturer. Such water was calculated as a part of the total water of the mix. As the foam was added to the mortar, they were blended in the mixer to obtain a homogeneous mixture. Finally, the fibres were added to the mix (lightweight foamed concrete). Glass fibres were included in different proportions of volume fractions, as shown in Table 6. The total mixing time was about 6 min. The mix should have a uniform dispersion of the fibres in order to prevent segregation or balling of the fibres during mixing. Most balling occurs during the fibres' addition process.

4.2. Casting, curing, and testing of lightweight foamed concrete specimens

Before casting, the fresh properties of lightweight foamed concrete were tested after completely mixing the materials. The fresh properties consist of flowability test and fresh density test. Each mix proportion was measured in terms of flowability by using flow table according to ASTM C 1437. The Fresh density was carried out according to ASTM C 138. It was measured by determining the net weight of freshly mixed concrete divided into the volume of concrete produced from a mixture at the moment of casting.

Three cubes were cast for compressive strength at age 7 and 28 days for each mix and size. Three cylinders were cast for compressive strength at age 7 and 28 days for each mix and size. The size of cubes and cylinders is presented in Table 6. All specimens were cast in one layer with compaction by vibration for about 10 s. The use of vibration was just for filling the mould and levelling. The specimens were kept in the laboratory for about 24 ± 8 h. The specimens were stripped approximately for 24 h after casting and placed in the water basin as a curing method with a controlled temperature of 23 °C ± 2 °C according to ASTM C 192.

The average of three cubes and cylinders was tested according to BS EN 12390-3 and ASTM C 39, respectively, to determine the compressive strength for each mix and size at age 7 and 28 days. The uniaxial testing machine with 2000 kN capacity was used and loading rate of 0.4 MPa/s was applied.

5. Results and discussion

5.1. Flowability and fresh density

The flowability (flow) was measured according to ASTM C 1437, the flowability of high performance lightweight foamed concrete reinforced with glass fibres varied among mixes depending on the volume fraction of glass fibres, the flow of mixes is as given in Table 7. The flow varied between (130–100%), the flow was about 130% for control mix (0.0% glass fibres), and flow reduced with the increase in glass fibres. Thus, the use of 0.6% of glass fibres reduced the flow to 100%. The addition of fibres may cause a decrease in flowability of concrete. Fibres hindered the flowability of fresh concrete and this caused a significant decrease in the flowability of concrete (Widodo, 2012; Dawood and Ramli, 2011; Neville and Brooks, 2010; Topcu and Canbaz, 2007).

The fresh density of high performance lightweight foamed concrete varied depending on the percentage of fibres. The high performance lightweight foamed concrete reinforced with glass fibres showed that the density of such concrete was greatly affected by the inclusion of glass fibres. And thus, the inclusion of glass fibres would significantly affect the density of such concrete as seen in Table 7. However, such results are attributed to the specific gravity of fibres.

5.2. Compressive strength

The compressive strength test results for different size cubes and different size cylinders are shown in Table 8. The compressive strength of high performance lightweight foamed concrete is affected by the added fibres. The compressive strength increased with the glass fibres percentage increase. The results in Fig. 3 indicate that there is a large increase in compressive strength with increase in fibres content. This increase can be attributed to the reduction in the porosity of high performance lightweight foamed concrete and an enhancement in mechanical bond strength (Miloud, 2005). It was observed that, the formation of cracks is extended in the specimens without glass fibres (control mix) with great numbers. Whereas, they were the least cracks in the specimens reinforced with the maximum

Table 5 Mix proportions.

Mix proportion	*w/c*	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	Foam agent (kg/m^3)	Voids (%)
(1:2.25) (cement: sand)	0.49	465	1046	228	1	23

Table 6 Specimen Size and Shape with volume fraction* of glass fibres.

Sample No.	Specimen Shape	Size (mm)	GF** (%)	No. of specimen concrete for compressive strength		Total No. of test specimens
				7-days	28-days	
S1	Cube	150 × 150 × 150	0	3	3	6
S2	Cube	100 × 100 × 100	0	3	3	6
S3	Cube	50 × 50 × 50	0	3	3	6
S4	Cube	150 × 150 × 150	0.06	3	3	6
S5	Cube	100 × 100 × 100	0.06	3	3	6
S6	Cube	50 × 50 × 50	0.06	3	3	6
S7	Cube	150 × 150 × 150	0.2	3	3	6
S8	Cube	100 × 100 × 100	0.2	3	3	6
S9	Cube	50 × 50 × 50	0.2	3	3	6
S10	Cube	150 × 150 × 150	0.4	3	3	6
S11	Cube	100 × 100 × 100	0.4	3	3	6
S12	Cube	50 × 50 × 50	0.4	3	3	6
S13	Cube	150 × 150 × 150	0.6	3	3	6
S14	Cube	100 × 100 × 100	0.6	3	3	6
S15	Cube	50 × 50 × 50	0.6	3	3	6
S16	Cylinder	150 × 300	0	3	3	6
S17	Cylinder	100 × 200	0	3	3	6
S18	Cylinder	150 × 300	0.06	3	3	6
S19	Cylinder	100 × 200	0.06	3	3	6
S20	Cylinder	150 × 300	0.2	3	3	6
S21	Cylinder	100 × 200	0.2	3	3	6
S22	Cylinder	150 × 300	0.4	3	3	6
S23	Cylinder	100 × 200	0.4	3	3	6
S24	Cylinder	150 × 300	0.6	3	3	6
S25	Cylinder	100 × 200	0.6	3	3	6
Total						150

* Volume fraction of glass fibres taken by total volume of concrete.
** GF: Glass fibres.

Table 7 Flowability and fresh density for each mix.

Fibres (%)	0.0	0.06	0.2	0.4	0.6
Flowability (%)	130	125	120	115	100
Fresh density (kg/m^3)	1755	1765	1790	1825	1860

glass fibres used in this study (0.6% glass fibres). These results are supported by other researches in this regard (Deshmukh et al., 2012; Kannan et al., 2010; Gornale et al., 2012; Al-Qadi and Al-Zaidyeen, 2014). Also the Fig. 3 shows the difference in the compressive strength between all mixes and size, where the small size specimen of cube gives the higher value of compressive strength at 28 days compared with other sizes. The increase in compressive strength of the high performance lightweight foamed concrete was up to for mix S15 (0.6% glass fibres) at 28 days compared with the other mixes and sizes. However, the increase in compressive strength due to glass fibres inclusions can be attributed to the improvement in the mechanical bond strength between the fibres and the matrix where the fibres contribute to delay of micro-crack formation and arrest their propagation afterwards up to a certain extent of fibres volume fraction (Sahmaran and Yaman, 2007; Felekoglu et al., 2007).

The results are conducted to realize the size and shape effect on the compressive strength of high performance lightweight foamed concrete. The compressive strength of 50 mm cube for mix S3 increased by 38% and 15% compared with the same mix, but different in size of 150 mm and 100 mm cube (S1 and S2), respectively. From these results it can be said that the smaller size of specimens give high compressive strength (Celik et al., 2012; Yaqub and Javed, 2006). For the largest percentage of glass fibres (0.6% glass fibres) the compressive strength of 50 mm cube (mix S15) increased by 5.3% and 3.4% compared with the 150 mm and 100 mm cubes (S13 and S14). It can be noticed that the effect of glass fibres reduce the affects the size of the concrete specimens.

The ratio of the compressive strength of the cubes (fcu) in size 100 × 100 × 100 mm to the cubes (fcu) in size 150 × 150 × 150 mm $\left(\frac{fcu(100\times100\times100)}{fcu(150\times150\times150)}\right)$ was between 1.2 and 1.01, and the average of this ratio was 1.1.The ratio of the compressive strength of the cylinders (fc) in size 150 × 300 mm to the cylinder (fc) in size 100 × 200 mm $\left(\frac{fc(100\times200)}{fc(150\times300)}\right)$ was between 1.22 and 1.06, and the average of this ratio was 1.15. Figs. 4 and 5 shows the relationship between

Table 8 Average compressive strength specimens of cubes and cylinders.

Sample No.	Specimen Shape	Size (mm)	GF (%)	Compressive strength (MPa)	
				7-days	28-days
S1	Cube	150 × 150 × 150	0	11.4	15.8
S2	Cube	100 × 100 × 100	0	14.2	19.0
S3	Cube	50 × 50 × 50	0	15.0	21.8
S4	Cube	150 × 150 × 150	0.06	13.5	17.4
S5	Cube	100 × 100 × 100	0.06	16.0	20.5
S6	Cube	50 × 50 × 50	0.06	17.6	24.3
S7	Cube	150 × 150 × 150	0.2	16.2	22.0
S8	Cube	100 × 100 × 100	0.2	18.0	24.4
S9	Cube	50 × 50 × 50	0.2	19.6	26.4
S10	Cube	150 × 150 × 150	0.4	19.4	26.2
S11	Cube	100 × 100 × 100	0.4	21.0	27.1
S12	Cube	50 × 50 × 50	0.4	22.3	28.3
S13	Cube	150 × 150 × 150	0.6	21.5	28.5
S14	Cube	100 × 100 × 100	0.6	22.6	29.0
S15	Cube	50 × 50 × 50	0.6	23.6	30.0
S16	Cylinder	150 × 300	0	10.1	13.5
S17	Cylinder	100 × 200	0	12.4	16.6
S18	Cylinder	150 × 300	0.06	11.8	15.2
S19	Cylinder	100 × 200	0.06	14.0	18.6
S20	Cylinder	150 × 300	0.2	14.3	19.5
S21	Cylinder	100 × 200	0.2	16.0	22.3
S22	Cylinder	150 × 300	0.4	17.6	23.4
S23	Cylinder	100 × 200	0.4	19.0	25.6
S24	Cylinder	150 × 300	0.6	19.5	26.0
S25	Cylinder	100 × 200	0.6	20.4	27.6

the compressive strength of cubes specimens vs cylinders specimens. The ratio of the compressive strength of the cylinders (fc)in size 150 × 300 mm to the cubes (fcu) in size 150 × 150 × 150 mm $\left(\frac{fc(150\times300)}{fcu(150\times150\times150)}\right)$ was between 0.85 and 0.91, and the average of this ratio was 0.88which means the compressive strength of cubes 150 × 150 × 150 mm are greater than the cylinders of size 150 × 300 mm. This is usually attributed to having an overlapped restrained zone in cubes while testing under uniaxial compression, hence a zone of tri-axial compression develops. On the other hand, cylinders with length/diameter ratio of 2 have an unrestrained zone away from the ends (Malaikah, 2005). Also the effect of glass fibres on the compressive strength of the cubes and cylinders specimens can be observed, whereas the disparity in the compressive strength for two sizes reduces with the rise in the volume fraction of glass fibres. The highest percentage of glass fibres which was 0.6% gives the lowest disparity (fc/fcu) (compressive strength of cylinder/compressive strength of cube) compared with other percentages of glass fibres, which means the ratio of (fc/fcu) was nearby 1. The ratio of the compressive strength of the cylinders (fc) in size 150 × 300 mm to the cubes (fcu) in size 100 × 100 × 100 mm was between 0.71 and 0.89, and the average ratio of compressive strength $\left(\frac{fc(150\times300)}{fcu(100\times100\times100)}\right)$ was 0.8. The compressive strength of cubes in size 100 × 100 × 100 mm is greater than the cylinders in size 150 × 300 mm. It can be noticed the ratio value of $\frac{fc(150\times300)}{fcu(100\times100\times100)}$ reduced when compared with $\frac{fc(150\times300)}{fcu(150\times150\times150)}$, this is attributed to the compressive strength of the 100 mm cubes which is greater than the compressive strength of the 150 mm cube. The ratio $\frac{fc(100\times200)}{fcu(150\times150\times150)}$ and $\frac{fc(100\times200)}{fcu(100\times100\times100)}$ was between 1.05–0.96 and 0.87–0.95, respectively, and the average ratio of compressive strength was 1.01 and 0.91 respectively. Overall, the addition of glass fibres to the high performance lightweight foamed concrete increases the compressive strength and reduces the effect of the size and shape of the concrete specimen.

Fig. 6 shows the slenderness ratio (H/D) equal to 2, but there was variation in size of the cylinders. The compressive strength of the cylinder 100 × 200 mm was more than the compressive strength of the cylinder 150 × 300 mm. The addition of glass fibres to the high performance lightweight foamed concrete increases the compressive strength, and also observed to reduce the difference in compressive strength between the two sizes of cylinder (100 × 200 and 150 × 300 mm).

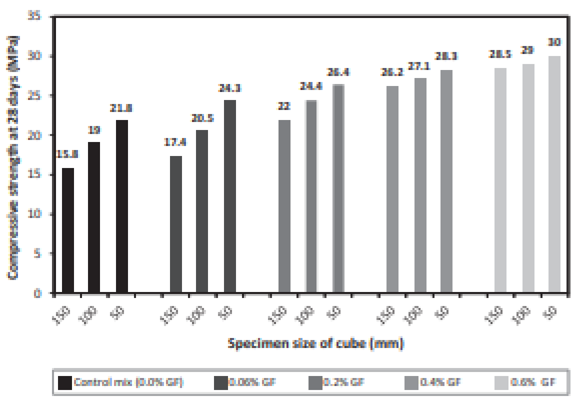

Figure 3 Average compressive strength of cubes specimens at 28 days.

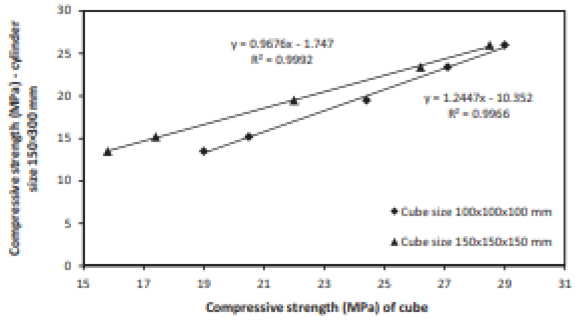

Figure 4 Compressive strength of 150 mm and 100 mm cubes specimens versus 150 × 300 mm cylinders specimens.

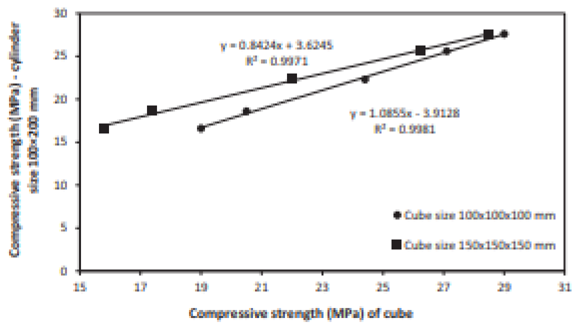

Figure 5 Compressive strength of 150 mm and 100 mm cubes specimens versus 100 × 200 mm cylinders specimens.

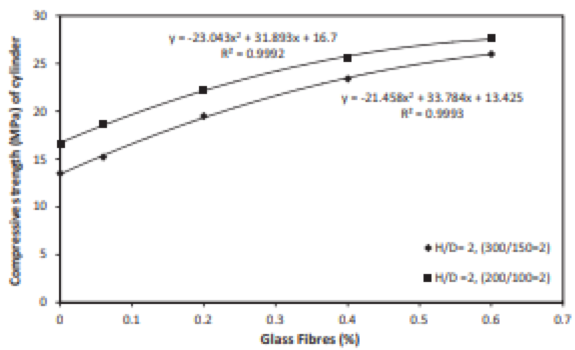

Figure 6 Relationship between glass fibres and compressive strength of cylinders, with influence the size specimen of cylinder.

6. Conclusions

The following conclusions are drawn from the experimental work on size and shape effects found on cube and cylinder of high performance lightweight foamed concrete reinforced with glass fibres.

1. The compressive strength of high performance lightweight foamed concrete increased with rising glass fibres content.
2. The small size of specimen for cubes or cylinder gives higher compressive strength of high performance lightweight foamed concrete compared with other sizes. The compressive strength of 50 mm cube for mix S3 increased

by 38% and 15% compared with the 150 mm and 100 mm cube (S1 and S2), respectively.

3. The average ratio of the compressive strength of high performance lightweight foamed concrete of 150 × 300 mm cylinders to 150 × 150 × 150 mm cubes was 0.88.
4. The average ratio of the compressive strength of high performance lightweight foamed concrete of 100 × 200 mm cylinders to 150 × 150 × 150 mm cubes was 1.01.
5. The average ratio of the compressive strength of high performance lightweight foamed concrete of 150 × 300 mm cylinders to 100 × 100 × 100 mm cubes was 0.8.
6. The average ratio of the compressive strength of high performance lightweight foamed concrete of 100 × 200 mm cylinders to 100 × 100 × 100 mm cubes was 0.91.
7. The average ratio of the compressive strength of high performance lightweight foamed concrete of 100 × 200 mm cylinders to 150 × 300 mm cubes was 1.15.
8. The average ratio of the compressive strength of high performance lightweight foamed concrete of 100 × 100 × 100 mm cylinders to 150 × 150 × 150 mm cubes was 1.1.
9. The disparity in the compressive strength for two sizes and shapes are reduced with the rise in the volume fraction of glass fibres.

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Anexo. 4 *ACI 211.1-91*

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Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete (ACI 211.1-91)

(Reapproved 2002)

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Describes, with examples, two methods for selecting and adjusting proportions for normal weight concrete, both with and without chemical admixtures pozzolanic, and slag materials. One method is based on an estimated weight of the concrete per unit volume; the other is based on calculations of the absolute volume occupied by the concrete ingredients. The procedures take into consideration the requirements for placeability, consistency, strength, and durability. Example calculations are shown for both methods, including adjustments based on the characteristics of the first trial batch.

The proportioning of heavyweight concrete for such purposes as radiation shielding and bridge counterweight structures is described in an appendix. This appendix uses the absolute volume method, which is generally accepted and is more convenient for heavyweight concrete.

There is also an appendix that provides information on the proportioning of mass concrete. The absolute volume method is used because of its general acceptance.

Keywords: absorption; admixtures; aggregates; blast-furnace slag; cementitious materials; concrete durability; concretes; consistency; durability; exposure; fine aggregates; fly ash; heavyweight aggregates; he avywe ighto nc retes mass con cret emix proportioning; pozzolans; quality control; radiation shielding; silica fume; slump tests; volume; water-cement ratio; water-cementitious ratio; workability.

CONTENTS

* Members of Subcommittee A who prepared this standard. The committee acknowledges the significant contribution of William L. Barringer to the work of the subcommittee.

† Members of Subcommittee A who prepared the 1991 revision.

This standard supersedes ACI 211.1-89. It was revised by the Expedited Standardization procedure, effective Nov. 1, 1991. This revision incorporates provisions related to the use of the mineral admixture silica fume in concrete. Chapter 4 has been expanded to cover in detail the effects of the use of silica fume on the proportions of concrete mixtures. Editorial changes have also been made in Chapters 2 through 4, and Chapters 6 through 8.

CHAPTER 1 - SCOPE

1.1 This Standard Practice describes methods for selecting proportions for hydraulic cement concrete made with and without other cementitious materials and chemical admixtures. This concrete consists of normal and/or high-density aggregates (as distinguished from lightweight aggregates) with a workability suitable for usual cast-in-place construction (as distinguished from special mixtures for concrete products manufacture). Also included is a description of methods used for selecting proportions for mass concrete. Hydraulic cements referred to in this Standard Practice are portland cement (ASTM C 150) and blended cement (ASTM C 595). The Standard does not include proportioning with condensed silica fume.

1.2 The methods provide a first approximation of proportions intended to be checked by trial batches in the laboratory or field and adjusted, as necessary, to produce the desired characteristics of the concrete.

1.3 U.S. customary units are used in the main body of the text. Adaption for the metric system is provided in Appendix 1 and demonstrated in an example problem in Appendix 2.

1.4 Test methods mentioned in the text are listed in Appendix 3.

CHAPTER 2 -- INTRODUCTION

2.1 Concrete is composed principally of aggregates, a portland or blended cement, and water, and may contain other cementitious materials and/or chemical admixtures. It will contain some amount of entrapped air and may also contain purposely entrained air obtained by use of an admixture or air-entraining cement. Chemical admixtures are frequently used to accelerate, retard, improve workability, reduce mixing water requirements, increase strength, or alter other properties of the concrete (see ACI 212.3R). Depending upon the type and amount, certain cementitious materials such as fly ash, (see ACI 226.3R) natural pozzolans, ground granulated blast-furnace (GGBF) slag (see ACI 226.1R) and silica fume may be used in conjunction with portland or blended cement for economy or to provide specific properties such as reduced early heat of hydration, improved late-age strength development, or increased resistance to alkali-aggregate reaction and sulfate attack, decreased permeability, and resistance to the intrusion of aggressive solutions (See ACI 225R and ACI 226.1R).

2.2 The selection of concrete proportions involves a balance between economy and requirements for placeability, strength, durability, density, and appearance. The required characteristics are governed by the use to which the concrete will be put and by conditions expected to be encountered at the time of placement. These characteristics should be listed in the job specifications.

2.3 The ability to tailor concrete properties to job needs reflects technological developments that have taken place, for the most part, since the early 1900s. The use of water-cement ratio as a tool for estimating strength was recognized about 1918. The remarkable improvement in durability resulting from the entrainment of air was recognized in the early 1940s. These two significant developments in concrete technology have been augmented by extensive research and development in many related areas, including the use of admixtures to counteract possible deficiencies, develop special properties, or achieve economy (ACI 212.2R). It is beyond the scope of this discussion to review the theories of concrete proportioning that have provided the background and sound technical basis for the relatively simple methods of this Standard Practice. More detailed information can be obtained from the list of references in Chapter 8.

2.4 Proportions calculated by any method must always be considered subject to revision on the basis of experience with trial batches. Depending on the circumstances, the trial mixtures may be prepared in a laboratory, or, perhaps preferably, as full-size field batches. The latter procedure, when feasible, avoids possible pitfalls of assuming that data from small batches mixed in a laboratory environment will predict performance under field conditions. When using maximum-size aggregates larger than 2 in., laboratory trial batches should be verified and adjusted in the field using mixes of the size and type to be used during construction. Trial batch procedures and background testing are described in Appendix 3.

2.5 Frequently, existing concrete proportions not containing chemical admixtures and/or materials other than hydraulic cement are reproportioned to include these materials or a different cement. The performance of the reproportioned concrete should be verified by trial batches in the laboratory or field.

CHAPTER 3 -- BASIC RELATIONSHIP

3.1 Concrete proportions must be selected to provide necessary placeability, density, strength, and durability for the particular application. In addition, when mass concrete is being proportioned, consideration must be given to generation of heat. Well-established relationships governing these properties are discussed next.

3.2 *Placeability* -- Placeability (including satisfactory finishing properties) encompasses traits loosely accumulated in the terms "workability" and "consistency." For the purpose of this discussion, workability is considered to be that property of concrete that determines its capacity to be placed and consolidated properly and to be finished without harmful segregation. It embodies such concepts as moldability, cohesiveness, and compactability. Workability is affected by: the grading, particle shape, and proportions of aggregate; the amount and qualities of cement and other cementitious materials; the presence of entrained air and chemical admixtures; and the consistency of the mixture. Procedures in this Standard Practice permit these factors to be taken into account to achieve satisfactory placeability economically.

3.3 *Consistency* -- Loosely defined, consistency is the relative mobility of the concrete mixture. It is measured in terms of slump -- the higher the slump the more mobile the mixture -- and it affects the ease with which the concrete will flow during placement. It is related to but not synonymous with workability. In properly proportioned concrete, the unit water content required to produce a given slump will depend on several factors. Water requirement increases as aggregates become more angular and rough textured (but this disadvantage may be offset by improvements in other characteristics such as bond to cement paste). Required mixing water decreases as the maximum size of well-graded aggregate is increased. It also decreases with the entrainment of air. Mixing water requirements usually are reduced significantly by certain chemical water-reducing admixtures.

3.4 *Strength* -- Although strength is an important characteristic of concrete, other characteristics such as durability, permeability, and wear resistance are often equally or more important. Strength at the age of 28 days is frequently used as a parameter for the structural design, concrete proportioning, and evaluation of concrete. These may be related to strength in a general way, but are also affected by factors not significantly associated with strength. In mass concrete, mixtures are generally proportioned to provide the design strength at an age greater than 28 days. However, proportioning of mass concrete should also provide for adequate early strength as may be necessary for form removal and form anchorage.

3.5 *Water-cement or water-cementitious ratio [w/c or w/(c + p)]* -- For a given set of materials and conditions, concrete strength is determined by the net quantity of water used per unit quantity of cement or total cementitious materials. The net water content excludes water absorbed by the aggregates. Differences in strength for a given water-cement ratio *w/c* or water-cementitious materials ratio *w/(c + p)* may result from changes in: maximum size of aggregate; grading, surface texture, shape, strength, and stiffness of aggregate particles; differences in cement types and sources; air content; and the use of chemical admixtures that affect the cement hydration process or develop cementitious properties themselves. To the extent that these effects are predictable in the general sense, they are taken into account in this Standard Practice. In view of their number and complexity, it should be obvious that accurate predictions of strength must be based on trial batches or experience with the materials to be used.

3.6 *Durability* -- Concrete must be able to endure those exposures that may deprive it of its serviceability -- freezing and thawing, wetting and drying, heating and cooling, chemicals, deicing agents, and the like. Resistance to some of these may be enhanced by use of special ingredients: low-alkali cement, pozzolans, GGBF slag, silica fume, or aggregate selected to prevent harmful expansion to the alkali-aggregate reaction that occurs in some areas when concrete is exposed in a moist environment; sulfate-resisting cement, GGBF slag, silica fume, or other pozzolans for concrete exposed to seawater or sulfate-bearing soils; or aggregate composed of hard minerals and free of excessive soft particles where resistance to surface abrasion is required Use of low water-cement or cementitious materials ratio *[w/c or w/(c + p)]* will prolong the life of concrete by reducing the penetration of aggressive liquids. Resistance to severe weathering, particularly freezing and thawing, and to salts used for ice removal is greatly improved by incorporation of a proper distribution of entrained air. Entrained air should be used in all exposed concrete in climates where freezing occurs. (See ACI 201.2R for further details).

3.7 *Density* -- For certain applications, concrete may be used primarily for its weight characteristic. Examples of applications are counterweights on lift bridges, weights for sinking oil pipelines under water, shielding from radiation, and insulation from sound. By using special aggregates, placeable concrete of densities as high as 350 lb/ft^3 can be obtained--see Appendix 4.

3.8 *Generation of heat* -- A major concern in proportioning mass concrete is the size and shape of the completed structure or portion thereof. Concrete placements large enough to require that measures be taken to control the generation of heat and resultant volume change within the mass will require consideration of temperature control measures. As a rough guide, hydration of cement will generate a concrete temperature rise of 10 to 15 F per 100 lb of portland $cement/yd^3$ in 18 to 72 hours. If the temperature rise of the concrete mass is not held to a minimum and the heat is allowed to dissipate at a reasonable rate, or if the concrete is subjected to severe temperature differential or thermal gradient, cracking is likely to occur. Temperature control measures can include a relatively low initial placing temperature, reduced quantities of cementitious materials, circulation of chilled water, and, at times, insulation of concrete surfaces as may be required to adjust for these various concrete conditions and exposures. It should be emphasized that mass concrete is not necessarily large-aggregate concrete and that concern about generation of an excessive amount of heat in concrete is not confined to massive dam or foundation structures. Many large structural elements may be massive enough that heat generation should be considered, particularly when the minimum cross-sectional dimensions of a solid concrete member approach or exceed 2 to 3 ft or when cement contents above 600 lb/yd^3 are being used.

CHAPTER 4--EFFECTS OF CHEMICAL ADMIXTURES, POZZOLANIC, AND OTHER MATERIALS ON CONCRETE PROPORTIONS

4.1 *Admixtures* -- By definition (ACI 116R), an admixture is "a material other than water, aggregates, hydraulic cement, and fiber reinforcement used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing." Consequently, the term embraces an extremely broad field of materials and products, some of which are widely used while others have limited application. Because of this, this Standard Practice is restricted to the effects on concrete proportioning of air-entraining admixtures, chemical admixtures, fly ashes, natural pozzolans, and ground granulated blast-furnace slags (GGBF slag).

4.2 *Air-entraining admixture* -- Air-entrained concrete is almost always achieved through the use of an air-entraining admixture, ASTM C 260, as opposed to the earlier practice in which an air-entraining additive is interground with the cement. The use of an air-entraining admixture gives the concrete producer the flexibility to adjust the entrained air content to compensate for the many conditions affecting the amount of air entrained in concrete, such as: characteristics of aggregates, nature and proportions of constituents of the concrete admixtures, type and duration of mixing, consistency, temperature, cement fineness and chemistry, use of other cementitious materials or chemical admixtures, etc. Because of the lubrication effect of the entrained air bubbles on the mixture and because of the size and grading of the air voids, air-entrained concrete usually contains up to 10 percent less water than non-air-entrained concrete of equal slump. This reduction in the volume of mixing water as well as the volume of entrained and entrapped air must be considered in proportioning.

4.3 *Chemical admixtures* -- Since strength and other important concrete qualities such as durability, shrinkage, and cracking are related to the total water content and the w/c or $w/(c+p)$, water-reducing admixtures are often used to improve concrete quality. Further, since less cement can be used with reduced water content to achieve the same w/c or $w/(c+p)$ or strength, water-reducing and set-controlling admixtures are used widely for reasons of economy (ACI 212.2R).

Chemical admixtures conforming to ASTM C 494, Types A through G, are of many formulations and their purpose purposes for use in concrete are as follows:

Type A -- Water-reducing
Type B -- Retarding
Type C -- Accelerating
Type D -- Water-reducing and retarding
Type E -- Water-reducing, and accelerating
Type F -- Water-reducing, high-range
Type G -- Water-reducing, high-range, and retarding

The manufacturer or manufacturer's literature should be consulted to determine the required dosage rate for each specific chemical admixture or combination of admixtures. Chemical admixtures have tendencies, when used in large doses, to induce strong side-effects such as excessive retardation and, possibly, increased air entrainment, in accordance with ASTM C 1017. Types A, B, and D, when used by themselves, are generally used in small doses (2 to 7 oz/100 lb of cementitious materials), so the water added to the mixture in the form of the admixture itself can be ignored. Types C, E, F, and G are most often used in large quantities (10 to 90 oz/100 lb of cementitious materials) so their water content should be taken into account when calculating the total unit water content and the w/c or $w/(c+p)$. When Types A, B, and D admixtures are used at higher than normal dosage rates in combination or in an admixture system with an accelerating admixture (Type C or E), their water content should also be taken into account.

Although chemical admixtures are of many formulations, their effect on water demand at recommended dosages is governed by the requirements of ASTM C 494. Recommended dosage rates are normally established by the manufacturer of the admixture or by the user after extensive tests. When used at normal dosage rates, Type A water-reducing, Type D water-reducing and retarding, and Type E water-reducing and accelerating admixtures ordinarily reduce mixing-water requirements 5 to 8 percent, while Type F water-reducing, high-range, and Type G water-reducing, high-range, and retarding admixtures reduce water requirements 12 to 25 percent or more. Types F and G water-reducing, high-range admixtures (HRWR) are often called "superplasticizers."

High-range, water-reducing admixtures are often used to produce flowing concrete with slumps between about 7$^1/_2$ or more with no increase in water demand other than that contained in the admixture itself. Types A, B, or D admixtures at high dosage rates, in combination with Types C or E (for acceleration), may also be used to produce the same effect. When flowing concrete is so produced, it is sometimes possible to increase the amount of coarse aggregate to take advantage of the fluidity of the concrete to flow into place in constricted areas of heavy reinforcement. Flowing concrete has a tendency to segregate; therefore, care must be taken to achieve a proper volume of mortar in the concrete required for cohesion without making the concrete undesirably sticky.

ASTM C 494 lists seven types of chemical admixtures as to their expected performance in concrete. It does not classify chemical admixtures as to their composition. ACI 212.2R lists five general classes of materials used to formulate most water-reducing, set-controlling chemical admixtures. This report, as well as ACI 301 and ACI 318, should be reviewed to determine when restrictions should be placed upon the use of certain admixtures for a given class of concrete. For example, admixtures containing purposely added calcium chloride have been found to accelerate the potential for stress-corrosion of tensioned cables imbedded in concrete when moisture and oxygen are available.

4.4 *Other cementitious materials* -- Cementitious materials other than hydraulic cement are often used in concrete in combination with portland or blended cement for economy, reduction of heat of hydration, improved workability, improved strength and/or improved durability under the anticipated service environment. These materials include fly ash, natural pozzolans (ASTM C 618), GGBF slag (ASTM C 989), and silica fune. Not all of these materials will provide all of the benefits listed.

As defined in ASTM C 618, pozzolans are: "Siliceous or siliceous and aluminous materials which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties . . . " Fly ash is the "finely divided residue that results from the combustion of ground or powdered coal . . . " Fly ash used in concrete is classified into two categories: Class F, which has pozzolanic properties, and Class C, which, in addition to having pozzolanic properties, also has some cemetitious properties in that this material may be self-setting when mixed with water. Class C fly ash may contain lime (CaO) amounts higher than 10 percent. The use of fly ash in concrete is more fully described and discussed in ACI 226.3R.

Blast-furnace slag is a by-product of the production of pig iron. When this slag is rapidly quenched and ground, it will possess latent cementitious properties. After processing, the material is known as GGBF slag, whose hydraulic properties may vary and can be separated into grades noted in ASTM C 989. The grade classification gives guidance on the relative strength potential of 50 percent GGBF slag mortars to the reference portland cement at 7 and 28 days. GGBF slag grades are 80, 100, and 120, in order of increasing strength potential.

Silica fume,* as used in concrete, is a by-product resulting from the reduction of high-purity quartz with coal and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. The silica fume, which condenses from the gases escaping from the furnaces, has a very high content of amorphous silicon dioxide and consists of very fiie spherical particles.

Uses of silica fume in concrete fall into three general categories:

a. Production of low permeability concrete with enhanced durability.
b. Production of high-strength concrete.
c. As a cement replacement (The current economics of cement costs versus silica fume costs do not usually make this a viable use for silica fume in the U.S.).

* Other names that have been used include silica dust, condensed or pre-compacted silica fume and micro silica; the most appropriate is silica fume.

Silica fume typically has a specific gravity of about 2.2. The lower specific gravity of silica fume compared with that of portland cement means that when replacement is based on weight (mass), a larger volume of silica fume is added than the volume of cement removed. Thus, the volume of cementitious paste increases and there is actually a lowering of the water-cementitious materials ratio on a volume basis.

The particle-size distribution of a typical silica fume shows that most particles are smaller than one micrometer (1 µm with an average diameter of about 0.1 µm, which is approximately one hundred times smaller than the average size cement particle).

The extreme fineness and high silica content of silica fume make it a highly effective pozzolanic material. The silica fume reacts pozzolanically with the calcium hydroxide produced during the hydration of cement to form the stable cementitious compound, calcium silicate hydrate (CSH).

Silica fume has been successfully used to produce very high strength (over 18,000 psi), low permeability, and chemically resistant concretes. Such concretes contain up to 25 percent silica fume by weight (mass) of cement. The use of this high amount of silica fume generally makes the concrete difficult to work. The mixing water demand of a given concrete mixture incorporating silica fume increases with increasing amounts of silica fume.

To maximize the full strength-producing potential of silica fume in concrete, it should always be used with a water-reducing admixture, preferably a high-range, water-reducing (HRWR) admixture. the dosage of the HRWR will depend on the percentages of silica fume and the type of HRWR used.

When proportioning concrete containing silica fume, the following should be considered:

a. Mixing -- The amount of mixing will depend on the percentage of silica fume used and the mixing conditions. Mixing time may need to be increased to achieve thorough distribution when using large quantities of silica fume with low water content concrete. The use of HRWR assists greatly in achieving uniform dispersion.
b. Air-entrainment -- The amount of air-entraining admixture to produce a required volume of air in concrete may increase with increasing amounts of silica fume due to the very high surface area of the silica fume and the presence of any carbon within the silica fume. Air entrainment is not usually used in high strength concretes unless they are expected to be exposed to freezing and thawing when saturated with water or to deicing salts.
c. Workability -- Fresh concrete containing silica fume is generally more cohesive and less prone to segregation than concrete without silica fume. This increase in cohesiveness and reduction to bleeding can provide improved pumping properties. Concrete containing silica fume in excess of 10 percent by

weight (mass) of the cementitious materials may become sticky. It may be necessary to increase the slump 2 to 5 in. to maintain the same workability for a given length of time.

d. Bleeding -- Concrete containing silica fume exhibits reduced bleeding. This reduced bleeding is primarily caused by the high surface area of the silica fume particles, resulting in very little water being left in the mixture for bleeding. As the result of reduced bleeding of concrete containing silica fume, there is a greater tendency for plastic shrinkage cracking to occur.

Typically, the materials listed previously are introduced into the concrete mixer separately. In some cases, however, these same materials may be blended with portland cement in fixed proportions to produce a blended cement, ASTM C 595. Like air-entraining admixtures added to the concrete at the time of batching, the addition of GGBF slag also gives the producer flexibility to achieve desired concrete performance.

When proportioning concrete containing a separately batched, cementitious material such as fly ash, natural pozzolan, GGBF slag, or silica fume, a number of factors must be considered. These include:

a. Chemical activity of the cementitious material and its effect on concrete strength at various ages.
b. Effect on the mixing-water demand needed for workability and placeability.
c. Density (or specific gravity) of the material and its effect on the volume of concrete produced in the batch.
d. Effect on the dosage rate of chemical admixtures and/or air-entraining admixtures used in the mixture.
e. Effect of combinations of materials on other critical properties of the concrete, such as time of set under ambient temperature conditions, heat of hydration, rate of strength development, and durability.
f. Amount of cementitious materials and cement needed to meet the requirements for the particular concrete.

4.4.1 Methods for proportioning and evaluating concrete mixtures containing these supplementary cementitious materials must be based on trial mixtures using a range of ingredient proportions. By evaluating their effect on strength, water requirement, time of set, and other important properties, the optimum amount of cementitious materials can be determined. In the absence of prior information and in the interest of preparing estimated proportions for a first trial batch or a series of trial batches in accordance with ASTM C 192, the following general ranges are given based on the percentage of the ingredients by the total weight of cementitious material used in the batch for structural concrete:

Class F fly ash -- 15 to 25 percent
Class C fly ash -- 15 to 35 percent
Natural pozzolans -- 10 to 20 percent
Ground granulated blast-furnace slag -- 25 to 70 percent
Silica fume -- 5 to 15 percent

For special projects, or to provide certain special required properties, the quantity of the materials used per yd^3 of concrete may be different from that shown above.

In cases where high early strengths are required, the total weight of cementitious material may be greater than would be needed if portland cement were the only cementitious material. Where high early strength is not required higher percentages of fly ash are frequently used.

Often, it is found that with the use of fly ash and GGBF slag, the amount of mixing water required to obtain the desired slump and workability of concrete may be lower than that used in a portland cement mixture using only portland cement. When silica fume is used, more mixing water is usually required than when using only portland cement. In calculating the amount of chemical admixtures to dispense for a given batch of concrete, the dosage should generally be applied to the total amount of cementitious material. Under these conditions the reduction in mixing water for conventional water-reducing admixtures (Types A, D, and E) should be at least 5 percent, and for water-reducing, high-range admixtures at least 12 percent. When GGBF slag is used in concrete mixtures containing some high-range water-reducing admixtures, the admixture dosage may be reduced by approximately 25 percent compared to mixtures containing only portland cement.

4.4.2 Due to differences in their specific gravities, a given weight of a supplementary cementitious material will not occupy the same volume as an equal weight of portland cement. The specific gravity of blended cements will be less than that of portland cement. Thus, when using either blended cements or supplementary cementitious materials, the yield of the concrete mixture should be adjusted using the actual specific gravities of the materials used.

4.4.3 Class C fly ash, normally of extremely low carbon content, usually has little or no effect on entrained air or on the air-entraining admixture dosage rate. Many Class F fly ashes may require a higher dosage of air-entraining admixture to obtain specified air contents; if carbon content is high, the dosage rate may be several times that of non-fly ash concrete. The dosage required may also be quite variable. The entrained air content of concrete containing high carbon-content fly ash may be difficult to obtain and maintain. Other cementitious materials may be treated the same as cement in determining the proper quantity of air-entraining admixtures per yd^3 of concrete or per 100 lb of cementitious material used.

4.4.4 Concrete containing a proposed blend of cement, other cementitious materials, and admixtures should be tested to determine the time required for setting at various temperatures. The use of most supplementary cementitious materials generally slows the time-of-set of the concrete, and this period may be prolonged by higher percentages of these materials in the cementitious blend, cold weather, and the presence of chemical admixtures not formulated especially for acceleration.

Because of the possible adverse effects on finishing time and consequent labor costs, in some cold climates the proportion of other cementitious materials in the blend may have to be reduced below the optimum amount for strength considerations. Some Class C fly ashes may affect setting time while some other cementitious materials may have little effect on setting time. Any reduction in cement content will reduce heat generation and normally prolong the setting time.

CHAPTER 5 -- BACKGROUND DATA

5.1 To the extent possible, selection of concrete proportions should be based on test data or experience with the materials actually to be used. Where such background is limited or not available, estimates given in this recommended practice may be employed.

5.2 The following information for available materials will be useful:

5.2.1 Sieve analyses of fine and coarse aggregates.

5.2.2 Unit weight of coarse aggregate.

5.2.3 Bulk specific gravities and absorptions of aggregates.

5.2.4 Mixing-water requirements of concrete developed from experience with available aggregates.

5.2.5 Relationships between strength and water-cement ratio or ratio of water-to-cement plus other cementitious materials, for available combinations of cements, other cementitious materials if considered, and aggregates.

5.2.6 Specific gravities of portland cement and other cementitious materials, if used.

5.2.7 Optimum combination of coarse aggregates to meet the maximum density gradings for mass concrete as discussed in Section 5.3.2.1 of Appendix 5.

5.3 Estimates from Tables 6.3.3 and 6.3.4, respectively, may be used when items in Section 5.2.4 and Section 6.3.5 are not available. As will be shown, proportions can be estimated without the knowledge of aggregate-specific gravity and absorption, Section 5.2.3.

CHAPTER 6 -- PROCEDURE

6.1 The procedure for selection of mix proportions given in this section is applicable to normal weight concrete. Although the same basic data and procedures can be used in proportioning heavyweight and mass concretes, additional information and sample computations for these types of concrete are given in Appendixes 4 and 5, respectively.

6.2 Estimating the required batch weights for the concrete involves a sequence of logical, straightforward steps which, in effect, fit the characteristics of the available materials into a mixture suitable for the work. The question of suitability is frequently not left to the individual selecting the proportions. The job specifications may dictate some or all of the following:

6.2.1 Maximum water-cement or water-cementitious material ratio.

6.2.2 Minimum cement content.

6.2.3 Air content.

6.2.4 Slump.

6.2.5 Maximum size of aggregate.

6.2.6 Strength.

6.2.7 Other requirements relating to such things as strength overdesign, admixtures, and special types of cement, other cementitious materials, or aggregate.

6.3 Regardless of whether the concrete characteristics are prescribed by the specifications or are left to the individual selecting the proportions, establishment of batch weights per yd^3 of concrete can be best accomplished in the following sequence:

6.3.1 *Step 1. Choice of slump* -- If slump is not specified, a value appropriate for the work can be selected from Table 6.3.1. The slump ranges shown apply when vibration is used to consolidate the concrete. Mixes of the stiffest consistency that can be placed efficiently should be used.

Table 6.3.1 -- Recommended slumps for various types of construction*

Types of construction	Slump, in. Maximum†	Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

*Slump may be increased when chemical admixtures are used, provided that the admixture-treated concrete has the same or lower water-cement or water-cementitious material ratio and does not exhibit segregation potential or excessive bleeding.

†May be increased 1 in. for methods of consolidation other than vibration.

6.3.2 *Step 2. Choice of maximum size of aggregate* -- Large nominal maximum sizes of well graded aggregates have less voids than smaller sizes. Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete. Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure. In no event should the nominal maximum size exceed one-fifth of the narrowest dimension between sides of forms, one-third the depth of slabs, nor three-fourths of the minimum clear spacing between individual reinforcing bars, bundles of bars, or pretensioning strands. These limitations are sometimes waived if workability and methods of consolidation are such that the concrete can be placed without honeycomb or void. In areas congested with reinforcing steel, post-tension ducts or conduits, the proportioner should select a nominal maximum size of the aggregate so concrete can be placed without excessive segregation, pockets, or voids. When high strength concrete is desired, best results may be obtained with reduced nominal maximum sizes of aggregate since these produce higher strengths at a given water-cement ratio.

Table 6.3.3 — Approximate mixing water and air content requirements for different slumps and nominal maximum sizes of aggregates

	Water, lb/yd³ of concrete for indicated nominal maximum sizes of aggregate							
Slump, in.	3/8 in.*	1/2 in.*	3/4 in.*	1 in.*	1-1/2 in.*	2 in.*†	3 in.†‡	6 in.†‡
	Non-air-entrained concrete							
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	—
More than 7*	—	—	—	—	—	—	—	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
	Air-entrained concrete							
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	—
More than 7*	—	—	—	—	—	—	—	—
Recommended averages§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**,††	1.0**,††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**,††	3.0**,††
Severe exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**,††	4.0**,††

*The quantities of mixing water given for air-entrained concrete are based on typical total air content requirements as shown for "moderate exposure" in the table above. These quantities of mixing water are for use in computing cement contents for trial batches at 68 to 77 F. They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. Rounded aggregate will generally require 30 lb less water for non-air-entrained and 25 lb less for air-entrained concretes. The use of water-reducing chemical admixtures, ASTM C 494, may also reduce mixing water by 5 percent or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water. The slump values of more than 7 in. are only obtained through the use of water-reducing chemical admixture; they are for concrete containing nominal maximum size aggregate not larger than 1 in.

†The slump values for concrete containing aggregate larger than 1½ in. are based on slump tests made after removal of particles larger than 1½ in. by wet-screening.

‡These quantities of mixing water are for use in computing cement factors for trail batches when 3 in. or 6 in. nominal maximum size aggregate is used. They are average for reasonably well-shaped coarse aggregates, well graded from coarse to fine.

§Additional recommendations for air content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201, 345, 318, 301, and 302. ASTM C 94 for ready-mixed concrete also gives air-content limits. The requirements in other documents may not always agree exactly, so in proportioning concrete consideration must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

**For concrete containing large aggregates that will be wet-screened over the 1½ in. sieve prior to testing for air content, the percentage of air expected in the 1½ in. minus material should be as tabulated in the 1½ in. column. However, initial proportioning calculations should include the air content as a pecent of the whole.

††When using large aggregate in low cement factor concrete, air entrainment need not be detrimental to strength. In most cases mixing water requirement is reduced sufficiently to improve the water-cement ratio and to thus compensate for the strength-reducing effect of air-entrained concrete. Generally, therefore, for these large nominal maximum sizes of aggregate, air contents recommended for extreme exposure should be considered even though there may be little or no exposure to moisture and freezing.

‡‡These values are based on the criteria that 9 percent air is needed in the mortar phase of the concrete. If the mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate the needed air content by taking 9 percent of the actual mortar volume.

6.3.3 *Step 3. Estimation of mixing water and air content* -- The quantity of water per unit volume of concrete required to produce a given slump is dependent on: the nominal maximum size, particle shape, and grading of the aggregates; the concrete temperature; the amount of entrained air; and use of chemical admixtures. Slump is not greatly affected by the quantity of cement or cementitious materials within normal use levels (under favorable circumstances the use of some finely divided mineral admixtures may lower water requirements slightly -- see ACI 212.1R). Table 6.3.3 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment. Depending on aggregate texture and shape, mixing water requirements may be somewhat above or below the tabulated values, but they are sufficiently accurate for the first estimate. The differences in water demand are not necessarily reflected in strength since other compensating factors may be involved. A rounded and an angular coarse aggregate, both well and similarly graded and of good quality, can be expected to produce concrete of about the same compressive strength for the same cement factor in spite of differences in w/c or $w/(c + p)$ resulting from the different mixing water requirements. Particle shape is not necessarily an indicator that an aggregate will be either above or below in its strength-producing capacity.

Chemical admixtures -- Chemical admixtures are used to modify the properties of concrete to make it more workable, durable, and/or economical; increase or decrease the time of set; accelerate strength gain; and/or control temperature gain. Chemical admixtures should be used only after an appropriate evaluation has been conducted to show that the desired effects have been accomplished in the particular concrete under the conditions of intended use. Water-reducing and/or set-controlling admixtures conforming to the requirements of ASTM C 494, when used singularly or in combination with other chemical admixtures, will reduce significantly the quantity of water per unit volume of concrete. The use of some chemical admixtures, even at the same slump, will improve such qualities as workability, finishability, pumpability, durability, and compressive and flexural strength. Significant volume of liquid admixtures should be considered as part of the mixing water. The slumps shown in Table 6.3.1, "Recommended Slumps for Various Types of Construction," may be increased when chemical admixtures are used, providing the admixture-treated concrete has the same or a lower water-cement ratio and does not exhibit segregation potential and excessive bleeding. When only used to increase slump, chemical admixtures may not improve any of the properties of the concrete.

Table 6.3.3 indicates the approximate amount of entrapped air to be expected in non-air-entrained concrete in the upper part of the table and shows the recommended average air content for air-entrained concrete in the lower part of the table. If air entrainment is needed or desired, three levels of air content are given for each aggregate size depending on the purpose of the entrained air and the severity of exposure if entrained air is needed for durability.

Mild exposure -- When air entrainment is desired for a beneficial effect other than durability, such as to improve workability or cohesion or in low cement factor concrete to improve strength, air contents lower than those needed for durability can be used. This exposure includes indoor or outdoor service in a climate where concrete will not be exposed to freezing or to deicing agents.

Moderate exposure -- Service in a climate where freezing is expected but where the concrete will not be continually exposed to moisture or free water for long periods prior to freezing and will not be exposed to deicing agents or other aggressive chemicals. Examples include: exterior beams, columns, walls, girders, or slabs that are not in contact with wet soil and are so located that they will not receive direct applications of deicing salts.

Severe exposure -- Concrete that is exposed to deicing chemicals or other aggressive agents or where the concrete may become highly saturated by continued contact with moisture or free water prior to freezing. Examples include: pavements, bridge decks, curbs, gutters, sidewalks, canal linings, or exterior water tanks or sumps.

The use of normal amounts of air entrainment in concrete with a specified strength near or about 5000 psi may not be possible due to the fact that each added percent of air lowers the maximum strength obtainable with a given combination of materials.' In these cases the exposure to water, deicing salts, and freezing temperatures should be carefully evaluated. If a member is not 'continually wet and will not be exposed to deicing salts, lower air-content values such as those given in Table 6.3.3 for moderate exposure are appropriate even though the concrete is exposed to freeziug and thawing temperatures. However, for an exposure condition where the member may be saturated prior to freezing, the use of air entrainment should not be sacrificed for strength. In certain applications, it may be found that the content of entrained air is lower than that specified, despite the use of usually satisfactory levels of air-entraining admixture. This happens occasionally, for example, when very high cement contents are involved. In such cases, the achievement of required durability may be demonstrated by satisfactory results of examination of air-void structure in the paste of the hardened concrete.

When trial batches are used to establish strength relationships or verify strength-producing capability of a mixture, the least favorable combination of mixing water and air content should be used. The air content should be the maximum permitted or likely to occur, and the concrete should be gaged to the highest permissrble slump. This will avoid developing an over-optimistic estimate of strength on the assumption that average rather than extreme conditions will prevail in the field. If the concrete obtained in the field has a lower slump and/or air content, the proportions of ingredients should be adjusted to maintain required yield. For additional information on air content recommendations, see ACI 201.2R, 301, and 302.1R.

6.3.4 *Step 4. Selection of water-cement or water-cementitious materials ratio* -- The required w/c or $w/(c + p)$ is determined not only by strength requirements but also by factors such as durability. Since different aggregates, cements, and cementitious materials generally produce different strengths at the same w/c or $w/(c + p)$, it is highly desirable to have or to develop the relationship between strength and w/c or $w/(c + p)$ for the materials actually to be used. In the absence of such data, approximate and relatively conservative values for concrete containing Type I portland cement can be taken from Table 6.3.4(a). With typical materials, the tabulated w/c or $w/(c + p)$ should produce the strengths shown, based on 28-day tests of specimens cured under standard laboratory conditions. The average strength selected must, of course, exceed the specific strength by a sufficient margin to keep the number of low tests within specific limits -- see ACI 214 and ACI 318.

Table 6.3.4(a) — Relationship between water-cement or water-cementitious materials ratio and compressive strength of concrete

Compressive strength at 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

*Values are estimated average strengths for concrete containing not more than 2 percent air for non-air-entrained concrete and 6 percent total air content for air-entrained concrete. For a constant w/c or $w/(c+p)$, the strength of concrete is reduced as the air content is increased. 28-day strength values may be conservative and maychange when various cementitious materials are used. The rate at which the 28-daystrengthis developed may also change.

Strength is based on 6 x 12 in. cylinders moist-cured for 28 days in accordance with the sections on "Initial Curin g" and "Curing of Cylinders for Checking the Adequacy of Laboratory Mixture Proportions for Strength or as the Basis for Acceptance or for Quality Control" of ASTM method C 31 for Making and Curing Concrete Specimens in the Field. These are cylinders cured moist a 73.4 ± 3 F (23 ± 1.7 C) prior to testing.

The relationship in this table assumes a nominal maximum aggregate size of about ¾ to 1 in. For a given source of aggregate, strength produced at a given w/c or $w/(c+p)$ will increase as nominal maximum size of aggregate decreases: see Sections 3.4 and 6.3.2.

For severe conditions of exposure, the w/c or $w/(c + p)$ ratio should be kept low even though strength requirements may be met with a higher value. Table 6.3.4(b) gives limiting values.

When natural pozzolans, fly ash, GGBF slag, and silica fume, hereafter referred to as pozzolanic materials, are used in concrete, a water-to-cement plus pozzolanic materials ratio (or water-to-cement plus other cementitious materials ratio) by weight must be considered in place of the traditional water-cement ratio by weight. There are two ap-

Table 6.3.4(b) — Maximum permissible water-cement or water-cementitious materials ratios for concrete in severe exposures*

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing+	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1 in. cover over steel	0.45	0.40+
All other structures	0.50	0.45+

*Based on report of ACI Committee 201. Cementitious materials other than cement should conform to ASTM C 618 and C 989.

'Concrete should also be air-entrained.

+If sulfate resisting cement (Type II or Type V of ASTM C 150) is used, permissible water-cement or water-cementitious materials ratio may be increased by 0.05.

proaches normally used in determining the $w/(c+p)$ ratio that will be considered equivalent to the w/c of a mixture containing only portland cement: (1) equivalent weight of pozzolanic materials or (2) equivalent absolute volume of pozzolanic materials in the mixture. For the first approach, the weight equivalency, the total weight of pozzolanic materials remains the same [that is, $w/(c+p) = w/c$ directly]: but the total absolute volume of cement plus pozzolanic materials will normally be slightly greater. With the second approach, using the Eq. (6.3.4.2), a $w/(c+p)$ by weight is calculated that maintains the same absolute volume relationship but that will reduce the total weight of cementitious material since the specific gravities of pozzolanic materials are normally less than that of cement.

The equations for converting a target water-cement ratio w/c to a weight ratio of water to cement plus pozzolanic materials $w/(c+p)$ by (1) weight equivalency or (2) volume equivalency are as follows:

Eq. (6.3.4.1)—Weight equivalency

$$\frac{w}{c+p} \text{ weight ratio, weight equivalency} = \frac{w}{c}$$

where

$\frac{w}{c+p}$ = *weight of water divided by weight of cement + pozzolanic materials*

$\frac{w}{c}$ = *target water-cement ratio by weight*

When the weight equivalency approach is used, the percentage or fraction of pozzolanic materials used in the cementitious material is usually expressed by weight. That is, F_w, the pozzolanic materials percentage by weight of total cement plus pozzolanic materials, expressed as a decimal factor, is

$$F_w = \frac{p}{c+p}$$

where

F_w = pozzolanic materials percentage by weight, expressed as a decimal factor

p = weight of pozzolanic materials

c = weight of cement

(Note: If only the desired pozzolanic materials percentage factor by absolute volume F_v is known, it can be converted to F_w as follows

$$F_w = \frac{1}{1 + \left(\frac{3.15}{G_p}\right)\left(\frac{1}{F_v} - 1\right)}$$

where

F_v = pozzolanic materials percentage by absolute volume of the total absolute volume of cement plus pozzolanic materials expressed as a decimal factor

G_p = specific gravity of pozzolanic materials

3.15 = specific gravity of portland cement [use actual value if known to be different])

Example 6.3.4.1 — Weight equivalency

If a water-cement ratio of 0.60 is required and a fly ash pozzolan is to be used as 20 percent of the cementitious material in the mixture by weight ($F_w = 0.20$), then the required water-to-cement plus pozzolanic material ratio on a weight equivalency basis is

$$\frac{w}{c+p} = \frac{w}{c} = 0.60, \text{ and}$$

$$F_w = \frac{p}{c+p} = 0.20$$

Assuming an estimated mixing-water requirement of 270 lb/yd^3, then the required weight of cement + pozzolan is 270 ÷ 0.60 = 450 lb; and the weight of pozzolan is (0.20)(450) = 90 lb. The weight of cement is, therefore, 450 - 90 = 360 lb. If instead of 20 percent fly ash by weight, 20 percent by absolute volume of cement plus pozzolan was specified (F_v = 0.20), the corresponding weight factor is computed as follows for a fly ash with an assumed gravity of 2.40:

$$F_w = \frac{1}{1+\left(\frac{3.15}{G_p}\right)\left(\frac{1}{F_v}-1\right)}$$

$$\frac{1}{1+\left(\frac{3.15}{2.40}\right)\left(\frac{1}{0.2}-1\right)}$$

$$F_w = \frac{1}{1+(1.31)(4)} = \frac{1}{1+5.24} = \frac{1}{6.24} = 0.16$$

In this case 20 percent by absolute volume is 16 percent by weight, and the weight of pozzolan in the batch would be (0.16)(450) = 72 lb, and the weight of cement 450 - 72 = 378 lb.

Eq. (6.3.4.2) -- Absolute volume equivalency

$\frac{W}{c+p}$ *weight ratio, absolute volume equivalency* =

$$\frac{3.15\frac{w}{c}}{3.15(1-F_v)+G_p(F_v)}$$

where

$\frac{w}{c+p}$ = weight of water divided by weight of cement + pozzolanic materials

$\frac{w}{c}$ = target water-cement ratio by weight

3.15 = specific gravity of portland cement (use actual value if known to be different)

F_v = pozzolan percentage by absolute volume of the total absolute volume of cement plus poxzolan, expressed as a decimal factor

(Note: If only the desired pozzolan percentage by weight F_w is known, it can be converted to F_v as follows

$$F_v = \frac{1}{1+\left(\frac{G_p}{3.15}\right)\left(\frac{1}{F_w}-1\right)}$$

where these symbols are the same as defined previously.)

Example 6.3.4.2 -- Absolute volume equivalency

Use the same basic data as Example 6.3.4.1, but it should be specified that the equivalent water-to-cement plus pozzolan ratio be established on the basis of absolute volume, which will maintain, in the mixture, the same ratio of volume of water to volume of cementitious material when changing from cement only to cement plus pozzolan. Again the required water-cement ratio is 0.60, and it is assumed initially that it is desired to use 20 percent by absolute volume of fly ash (F_v = 0.20). The specific gravity of the fly ash is assumed to be 2.40 in this example

$$\frac{w}{c+p} = \frac{3.15\left(\frac{w}{c}\right)}{3.15(1-F_v)+G_p(F_v)}$$

$$= \frac{(3.15)\ (0.60)}{(3.15)\ 0.80) + (2.40)\ (0.20)} = \frac{1.89}{2.52+0.48} = \frac{1.89}{3.00} = 0.63$$

So the target weight ratio to maintain an absolute volume equivalency is $w/(c+p)$ = 0.63. If the mixing water is again 270 lb/yd^3, then the required weight of cement + pozzolan is 270 ÷ 0.63 = 429 lb, and, since the corresponding weight percentage factor for F_v = 0.20 is F_w = 0.16 as calculated in Example 6.3.4.1, the weight of fly ash to be used is (0.16)(429) = 69 lb and the weight of cement is 429 - 69 = 360 lb. The volume equivalency procedure provides lower weights of cementitious materials. Checking the absolute volumes

$$\textit{fly ash} = \frac{69}{(2.40)(62.4)} = 0.461\text{ ft}^3$$

$$\textit{cement} = \frac{360}{(3.15)\ (62.4)} = 1.832\text{ ft}^3$$

$$\text{total} = 0.461 + 1.832 = 2.293\text{ ft}^3$$

$$\textit{percent pozzolan by volume} = \frac{0.461 \times 100}{2.293} = 20\ \textit{percent}$$

If, instead of 20 percent fly ash by volume (F_v = 0.20), a weight percentage of 20 percent was specified (F_w = 0.20), it could be converted to F_v using G_p = 2.40 and the appropriate formula

$$F_v = \frac{1}{1+\left(\frac{G_p}{3.15}\right)\left(\frac{1}{F_w}-1\right)}$$

$$F_v = \frac{1}{1+\left(\frac{2.40}{3.15}\right)\left(\frac{1}{0.2}-1\right)}$$

$$F_v = \frac{1}{1+(0.762)(4)} = \frac{1}{4.048} = 0.247$$

In this case 20 percent by weight is almost 25 percent by absolute volume. The equivalent w/(c + p) ratio by volume will have to be recomputed for this condition since F_v has been changed from that originally assumed in this example

$$\frac{W}{c+p} = \frac{3.15\left(\frac{w}{c}\right)}{3.15(1-F_v)+G_p(F_v)} = \frac{(3.15)(0.60)}{3.15(0.75)+2.40(0.25)} = \frac{1.89}{2.36+0.60} = \frac{1.89}{2.96} = 0.64$$

Total cementitious material would be 270 ÷ 0.64 = 422 lb. Of this weight 20 percent (F_w = 0.20) would be fly ash; (422)(0.20) = 84 lb of fly ash and 422 - 84 = 338 lb of cement.

6.3.5 *Step 5. Calculation of cement content* -- The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above. The required cement is equal to the estimated mixing-water content (Step 3) divided by the water-cement ratio (Step 4). If, however, the specification includes a separate minimum limit on cement in addition to requirements for strength and durability, the mixture must be based on whichever criterion leads to the larger amount of cement.

The use of pozzolanic or chemical admixtures will affect properties of both the fresh and hardened concrete. See ACI 212.

6.3.6 *Step 6. Estimation of coarse aggregate content* -- Aggregates of essentially the same nominal maximum size and grading will produce concrete of satisfactory workability when a given volume of coarse aggregate, on an oven-dry-rodded basis, is used per unit volume of concrete. Appropriate values for this aggregate volume are given in Table 6.3.6. It can be seen that, for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent only on its nominal maximum size and the fineness modulus of the fine aggregate. Differences in the amount of mortar required for workability with different aggregates, due to differences in particle shape and grading, are compensated for automatically by differences in oven-dry-rodded void content.

The volume of aggregate in ft^3, on an oven-dry-rodded basis, for a yd^3 of concrete is equal to the value from Table 6.3.6 multiplied by 27. This volume is converted to dry weight of coarse aggregate required in a yd^3 of concrete by multiplying it by the oven-dry-rodded weight per ft^3 of the coarse aggregate.

6.3.6.1 For more workable concrete, which is sometimes required when placement is by pump or when concrete must be worked around congested reinforcing steel, it may be desirable to reduce the estimated coarse aggregate content determined using Table 6.3.6 by up to 10 percent. However, caution must be exercised to assure that the resulting slump, water-cement or water-cementitious materials ratio, and strength properties of the concrete are consistent with the recommendations in Sections 6.3.1 and 6.3.4 and meet applicable project specification requirements.

6.3.7 *Step 7. Estimation of fine aggregate content* -- At completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Either of two procedures may be employed: the weight method (Section 6.3.7.1) or the absolute volume method (Section 6.3.7.2).

6.3.7.1 If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Often the unit weight of concrete is known with reasonable accuracy from previous experience with the materials. In the absence of such information, Table 6.3.7.1 can be used to make a first estimate. Even if the estimate of concrete weight per yd^3 is rough, mixture proportions will be sufficiently accurate to permit easy adjustment on the basis of trial batches as will be shown in the examples.

Table 6.3.6 — Volume of coarse aggregate per unit of volume of concrete

Nominal maximum size of aggregate, in.	Volume of oven-dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli of fine aggregate†			
	2.40	2.60	2.80	3.00
⅜	0.50	0.48	0.46	0.44
½	0.59	0.57	0.55	0.53
¾	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1½	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in oven dry rodded condition as described in ASTM C 29.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete, such as required for concrete pavement construction, they may be increased about 10 percent. For more workable concrete see Section 6.3.6.1.

†See ASTM C 136 for calculation of fineness modulus.

Table 6.3.7.1 — First estimate of weight of fresh concrete

Nominal maximum size of aggregate, in.	First estimate of concrete weight, lb/yd³*	
	Non-air-entrained concrete	Air-entrained concrete
⅜	3840	3710
½	3890	3760
¾	3960	3840
1	4010	3850
1½	4070	3910
2	4120	3950
3	4200	4040
6	4260	4110

*Values calculated by Eq. (6-1) for concrete of medium richness (550 lb of cement per yd^3) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 3 to 4 in. slump in Table 6.3.3. If desired, the estimated weight may be refined as follows if necessary information is available: for each 10 lb difference in mixing water from the Table 6.3.3 values for 3 to 4 in. slump, correct the weight per yd^3 15 lb in the opposite direction; for each 100 lb difference in cement content from 550 lb, correct the weight per yd^3 15 lb in the same direction; for each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete weight 100 lb in the same direction. For air-entrained concrete the air content for severe exposure from Table 6.3.3 was used. The weight can be increased 1 percent for each percent reduction in air content from that amount.

If a theoretically exact calculation of fresh concrete weight per yd^3 is desired, the following formula can be used

$$U = 16.85 \quad G_a \; (100 - A) + c(1 - \quad G_a/G_c) \quad w(G_a - 1) \qquad (6\text{-}1)$$

where

U = weight in lb of fresh concrete per yd^3
G_a = weighted average specific gravity of combined fine and coarse aggregate, bulk SSD*
G_c = specific gravity of cement (generally 3.15)
A = air content, percent
w = mixing water requirement, lb/yd^3
c = cement requirement, lb/yd^3

6.3.7.2 A more exact procedure for calculating the required amount of fine aggregate involves the use of volumes displaced by the ingredients. In this case, the total volume displaced by the known ingredients--water, air, cementitious materials, and coarse aggregate--is subtracted from the unit volume of concrete to obtain the required volume of fiie aggregate. The volume occupied in concrete by any ingredient is equal to its weight divided by the density of that material (the latter being the product of the unit weight of water and the specific gravity of the material).

6.3.8 *Step 8. Adjustments for aggregate moisture* -- The aggregate quantities actually to be weighed out for the concrete must allow for moisture in the aggregates. Generally, the aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface. The mixing water added to the batch must be reduced by an amount equal to the free moisture contributed by the aggregate -- i.e., total moisture minus absorption.

6.3.8.1 In some cases, it may be necessary to batch an aggregate in a dry condition. If the absorption (normally measured by soaking one day) is higher than approximately one percent, and if the pore structure within the aggregate particles is such that a significant fraction of the absorption occurs during the time prior to initial set, there may be a noticeable increase in the rate of slump loss due to an effective decrease in mixing water. Also, the effective water-cement ratio would be decreased for any water absorbed by the aggregate prior to set; this, of course, assumes that cement particles are not carried into aggregate particle pores.

6.3.8.2 Laboratory trial batch procedures according to ASTM C 192 allow the batching of laboratory air-dried aggregates if their absorption is less than 1.0 percent with an allowance for the amount of water that will be absorbed from the unset concrete. It is suggested by ASTM C 192 that the amount absorbed may be assumed to be 80 percent of the difference between the actual amount of water in the pores of the aggregate in their air-dry state and the nominal 24-hr absorption determined by ASTM C 127 or C 128. However, for higher-absorption aggregates, ASTM C 192 requires preconditioning of aggregates to satisfy absorption with adjustments in aggregate weight based on total moisture content and adjustment to include surface moisture as a part of the required amount of mixing water.

6.3.9 *Step 9. Trial batch adjustments* -- The calculated mixture proportions should be checked by means of trial batches prepared and tested in accordance with ASTM C 192 or full-sized field batches. Only sufficient water should be used to produce the required slump regardless of the amount assumed in selecting the trial proportions. The concrete should be checked for unit weight and yield (ASTM C 138) and for air content (ASTM C 138, C 173, or C 231). It should also be carefully observed for proper workability, freedom from segregation, and finishing properties. Appropriate adjustments should be made in the proportions for subsequent batches in accordance with the following procedure.

6.3.9.1 Re-estimate the required mixing water per yd^3 of concrete by multiplying the net mixing water content of the trial batch by 27 and dividing the product by the yield of the trial batch in ft^3. If the slump of the trial batch was not correct, increase or decrease the re-estimated amount of water by 10 lb for each 1 in. required increase or decrease in slump.

6.3.9.2 If the desired air content (for air-entrained concrete) was not achieved, re-estimate the admixture content required for proper air content and reduce or increase the mixing-water content of Paragraph 6.3.9.1 by 5 lb for each 1 percent by which the air content is to be increased or decreased from that of the previous trial batch.

6.3.9.3 If estimated weight per yd^3 of fresh concrete is the basis for proportioning, re-estimate that weight by multiplying the unit weight in lb/ft^3 of the trial batch by 27 and reducing or increasing the result by the anticipated percentage increase or decrease in air content of the adjusted batch from the first trial batch.

6.3.9.4 Calculate new batch weights starting with Step 4 (Paragraph 6.3.4), modifying the volume of coarse aggregate from Table 6.3.6 if necessary to provide proper workability.

CHAPTER 7 -- SAMPLE COMPUTATIONS

7.1 Two example problems will be used to illustrate application of the proportioning procedures. The following conditions are assumed:

7.1.1 Type I non-air-entraining cement will be used and its specific gravity is assumed to be 3.15.†

* SSD indicates saturated-surface-dry basis used in considering aggregate displacement. The aggregate specific gravity used in calculations must be consistent with the moisture condition assumed in the basic aggregate batch weights -- i.e., bulk dry if aggregate weights are stated on a dry basis, and bulk SSD if weights are stated on a saturated-surface-dry basis.

†The specific gravity values are not used if proportions are selected to provide a weight of concrete assumed to occupy 1 yd^3.

7.1.2 Coarse and fine aggregates in each case are of satisfactory quality and are graded within limits of generally accepted specifications. See ASTM C 33.

7.1.3 The coarse aggregate has a bulk specific gravity of 2.68* and an absorption of 0.5 percent.

7.1.4 The fine aggregate has a bulk specific gravity of 2.64,* an absorption of 0.7 percent, and a fineness modulus of 2.8.

7.2 *Example 1* -- Concrete is required for a portion of a structure that will be below ground level in a location where it will not be exposed to severe weathering or sulfate attack. Structural considerations require it to have an average 28-day compressive strength of 3500 psi.† On the basis of information in Table 6.3.1, as well as previous experience, it is determined that under the conditions of placement to be employed, a slump of 3 to 4 in. should be used and that the available No. 4 to M-in. coarse aggregate will be suitable. The dry-rodded weight of coarse aggregate is found to be 100 lb/ft^3. Employing the sequence outlined in Section 6, the quantities of ingredients per yd^3 of concrete are calculated as follows:

7.2.1 *Step 1* -- As indicated previously, the desired slump is 3 to 4 in.

7.2.2 *Step 2* -- The locally available aggregate, graded from No. 4 to 1½ in., has been indicated as suitable.

7.2.3 *Step 3* -- Since the structure will not be exposed to severe weathering, non-air-entrained concrete will be used. The approximate amount of mixing water to produce 3 to 4-in. slump in non-air-entrained concrete with M-in aggregate is found from Table 6.3.3 to be 300 lb/yd^3. Estimated entrapped air is shown as 1 percent.

7.2.4 *Step 4* -- From Table 6.3.4(a), the water-cement ratio needed to produce a strength of 3500 psi in non-air-entrained concrete is found to be about 0.62.

7.2.5 *Step 5* -- From the information derived in Steps 3 and 4, the required cement content is found to be 300/0.62 = 484 lb/yd^3.

7.2.6 *Step 6* -- The quantity of coarse aggregate is estimated from Table 6.3.6. For a fine aggregate having a fineness modulus of 2.8 and a 1½ in. nominal maximum size of coarse aggregate, the table indicates that 0.71 ft^3 of coarse aggregate, on a dry-rodded basis, may be used in each ft^3 of concrete. For each yd^3, therefore, the coarse aggregate will be 27 x 0.71 = 19.17 ft^3. Since it weighs 100 lb per ft^3, the dry weight of coarse aggregate is 1917 lb.

7.2.7 *Step 7* -- With the quantities of water, cement, and coarse aggregate established, the remaining material comprising the yd^3 of concrete must consist of fine aggregate and whatever air will be entrapped. The required fine aggregate may be determined on the basis of either weight or absolute volume as shown:

7.2.7.1 *Weight basis* -- From Table 6.3.7.1, the weight of a yd^3 of non-air-entrained concrete made with aggregate having a nominal maximum size of 1½ in. is estimated to be 4070 lb. (For a first trial batch, exact adjustments of this value for usual differences in slump, cement factor, and aggregate specific gravity are not critical.) Weights already known are:

Water, net mixing	300 lb
Cement	484 lb
Coarse aggregate	1917 lb (dry)‡
Total	2701 lb

The weight of fine aggregate, therefore, is estimated to be

$$4070 - 2701 = 1369 \text{ lb (dry)}‡$$

7.2.7.2 *Absolute volume basis* -- With the quantities of cement, water, and coarse aggregate established, and the approximate entrapped air content (as opposed to purposely entrained air) taken from Table 6.3.3, the fine aggregate content can be calculated as follows:

$$\text{Volume of water} = \frac{300}{62.4} = 4.81 \text{ ft}^3$$

$$\text{Solid volume of cement} = \frac{484}{3.15 \times 62.4} = 2.46 \text{ ft}^3$$

$$\text{Solid volume of coarse aggregate} = \frac{1917}{2.68 \times 62.4} = 11.46 \text{ ft}^3$$

$$\text{Volume of entrapped air} = 0.01 \times 27 = 0.27 \text{ ft}^3$$

$$\text{Total solid volume of ingredients except fine aggregate} = 19.00 \text{ ft}^3$$

$$\text{Solid volume of fine aggregate required} = 27 - 19.00 = 8.00 \text{ ft}^3$$

$$\text{Required weight of dry aggregate} = 8.00 \times 2.64 \times 62.4 = 1318 \text{ lb}$$

7.2.7.3 Batch weights per yd^3 of concrete calculated on the two bases are compared as follows:

	Based on estimated concrete weight, lb	Based on absolute volume of ingredients, lb
Water, net mixing	300	300
Cement	484	484
Coarse aggregate, dry	1917	1917
Fine aggregate, dry	1369	1318

* The specific gravity values are not used if proportions are selected to provide a weight of concrete assumed to occupy 1 yd^3.

† This is not the specified strength used for structural design but a higher figure expected to be produced on the average. For the method of determining the amount by which average strength should exceed design strength, see ACI 214.

‡ Aggregate absorption of 0.5 percent is disregarded since its magnitude is inconsequential in relation to other approximations.

7.2.8 *Step 8* -- Tests indicate total moisture of 2 percent in the coarse aggregate and 6 percent in the fine aggregate. If the trial batch proportions based on assumed concrete weight are used, the adjusted aggregate weights become:

Coarse aggregate, wet	1917 (1.02) = 1955 lb
Fine aggregate, wet	1369 (1.06) = 1451 lb

Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2 - 0.5 = 1.5 percent; that contributed by the fine aggregate to 6 - 0.7 = 5.3 percent. The estimated requirement for added water, therefore, becomes

$$300 - 1917(0.015) - 1369(0.053) = 199 \text{ lb}$$

The estimated batch weights for a yd^3 of concrete are:

Water, to be added	199 lb
Cement	484 lb
Coarse aggregate, wet	1955 lb
Fine aggregate, wet	1451 lb

7.2.9 *Step 9* -- For the laboratory trial batch, it was found convenient to scale the weights down to produce 0.03 yd^3 or 0.81 ft^3 of concrete. Although the calculated quantity of water to be added was 5.97 lb, the amount actually used in an effort to obtain the desired 3 to 4 in. slump is 7.00 lb. The batch as mixed therefore consists of:

Water, to be added	7.00 lb
Cement	14.52 lb
Coarse aggregate, wet	58.65 lb
Fine aggregate, wet	43.53 lb
Total	123.70 lb

The concrete has a measured slump of 2 in. and unit weight of 149.0 lb per ft^3. It is judged to be satisfactory from the standpoint of workability and finishing properties. To provide proper yield and other characteristics for future batches, the following adjustments are made:

7.2.9.1 Since the yield of the trial batch was

$$123.70/149.0 = 0.830 \text{ ft}^3$$

and the mixing water content was 7.00 (added) + 0.86 on coarse aggregate + 2.18 on fine aggregate = 10.04 lb, the mixing water required for a yd^3 of concrete with the same slump as the trial batch should be

$$10.04 \times 27/0.830 = 327 \text{ lb}$$

As indicated in Paragraph 6.3.9.1, this amount must be increased another 15 lb to raise the slump from the measured 2 in. to the desired 3 to 4 in. range, bringing the net mixing water to 342 lb.

7.2.9.2 With the increased mixing water, additional cement will be required to provide the desired water-cement ratio of 0.62. The new cement content becomes

$$342/0.62 = 552 \text{ lb}$$

7.2.9.3 Since workability was found to be satisfactory, the quantity of coarse aggregate per unit volume of concrete will be maintained the same as in the trial batch. The amount of coarse aggregate per yd^3 becomes

$$\frac{58.65}{0.83} \times 27 = 1908 \textit{ lb wet}$$

which is

$$\frac{1908}{1.02} = 1871 \textit{ lb dry}$$

and

$$1871\ (1.005) = 1880 \text{ SSD*}$$

7.2.9.4 The new estimate for the weight of a yd^3 of concrete is 149.0 x 27 = 4023 lb. The amount of fine aggregate required is therefore

$$4023 - (342 + 552 + 1880) = 1249 \text{ lb SSD}$$

or

$$1249/1.007 = 1240 \text{ lb dry}$$

The adjusted basic batch weights per yd^3 of concrete are:

Water, net mixing	342 lb
Cement	522 lb
Coarse aggregate, dry	1871 lb
Fine aggregate, dry	1240 lb

7.2.10 Adjustments of proportions determined on an absolute volume basis follow a procedure similar to that just outlined. The steps will be given without detailed explanation:

7.2.10.1 Quantities used in nominal 0.81 ft^3 batch are:

Water, added	7.00 lb
Cement	14.52 lb
Coarse aggregate, wet	58.65 lb
Fine aggregate, wet	41.91 lb
Total	122.08 lb

Measured slump 2 in.; unit weight 149.0 lb/ft^3; yield 122.08/149.0 = 0.819 ft^3, workability o.k.

7.2.10.2 Re-estimated water for same slump as

* Saturated-surface-dry

trial batch

$$\frac{27(7.00 + 0.86 + 2.09)}{0.819} = 328 \text{ lb}$$

Mixing water required for slump of 3 to 4 in.

$$328 + 15 = 343 \text{ lb}$$

7.2.10.3 Adjusted cement content for increased water

$$343/0.62 = 553 \text{ lb}$$

7.2.10.4 Adjusted coarse aggregate requirement

$$\frac{58.65 \times 27}{0.819} = 1934 \textit{ lb wet}$$

or

$$1934/1.02 = 1896 \text{ lb dry}$$

7.2.10.5 The volume of ingredients other than air in the original trial batch was

Water	$\frac{9.95}{62.4}$	=	0.159 ft^3
Cement	$\frac{14.52}{3.15 \times 62.4}$	=	0.074 ft^3
Coarse aggregate	$\frac{57.50}{2.68 \times 62.4}$	=	0.344 ft^3
Fine aggregate	$\frac{39.54}{2.64 \times 62.4}$	=	0.240 ft^3
Total		=	0.817 ft^3

Since the yield was 0.819 ft^3, the air content was

$$\frac{0.819 - 0.817}{0.819} = 0.2 \textit{ percent}$$

With the proportions of all components except fine aggregate established, the determination of adjusted yd^3 batch quantities can be completed as follows:

Volume of water	= $\frac{343}{62.4}$	=	5.50 ft^3
Volume of cement	= $\frac{553}{3.15 \times 62.4}$	=	2.81 ft^3
Volume of air	= 0.002 x 27	=	0.05 ft^3
Volume of coarse aggregate	= $\frac{1896}{2.68 \times 62.4}$	=	11.34 ft^3
Total volume exclusive of fine aggregate		=	19.70 ft^3
Volume of fine aggregate required	= 27 - 19.70	=	7.30 ft^3
Weight of fine aggregate (dry basis)	= 7.30 x 2.64 x 62.4	=	1203 lb

The adjusted basic batch weights per yd^3 of concrete are then:

Water, net mixing	343 lb
Cement	553 lb
Coarse aggregate, dry	1896 lb
Fine aggregate, dry	1203 lb

These differ only slightly from those given in Paragraph 7.2.9.4 for the method of assumed concrete weight. Further trials or experience might indicate small additional adjustments for either method.

7.3 *Example 2* -- Concrete is required for a heavy bridge pier that will be exposed to fresh water in a severe climate. An average 28-day compressive strength of 3000 psi will be required. Placement conditions permit a slump of 1 to 2 in. and the use of large aggregate, but the only economically available coarse aggregate of satisfactory quality is graded from No. 4 to 1 in. and this will be used. Its dry-rodded weight is found to be 95 lb/ft^3. Other characteristics are as indicated in Section 7.1.

The calculations will be shown in skeleton form only. Note that confusion is avoided if all steps of Section 6 are followed even when they appear repetitive of specified requirements.

7.3.1 *Step 1* -- The desired slump is 1 to 2 in.

7.3.2 *Step 2* -- The locally available aggregate, graded from No. 4 to 1 in., will be used.

7.3.3 *Step 3* -- Since the structure will be exposed to severe weathering, air-entrained concrete will be used. The approximate amount of mixing water to produce a 1 to 2-in. slump in air-entrained concrete with 1-in. aggregate is found from Table 6.3.3 to be 270 lb/yd^3. The recommended air content is 6 percent.

7.3.4 *Step 4* -- From Table 6.3.4(a), the water-cement ratio needed to produce a strength of 3000 psi in air-entrained concrete is estimated to be about 0.59. However, reference to Table 6.3.4(b), reveals that, for the severe weathering exposure anticipated, the water-cement ratio should not exceed 0.50. This lower figure must govern and will be used in the calculations.

7.3.5 *Step 5* -- From the information derived in Steps 3 and 4, the required cement content is found to be 270/0.50

= 540 lb/yd³.

7.3.6 *Step 6* -- The quantity of coarse aggregate is estimated from Table 6.3.6. With a fine aggregate having a fineness modulus of 2.8 and a 1 in. nominal maximum size of coarse aggregate, the table indicates that 0.67 ft³ of coarse aggregate, on a dry-rodded basis, may be used in each ft³ of concrete. For a ft³, therefore, the coarse aggregate will be 27 x 0.67 = 18.09 ft³. Since it weighs 95 lb/ft³, the dry weight of coarse aggregate is 18.09 x 95 = 1719 lb.

7.3.7 *Step 7* -- With the quantities of water, cement, and coarse aggregate established, the remaining material comprising the yd³ of concrete must consist of fine aggregate and air. The required fine aggregate may be determined on the basis of either weight or absolute volume as shown below.

7.3.7.1 *Weight basis* -- From Table 6.3.7.1 the weight of a yd³ of air-entrained concrete made with aggregate of 1 in. maximum size is estimated to be 3850 lb. (For a first trial batch, exact adjustments of this value for differences in slump, cement factor, and aggregate specific gravity are not critical.) Weights already known are:

Water, net mixing	270 lb
Cement	540 lb
Coarse aggregate, dry	1719 lb
Total	2529 lb

The weight of fiie aggregate, therefore, is estimated to be

3850 - 2529 = 1321 lb (dry)

7.3.7.2 *Absolute volume basis* -- With the quantities of cement, water, air, and coarse aggregate established, the fine aggregate content can be calculated as follows:

Volume of water $= \frac{270}{62.4}$ = 4.33 ft³

Solid volume of cement $= \frac{540}{3.15 \times 62.4} =$ 2.75 ft³

Solid volume of coarse aggregate $= \frac{1719}{2.68 \times 62.4} =$ 10.28 ft³

Volume of air = 0.06 x 27 = 1.62 ft³

Total volume of ingredients except fine aggregate = 18.98 ft³

Solid volume of fine aggregate required = 27-18.98 = 8.02 ft³

Required weight of dry fine aggregate = 8.02 x 2.64 x 62.4 = 1321 lb

7.3.7.3 Batch weights per yd³ of concrete calculated on the two bases are compared as follows:

	Based on estimated concrete weight, lb	Based on absolute volume of ingredients, lb
Water, net mixing	270	270
Cement	540	540
Coarse aggregate, dry	1719	1719
Fine aggregate, dry	1321	1321

7.3.8 *Step 8* -- Tests indicate total moisture of 3 percent in the coarse aggregate and 5 percent in the fine aggregate. If the trial batch proportions based on assumed concrete weight are used, the adjusted aggregate weights become:

Coarse aggregate, wet	1719(1.03) = 1771 lb
Fine aggregate, wet	1321(1.05) = 1387 lb

Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 3 - 0.5 = 2.5 percent; by the fine aggregate 5 - 0.7 = 4.3 percent. The estimated requirement for added water, therefore, becomes

270 - 1719(0.025) - 1321(0.043) = 170 lb

The estimated batch weights for a yd³ of concrete are:

Water, to be added	170 lb
Cement	540 lb
Coarse aggregate, wet	1771 lb
Fine aggregate, wet	1387 lb
Total	3868 lb

7.3.9 *Step 9* -- For the laboratory trial batch, the weights are scaled down to produce 0.03 yd³ or 0.81 ft³ of concrete. Although the calculated quantity of water to be added was 5.10 lb, the amount actually used in an effort to obtain the desired 1 to 2-in. slump is 4.60 lb. The batch as mixed, therefore, consists of:

Water, added	4.60 lb
Cement	16.20 lb
Coarse aggregate, wet	53.13 lb
Fine aggregate, wet	41.61 lb
Total	115.54 lb

The concrete has a measured slump of 2 in., unit weight of 141.8 lb/ft^3 and air content of 6.5 percent. It is judged to be slightly oversanded for the easy placement condition involved. To provide proper yield and other characteristics for future batches, the following adjustments are made.

7.3.9.1 Since the yield of the trial batch was

$$115.543/141.8 = 0.815 \text{ ft}^3$$

and the mixing water content was 4.60 (added) + 1.29 on coarse aggregate + 1.77 on fine aggregate = 7.59 lb, the mixing water required for a yd^3 of concrete with the same slump as the trial batch should be

$$\frac{7.59 \times 27}{0.815} = 251 \text{ lb}$$

The slump was satisfactory, but since the air content was too high by 0.5 percent, more water will be needed for proper slump when the air content is corrected. As indicated in Paragraph 6.3.9.2, the mixing water should be increased roughly 5 x 0.5 or about 3 lb, bringing the new estimate to 254 lb/yd^3.

7.3.9.2 With the decreased mixing water, less cement will be required to provide the desired water-cement ratio of 0.5. The new cement content becomes

$$254/0.5 = 508 \text{ lb}$$

7.3.9.3 Since the concrete was found to be oversanded, the quantity of coarse aggregate per unit volume will be increased 10 percent to 0.74, in an effort to correct the condition. The amount of coarse aggregate per yd^3 becomes

$$0.74 \times 27 \times 95 = 1898 \text{ lb dry}$$

or

$$1898 \times 1.03 = 1955 \text{ wet}$$

and

$$1898 \times 1.005 = 1907 \text{ lb SSD}$$

7.3.9.4 The new estimate for the weight of the concrete with 0.5 percent less air is 141.8/0.995 = 142.50 lb/ft^3 or 142.50 x 27 = 3848 lb/yd^3. The weight of sand, therefore, is

$$3848 - (254 + 508 + 1907) = 1179 \text{ lb SSD}$$

or

$$1179/1.007 = 1170 \text{ lb dry}$$

The adjusted basic batch weights per yd^3 of concrete are:

Water, net mixing	254 lb
Cement	508 lb
Coarse aggregate, dry	1898 lb
Fine aggregate, dry	1170 lb

Admixture dosage must be reduced to provide the desired air content.

7.3.10 Adjustments of proportions determined on an absolute volume basis would follow the procedure outlined in Paragraph 7.2.10, which will not be repeated for this example.

CHAPTER 8 -- REFERENCES

8.1 -- *Recommended references*

The documents of the various standards-producing organizations referred to in this document are listed below with their serial designation, including year of adoption or revision. The documents listed were the latest effort at the time this document was revised. Since some of these documents are revised frequently, generally in minor detail only, the user of this document should check directly with the sponsoring group if it is desired to refer to the latest revision.

American Concrete Institute

116R-90	Cement and Concrete Terminology, SP-19(90)
201.2R-77 (Reapproved 1982)	Guide to Durable Concrete
207.1R-87	Mass Concrete
207.2R-90	Effect of Restraint, Volume Change, and Reinforcement on Cracking of Mass Concrete
207.4R-80(86)	Cooling and Insulating Systems for Mass Concrete
212.3R-89	Chemical Admixtures for Concrete
214-77 (Reapproved 1989)	Recommended Practice for Evaluation of Strength Test Results of Concrete
224R-90	Control of Cracking in Concrete Structures
225 R-85	Guide to the Selection and Use of Hydraulic Cements
226.1 R-87	Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete
226.3R-87	Use of Fly Ash in Concrete
301-89	Specifications for Structural Concrete for Buildings
302.1R-89	Guide for Concrete Floor and Slab Construction
304R-89	Guide for Measuring, Mixing, Transporting, and Placing Concrete
304.3R-89	Heavyweight Concrete: Measuring, Mixing, Transporting, and Placing
318-83	Building Code Requirements for Reinforced Concrete

345-82 Standard Practice for Concrete Highway Bridge Deck Construction

ASTM

C 29-78 Standard Test Method for Unit Weight and Voids in Aggregate

31-87a Standard Method of Making and Curing Concrete Test Specimens in the Field

C 33-86 Standard Specification for Concrete Aggregates

C 39-86 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 70-79(1985) Standard Test Method for Surface Moisture in Fine Aggregate

C 78-84 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

C 94-86b Standard Specification for Ready-Mixed Concrete

C 125-86 Standard Definitions of Terms Relating to Concrete and Concrete Aggregates

C 127-84 Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate

C 128-84 Standard Test Method for Specific Gravity and Absorption of Fine Aggregate

C 136-84a Standard Method for Sieve Analysis of Fine and Coarse Aggregates

C 138-81 Standard Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete

C 143-78 Standard Test Method for Slump of Portland Cement Concrete

C 150-86 Standard Specification for Portland Cement

C 172-82 Standard Method of Sampling Freshly Mixed Concrete

C 173-78 Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C 192-81 Standard Method of Making and Curing Concrete Test Specimens in the Laboratory

C 231-82 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C 260-86 Standard Specification for Air-Entraining Admixtures for Concrete

C 293-79 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)

C 494-86 Standard Specification for Chemical Admixtures for Concrete

C 496-86 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

C 566-84 Standard Test Method for Total Moisture Content of Aggregate by Drying

C 595-86 Standard Specification for Blended Hydraulic Cements

C 618-85 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete

C 637-84 Standard Specification for Aggregates for Radiation-Shielding Concrete

C 638-84 Standard Descriptive Nomenclature of Constituents of Aggregates for Radiation-Shielding Concrete

C 989-87a Standard Specification for Granulated Blast-Furnace Slag for Use in Concrete and Mortars

C 1017-85 Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete

C 1064-86 Standard Test Method for Temperature of Freshly Mixed Portland-Cement Concrete

D 75-82 Standard Practice for Sampling Aggregates

D 3665-82 Standard Practice for Random Sampling of Construction Materials

E 380-84 Standard for Metric Practice

The above publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 19150
Detroit, MI 48219-0150

ASTM
1916 Race Street
Philadelphia, PA 19103

8.2 -- *Cited references*

1. "Silica Fume in Concrete," ACI Committee 226 Preliminary Report, ACI Materials Journal, ***Proceedings*** V. 84, Mar.-Apr. 1987, pp. 158-166.

8.3 -- *Additional references*

1. "Standard Practice for Concrete," ***Engineer Manual*** No. EM 1110-2-2000, Office, Chief of Engineers, U.S. Army Corps of Engineers, Washington, D.C., June 1974.

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3. ***Proportioning Concrete Mixes***, SP-46, American Concrete Institute, Detroit, 1974, 223 pp.

4. Townsend, Charles L., "Control of Temperature Cracking in Mass Concrete," *Causes, Mechanism, and Control of Cracking in Concrete*, SP-20, American Concrete Institute, Detroit, 1968, pp. 119-139.

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6. Fuller, William B., and Thompson, Sanford E., "The Laws of Proportioning Concrete," *Transactions*, ASCE, V. 59, Dec. 1907, pp. 67-143.

7. Powers, Treval C., *The Properties of Fresh Concrete*, John Wiley & Sons, New York, 1968, pp. 246-256.

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10. Edwards, L. N., "Proportioning the Materials of Mortars and Concretes by Surface Areas of Aggregates," *Proceedings*, ASTM, V. 18, Part 2, 1918, p. 235.

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APPENDIX 1 -- METRIC (SI) SYSTEM ADAPTATION

A1.1 Procedures outlined in this standard practice have been presented using inch-pound units of measurement. The principles are equally applicable in SI system with proper adaptation of units. This Appendix provides all of the information necessary to apply the proportioning procedure using SI measurements. Table A1.1 gives relevant conversion factors. A numerical example is presented in Appendix 2.

TABLE A1.1-CONVERSION FACTORS, in.-lb TO SI UNITS*

Quantity	in-lb unit	SI† unit	Conversion factor (Ratio: in.-lb/SI)
Length	inch (in.)	millimeter (mm)	25.40
Volume	cubic foot (ft^3) cubic yard (yd^3)	cubic meter (m^3) cubic meter (m^3)	0.02832 0.7646
Mass	pound (lb)	kilogram (kg)	0.4536
Stress	pounds per square inch (psi)	megapascal (MPa)	6.895×10^{-3}
Density	pounds per cubic foot (lb/ft^3) pounds per cubic yard (lb/yd^3)	kilograms per cubic meter (kg/m^3) kilograms per cubic meter (kg/m^3)	16.02 0.5933
Temperature	degrees Fahrenheit (F)	degrees Celsius (C)	‡

*Gives names (and abbreviations) of measurement units in the inch-pound system as used in the body of this report and in the SI (metric) system, along with multipliers for converting the former to the latter. From ASTM E 380.
†Systéme International d'Unites
‡C = (F − 32)/1.8

A1.2 For convenience of reference, numbering of subsequent paragraphs in this Appendix corresponds to the body of the report except that the designation "A1" is prefixed. All tables have been converted and reproduced. Descriptive portions are included only where use of the SI system requires a change in procedure or formula. To the extent practicable, conversions to metric units have been made in such a way that values are realistic in terms of usual practice and significance of numbers. For example, aggregate and sieve sizes in the metric tables are ones commonly used in Europe. Thus, there is not always a precise mathematical correspondence between inch-pound and SI values in corresponding tables.

A1.5.3 *Steps in calculating proportions* -- Except as discussed below, the methods for arriving at quantities of ingredients for a unit volume of concrete are essentially the same when SI units are employed as when inch-pound units are employed. The main difference is that the unit volume of concrete becomes the cubic meter and numerical values must be taken from the proper "A1" table instead of the one referred to in the text.

A1.5.3.1 *Step 1. Choice of slump* -- See Table A1.5.3.1.

TABLE A1.5.3.1 — RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION (SI)

Types of construction	Slump, mm	
	Maximum*	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

*May be increased 25 mm for methods of consolidation other than vibration.

A1.5.3.2 *Step 2. Choice of nominal maximum size of aggregate.*

A1.5.3.3 *Step 3. Estimation of mixing water and air content* -- See Table A1.5.3.3.

A1.5.3.4 *Step 4. Selection of water-cement ratio* -- See Table A1.5.3.4.

A1.5.3.5 *Step 5. Calculation of cement content.*

A1.5.3.6 *Step 6. Estimation of coarse aggregate content* -- The dry mass of coarse aggregate required for a cubic meter of concrete is equal to the value from Table A1.5.3.6 multiplied by the dry-rodded unit mass of the aggregate in kilograms per cubic meter.

A1.5.3.7 *Step 7. Estimation of fine aggregate content* -- In the SI, the formula for calculation of fresh concrete mass per cubic meter is:

$$U_M = 10G_a(100 - A) + C_M(1 - G_a/G_c) - W_M(G_a - 1)$$

where

U_M = unit mass of fresh concrete, kg/m^3
G_a = weighted average specific gravity of combined fine and coarse aggregate, bulk, SSD
G_c = specific gravity of cement (generally 3.15)
A = air content, percent
W_M = mixing water requirement, kg/m^3
C_M = cement requirement, kg/m^3

A1.5.3.9 *Step 9. Trial batch adjustments* -- The following "rules of thumb" may be used to arrive at closer approximations of unit batch quantities based on results for a trial batch:

A1.5.3.9.1 The estimated mixing water to produce the same slump as the trial batch will be equal to the net amount of mixing water used divided by the yield of the trial batch in m^3. If slump of the trial batch was not correct, increase or decrease the re-estimated water content by 2 kg/m^3 of concrete for each increase or decrease of 10 mm in slump desired.

A1.5.3.9.2 To adjust for the effect of

TABLE A1.5.3.3 — APPROXIMATE MIXING WATER AND AIR CONTENT REQUIREMENTS FOR DIFFERENT SLUMPS AND NOMINAL MAXIMUM SIZES OF AGGREGATES (SI)

Slump, mm	Water, Kg/m³ of concrete for indicated nominal maximum sizes of aggregate: 9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

*The quantities of mixing water given for air-entrained concrete are based on typical total air content requirements as shown for "moderate exposure" in the Table above. These quantities of mixing water are for use in computing cement contents for trial batches at 20 to 25 C. They are maximum for reasonably well-shaped angular aggregates graded within limits of accepted specifications. Rounded coarse aggregate will generally require 18 kg less water for non-air-entrained and 15 kg less for air-entrained concretes. The use of water-reducing chemical admixtures, ASTM C 494, may also reduce mixing water by 5 percent or more. The volume of the liquid admixtures is included as part of the total volume of the mixing water.

†The slump values for concrete containing aggregate larger than 40 mm are based on slump tests made after removal of particles larger than 40 mm by wet-screening.

‡These quantities of mixing water are for use in computing cement factors for trial batches when 75 mm or 150 mm normal maximum size aggregate is used. They are average for reasonably well-shaped coarse aggregates, well-graded from coarse to fine.

§Additional recommendations for air-content and necessary tolerances on air content for control in the field are given in a number of ACI documents, including ACI 201, 345, 318, 301, and 302. ASTM C 94 for ready-mixed concrete also gives air content limits. The requirements in other documents may not always agree exactly so in proportioning concrete consideration must be given to selecting an air content that will meet the needs of the job and also meet the applicable specifications.

**For concrete containing large aggregates which will be wet-screened over the 40 mm sieve prior to testing for air content, the percentage of air expected in the 40 mm minus material should be as tabulated in the 40 mm column. However, initial proportioning calculations should include the air content as a percent of the whole.

††When using large aggregate in low cement factor concrete, air entrainment need not be detrimental to strength. In most cases mixing water requirement is reduced sufficiently to improve the water-cement ratio and to thus compensate for the strength reducing effect of entrained air concrete. Generally, therefore, for these large nominal maximum sizes of aggregate, air contents recommended for extreme exposure should be considered even though there may be little or no exposure to moisture and freezing.

‡‡These values are based on the criteria that 9 percent air is needed in the mortar phase of the concrete. If the mortar volume will be substantially different from that determined in this recommended practice, it may be desirable to calculate the needed air content by taking 9 percent of the actual mortar volume.

TABLE A1.5.3.4(a) — RELATIONSHIPS BETWEEN WATER-CEMENT RATIO AND COMPRESSIVE STRENGTH OF CONCRETE (SI)

Compressive strength at 28 days, MPa*	Water-cement ratio, by mass: Non-air-entrained concrete	Air-entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

*Values are estimated average strengths for concrete containing not more than 2 percent air for non-air-entrained concrete and 6 percent total air content for air-entrained concrete. For a constant water-cement ratio, the strength of concrete is reduced as the air content is increased.

Strength is based on 152 x 305 mm cylinders moist-cured for 28 days in accordance with the sections on "Initial Curing" and "Curing of Cylinders for Checking the Adequacy of Laboratory Mixture Proportions for Strength or as the Basis for Acceptance or for Quality Control" of ASTM Method C 31 for Making and Curing Concrete Specimens in the Field. These are cylinders cured moist at 23 ± 1.7 C prior to testing.

The relationship in this Table assumes a nominal maximum aggregate size of about 19 to 25 mm. For a given source of aggregate, strength produced at a given water-cement ratio will increase as nominal maximum size of aggregate decreases; see Sections 3.4 and 5.3.2.

incorrect air content in a trial batch of air-entrained concrete on slump, reduce or increase the mixing water content of A1.5.3.9.1 by 3 kg/m³ of concrete for each 1 percent by which the air content is to be increased or decreased from that of the trial batch.

A1.5.3.9.3 The re-estimated unit mass of the fresh concrete for adjustment of trial batch proportions is equal to the unit mass in kg/m³ measured on the trial batch, reduced or increased by the percentage increase or decrease in air content of the adjusted batch from the first trial batch.

TABLE A1.5.3.4(b) — MAXIMUM PERMISSIBLE WATER-CEMENT RATIOS FOR CONCRETE IN SEVERE EXPOSURES (SI)*

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing†	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 5 mm cover over steel	0.45	0.40‡
All other structures	0.50	0.45‡

*Based on ACI 201.2R.

†Concrete should also be air-entrained.

‡If sulfate resisting cement (Type II or Type V of ASTM C 150) is used, permissible water-cement ratio may be increased by 0.05.

TABLE A1.5.3.6 — VOLUME OF COARSE AGGREGATE PER UNIT OF VOLUME OF CONCRETE (SI)

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in dry-rodded condition as described in ASTM C 29.

These volumes are selected from empirical relationships to produce concrete with a degree of workability suitable for usual reinforced construction. For less workable concrete such as required for concrete pavement construction they may be increased about 10 percent. For more workable concrete, such as may sometimes be required when placement is to be by pumping, they may be reduced up to 10 percent.

†See ASTM Method 136 for calculation of fineness modulus.

TABLE A1.5.3.7.1 — FIRST ESTIMATE OF MASS OF FRESH CONCRETE (SI)

Nominal maximum size of aggregate, mm	First estimate of concrete unit mass, kg/m³*	
	Non-air-entrained concrete	Air-entrained concrete
9.5	2280	2200
12.5	2310	2230
19	2345	2275
25	2380	2290
37.5	2410	2350
50	2445	2345
75	2490	2405
150	2530	2435

*Values calculated by Eq. (A1.5.3.7) for concrete of medium richness (330 kg of cement per m3) and medium slump with aggregate specific gravity of 2.7. Water requirements based on values for 75 to 100 mm slump in Table A1.5.3.3. If desired, the estimate of unit mass may be refined as follows if necessary information is available: for each 5 kg difference in mixing water from the Table A1.5.3.3 values for 75 to 100 mm slump, correct the mass per m^3 8 kg in the opposite direction; for each 20 kg difference in cement content from 330 kg, correct the mass per m^3 3 kg in the same direction; for each 0.1 by which aggregate specific gravity deviates from 2.7, correct the concrete mass 60 kg in the same direction. For air-entrained concrete the air content for severe exposure from Table A.1.5.3.3 was used. The mass can be increased 1 percent for each percent reduction in air content from that amount.

APPENDIX 2 -- EXAMPLE PROBLEM IN METRIC (SI) SYSTEM

A2.1 *Example 1* -- Example 1 presented in Section 6.2 will be solved here using metric units of measure. Required average strength will be 24 MPa with slump of 75 to 100 mm. The coarse aggregate has a nominal maximum size of 37.5 mm and dry-rodded mass of 1600 kg/m³. As stated in Section 6.1, other properties of the ingredients are: cement -- Type I with specific gravity of 3.15; coarse aggregate -- bulk specific gravity 2.68 and absorption 0.5 percent; fine aggregate -- bulk specific gravity 2.64, absorption 0.7 percent, and fineness modulus 2.8.

A2.2 All steps of Section 5.3 should be followed in sequence to avoid confusion, even though they sometimes merely restate information already given.

A2.2.1 *Step 1* -- The slump is required to be 75 to 100 mm.

A2.2.2 *Step 2* -- The aggregate to be used has a nominal maximum size of 37.5 mm.

A2.2.3 *Step 3* -- The concrete will be non-air-entrained since the structure is not exposed to severe weathering. From Table A1.5.3.3, the estimated mixing water for a slump of 75 to 100 mm in non-air-entrained concrete made with 37.5 mm aggregate is found to be 181 kg/m³.

A2.2.4 *Step 4* -- The water-cement ratio for non-air-entrained concrete with a strength of 24 MPa is found from Table A1.5.3.4(a) to be 0.62.

A2.2.5 *Step 5* -- From the information developed in Steps 3 and 4, the required cement content is found to be 181/0.62 = 292 kg/m³.

A2.2.6 *Step 6* -- The quantity of coarse aggregate is estimated from Table A 1.5.3.6. For a fine aggregate having a fineness modulus of 2.8 and a 37.5 mm nominal maximum size of coarse aggregate, the table indicates that 0.71 m³ of coarse aggregate, on a dry-rodded basis, may be used in each cubic meter of concrete. The required dry mass is, therefore, 0.71 x 1600 = 1136 kg.

A2.2.7 *Step 7* -- With the quantities of water, cement and coarse aggregate established, the remaining material comprising the cubic meter of concrete must consist of fine aggregate and whatever air will be entrapped. The required fine aggregate may be determined on the basis of either mass or absolute volume as shown below:

A2.2.7.1 *Mass basis* -- From Table A1.5.3.7.1, the mass of a cubic meter of non-air-entrained concrete made with aggregate having a nominal maximum size of 37.5 mm is estimated to be 2410 kg. (For a first trial batch, exact adjustments of this value for usual differences in slump, cement factor, and aggregate specific gravity are not critical.) Masses already known are:

Water (net mixing)	181 kg
Cement	292 kg
Coarse aggregate	1136 kg
Total	1609 kg

The mass of fine aggregate, therefore, is estimated to be

$$2410 - 1609 = 801 \text{ kg}$$

A2.2.7.2 *Absolute volume basis* -- With the quantities of cement, water, and coarse aggregate established, and the approximate entrapped air content (as opposed to purposely entrained air) of 1 percent determined from Table A1.5.3.3, the sand content can be calculated as follows:

$$\text{Volume of water} = \frac{181}{1000} \quad 0.181 \text{ m}^3$$

$$\text{Solid volume of cement} = \frac{292}{3.15 \times 1000} \quad 0.093 \text{ m}^3$$

Solid volume of coarse aggregate =	$\frac{1136}{2.68 \times 1000}$	0.424 m³
Volume of entrapped air =	0.01 x 1.000	0.010 m³
Total solid volume of ingredients except fine aggregate		0.708 m³
Solid volume of fine aggregate required =	1.000 - 0.705	0.292 m³
Required weight of dry fiie aggregate =	0.292 x 2.64 x 1000	771 kg

A2.2.7.3 Batch masses per cubic meter of concrete calculated on the two bases are compared below:

	Based on estimated concrete mass, kg	Based on absolute volume of ingredients, kg
Water (net mixing)	181	181
Cement	292	292
Coarse aggregate (dry)	1136	1136
Sand (dry)	801	771

A2.2.8 *Step 8* -- Tests indicate total moisture of 2 percent in the coarse aggregate and 6 percent in the fine aggregate. If the trial batch proportions based on assumed concrete mass are used, the adjusted aggregate masses become

Coarse aggregate (wet) = 1136(1.02) = 1159 kg
Fine aggregates (wet) = 801(1.06) = 849kg

Absorbed water does not become part of the mixing water and must be excluded from the adjustment in added water. Thus, surface water contributed by the coarse aggregate amounts to 2 - 0.5 = 1.5 percent; by the fine aggregate 6 - 0.7 = 5.3 percent. The estimated requirement for added water, therefore, becomes

$$181 - 1136(0.015) - 801(0.053) = 122 \text{ kg}$$

The estimated batch masses for a cubic meter of concrete are:

Water (to be added)	122 kg
Cement	292 kg
Coarse aggregate (wet)	1159 kg
Fine aggregate (wet)	849 kg
Total	2422 kg

A2.2.9 *Step 9* -- For the laboratory trial batch, it is found convenient to scale the masses down to produce 0.02 m³ of concrete. Although the calculated quantity of water to be added was 2.44 kg, the amount actually used in an effort to obtain the desired 75 to 100 mm slump is 2.70 kg. The batch as mixed, therefore, consists of

Water (added)	2.70 kg
Cement	5.84 kg
Coarse aggregate (wet)	23.18 kg
Fine aggregate (wet)	16.98 kg
Total	48.70 kg

The concrete has a measured slump of 50 mm and unit mass of 2390 kg/m? It is judged to be satisfactory from the standpoint of workability and finishing properties. To provide proper yield and other characteristics for future batches, the following adjustments are made:

A2.2.9.1 Since the yield of the trial batch was

$$48.70/2390 = 0.0204 \text{ m}^3$$

and the mixing water content was 2.70 (added) + 0.34 (on coarse aggregate) + 0.84 (on fine aggregate) = 3.88 kg, the mixing water required for a cubic meter of concrete with the same slump as the trial batch should be

$$3.88/0.0204 = 190 \text{ kg}$$

As indicated in A1.5.3.9.1, this amount must be increased another 8 kg to raise the slump from the measured 50 mm to the desired 75 to 100 mm range, bringing the total mixing water to 198 kg.

A2.2.9.2 With the increased mixing water, additional cement will be required to provide the desired water-cement ratio of 0.62. The new cement content becomes

$$198/0.62 = 319 \text{ kg}$$

A2.2.9.3 Since workability was found to be satisfactory, the quantity of coarse aggregate per unit volume of concrete will be maintained the same as in the trial batch. The amount of coarse aggregate per cubic meter becomes

$$\frac{23.18}{0.0204} = 1136 \text{ kg wet}$$

which is

$$\frac{1136}{1.02} = 1114 \text{ kg dry}$$

and

$$1114 \times 1.005 = 1120 \text{ kg SSD*}$$

A2.2.9.4 The new estimate for the mass of a cubic meter of concrete is the measured unit mass of 2390 kg/m³. The amount of fine aggregate required is, therefore

$$2390 - (198 + 319 + 1120) = 753 \text{ kg SSD*}$$

or

$$753/1.007 = 748 \text{ kg dry}$$

The adjusted basic batch masses per cubic meter of concrete are

Water (net mixing)	198 kg
Cement	319 kg
Coarse aggregate (dry)	1114 kg
Fine aggregate (dry)	748 kg

A2.2.10 Adjustments of proportions determined on an absolute volume basis follow a procedure similar to that just outlined. The steps will be given without detailed explanation:

A2.2.10.1 Quantities used in the nominal 0.02 m³ batch are

Water (added)	2.70 kg
Cement	5.84 kg
Coarse aggregate (wet)	23.18 kg
Fine aggregate (wet)	16.34 kg
Total	48.08 kg

Measured slump 50 mm; unit mass 2390 kg/m³; yield 48.08/2390 = 0.0201 m³; workability o.k.

A2.2.10.2 Re-estimated water for same slump as trial batch:

$$\frac{2.70 + 0.34 + 0.81}{0.0201} = 192 \ kg$$

Mixing water required for slump of 75 to 100 mm:

$$192 + 8 = 200 \text{ kg}$$

A2.2.10.3 Adjusted cement content for increased water:

$$200/0.62 = 323 \text{ kg}$$

A2.2.10.4 Adjusted coarse aggregate requirement:

$$\frac{23.18}{0.0202} = 1153 \ kg \ wet$$

or

$$1163/1.02 = 1130 \text{ kg dry}$$

A2.2.10.5 The volume of ingredients other than air in the original trial batch was

Water	$\frac{3.85}{1000}$	= 0.0039 m3
Cement	$\frac{5.84}{3.15 \times 1000}$	= 0.0019 m3
Coarse aggregate	$\frac{22.72}{2.68 \times 1000}$	= 0.0085 m3
Fine aggregate	$\frac{15.42}{2.64 \times 1000}$	= 0.0058 m3
Total		0.0201 m3

Since the yield was also 0.0201 m³, there was no air in the concrete detectable within the precision of the unit mass test and significant figures of the calculations. With the proportions of all components except fine aggregate established, the determination of adjusted cubic meter batch quantities can be completed as follows:

Volume of water	= $\frac{200}{1000}$	= 0.200 m³
Volume of cement	= $\frac{323}{3.15 \times 1000}$	= 0.103 m³
Allowance for volume of cement		= 0.000 m³
Volume of coarse aggregate	= $\frac{1130}{2.68 \times 1000}$	= 0.422 m³
Total volume exclusive of fine aggregate		= 0.725 m³
Volume of fine aggregate required	= 1.000 - 0.725	= 0.275 m³
Mass of fine aggregate (dry basis)	= 0.275 x 2.64 x 1000	= 726 kg

The adjusted basic batch weights per cubic meter of concrete, then, are:

Water (net mixing)	200 kg

*Saturated-surface-dry.

Cement	323 kg
Coarse aggregate (dry)	1130 kg
Fine aggregate (dry)	726 kg

These differ only slightly from those given in Paragraph A2.2.9.4 for the method of assumed concrete weight. Further trials or experience might indicate small additional adjustments for either method.

APPENDIX 3 -- LABORATORY TESTS

A3.1 Selection of concrete mix proportions can be accomplished effectively from results of laboratory tests which determine basic physical properties of materials to be used, establish relationships between water-cement ratio or water to cement and pozzolan ratio, air content, cement content, and strength, and which furnish information on the workability characteristics of various combinations of ingredient materials. The extent of investigation desirable for any given job will depend on its size and importance and on the service conditions involved. Details of the laboratory program will also vary, depending on facilities available and on individual preferences.

A3.2 *Properties of cement*

A3.2.1 Physical and chemical characteristics of cement influence the properties of hardened concrete. However, the only property of cement used directly in computation of concrete mix proportions is specific gravity. The specific gravity of portland cements of the types covered by ASTM C 150 and C 175 may usually be assumed to be 3.15 without introducing appreciable error in mix computations. For other types such as the blended hydraulic cements of ASTM C 595, slag cement in C 989 or pozzolan covered in C 618, the specific gravity for use in volume calculations should be determined by test.

A3.2.2 A sample of cement should be obtained from the mill which will supply the job, or preferably from the concrete supplier. The sample should be ample for tests contemplated with a liberal margin for additional tests that might later be considered desirable. Cement samples should be shipped in airtight containers, or at least in moisture-proof packages. Pozzolans should also be carefully sampled.

A3.3 *Properties of aggregate*

A3.3.1 Sieve analysis, specific gravity, absorption, and moisture content of both fine and coarse aggregate and dry-rodded unit weight of coarse aggregate are physical properties useful for mix computations. Other tests which may be desirable for large or special types of work include petrographic examination and tests for chemical reactivity, soundness, durability, resistance to abrasion, and various deleterious substances. Such tests yield information of value in judging the long-range serviceability of concrete.

A3.3.2 Aggregate gradation as measured by the sieve analysis is a major factor in determining unit water requirement, proportions of coarse aggregate and sand, and cement content for satisfactory workability. Numerous "ideal" aggregate grading curves have been proposed, and these, tempered by practical considerations, have formed the basis for typical sieve analysis requirements in concrete standards. ASTM C 33 provides a selection of sizes and gradings suitable for most concrete. Additional workability realized by use of air-entrainment permits, to some extent, the use of less restrictive aggregate gradations.

A3.3.3 Samples for concrete mix tests should be representative of aggregate available for use in the work. For laboratory tests, the coarse aggregates should be separated into required size fractions and reconstituted at the time of mixing to assure representative grading for the small test batches. Under some conditions, for work of important magnitude, laboratory investigation may involve efforts to overcome grading deficiencies of the available aggregates. Undesirable sand grading may be corrected by (1) separation of the sand into two or more size fractions and recombining in suitable proportions; (2) increasing or decreasing the quantity of certain sizes to balance the grading; or (3) reducing excess coarse material by grinding or crushing. Undesirable coarse-aggregate gradings may be corrected by: (1) crushing excess coarser fractions; (2) wasting sizes that occur in excess; (3) supplementing deficient sizes from other sources; or (4) a combination of these methods. Whatever grading adjustments are made in the laboratory should be practical and economically justified from the standpoint of job operation. Usually, required aggregate grading should be consistent with that of economically available materials.

A3.4 *Trial batch series*

A3.4.1 The tabulated relationships in the body of this report may be used to make rough estimates of batch quantities for a trial mix. However, they are too generalized to apply with a high degree of accuracy to a specific set of materials. If facilities are available, therefore, it is advisable to make a series of concrete tests to establish quantitative relationships for the materials to be used. An illustration of such a test program is shown in Table A3.4.1.

A3.4.2 First, a batch of medium cement content and usable consistency is proportioned by the described methods. In preparing Mix No. 1, an amount of water is used which will produce the desired slump even if this differs from the estimated requirement. The fresh concrete is tested for slump and unit weight and observed closely for workability and finishing characteristics. In the example, the yield is too high and the concrete is judged to contain an excess of fine aggregate.

A3.4.3 Mix No. 2 is prepared, adjusted to correct the errors in Mix No. 1, and the testing and evaluation repeated. In this case, the desired properties are achieved within close tolerances and cylinders are molded to check the compressive strength. The information derived so far can now be used to select proportions for a series of additional mixes, No. 3 to 6, with cement contents above and below that of Mix No. 2, encompassing the range likely to be needed. Reasonable

TABLE A3.4.1 — TYPICAL TEST PROGRAM TO ESTABLISH CONCRETE-MAKING PROPERTIES OF LOCAL MATERIALS

	Cubic yard batch quantities, lb							Concrete characteristics			
Mix No.	Cement	Sand	Coarse Aggregate	Water Estimated	Water Used	Total used	Slump in.	Unit wt., lb per cu ft	Yield cu ft	28-day Compressive strength, psi	Workability
1	500	1375	1810	325	350	4035	4	147.0	27.45	—	Oversanded
2	500	1250	1875	345	340	3965	3	147.0	26.97	3350	o.k.
3	400	1335	1875	345	345	3955	4.5	145.5	27.18	2130	o.k.
4	450	1290	1875	345	345	3960	4	146.2	27.09	2610	o.k.
5	550	1210	1875	345	345	3980	3	147.5	26.98	3800	o.k.
6	600	1165	1875	345	345	3985	3.5	148.3	26.87	4360	o.k.

refinement in these batch weights can be achieved with the help of corrections given in the notes to Table 6.3.7.1.

A3.4.4 Mix No. 2 to 6 provide the background, including the relationship of strength to water-cement ratio for theparticular combination of ingredients, needed to select proportions for a range of specified requirements.

A3.4.5 In laboratory tests, it seldom will be found, even by experienced operators, that desired adjustments will develop as smoothly as indicated in Table A3.4.1. Furthermore, it should not be expected that field results will check exactly with laboratory results. An adjustment of the selected trial mix on the job is usually necessary. Closer agreement between laboratory and field will be assured if machine mixing is employed in the laboratory. This is especially desirable if air-entraining agents are used since the type of mixer influences the amount of air entrained. Before mixing the first batch, the laboratory mixer should be "buttered" or the mix "overmortared" as described in ASTM C 192. Similarly, any processing of materials in the laboratory should simulate as closely as practicable corresponding treatment in the field.

A3.4.6 The series of tests illustrated in Table A3.4.1 may be expanded as the size and special requirements of the work warrant. Variables that may require investigation include: alterative aggregate sources; maximum sizes and gradings; different types and brands of cement; pozzolans; admixtures; and considerations of concrete durability, volume change, temperature rise, and thermal properties.

A3.5 *Test methods*

A3.5.1 In conducting laboratory tests to provide information for selecting concrete proportions, the latest revisions of the following methods should be used:

A3.5.1.1 For tests of ingredients:

Sampling hydraulic cement--ASTM C 183

Specific gravity of hydraulic cement--ASTM C 188

Sampling stone, slag, gravel, sand, and stone block for use as highway materials--ASTM D 75

Sieve or screen analysis of fine and coarse aggregates--ASTM C 136

Specific gravity and absorption of coarse aggregates--ASTM C 127

Specific gravity and absorption of fine aggregates--ASTM C 128

Surface moisture in fine aggregate--ASTM C 70

Total moisture content of aggregate by drying--ASTM C 566

Unit weight of aggregate--ASTM C 29

Voids in aggregate for concrete--ASTM C 29

Fineness modulus--Terms relating to concrete and concrete aggregates, ASTM C 125

A3.5.1.2 For tests of concrete:

Sampling fresh concrete--ASTM C 172

Air content of freshly mixed concrete by the volumetric method--ASTM C 173

Air content of freshly mixed concrete by the pressure method--ASTM C 231

Slump of portland cement concrete--ASTM C 143

Weight per cubic foot, yield, and air content (gravimetric) of concrete--ASTM C 138

Concrete compression and flexure test specimens, making and curing in the laboratory--ASTM C 192

Compressive strength of molded concrete cylinders--ASTM C 39

TABLE A3.6.1 — CONCRETE MIXES FOR SMALL JOBS

Procedure: Select the proper nominal maximum size of aggregate (see Section 5.3.2). Use Mix B, adding just enough water to produce a workable consistency. If the concrete appears to be undersanded, change to Mix A and, if it appears oversanded, change to Mix C.

Nominal maximum size of aggregate, in.	Mix designation	Approximate weights of solid ingredients per cu ft of concrete, lb: Cement	Sand*: Air-entrained concrete†	Sand*: Concrete without air	Coarse aggregate: Gravel or crushed stone	Coarse aggregate: Iron blast furnace slag
½	A	25	48	51	54	47
	B	25	46	49	56	49
	C	25	44	47	58	51
¾	A	23	45	49	62	54
	B	23	43	47	64	56
	C	23	41	45	66	58
1	A	22	41	45	70	61
	B	22	39	43	72	63
	C	22	37	41	74	65
1½	A	20	41	45	75	65
	B	20	39	43	77	67
	C	20	37	41	79	69
2	A	19	40	45	79	69
	B	19	38	43	81	71
	C	19	36	41	83	72

*Weights are for dry sand. If damp sand is used, increase tabulated weight of sand 2 lb and, if very wet sand is used, 4 lb.

†Air-entrained concrete should be used in all structures which will be exposed to alternate cycles of freezing and thawing. Air-entrainment can be obtained by the use of an air-entraining cement or by adding an air-entraining admixture. If an admixture is used, the amount recommended by the manufacturer will, in most cases, produce the desired air content.

Flexural strength of concrete (using simple beam with third-point loading)--ASTM C 78

Flexural strength of concrete (using simple beam with center point loading--ASTM C 293

splitting tensile strength of molded concrete cylinders--ASTM C 496

A3.6 *Mixes for small jobs*

A3.6.1 For small jobs where time and personnel are not available to determine proportions in accordance with the recommended procedure, mixes in Table A3.6.1 will usually provide concrete that is amply strong and durable if the amount of water added at the mixer is never large enough to make the concrete overwet These mixes have been predetermined in conformity with the recommended procedure by assuming conditions applicable to the average small job, and for aggregate of medium specific gravity. Three mixes are given for each nominal maximum size of coarse aggregate. For the selected size of coarse aggregate, Mix B is intended for initial use. If this mix proves to be oversanded, change to Mix C; if it is undersanded, change to Mix A It should be noted that the mixes listed in the table are based on dry or surface-dry sand. If the fine aggregate is moist or wet, make the corrections in batch weight prescribed in the footnote.

A3.6.2 The approximate cement content per cubic foot of concrete listed in the table will be helpful in estimating cement requirements for the job. These requirements are based on concrete that has just enough water in it to permit ready working into forms without objectionable segregation. Concrete should slide, not run, off a shovel.

APPENDIX 4 -- HEAVYWEIGHT CONCRETE MIX PROPORTIONING

A4.1 Concrete of normal placeability can be proportioned for densities as high as 350 lb per cu ft by using heavy aggregates such as iron ore, iron or steel shot, barite, and iron or steel punchings. Although each of the materials has its own special characteristics, they can be processed to meet the standard requirements for grading, soundness cleanliness, etc. The selection of the aggregate should depend on its intended use. In the case of radiation shielding, determination should be made of trace elements within the material which may become reactive when subjected to radiation. In the selection of materials and proportioning of heavyweight concrete, the data needed and procedures used are similar to those required for normal weight concrete.

Aggregate density and composition for heavyweight concrete should meet requirements of ASTM C 637 and C 638. The following items should be considered.

A4.1.1 Typical materials used as heavy aggregates are listed in Table A4.1.1.

A4.1.2 If the concrete in service is to be exposed to a hot, dry environment resulting in loss of weight, it should be proportioned so that the fresh unit weight is higher than the required dry unit weight by the amount of the anticipated loss determined by performing an oven dry unit weight on concrete cylinders as follows. Three cylinders are cast and the wet unit weight determined in accordance with ASTM C 138. After 72 hours of standard curing, the cylinders are oven dried to a constant weight at 211 to 230 F and the average unit weight determined. The amount of water lost is determined by subtracting the oven dry unit weight from the wet unit weight. This difference is added to the required dry unit weight when calculating mixture proportions to allow for this loss. Normally, a freshly mixed unit weight is 8 to 10 lb per cu ft higher than the oven dry unit weight[2].

A4.1.3 If entrained air is required to resist conditions of exposure, allowance must be made for the loss in weight due to the space occupied by the air. To compensate for the loss of entrained air as a result of vibration, the concrete mixture should be proportioned with a higher air content to anticipate this loss.

A4.2 Handling of heavyweight aggregates should be in accordance with ACI 304.3R. (See also ASTM C 637 and C 638.) Proportioning of heavyweight concrete to be placed by conventional means can be accomplished in accordance with ACI 211.1 Sections 5.2 through 5.3.7 and the absolute volume method in Section 5.3.7.2. Typical proportions are shown in Table 2 of ACI 304.3R.

A4.3 *Preplaced heavyweight concrete* -- Heavyweight preplaced-aggregate concrete should be proportioned in the same manner as normal weight preplaced-aggregate concrete. (Refer to ACI 304, Table 7.3.2 -- Gradation limits for fine and coarse aggregate for preplaced aggregate concrete.) Example mixture proportions for the preplaced-aggregate method are shown in ACI 304.3R, Table 2 -- Typical proportions for high density concrete, and typical grout proportions can be found in ACI 304.3R, Table 3 -- Typical grout proportions.

A4.4 *Example* -- Concrete is required for counterweights on a lift bridge that will not be subjected to freezing and

TABLE A4.1.1 -TYPICAL HEAVYWEIGHT AGGREGATES

Material	Description	Specific gravity	Concrete, unit wt (lb/cu ft)
Limonite Goethite	Hydrous iron ores	3.4-3.8	180-195
Barite	Barium sulfate	4.0-4.4	205-225
Ilmenite Hematite Magnetite	Iron ores	4.2-5.0	215-240
Steel/iron	Shot, pellets, punchings, etc.	6.5-7.5	310-350

Note: Ferrophosphorus and ferrosilicon (heavyweight slags) materials should be used only after thorough investigation. Hydrogen gas evolution in heavyweight concrete containing these aggregates has been known to result from a reaction with the cement.

thawing conditions. An average 28 day compressive strength of 4500 psi will be required. Placement conditions permit a slump of 2 to 3 in. at point of placement and a nominal maximum size aggregate of 1 in. The design of the counter-weight requires* an oven dry unit weight of 225 lb per cu ft. An investigation of economically available materials has indicated the following:

Cement	ASTM C 150 Type I (non-air-entraining)
Fine aggregate	Specular hematite
Coarse aggregate	Ilmenite

Table A4.1.1 indicates that this combination of materials may result in an oven dry unit weight of 215 to 240 lb per cu ft. The following properties of the aggregates have been obtained from laboratory tests.

	Fine aggregate	Coarse aggregate
Fineness modulus	2.30	--
Specific gravity (Bulk SSD)	4.95	4.61
Absorption (percent)	0.05	0.08
Dry rodded weight	--	165 lb per cu ft
Nominal maximum size	-	1 in.

Employing the sequence outlined in Section 5 of this standard practice, the quantities of ingredients per cubic yard of concrete are calculated as follows:

A4.4.1 *Step 1* -- *As* indicated, the desired slump is 2 to 3 in. at point of placement.

A4.4.2 *Step* 2 -- The available aggregate sources have been indicated as suitable, and the course aggregate will be a well-graded and well-shaped crushed ilmenite with a nominal maximum size of 1 in. The fine aggregate will be hematite.

A4.4.3 *Step* 3 -- By interpolation in Table 6.3.3, non-air-entrained concrete with a 2 to 3 in. slump and a 1 in. nominal maximum size aggregate requires a water content of approximately 310 lb per cu yd. The estimated entrapped air is 1.5 percent. (Non-air-entrained concrete will be used because (1) the concrete is not to be exposed to severe weather, and (2) a high air content could reduce the dry unit weight of the concrete.)

Note: Values given in Table 6.3.3 for water requirement are based on the use of well-shaped crushed coarse aggregates. Void content of compacted dry fine or coarse aggregate can be used as an indicator of angularity. Void contents of compacted 1 in. coarse aggregate of significantly more than 40 percent indicate angular material that will probably require more water than that listed in Table A1.5.3.3. Conversely, rounded aggregates with voids below 35 percent will probably need less water.

* Oven dry is specified and is considered a more conservative value than that of the air dry.

A4.4.4 *Step* 4 -- From Table 6.3.4(a) the water-cement ratio needed to produce a strength of 4500 psi in non-air-entrained concrete is found to be approximately 0.52.

A4.4.5 *Step 5* -- From the information derived in Steps 3 and 4, the required cement content is calculated to be 310/0.52 = 596 lb per cu yd.

A4.4.6 *Step 6* -- *The* quantity of coarse aggregate is estimated by extrapolation from Table 6.3.6. For a fine aggregate having a fineness modulus of 2.30 and a 1 in. nominal maximum size aggregate, the table indicates that 0.72 cu ft of coarse aggregate, on a dry-rodded basis, may be used in each cubic foot of concrete. For a cubic yard, therefore, the coarse aggregate will be 27 x 0.72 = 19.44 cu ft, and since the dry-rodded unit weight of coarse aggregate is 165 lb per cu ft, the dry weight of coarse aggregate to be used in a cubic yard of concrete will be 19.44 x 165 = 3208 lb. The angularity of the coarse aggregate is compensated for in the ACI proportioning method through the use of the dry-rodded unit weight; however, the use of an extremely angular fine aggregate may require a higher proportion of fine aggregate, an increased cement content, or the use of air entrainment to produce the required workability. The use of entrained air reduces the unit weight of the concrete, but in some instances is necessary for durability.

A4.4.7 *Step* 7 -- For heavyweight concrete, the required fine aggregate should be determined on the absolute volume basis. With the quantities of cement, water, air, and coarse aggregate established, the fine aggregate content can be calculated as follows:

Volume of water	=	$\frac{310 \text{ lb}}{62.4 \text{ lb per cu ft}}$	= 4.97 cu ft
Volume of air	=	0.015 x 27 cu ft	= 0.40 cu ft
Solid volume of cement	=	$\frac{596 \text{ lb}}{3.15 \times 62.4 \text{ lb per cu ft}}$	= 3.03 cu ft
Solid volume of coarse aggregate	=	$\frac{3208 \text{ lb}}{4.61 \times 62.4 \text{ lb per cu ft}}$	= 11.15 cu ft
Total volume of all ingredients except fine aggregate			= 19.55 cu ft
Solid volume of fine aggregate	=	27 cu ft - 19.55 cu ft	= 7.45 cu ft
Required weight of fine aggregate	=	7.45 cu ft x 4.95 x 62.4 lb per cu ft	= 2301 lb

The actual test results indicated the concrete possessed the following properties:

Unit weight (freshly mixed)	235.7 lb per cu ft
Oven dry unit weight	228.2 lb per cu ft
Air content	2.8 percent
Slump	$2^1/_2$ in.
Strength	5000 psi at 28 days

Note: Oven dry unit weight of the concrete having a combination of hematite and ihnenite aggregates was 7.5 lb per cu ft less than the freshly mixed unit weight.

APPENDIX 5 -- MASS CONCRETE MIX PROPORTIONING

A5.1 *Introduction* -- Mass concrete is defined as "any volume of concrete with dimensions large enough to require that measures be taken to cope with generation of heat of hydration from the cement and attendant volume change to minimize cracking."[a3] The purpose of the mass concrete proportioning procedure is to combine the available cementitious materials, water, fine and coarse aggregate, and admixtures such that the resulting mixture will not exceed some established allowable temperature rise, and yet meet requirements for strength and durability. In some instances, two mixtures may be required -- an interior mass concrete and an exterior concrete for resistance to the various conditions of exposure. Accordingly, concrete technologists and designers during the design stage should consider the effects of temperature on the properties of concrete. A 6-in. wall, for example, will dissipate the generated heat quite readily, but as the thickness and size of the placement increase, a point is reached, whereby, the rate of heat generated far exceeds the rate of heat dissipated. This phenomenon produces a temperature rise within the concrete and may cause sufficient temperature differential between the interior and exterior of the mass or between peak and ultimate stable temperature to induce tensile stresses. The temperature differential between interior and exterior of the concrete generated by decreases in ambient air temperature conditions may cause cracking at exposed surfaces. Furthermore, as the concrete reaches its peak temperature and subsequent cooling takes place, tensile stresses are induced by the cooling if the change in volume is restrained by the foundation or connections to other parts of the structure.

The tensile stress developed by these conditions can be expressed by the equation $S = REeT$; where R is the restraint factor, E is the modulus of elasticity, e is the thermal coefficient of expansion, and T is the temperature difference between the interior and exterior of the concrete or between the concrete at maximum temperature and at ambient air temperature. Detailed discussions on this subject of mass concrete can be found in References A5.l, A5.2, A5.3, A5.5 and A5.14.

Thermal cracking of bridge piers, foundations, floor slabs, beams, columns, and other massive structures (locks and dams) can or may reduce the service life of a structure by promoting early deterioration or excessive maintenance. Furthermore, it should be recognized that the selection of proper mixture proportions is only one means of controlling temperature rise, and that other aspects of the concrete work should be studied and incorporated into the design and construction requirements. For additional information on heat problems and solutions, consult References A5.2 and A5.14.

A5.2 *Mass concrete properties* -- During the design stage of a proposed project, desired specified compressive strength with adequate safety factors for various portions of the structure are normally first established. The engineer will then expand on the other desired properties required of the concrete.

The proportioning of ingredients such that a mass concrete mixture will have the desired properties requires an evaluation of the materials to be used. If adequate data are not available from recent construction projects using the proposed materials, representative samples of all materials proposed for use in the concrete must be tested to determine their properties and conformance with applicable specifications.

A5.3 *Properties of material related to heat generation* --

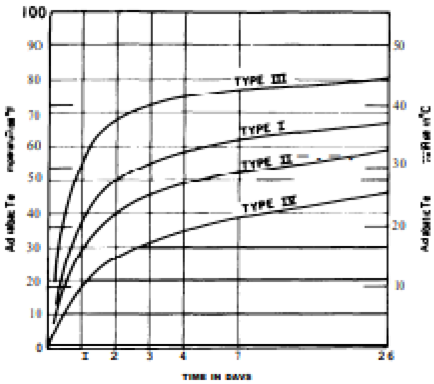
A5.3.1 *Cementitious materials* -- Cementitious material for mass concrete work may consist of portland cement or blended hydraulic cements as specified in ASTM C 150 and ASTM C 595, respectively, or a combination of portland cement and pozzolan. Pozzolans are specified in ASTM C 618.

A5.3.1.1 *Portland cement* -- The hydration of portland cement is exothermic; that is, heat is generated during the reaction of cement and water. The quantity of heat produced is a function of the chemical composition of the cement as shown in Fig. A5.3 and the initial temperature.

Type II cement is most commonly used in mass concrete, since it is a moderate heat cement and generally has favorable properties for most types of construction. When used with a pozzolanic admixture, which will be discussed later, the heat generated by a combination of Type II and pozzolan is comparative with that of Type IV. In addition, Type II is more readily available than Type IV. Optional heat of hydration requirements may be specified for Type II cement by limitations on the chemical compounds or actual heat of hydration at 7 days.

Low initial concrete placing temperature, commonly used in mass concrete work, will generally decrease the rate of cement hydration and initial heat generated. Correspondingly, strength development in the first few days may also be reduced.

The fineness of the cement also affects the rate of heat of hydration; however, it has little effect on the initial heat



Cement Type	Fineness ASTM C 115 cm^2/gm	28 Day Heat of Hydration Calories per gm
I	1790	87
II	1890	76
III	2030	105
IV	1910	60

Fig. A5.3-Temperature rise of mass concrete containing 376 pcy (223 kg/m³) of cement.

generated. Fine-ground cements will produce heat more rapidly during the early ages than a coarse-ground cement, all other cement properties being equal.

A5.3.1.2 *Blended hydraulic cements* -- Blended hydraulic cements conforming to the requirements of ASTM C 595, if available and economical, may be used effectively in mass concrete. These cements are composed of a blend of portland cement and blast-furnace slag or pozzolan. The suffix (MH) or (LH) may be used with the designated type of blended cement to specify moderate heat or low heat requirements where applicable.

A5.3.1.3 *Pozzolans* -- Major economic and temperature rise benefits have been derived from the use of pozzolans. Pozzolan is defined as "a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties."[A5.9] Pozzolans include some diatomaceous earths, opaline cherts and shales, tuffs and volcanic ashes or pumicites, any of which may or may not be processed by calcination, and other various materials requiring calcination to induce satisfactory properties, such as some clays and shales. Fly ash, the finely divided residue that results from the combustion of ground or powdered coal and is transported from the combustion chamber by exhaust gases is also a pozzolan.

Utilization of pozzolans in mass concrete provides a partial replacement of cement with a material which generates considerably less heat at early ages. The early age heat contribution of a pozzolan may conservatively be estimated to range between 15 to 50 percent of that of an equivalent weight of cement.

The effects of pozzolan on the properties of freshly mixed concrete vary with the type and fineness; the chemical, mineralogical and physical characteristics of the pozzolan; the fineness and composition of the cement; the ratio of cement to pozzolan; and the weight of cement plus pozzolan used per unit volume of concrete. For example, it has been reported that some pozzolans may reduce water requirements by as much as 7 percent with a reduction of air-entraining admixture needs by up to about 20 percent. Since certain other pozzolans may require as much as 15 percent additional water and over 60 percent more air-entraining admixture, it is important to evaluate the pozzolan intended for use prior to the start of proportioning.

The proportion of cement to pozzolan depends upon the strength desired at a given age, heat considerations, the chemical and physical characteristics of both cement and pozzolan and the cost of the respective materials. Typical quantities of various types of pozzolan and other materials blended with portland cement to reduce heat generation are shown in Table A5.1.

A5.3.2 *Aggregates* -- The nominal maximum size aggregates recommended for use under various placing conditions are shown in Table A5.2. A nominal maximum size aggregate up to 6 in. (150 mm) should be considered, if large size aggregate is available, economical, and placing conditions permit. Because the larger aggregate provides less surface area to be coated by cement paste, a reduction in the quantity of cement and water can be realized for the same water-cement ratio. This relationship is reflected in Table 6.3.3. Typical gradations for individual size fractions of coarse aggregate are shown in Table A5.3. Gradings and other physical properties of fine aggregate should comply with the requirements of ASTM C 33.

A5.3.2.1 *Coarse aggregate combination* -- Upon determining the nominal maximum size, the individual aggregate size groups available should be combined to produce a gradation approaching maximum density and minimum voids. This results in the maximum amount of mortar available for placeability, workability, and finishability. The dry rodded unit weight method is generally applicable for combining size groups up to a nominal maximum size of 1½ in. (37.5 mm); however, this method is impractical for combining size groups of 3 in. (75 mm) or 6 in. (150 mm) nominal maximum size. Eq. (A5.3) gives an approximate percentage of material passing each sieve size required for a given aggregate type. This equation was developed from work by Fuller and Thompson (Reference A5.13) on the packing characteristics of particulate material. The parabolic curve generated from the equation approximates the ideal gradation for maximum density and minimum voids according to the particle shape of the aggregate. Combining the individual coarse aggregate size groups to approximate the ideal curve is the recommended procedure for use with 6 in. (150 mm) and 3 in. (75 mm) nominal maximum size aggregate mixtures in place of the dry rodded unit weight method.

$$P = \frac{d^x - 0.1875^x}{D^x - 0.1875^x}(100)$$

where

- P = cumulative percent passing the d-size sieve
- d = sieve opening, in. (mm)
- D = nominal maximum size aggregate, in. (mm)
- x = exponent (0.5 for rounded and 0.8 for crushed aggregate)

Based on the above equation, the ideal combined gradings for 6 in. and 3 in. (150 and 75 mm) crushed and rounded aggregates are shown in Table A5.4. An acceptable grading for an aggregate that is partially crushed or partially rounded may be interpolated from the gradations in Table A5.4. Using the individual gradation of each size group, 6 in. to 3 in. (150 mm to 75 mm), 3 in. to 1½ in. (75 mm to 37.5 mm) 1½ in. to ¾ in. (37.5 mm to 19 mm), and ¾ in. to No. 4 (19 mm to 4.75 mm), a trial and error method of selecting the percentage of each size group will be necessary to produce a combined grading of the total coarse aggregate approximating the idealized gradation. Selection of the percentage of each size group can usually be done such that the combined grading is generally within 2 or 3 percent of the ideal grading if the individual size group gradings are within the limits of Table A5.3. Where grading limits other than those of Table A5.3 may be used, more tolerance may be required on certain sieve sixes. Furthermore, natural aggregates in some areas may be deficient of certain sizes and, in such cases, modification of the idealized grading to permit use of this aggregate is recommended.

A5.3.2.2 *Coarse aggregate content* — The proportion of fine aggregate for mass concrete depends on the final combined grading of coarse aggregate, particle shape, fineness modulus of the fine aggregate, and the quantity of cementitious material. Coarse aggregate amount can be found using the b/b, method, Table 5.3.6 of ACI 211.1, if the ASTM C 29 bulk unit weight has been determined. For large 3 in. (75 mm) and 6 in. (150 mm) nominal maximum size aggregate Table A5.5 approximates the amount of coarse aggregate as a percent of the total aggregate volume for different moduli of fine aggregate and nominal maximum

TABLE A5.1 — TYPICAL QUANTITIES OF POZZOLANS AND OTHER MATERIALS*

Material or class of material	Percent of total cementing material by absolute volume: Unexposed concrete†	Exposed concrete‡
Pozzolans (ASTM C 6 1 8):		
Class F	35	25
Class N, all types except uncalcined diatomite	30	20
Class N. uncalcined diatomite	20	20
Other materials:		
Slag or natural cement	35	25

*Other quantities of pozzolan or other materials may be used if verified to be acceptable by laboratory mixture evaluations or previous experience. No typical quantities have been established for Class C pozzolan

†Unexposed concrete for massive structures (i.e., gravity dams, spillways, lock walls, and similar massive structures)

‡Exposed concrete for massive structures (see previous note), and exposed structural concrete (i.e., floodwalls, building foundations, pavements, and similar moderate-size structures)

TABLE A5.2 — NOMINAL MAXIMUM SIZE OF AGGREGATE RECOMMENDED FOR VARIOUS TYPES OF CONSTRUCTION

Features	Nominal maximum size, in. (mm)
Sections over 7½ in (190mm) wide and in which the clear distance between reinforcement bars is at least 2¼ in. (57 mm)	1½(37.5)
Unreinforced sections over 12 in. (300 mm) wide and reinforced sections over 18 in (457 mm) wide, in which the clear distance between reinforcement bars is over 6 in (150 mm) and under 10 in (250 mm)	3(75)
Massive sections in which the cleardistance between reinforcement bars is at least 10 in. (250 mm) and for which suitable provision is made for placing concrete containing the larger sizes of aggregate without producing rock pockets or other undesirable conditions.	6(150)

TABLE A5.3 — TYPICAL COARSE AGGREGATE GRADATION LIMITS

Sieve size in. (mm)	Size separation — Percent by weight passing individual sieves: No.4 to ¾ in. (4.75 mm to 19 mm)	¾ in. to 1½ in. (19 mm to 37.5 mm)	1½ in. to 3 in. (37.5 mm to 75 mm)	3 in. to 6 in. (75 mm to 150 mm)
7(177)				100
6(150)				90-100
4(100)			100	20-55
3(75)			90-100	0-15
2(50)		100	20-55	0-5
1-1/2(37.5)		90-100	0-10	
1(25)	100	20-55	0-5	
3/4(19)	90-100	0-15		
3/8(9.5)	20-55	0-5		
No. 4(4.75)	0-10			
No. 8(2.36)	0-5			

TABLE A5.4-IDEALIZED COMBINED GRADING FOR 6 IN. (150 mm) and 3 IN. (75 mm) NOMINAL MAXIMUM SIZE AGGREGATE FROM EQ. (A5.3)

Sievesize — in. (mm)	6 in. (150 mm) Percent passing: Crushed	Rounded	3 in. (75 mm) Percent passing: Crushed	Rounded
6(150)	100	100	—	—
5(125)	85	89		—
4(100)	70	78		—
3(75)	54	64	100	100
2(50)	38	49	69	75
1-1/2(37.5)	28	39	52	61
1(25)	19	28	34	44
3/4(19)	13	21	25	33
3/8(9.5)	5	9	9	14

sizes of coarse aggregate. The table is only applicable for 3 in. (75 mm) and 6 in. (150 mm) nominal maximum size aggregate.

A5.3.3 *Admixtures* -- When proportioning mass concrete use of admixtures should always be considered. The two most commonly used admixtures in mass concrete are air-entraining and water-reducing admixtures.

A5.3.3.1 *Air entrainment* -- Air entrainment in mass concrete is necessary if for no other reason than to increase workability of lean concrete mixtures. The use of air entrainment in mass concrete, as in other concrete, permits a marked improvement in durability, improvement in plasticity and workability, and reduction in segregation and bleeding. The effect of air entrainment on the strength of mass concrete is minimized due to the reduction in the quantity of paste in concrete which contains 3 in. (75 mm) and 6 in. (150 mm) nominal maximum size aggregate. However, such effects should be considered in the design of mass concrete having 1½ in. (37.5 mm) or ¾ in. (19 mm) nominal maximum size aggregate. In lean mixtures strengths are not reduced as much when air entrainment is used; in some cases strengths may increase due to the reduction in mixing water requirements with air entrainment. Air contents should be in accordance with those recommended in Table A5.6.

TABLE A5.5 — APPROXIMATE COARSE AGGREGATE CONTENT WHEN USING NATURAL (N) OR MANUFACTURE (M) FINE AGGREGATE (Percent of total aggregate by absolute volume)

Nominal maximum size and type coarse aggregate	Sand type:	Fineness modulus 2.40 N	2.40 M	2.60 N	2.60 M	2.80 N	2.80 M	3.00 N	3.00 M
6 in. (150 mm) crushed		80	78	78	77	78	76	77	76
6 in. (150 mm) rounded		82	80	81	79	80	78	79	77
3 in. (75 mm) crushed		75	73	74	72	73	71	72	70
3 in. (75 mm) rounded		77	75	76	74	75	73	74	72

Note: For concrete containing 4½ percent air content and a slump of 2 in. (50 mm), both measured on the minus 1½ in. (37.5 mm) portion. The coarse aggregate contents given above may be increased approximately 1 or 2 percent if good control procedures are followed. The coarse aggregate content in the table pertains primarily to the particle shape in the minus 1½ in. (37.5 mm) portion.

TABLE A5.6—APPROXIMATE MORTAR AND AIR CONTENT FOR VARIOUS NOMINAL MAXIMUM SIZE AGGREGATES [1½ in. (37.5 mm) slump and air content of 5 to 6 percent in minus 1½ in. (37.5 mm) portion]

Nominal maximum size and type coarse aggregate	Mortar content cu ft/cu yd ± 0.2 (m3/m3 + 0.01)	Air content Total mixture, percent
6 in. (150 mm) crushed	10.5 (0.39)	3.0-4.0
6 in. (150 mm) rounded	10.0 (0.37)	3.0-4.0
3 in. (75 mm) crushed	12.0(0.44)	3.5-4.5
3 in. (75 mm) rounded	11.5 (0.43)	3.5-4.5

TABLE A5.7 — APPROXIMATE COMPRESSIVE STRENGTHS OF AIR-ENTRAINED CONCRETE FOR VARIOUS WATER-CEMENT RATIOS [Based on the use of 6 x 12-in. (152 x 305-mm) cylinders.]

Water-cement ratio by weight*	Approximate 28-day compressive strength, psi (MPa) (f'_c)† Natural aggregate	Crushed aggregate
0.40	4500 (31.0)	5000(34.5)
0.50	3400(23.4)	3800(26.2)
0.60	2700(18.6)	3100(21.4)
0.70	2100(14.5)	2500(17.2)
0.80	1600(11.0)	1900(13.1)

*These w/c ratios may be converted to w/(c + p) ratios by the use of the equation in Section 5.3.4
†90 days when using pozzolan

TABLE A5.8 — MAXIMUM PERMISSIBLE WATER-CEMENT RATIOS FOR MASSIVE SECTIONS

Location of structure	Water-cement ratios, by weight: Severe or moderate climate	Mild climate, little snow or frost
At the waterline in hydraulic or waterfront structures where intermittent saturation is possible	0.50	0.55
Unexposed portions of massive structure	No limit*	No limit
Ordinary exposed structures	0.50	0.55
Complete continuous submergence in water	0.58	0.58
Concrete deposited in water	0.45	0.45
Exposure to strong sulfate groundwater or other corrosive liquid, salt or sea water	0.45	0.45
Concrete subjected to high velocity flow of water (>40 ft/s) (>12 m/s)	0.45	0.45

Note 1. These w/c ratios may be converted to w/(c + P) ratios by use of equation in Section 5.3.4
*Limit should be based on the minimum required for workability or Table A5.7 for strength

A5.3.3.2 *Water-reducing admixture* -- Water-reducing admixtures meeting the requirements of ASTM C 494 have been found effective in mass concrete mixtures. The water reduction permits a corresponding reduction in the cement content while maintaining a constant water-cement ratio. The amount of water reduction will vary with different concretes; however, 5 to 8 percent is normal. In addition, certain types of water-reducing admixture tend to improve the mobility of concrete and its response to vibration, particularly in large aggregate mixtures.

A5.4 *Strength and durability* -- The procedure for proportioning mass concrete is used primarily for controlling the generation of heat and temperature rise, while satisfying the requirements for strength and durability. The strength and durability properties are primarily governed by the water-cement ratio. The water-cement ratio is the ratio, by

TABLE A5.9 — QUANTITIES OF MATERIALS SUGGESTED FOR CONCRETE PROPORTIONING TRIAL MIXTURES

Nominal maximum size aggregate in mixture in. (mm)	Quantities of aggregates, lb (kg)					Cement, lb. (kg)
	Fine aggregate	Coarse aggregates				
		No. 4 to ¾ in. (4.75 mm to 19 mm)	¾ in. to 1½ in. (19 mm to 37.5 mm)	1½ in. to 3 in. (37.5 to 75 mm)	3 in. to 6 in. (75 mm to 150 mm)	
¾ (19)	1200 (544)	1200 (544)	—	—	—	400 (181)
1½ (37.5)	1000 (454)	1000 (454)	1000 (454)	—	—	400 (181)
3 (75)	2000 (907)	1500 (680)	1000 (454)	2000 (907)	—	500 (227)
6 (150)	3000 (1361)	2000 (907)	1500 (680)	2500 (1134)	3000 (1361)	700 (318)

Note 1 The actual quantity of materials required depends upon the laboratory equipment availability of materials, and extent of the testing program
Note 2 If a pozzolan or fly ash is to be used in the concrete, the quantity furnished should be 35 percent of the weight of the cement
Note 3 One gal (3.8 l) of a proposed air-entraining admixture or chemical admixture will be sufficient

weight, of amount of water, exclusive of that absorbed by theaggregates, to the amount of cement in a concrete or mortar mixture. Unless previous water-cement ratio-compressive strength data are available, the approximate compressive strength of concrete tested in 6 x 12-in. (152 x 305-mm) cylinders for various water-cement ratios can be estimated from Table A5.7. The recommended maximum permissiblewater-cement ratio for concrete subject to various conditions of exposure are shown in Table A5.8. The water-cement ratio determined by calculation should be verified by trial batches to ensure that the specified properties of the concrete are met. Results may show that strength or durability rather than heat generation govern the propor-tions. When this situation occurs alterative measures to control heat will be necessary. For example, in gravity dam construction an exterior-facing mix may be used which con-tains additional cement to provide the required durability. Other measures may include a reduction in the initial temp-erature of concrete at placement or a limitation on the size of the placement. If compressive strengths are given for full mass mixture containing aggregate larger than 1½ in. (75 mm), approximate relationships between strength of the full mass mixture and wet screened 6 x 12-in. (152 x 305-mm) cylinder are available from sources such as Reference A5.6.

A5.5 *Placement and workability* -- Experience has demonstrated that large aggregate mixtures, 3 in. (75 mm) and 6 in. (150 mm) nominal maximum size aggregate, require a minimum mortar content for suitable placing and workability properties. Table A5.6 reflects the total absolute volume of mortar (cement, pozzolan, water, air, and fine aggregate) which is suggested for use in mixtures containing large aggregate sixes. These values should be compared with those determined during the proportioning procedure and appropriate adjustments made by either increasing or decreasing the trial mixture mortar contents for improved workability.

A5.6 *Procedure* -- Upon determining the properties of the materials and knowing the properties of the concrete, the proportioning procedure follows a series of straight-forward steps outlined in A5.6.1 to A5.6.12. Proportions should be determined for the anticipated maximum placing temperature due to the influence on the rate of cement hydration and heat generated. With the use of 3 in. (75 mm) or 6 in. (150 mm) nominal maximum size aggregate, the pro-cedure may be somewhat different from ACI 211. 1, mainly because of the difficulty in determining the density of the large aggregate by the dry rodded unit weight method. For nominal maximum size aggregate 1½ in. (37.5 mm) or less, proportioning in accordance with ACI 211.1 may be used.

A5.6.1 *Step 1* -- Determine all requirements relating to the properties of the concrete including:

1. Nominal maximum size of aggregates that can be used.
2. Slump range.
3. Water-cement ratio limitations.
4. Expected maximum placing temperature.
5. Air content range.
6. Specified strengths and test ages.
7. Expected exposure conditions.
8. Expected water velocities, when concrete is to be subjected to flowing water.
9. Aggregate quality requirements.
10. Cement and/or pozzolan properties.

A5.6.2 *Step 2* -- Determine the essential properties of materials if sufficient information is not available. Representative samples of all materials to be incorporated in the concrete should be obtained in sufficient quantities to provide verification tests by trial batching. The suggested quantities of materials necessary to complete the required tests are shown in Table A5.9. If pozzolan is economically available, or required by the specification, the percentage as suggested in Table A5.1 should be used as a starting point in the trial mixes.

From the material submitted for the test program, determine the following properties:

1. Sieve analysis of all aggregates.
2. Bulk specific gravity of aggregates.
3. Absorption of aggregates.
4. Particle shape of coarse aggregates.
5. Fineness modulus of fine aggregate.
6. Specificgravity of portland cement, and/or pozzolans and blended cement.
7. Physical and chemical properties of portland cement and/or pozzolans and blended cement including heat of hydration at 7 days.

A complete record of the above properties should be made available for field use; this information will assist in adjusting the mixture should any of the properties of the materials used in the field change from the properties of the materials used in the laboratory trial mix program.

A5.6.3 *Step 3* -- Selection of *W/C* ratio. If the water-cement ratio is not given in the project document, select from Table A5.8 the maximum permissible water-cement (*W/C*) ratio for the particular exposure conditions. Compare this *W/C* ratio with the maximum permissible *W/C* ratio required in Table A5.7 to obtain the average strength which includes the specified strength plus an allowance for anticipated variation and use the lowest *W/C* ratio. The *W/C* ratio should be reduced 0.02 to assure that the maximum permissible *W/C* ratio is not exceeded during field adjustments. This *W/C* ratio, if required, can be converted to a water-cement plus pozzolan ratio by the use of Eq. (6.3.4.1).

A5.6.4 *Step 4* -- Estimate of mixing water requirement. Estimate the water requirement from Table 6.3.3 for the specified slump and nominal maximum size aggregate. Initial placing temperature may affect this water requirement; for additional information consult Reference A5.6.

A5.6.5 *Step 5* -- Selection of air content. Select a total air content of the mixture as recommended in Table A5.6. An accurate measure of air content can be made during future adjustment of the mixture by use of Eq. (A5.6).

$$A = \frac{a}{1 + r\left(1 - \frac{a}{100}\right)} \qquad \text{(A5.6)}$$

where

- A = air content of total mixture, expressed as a percent
- a = air content of minus 1½ in. (37.5 mm) fraction of mixture, expressed as a percent
- r = ratio of the absolute volume of plus 1½ in. (37.5 mm) aggregate to the absolute volume of all other materials in the mixture except air. If 100 percent of the aggregate passes the 1½ in. (37.5 mm) sieve, r =O, and A=a

A5.6.6 *Step 6* -- Compute the required weight of cement from the selected *W/C* (A5.6.3) and water requirement (A5.6.4).

A5.6.7 *Step 7* -- Determine the absolute volume for the cementitious materials, water content, and air content from information obtained in Steps 4, 5, and 6. Compute individual absolute volumes of cement and pozzolan.

$$V_{c+p} = \frac{C_w}{G_c(62.4)} \text{ cu ft or } \frac{C_w}{G_c(1000)} \text{ m}^3 \qquad \text{(A5.6A)}$$

$$V_c = V_{c+p}(1 - F_v) \qquad \text{(A5.6B)}$$

$$V_p = V_{c+p}(F_v) \qquad \text{(A5.6C)}$$

where

- C_w = weight of the equivalent portland cement as determined from Step 6
- G_c = specific gravity of portland cement
- V_c = volume of cement (cu ft) (m³)
- V_p = volume of pozzolan (cu ft) (m³)
- V_{c+p} = volume of cement and pozzolan (cu ft) (m³)
- F_v = percent pozzolan by absolute volume of the total absolute volume of cement plus pozzolan expressed as a decimal factor

A5.6.8 *Step 8* -- Select percent of coarse aggregate. From Table A5.5, and based on the fineness modulus of the fine aggregate as well as the nominal maximum size and type of coarse aggregate, determine the coarse aggregate percentage of the total volume of aggregate.

A5.6.9 *Step 9* -- Determine the absolute volume of the total aggregate by subtracting from the unit volume the absolute volumes of each material as computed in Step 7. Based on the amount of coarse aggregate selected in Step 8, determine the absolute volume of the coarse aggregate. The remainder of the absolute volume represents the quantity of fine aggregate in the mix.

A5.6.10 *Step 10* -- Establish the desired combination of the separate coarse aggregates size groups. Using the individual coarse aggregates gradings, combine all coarse aggregate to a uniform grading approximating the gradings shown in Table A5.4 for 6 in. (150 mm) nominal maximum size aggregate (NMSA) or 3 in. (75 mm) NMSA. The percentage of each size group should be rounded to the nearest whole percent.

A5.6.11 *Step 11* -- Convert all absolute volumes to weight per unit volume of all ingredients in the mixture.

A5.6.12 *Step 12* -- Check the mortar content. From the absolute volumes computed earlier, compute the mortar content and compare the results with values given in Table A5.6. Values in Table A5.6 will provide an indication of the workability of the mixture as determined by past field performance. Table A5.6 can be used as an aid in making laboratory adjustments of the mixture.

A5.7 *Example problem* -- Concrete is required for a heavy bridge pier that will be exposed to fresh water in a severe climate, The design compressive strength is 3000 psi (20.7 MPa) at 28 days. Placement conditions permit the use of a large nominal maximum size aggregate, and 6 in. (150 mm) nominal maximum size crushed stone is available. Laboratory tests indicate that 6,3, 1½, and ¾ in. (150,75,37.5, and 19 mm) size groups of crushed stone have bulk specific gravities (saturated-surface-dry, S.S.D. basis) of 2.72, 2.70, 2.70, and 2.68, respectively; the natural fine aggregate available has a bulk specific gravity of 2.64 with a fineness modulus of 2.80. A Class F (fly ash) pozzolan is available and should be used to reduce the generation of heat in the concrete. The pozzolan has a specific gravity of 2.45, and Type II portland cement is available.

A5.7.1 *Step 1* -- Determine desired properties. The following properties have been specified upon review of the project documents and consultation with the engineer:

1. A 6 in. (150 mm) nominal maximum size crushed stone aggregate is available and economically feasible to use.
2. Slump range of the concrete will be 1 to 2 in. (25 to 50 mm) as measured in the minus 1½ in. (37.5 mm) portion.
3. Maximum permissible *W/C* ratio by weight required to be 0.50 for durability purposes.
4. Project documents require the concrete to be placed at 65 F (18 C) or below.
5. The concrete is required to be air entrained within a range of 1½ percent of 5 percent when tested on the minus 1½ in. (37.5 mm) material.
6. Assuming a standard deviation of 500 psi (3.45 MPa), considered good overall general construction control, and 80 percent of the tests above design strength, an average compressive strength of no less than 3400 psi (23.4 MPa) at 28 days (90 days with pozzolan) is required in accordance with ACI 214-77.
7. The concrete will be subjected to severe exposure conditions.
8. Water velocities around the concrete will not exceed 40 ft/sec (12 m/s).
9. Aggregates meeting the requirements of the project specifications are available.
10. The project specifications require the use of portland cement Type II and permit the use of pozzolan.

A5.7.2 *Step 2* -- Determine properties of the materials.

1. The coarse aggregates have the following sieve analyses:

	Percent by weight passing individual sieves			
Sievesize in. (mm)	No. 4 to ¾ in. (4.75 mm to 19 mm)	¾ in. to 1½ in. (19 mm to 37.5 mm)	1½ in. to 3in. (37.5 mm to 75 mm)	3in. to 6in. (75 mm to 150 mm)
7 (175)				100
6 (150)				98
5 (125)				60
4 (100)			100	30
3 (75)			92	10
2 (50)		100	30	2
1½ (37.5)		94	6	
1 (25)	100	36	4	
¾ (19)	92	4		
⅜ (9.5)	30	2		
No. 4(4.75)	2			

2. The bulk specific gravities (saturated-surface-dry, S.S.D. basis) of the coarse and fine (sand) aggregates are determined to be:

Size group	Specific gravity
6 in. to 3 in. (150 to 75 mm)	2.72
3 in. to 1½ in. (75 to 37.5 mm)	2.70
1½ in. to ¾ in. (37.5 to 19 mm)	2.70
¾ in. to No. 4 (19 to 4.75 mm)	2.68
Fine aggregate	2.64

3. The absorptions of the coarse and fine aggregates are as follows:

Size group	Absorption (percent)
6 in. to 3 in. (150 to 75 mm)	0.5
3 in. to 1½ in. (75 to 37.5 mm)	0.75
1½ in. to ¾ in. (37.5 to 19 mm)	1.0
¾ in. to No. 4 (19 to 4.75 mm)	2.0
Fine aggregate	3.2

4. The coarse and fine aggregate are totally crushed and natural, respectively.
5. The fineness modulus of the fine aggregate is 2.80.
6. Specific gravities of the portland cement and pozzolan are 3.15 and 2.45, respectively.
7. Physical and chemical tests of the portland cement and pozzolan verify compliance with the requirements of the project specifications.

A5.7.3 *Step 3* -- Selection of *W/C* ratio. From Table A5.8, the exposure conditions permit a maximum permissible *W/C* ratio of 0.50 and Table A5.7 recommends a maximum *W/C* ratio of 0.57 to obtain the desired average strength of 3400 psi (23.44 MPa). Since the exposure conditions require the lower *W/C* ratio, the designed *W/C* ratio will be 0.48 or 0.02 less than that permitted to allow for field adjustments.

Since a fly ash pozzolan is available and the quantity of concrete in the project justifies its use economically, 25 percent by volume will be used according to Table A5.1.

A5.7.4 *Step 4* -- Estimate of mixing water requirement. From Table 6.3.3 the estimated water content is 180 lb/cu yd (107 kg/m^3) based on the use of a 6 in. (150 mm) crushed stone (NMSA) and a slump of 1 to 2 in. (25 to 50 mm).

A5.7.5 *Step 5* -- Selection of air content. A total air content of 3.2 percent is selected which is within the range recommended in Table A5.6. During later adjustments, after all ingredients are determined, a more accurate total air content can be derived by the use of Eq. (A5.6).

A5.7.6 *Step 6* -- Determine weight of cement from selected *W/C* ratio and water demand.

from Step 3 *W/C* = 0.48

therefore: weight of cement in a total portland cement mixture equals

Combined grading computations

Sieve size in. (mm)	Grading of individual size groups percent passing				Trial and error selection Size group percentages and gradings 45 percent	25 percent	15 percent	15 percent	Combined grading percent passing	Idealize* grading percent passing
	6 in. to 3 in. (150 mm to 75 mm)	3 in. to 1½ in. (75 mm to 37.5 mm)	1½ in. to ¾ in. (37.5 mm to 19 mm)	¾ in. to No. 4 (19 mm to 4.75 mm)	6 in. to 3 in. (150 mm to 75 mm)	3 in. to 1½ in. (75 mm to 37.5 mm)	1½ in. to ¾ in. (37.5 mm to 19 mm)	¾ in. to No. 4 (19 mm to 4.75 mm)		
7 (175)	100				45	25	15	15	100	
6 (150)	98				44	25	15	15	99	100
4 (100)	30	100			14	25	15	15	69	70
3 (75)	10	92			4	23	15	15	57	54
2 (50)	2	30	100		1	8	15	15	39	38
1½ (37.5)		6	94			2	14	15	31	28
1 (25)		4	36	100		1	5	15	21	21
¾ (19)			4	92			1	14	15	15
⅜ (9.5)			2	30			0	5	5	5
No.4(4.75)				2				0	0	0

*From Table A5.4 for 6 in. (150 mm) nominal maximum size crushed material.

$$\frac{180}{0.48} = 375\ lb/cu\ yd\ or\ (222\ kg/m^3)$$

A5.7.7 *Step 7* – Determine absolute volume per cubic yard (cubic meter) for the cementitious materials, water content and air content. As recommended in Table A5.1, 25 percent pozzolan by volume will be used. Using Eq. (A5.6.7A), (B), and (C), the absolute volume of cementitious material can be determined.

$$V_{c+p} = \frac{C_w}{G_c(62.4)} = \frac{375}{3.15(62.4)} = \underline{1.91\ cu\ ft/cu\ yd}\ or \left(\frac{222}{3.15(1000)}\ \underline{0.070\,m^3/m^3}\right)$$

$$V_c = V_{c+p}(1 - F_v) = 1.91(1\text{-}0.25) = \underline{1.43\ cu\ ft/cu\ yd}\ or\ (0.070\,(1 - 0.25) = \underline{0.052\ m^3/m^3})$$

$$V_p = V_{c+p}(F_v) = 1.91(0.25)\ \underline{0.48\ cu\ ft/cu\ yd}\ or\ (0.070(0.25) = \underline{0.018\,m^3/m^3})$$

$$V_w = \frac{180}{62.4} = \underline{2.88\,cu\,ft}\ or \left(\frac{107}{1000} = \underline{0.107\,m^3/m^3}\right)$$

$$V_A = 0.032\ (27)\ \underline{yd\ or = 0.86\ cu\ ft/cu\ yd}\ or\ (0.032(1.0) = \underline{0.032\,m^3/m^3})$$

A5.7.8 *Step 8* – For a natural fine aggregate with an F.M. of 2.80 and a 6-in (152 mm) (NMSA) crushed stone, the volume of coarse aggregate to be used in the trial batch is 78 percent--see Table A5.5.

A5.7.9 *Step 9* – Determine the absolute volume of fine and coarse aggregates.

$27 - V_W - V_A - V_{c+p}$ = Vol of aggregate/cu yd or
($1.0 - V_W - V_A - V_{c+p}$ = Vol of aggregate/m³)
27 - 2.88 - 0.86 - 1.91 = 21.35 cu ft/cu yd or (0.79m³/m³)

Vol of coarse aggregate	= 21.35 (0.78) cu ft/cu yd or [0.79(0.78) m³/m³] = 16.65 cu ft/cu yd or (0.62 m3/m3)
Vol of fine aggregate	= 21.35(0.22) cu ft/cu yd or [0.79(0.22) m³/m³] = 4.70 cu ft/cu yd or (0. 17m³/m³)

A5.7.10 *Step 10* – Combine the various size groups of coarse aggregate. The existing coarse aggregate gradings were combined by trial-and-error computations, resulting in the following percentages of each size group:

No. 4 to ¾ in.	(4.75 to 19 mm)	15 percent
¾ in. to 1½ in.	(19 to 75 mm)	15 percent
1½ in. to 3 in.	(75 to 150 mm)	25 percent
3 in. to 6 in.	(150 to 300 mm)	45 percent

A5.7.11 *Step 11* -- Convert all absolute volumes to weight per unit volume.

Material	Absolute volume x specific gravity x 62.4	lb/cu yd (kg/m^3)
Portlandcement	1.43(3.15)62.4	281(167)
Pozzolan	0.48(2.45)62.4	73 (43)
Water	2.88(1.00)62.4	180(107)
Air	0.86	
Fine aggregate	4.70(2.64)62.4	774(459)S.S.D.*
Coarse aggregate		
No. 4-¾ in. (4.75 -19 mm)	16.65(0.15)(2.68)62.4	418(248)S.S.D.*
¾–1½ in. (19mm-75 mm)	16.65(0.15)(2.70)62.4	421(250)S.S.D.*
1½–3 in. (75mm-150 mm)	16.65(0.25)(2.70)62.4	701(416)S.S.D.*
3-6 in. (150-300 mm)	16.65(0.45)(2.72)62.4	1272(755)S.S.D.*

*Weights based on aggregates in a saturated-surface-dry condition.

A5.7.12 *Step 12* -- Check mortar content and compare with Table A5.6

Mortar content $= V_c + V_p + V_w + V_s + V_A$
$= 1.43 + 0.48 + 2.88 + 4.70 + 0.86$
$= 10.35$ cu ft/cu yd ($0.383\ m^3/m^3$)

From Table A5.6 the mortar content is estimated to be 10.5 cu ft/cu yd ($0.39\ m^3/m^3$) which is within the ±0.2 cu ft (2 0.01 m^3) of the actual value.

A5.7.13 *Trial batch* -- From the above information the absolute volume and weight per cubic yard of each ingredient computes as follows:

Material	Absolute volume ft^3/yd^3 (m^3/m^3)	Weight lb/yd^3 (kg/m^3)
Portland cement	1.43(0.052)	281 (167)
Pozzolan	0.48(0.018)	73 (43)
Water	2.88(0.107)	180(107)
Air	0.86(0.032)	—
Fine aggregate	4.70(0.174)	774 (459)S.S.D.*
No. 4-¾ in. (4.75 -19 mm)	2.50(0.093)	418 (248)S.S.D.*
¾–1½ in. (19mm-75 mm)	2.50(0.093)	421 (250)S.S.D.*
1½–3 in. (75mm-150 mm)	4.16(0.154)	701 (416)S.S.D.*
3-6 in. (150-300 mm)	7.49(0.277)	1272 (755)S.S.D.*
Total	27.00(1.000)	4120 (2444)

*Weights are based on aggregate in a saturated-surface-dty condition.

The weights above should be reduced proportionately to facilitate the preparation of trial batches which in turn should be evaluated for proper moisture correction, slump, air content, and general workability. After the necessary adjustments, trial mixtures for strength verification and other desired properties of concrete should be made. Reference 2 will provide guidance in estimating the heat generated by the trial mixture and in determining whether or not other temperature control measures are needed.

A5.8 *References*

A5.1 Townsend, Charles L., "Control of Temperature Cracking in Mass Concrete," *Causes, Mechanism, and Control of Cracking in Concrete, SP-20,* American Concrete Institute, Detroit, 1968, pp. 119-139.

A5.2 ACI Committee 207, "Effect of Restraint, Volume Change, and Reinforcement on Cracking of Massive Concrete," ACI Journal, *Proceedings V. 70, No. 7,* July 1973, pp. 445-470. Also, *ACI Manual of Concrete Practice,* Part 1.

A5.3 Townsend, C. L., 'Control of Cracking in Mass Concrete Structures," *Engineering Monograph No. 34,* U.S. Bureau of Reclamation, Denver, 1965.

A5.4 ACI Committee 207, "Mass Concrete for Dams and Other Massive Structures," ACI Journal, *Proceedings* V. 67, No. 4, Apr. 1970, pp. 273-309. Also, ACI Manual of Concrete Practice, Part 1.

A5.5 ACI Committee 224, "Control of Cracking in Concrete Structures," ACI Journal, *Proceedings* V. 69, No. 12, Dec. 1972, pp. 717-753.

A5.6 *Concrete Manual,* 8th Edition, U.S. Bureau of Reclamation, Denver, 1975, 627 pp.

A5.7 *Proportioning Concrete Mixes, SP-46,* American Concrete Institute, Detroit, 1974, 223 pp.

A5.8 Tynes, W. O., "Effect of Fineness of Continuously Graded Coarse Aggregate on Properties of Concrete," *Technical Report No.* 6-819, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Apr. 1968, 28 pp.

A5.9 ACI Committee 116, *Cement and Concrete Terminology,* 2nd Edition, SP-19(78), American Concrete Institute, Detroit, 1978, 50 pp.

A5.10 *Handbook for Concrete and Cement,* CRD-C 3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, 1949 (with quarterly supplements).

A5.11 "Standard Practice for Concrete," EM 1110-2-2000 Office, Chief of Engineers, U.S. Army Corps of Engineers, Washington, D.C., June 1974.

A5.12 Hansen, Kenneth, "Cost of Mass Concrete in Dams," *Publication No. MS260W,* Portland Cement Association, Skokie, 1973, 4 pp.

A5.13 Powers, Treval C., *The Properties of Fresh Concrete,* John Wiley and Sons, New York, 1968, pp. 246-256.

A5.14 ACI Committee 207, "Cooling and Insulating Systems for Mass Concrete," (ACI 207.4R-80) *Concrete International--Des&n and Construction, V.2, No. 5,* May 1980, pp. 45-64.

Anexo 5. *ACI 211.5R-01*

ACI 211.5R-01
(Reapproved 2009)

Guide for Submittal of Concrete Proportions

Reported by ACI Committee 211

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Information required for the preparation and review of a concrete mixture submittal is contained in reference documents such as codes and standards, project drawings and specifications, and other contract documents. These requirements depend on the intended use of the concrete, the available information, and the size of the project. This guide is intended to assist both the submitter and reviewer by providing a description of necessary information to ensure that the appropriate information is provided. Use of the guide may be limited when contract documents define the submittal format. The guide emphasizes that the concrete mixture is a unique combination of specific ingredients, from particular sources, and in quantities necessary to achieve the intended purpose.

Keywords: admixture; aggregate; compressive strength; fiber reinforcement; hydraulic cement; mixture proportion; required strength; water-cementitious materials ratio.

CONTENTS

ACI 211.5R-01 supersedes ACI 211.5R-96 and became effective September 7, 2001.

CHAPTER 1—INTRODUCTION

1.1—General

Project specifications, reference publications, drawings, and other contract documents contain the requirements for concrete materials, proportions, and characteristics. Concrete mixture proportions, intended to satisfy these requirements, are usually submitted based on field test results, laboratory trial batch test results, or both. The purchaser's acceptance of materials and proportions is based on conformance of the submitted details to the criteria contained in the contract documents.

1.2—Purpose

This guide provides information to assist in the submittal and review of materials and concrete mixture proportions. It is intended to benefit both the submitter and the reviewer. Beginning with the preparation of the concrete mixture proportions and supporting documentation by the concrete producer, followed by the actual submittal of the mixture proportions by the concrete contractor to the general contractor, and subsequently to the architect and engineer, each should find this information helpful.

1.3—Scope

This guide is limited to the preparation and review of the submittal of proposed materials and concrete mixture proportions for conformance with the requirements of the contract documents. It is not intended to impose additional requirements, but rather to help the user recognize and implement current ACI practices and procedures that may be required for the project.

1.4—Definitions

Admixture—A material other than water, aggregate, hydraulic cement, and fiber reinforcement, used as an ingredient of concrete or mortar and added to the batch immediately before or during its mixing (ACI 116R).

Aggregate—Granular material, such as sand, gravel, crushed stone, crushed hydraulic-cement concrete, or iron blast-furnace slag, used with a hydraulic cementing medium to produce either concrete or mortar (ACI 116R).

Aggregate, lightweight—Aggregate of low density, such as: expanded or sintered clay, shale, slate, diatomaceous shale, perlite, vermiculite, or slag; natural pumice, scoria, volcanic cinders, tuff, and diatomite; and sintered fly ash or industrial cinders, used in lightweight concrete (ACI 116R).

Cement, hydraulic—A cement that sets and hardens by chemical interaction with water and is capable of doing so underwater (ACI 116R).

Concrete—A composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate, usually a combination of fine aggregate and coarse aggregate; in portland-cement concrete, the binder is a mixture of portland cement and water, with or without admixtures (ACI 116R).

f'_c—Specified compressive strength of concrete used in design (ACI 104R).

f'_{cr}—Required average compressive strength of concrete, used as the basis for selection of concrete proportions (ACI 104R).

Fiber reinforcement—Discontinuous discrete fibers produced from steel, synthetic (organic), glass, or natural materials, in various shapes and sizes that are added before or during mixing of the concrete.

Materials, cementitious—Cements and pozzolans used in concrete and masonry construction (ACI 116R).

Water-cementitious materials ratio—The ratio of the mass of water, exclusive only of that absorbed by the aggregate, to the mass of cementitious material (hydraulic) in concrete, mortar, or grout (ACI 116R).

CHAPTER 2—MATERIALS AND PRODUCTION

2.1—Quality of materials

Cementitious materials, aggregates, admixtures, fibers, and water should comply with the contract documents. Evidence of satisfactory performance of each material should be provided on request. If a deviation from the specified material is necessary, a full explanation to the architect and engineer should be included in the submittal.

2.2—Submittal information

Cement/cementitious materials—The source and type of each material proposed for use on the project should be identified and included. Mill test reports, manufacturer's certification of compliance, or both, should be submitted, if required, or be available upon request by the purchaser.

Aggregates—The sources, types, and individual gradings for each aggregate should be identified. In conformance with ASTM C 33 and C 330, the combined gradings of the total blended aggregate when combined aggregate concepts are used and should be included for each mixture as described in ACI 301. The fineness modulus of fine aggregate should be reported. The saturated-surface-dry (SSD) specific gravity and absorption of all aggregates as per ASTM C 127 and C 128, and dry-rodded unit weight for coarse aggregate as per ASTM C 29, should be provided. Similarly, loose unit weight of lightweight aggregate (oven dry) should be provided when lightweight aggregate is used.

For coarse aggregates, the size designation (as described in ASTM C 29, C 33, C 330, or D 448) or the nominal maximum size is needed. Because all of these aggregate properties influence the proportioning of the concrete mixture, they should be submitted to support the proposed mixture proportions.

Admixtures—The vendor and type of all admixtures proposed for use should be identified in accordance with ASTM C 260, C 494, or another governing standard. These admixtures should be of the same type as those used in the trial mixtures from which strength data were obtained. If admixtures are to be added at a point other than the concrete batching facilities, the location should be identified.

Water—The source of mixing water should be identified. Nonpotable water requires evidence of satisfactory use in mortar or concrete in accordance with ASTM C 94, Table 2. Some specifications may restrict the chloride-ion content of the concrete.

Chloride-ion content—Evidence of soluble chloride-ion content for each ingredient or for the hardened concrete may be required.

Fibers, color pigments, and other additions—Where the source and type of specific additions are required by the contract, they should be contained in mixtures from which strength data were obtained. Materials identified in the submittal as alternates to products specified by name should include evidence of satisfactory performance and compliance to appropriate material standards.

Production—Information supporting compliance with the contract documents or ASTM C 94 should be available upon request by the purchaser. If more than one production facility is proposed for use, the above information should be available for each facility.

CHAPTER 3—CONCRETE MIXTURE PROPORTIONS

3.1—Proportioning

The concrete mixture proportions expressed in terms of quantity of each component per unit volume of concrete, combined with the freshly mixed concrete properties and the hardened concrete characteristics, constitute the submittal. The mass and the absolute volume contributed by each material in the mixture should be included in the submittal of the mixture proportions. Omission of components, quantities, or properties by the submitter may result in rejection of the submittal.

3.2—Quantities by mass

The quantity of cementitious material added in the powder state should be expressed as pound-mass per cubic yard (lb/yd^3) or kilograms per cubic meter (kg/m^3). Pozzolans that are added in a slurry should have their respective solid and water contents expressed as pound-mass per cubic yard or kilograms per cubic meter. The quantity of each separately batched size of coarse aggregate and fine aggregate should be expressed as pound-mass per cubic yard or kilograms per cubic meter in an SSD condition. If lightweight aggregate is used, the oven-dry and estimated wet weight should be stated.

Admixtures dispensed as liquids should be expressed as fluid ounces per cubic yard ($fl\ oz/yd^3$) or liters per cubic meter (L/m^3) and where applicable, the expected dosage range should be stated. The quantity of any premeasured, prepackaged additives, such as fibers or color pigments, should be expressed in incremental units (sacks, bags, boxes, or tins) and pound-mass per cubic yard or kilograms per cubic meter.

3.3—Quantities by volume

The absolute volume of each material, air content, and the total sum of the absolute volumes of all materials should be provided in cubic feet (ft^3) or cubic meters (m^3). If lightweight aggregate is used, the bulk volume in the saturated condition should be stated. It is customary and acceptable in most localities to proportion mixtures to yield slightly in excess of 27.00 ft^3/yd^3 or (1.00 m^3/m^3). The practice provides producers with a systematic means of handling charges of short yield due to air content fluctuation provided that the actual expected yield is identified in the submittal.

3.4—Freshly mixed concrete properties

Slump, unit weight, and air content should be reported for each set of mixture proportions intended for use. Placement methods, such as pumping and slip forming, associated with each proposed mixture should be indicated where appropriate. Sometimes, different freshly mixed concrete properties will be needed for different placement procedures and conditions; these should be consistent with the limits set in the contract documents. When the concrete is to be delivered to the point of placement by concrete pump or other conveyance, the location at which the above properties are to be achieved should be clarified in advance. Sampling of the concrete should be in accordance with ASTM C 172.

CHAPTER 4—DOCUMENTATION OF COMPRESSIVE STRENGTH

4.1—Required average strength (f'_{cr})

A submittal of concrete mixture proportions should demonstrate a compressive strength equal to or exceeding the required average strength (f'_{cr}). Provisions for calculating f'_{cr} are contained in ACI 211.1, ACI 214, ACI 301, and ACI 318. The required average strength is based on the specified compressive strength (f'_c) for a class of concrete, which should include an overdesign amount as found in ACI 301, and ACI 318, when based on laboratory trial batches. When past performance records of uniformity of the concrete production are available, the statistical probability of a certain number of test results falling below the design strength is anticipated and controlled by selection of the appropriate f'_{cr}. Submittal of concrete mixture proportions should contain the method used to select f'_{cr} for each class of concrete.

4.2—Past performance record submittal

When compressive strength data are available from concrete production using the proposed materials and batching facilities, the statistical analysis of the data should be calculated in accordance with ACI 214, ACI 301, or ACI 318. A data summary identifying the mixture proportions and individual test results and batching facilities should be part of the submittal. These records become the basis for verifying the required average strength and validation of the proposed mixture. Concrete sampled and tested under conditions more stringent than those imposed by the contract documents may be excluded from use in calculation of the required average strength based on past performance.

4.3—Trial batch record submittal

If past performance records for the proposed mixture proportions are not available, trial batches may be required by specification. When trial batches are used to establish strength relationships or to verify strength characteristics of the mixture, the least favorable combination of mixing water and air content should be used (ACI 211.1, ACI 301, ACI 318). This will provide a conservative estimate of strength. Trial batch procedures and report records should comply with ASTM C 192.

4.4—Resubmittals

During the conduct of work, if any changes to the mixture proporitions or materials are made, the revised proportions should demonstrate a compressive strength equal to or exceeding the current required average strength established by job records.

CHAPTER 5—ADDITIONAL SUGGESTED DOCUMENTATION

5.1—Transmittal letter

Each submittal should be introduced by an original transmittal letter identifying the proposed concrete mixture(s) to be furnished, the project for which it is submitted, and the method used to select proportions. The transmittal should be signed and dated by the person that prepared the submittal and the person selecting the mixture proportions. If more than one party contributed to the submittal, each contributor's role should be identified.

5.2—Certification of compliance

A statement certifying compliance of all materials proposed for the work, excepting those instances where a variance is requested, with the requirements of the contract documents is suggested. This can be conveniently handled by inclusion in the transmittal letter or by attaching separately.

5.3—Submittal forms

The quantity of each ingredient, as described in Chapter 3, and the mixture proportions format should be prepared as an independent document suitable for distribution. There are several commercial, computerized formats available that conveniently handle source information, mixture proportions, physical properties of materials used to establish the proportions, and strength documentation. For this reason, a specified format is discouraged because it can either preclude the use of commercial computerized submittals, be repetitive in nature, or both. All of the information identified herein should be included on the submittal form(s) or in the documentation submitted.

Additional data summarizing the past performance records or trial batch data should be integral parts of the submittal, as should special certification test data of materials. The form should be signed and dated by the person compiling or verifying the tabulation.

CHAPTER 6—REFERENCES

6.1—Referenced standards and reports

The standards and reports listed below were the latest editions at the time this document was prepared. Because these documents are revised frequently, the reader is advised to contact the proper sponsoring group if it is desired to refer to the latest version.

American Concrete Institute (ACI)

104R	Preparation of Notation for Concrete
116R	Cement and Concrete Terminology
211.1	Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
214	Recommended Practice for Evaluation of Strength Test Results of Concrete
301	Specifications for Structural Concrete
318	Building Code Requirements for Structural Concrete
544.3R	Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete

American Society for Testing and Materials (ASTM)

C 29	Standard Test Method for Unit Weight and Voids in Aggregates
C 33	Standard Specification for Concrete Aggregates
C 127	Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate
C 128	Standard Test Method for Specific Gravity and Absorption of Fine Aggregate
C 172	Standard Practice for Sampling Freshly Mixed Concrete
C 192	Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
C 260	Standard Specification for Air-Entraining Admixtures for Concrete
C 330	Standard Specification for Lightweight Aggregate for Structural Concrete
C 494	Standard Specification for Chemical Admixtures for Concrete
D 448	Classification for Sizes of Aggregate for Road and Bridge Construction

The publications listed above may be obtained from the following organizations:

American Association of State Highway and Transportation Officials (AASHTO)
444 North Capitol Street NW, Suite 225
Washington, DC 20001

American Concrete Institute (ACI International)
P.O. Box 9094
Farmington Hills, MI 48333-9094

American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428

6.2—Other references

ACI Committee 201, 1992, "Guide to Durable Concrete, (ACI 201.2R-92)," American Concrete Institute, Farmington Hills, Mich., 41 pp.

ACI Committee 211, 1993, "Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash (ACI 211.4R-93)," American Concrete Institute, Farmington Hills, Mich., 13 pp.

ACI Committee 211, 1998, "Standard Practice for Selecting Proportions for Structural Lightweight Concrete, (ACI 211.2-98)," American Concrete Institute, Farmington Hills, Mich., 18 pp.

ACI Committee 212, 1991, "Chemical Admixtures for Concrete (ACI 212.3R-91)," American Concrete Institute, Farmington Hills, Mich., 31 pp.

ACI Committee 223, 1998, "Standard Practice for the Use of Shrinkage-Compensating Concrete, (ACI 223-98)," American Concrete Institute, Farmington Hills, Mich., 28 pp.

ACI Committee 232, 1996, "Use of Fly Ash in Concrete (ACI 232.2R-96)," American Concrete Institute, Farmington Hills, Mich., 34 pp.

ACI Committee 233, 1995, "Ground Granulated Blast-Furnace Slag as a Cementitious Constituent in Concrete (ACI 233R-95)," American Concrete Institute, Farmington Hills, Mich., 18 pp.

ACI Committee 303, 1997, "Standard Specification for Cast-in-Place Architectural Concrete (ACI 303.1-97)," American Concrete Institute, Farmington Hills, Mich., 10 pp.

ACI Committee 304, 1997, "Guide for Measuring, Mixing, Transporting, and Placing Concrete (ACI 304R-97)," American Concrete Institute, Farmington Hills, Mich., 41 pp.

ACI Committee 363, 1992, "State-of-the-Art Report on Fiber Reinforced Concrete (ACI 363R-92)," American Concrete Institute, Farmington Hills, Mich., 55 pp.

ACI Committee 544, 1993, "Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete (ACI 544.3R-93)," American Concrete Institute, Farmington Hills, Mich., 10 pp.

ACI Committee 544, 1996, "State-of-the-Art Report on Fiber Reinforced Concrete (ACI 544.1R-96)," American Concrete Institute, Farmington Hills, Mich., 66 pp.

ASTM C 31, 2000, "Standard Practice for Making and Curing Test Specimens in the Field, ASTM C 31/ C 31M-00e1," American Society for Testing and Materials, West Conshohocken, Pa., 5 pp.

ASTM C 39, 2001, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, ASTM C 39/C 39M-01," American Society for Testing and Materials, West Conshohocken, Pa., 5 pp.

ASTM C 94, 2000, "Standard Specification for Ready-Mixed Concrete, ASTM C 94/C 94M-00e1," American Society for Testing and Materials, West Conshohocken, Pa., 10 pp.

ASTM C 143, 2000, "Standard Test Method for Slump of Hydraulic Cement Concrete, ASTM C 143/C 143M-00," American Society for Testing and Materials, West Conshohocken, Pa., 3 pp.

ASTM C 150, 2000, "Standard Specification for Portland Cement, ASTM C 150-00," American Society for Testing and Materials, West Conshohocken, Pa., 7 pp.

ASTM C 173, 2001, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method, ASTM C 173/C 173M-01," American Society for Testing and Materials, West Conshohocken, Pa., 9 pp.

ASTM C 231, 1997, "Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method, ASTM C 231-97e1," American Society for Testing and Materials, West Conshohocken, Pa., 8 pp.

ASTM C 595, 2000, "Standard Specification for Blended Hydraulic Cements, ASTM C 595-00ae1," American Society for Testing and Materials, West Conshohocken, Pa., 7 pp.

ASTM C 618, 2000, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete, ASTM C 618-00," American Society for Testing and Materials, West Conshohocken, Pa., 4 pp.

ASTM C 845, 1996, "Standard Specification for Expansive Hydraulic Cements, ASTM C 845-96," American Society for Testing and Materials, West Conshohocken, Pa., 3 pp.

ASTM C 989, 1999, "Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars, ASTM C 989-99," American Society for Testing and Materials, West Conshohocken, Pa., 5 pp.

ASTM C 1017, 1998, "Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete, ASTM C 1017/C 1017M-98," American Society for Testing and Materials, West Conshohocken, Pa., 8 pp.

ASTM C 1116, 2000, "Standard Specification for Fiber-Reinforced Concrete and Shotcrete, ASTM C 1116-00," American Society for Testing and Materials, West Conshohocken, Pa., 8 pp.

6.3—Suggested checklist

Section/Part/Article	Submittal items and notes to Submitter/Contractor/Engineer
2.2—Submittal information	Cementitious materials—Mill test reports may be needed if there is a special concern for alkali-aggregate reaction or sulfate attack. Aggregates—Source, geological type, size, shape, grading, specific gravity, and absorption are necessary to evaluate proper proportioning and performance characteristics. Admixtures—Vendor and type are essential in evaluating performance for an intended usage. Water—Source of water should be identified. Nonpotable water, such as gray water, requires evidence of satisfactory use in mortar or concrete in accordance with ASTM C 94, Table 1. Chloride-ion content—If corrosion is a design concern, such as in the case of reinforced concrete, that will be more than superficially wet, evidence of soluble chloride-ion content for each ingredient indicated in the hardened concrete may be required. Caution should be used when evaluating chloride-ion content in a mixture by individual ingredients because this method usually results in a greater chloride content than that obtained from samples of hardened concrete. Chloride requirements should comply with ACI 318 and ACI 301. Fibers, color pigments, and other additions—Should be included in the mixture from which the strength data were obtained unless evidence is provided indicating no influence on strength.
3.2—Quantities by mass	Individual ingredients will be proportioned by mass. Liquid slurry-type pozzolans should have their respective solid and water contents expressed as a mass unit. Liquid admixtures may be expressed in liquid volumetric units. Aggregates should be expressed in SSD mass units. To verify these, it will be necessary to list the absorption values for the fine and coarse aggregates.
3.3—Quantities by volume	Absolute volumes of each respective material and the entrapped and entrained air. To verify absolute volumes of the proposed materials and their respected total, it is necessary to list their respective Bulk Specific Gravities (in the case of the aggregate, Bulk Specific Gravity—SSD).
4.0—Documentation of average strength	In accordance with contract documents, ACI 301, or ACI 318 requirements.
4.2—Past performance record submittal, or 4.3—Trial batches	Method used should be identified in the submittal.

ACI 211.4R-93

(Reapproved 1998)

Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash

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This guide presents a generally applicable method for selecting mixture proportions for high-strength concrete and optimizing these mixture proportions on the basis of trial batches. The method is limited to high-stmngth concrete produced using conventional materials and production techniques.

Recommendations and tables are based on current practice and information provided by contractors, concrete suppliers, and engineers who have been involved in projects dealing with high-strength concrete.

Keywords: aggregates; capping; chemical admixtures; fine aggregates; **fly ash**; **high-strength concretes**; **mixture proportioning**; quality control; specimen size; strength requirements; superplasticizers.

CONTENTS

CHAPTER 1-INTRODUCTION

1.1-Purpose

The current ACI 211.1 mixture proportioning proce-

ACI 211.4R-93 became effective September 1.1993.

dure describes methods for selecting proportions for normal strength concrete in the range of 2000 to 6000 psi. Mixture proportioning is more critical for high-strength concrete than for normal strength concrete. Usually, specially selected pozzolanic and chemical admixtures are employed, and attainment of a low water-to-cementitious material ratio ($w/c+p$) is considered essential. Many trial mixtures are often required to generate the data necessary to identify optimum mixture proportions. The purpose of this guide is to present a generally applicable method for selecting mixture proportions for high-strength concrete and for optimizing these mixture proportions on the basis of trial batches.

1.2-Scope

Discussion in this guide is limited to high-strength concrete produced using conventional materials and production methods. Consideration of silica fume and ground granulated blast furnace slag (GGBFS) is beyond the scope of this document. Information on proportioning of silica fume concrete is limited at this time. ACI Committee 234, Silica Fume in Concrete, is developing information on the use of silica fume for a committee report. Proportioning GGBFS concrete is discussed in ACI 226-1R (now ACI Committee 233). When additional data becomes available, it is expected that an ACI guide for proportioning concrete with these materials will be developed. Currently, silica fume and GGBFS suppliers, as well as experienced concrete suppliers, represent the best source of proportioning information for these materials.

High-strength concrete is defined as concrete that has a specified compressive **strength** f_c' of 6000 psi or greater. This guide is intended to cover field strengths up to 12,000 psi as a practical working range, although greater strengths may be obtained. Recommendations are based on current practice and information from contractors, concrete suppliers, and engineers who have been involved in projects dealing with high-strength concrete. For a more complete list of references and available publications on the topic, the reader should refer to ACI 363R.

CHAPTER 2-PERFORMANCE REQUIREMENTS

2.1-Test age

The selection of mixture proportions can be influenced by the testing age. High-strength concretes can gain considerable strength after the normally specified 28-day age. To take advantage of this characteristic, many specifications for compressive strength have been modified from the typical 28-day criterion to 56 days, 91 days, or later ages. Proportions of cementitious components usually have been adjusted to produce the desired strength at the test age selected.

2.2-Required strength

ACI 318 allows concrete mixtures to be proportioned based on field experience or laboratory trial batches. To meet the specified strength requirements, the concrete must be proportioned in such a manner that the average compressive strength results of field tests exceed the specified design compressive strength f_c' by an amount sufficiently high to make the probability of low tests small. When the concrete producer chooses to select high-strength concrete mixture proportions based upon field experience, it is recommended that the required average strength f_{cr}' used as the basis for selection of concrete proportions be taken as the larger value calculated from the following equations

$$f_{cr}' = f_c' + 1.34s \qquad (2\text{-}1)$$

$$f_{cr}' = 0.90f_c' + 2.33s \qquad (2\text{-}2)$$

where s = sample standard deviation in psi.

Eq. (2-l) is Eq. (5-l) of the ACI 318 Building Code. Eq. (2-2) is a modified version of Eq. (5-2) ($f_{cr}' = f_c' + 2.33s - 500$) of ACI 318 because, to date, job specifications for high-strength concrete have usually been modified to allow no more than 1 in 100 individual tests to fall below 90% of the specified strength. When job specifications cite ACI 318 acceptance criteria, Eq. (5-2) of ACI 318 should be used instead of Eq. (2-2) of this report.

When the concrete producer selects high-strength concrete proportions on the basis of laboratory trial batches, the required average strength f_{cr}' may be determined from the equation

$$f_{cr}' = \frac{(f_c' + 1400)}{0.90} \qquad (2\text{-}3)$$

Eq. (2-3) gives a higher required average strength value than that required in Table 5.3.2.2 of the ACI Building Code (ACI 318). Experience has shown that strength tested under ideal field conditions attains only 90 percent of the strength measured by tests performed under laboratory conditions. To assume that the average strength of field production concrete will equal the strength of a laboratory trial batch is not realistic, since many factors can influence the variability of strengths and strength measurements in the field. Initial use of a high-strength concrete mixture in the field may require some adjustments in proportions for air content and yield, and for the requirements listed below, as appropriate. Once sufficient data have been generated from the job, mixture proportions should be reevaluated using ACI 214 and adjusted accordingly.

2.3-Other requirements

Considerations other than compressive strength may influence the selection of materials and mixture proportions. These include: a) modulus of elasticity, b) flexural and tensile strengths, c) heat of hydration, d) creep and drying shrinkage, e) durability, f) permeability, g) time of setting, h) method of placement, and i) workability.

CHAPTER 3-FUNDAMENTAL RELATIONSHIPS

3.1-Selection of materials

Effective production of high-strength concrete is achieved by carefully selecting, controlling, and proportioning all of the ingredients. To achieve higher strength concretes, optimum proportions must be selected, considering the cement and fly ash characteristics, aggregate quality, paste proportion, aggregate-paste interaction, admixture type and dosage rate, and mixing. Evaluating cement, fly ash, chemical admixture, and aggregate from various potential sources in varying proportions will indicate the optimum combination of materials. The supplier of high-strength concrete should implement a program of uniformity and acceptance tests for all materials used in the production of high-strength concrete.

3.1.1 *Portland cement*-Proper selection of the type and source of cement is one of the most important steps in the production of high-strength concrete. ASTM C 917 may be useful in considering cement sources. Variations in the chemical composition and physical properties of the cement affect the concrete compressive strength more than variations in any other single material. For any given set of materials, there is an optimum cement content beyond which little or no additional increase in strength is achieved from increasing the cement content.

3.1.2 *Other cementitious materials*-Finely divided cementitious materials other than portland cement, consisting mainly of fly ash, ground blast furnace slag, or silica fume (microsilica), have been considered in the production of high-strength concrete because of the required high cementitious materials content and low $w/(c+p)$. These materials can help control the temperature rise in concrete at early ages and may reduce the water demand for a given workability. However, early strength gain of the concrete may be decreased.

ASTM C 618 specifies the requirements for Class F and Class C fly ashes, and for raw or calcined natural pozzolans, Class N, for use in concrete. Fly ash properties may vary considerably in different areas and from different sources within the same area. The preferred fly ashes for use in high-strength concrete have a loss on ignition no greater than 3 percent, have a high fineness, and come from a source with a uniformity meeting ASTM C 618 requirements.

3.13 *Mixing water*-The acceptability of the water for high-strength concrete is not of major concern if potable water is used. Otherwise, the water should be tested for suitability in accordance with ASTM C 94.

3.1.4 *Coarse aggregate*--In the proportioning of high-strength concrete, the aggregates require special consideration since they occupy the largest volume of any ingredient in the concrete, and they greatly influence the strength and other properties of the concrete. Usually, high-strength concretes are produced with normal weight aggregates. However, there have been reports of high-strength concrete produced using lightweight aggregates for structural concrete and heavyweight aggregates for high-density concrete.

The coarse aggregate will influence significantly the strength and structural properties of the concrete. For this reason, a coarse aggregate should be chosen that is sufficiently hard, free of fissures or weak planes, clean, and free of surface coatings. Coarse aggregate properties also affect aggregate-mortar bond characteristics and mixing water requirements. Smaller size aggregates have been shown to provide higher strength potential.

For each concrete strength level, there is an optimum size for the coarse aggregate that will yield the greatest compressive strength per pound of cement. A 1 or 3/4-in. nominal maximum-size aggregate is common for producing concrete strengths up to 9000 psi; and ½ or 3/8-in. above 9000 psi. In general, the smallest size aggregate produces the highest strength for a given $w/c+p$. However, compressive strengths in excess of 10,000 psi are feasible using a l-in. nominal maximum-size aggregate when the mixture is proportioned with chemical admixtures. The use of the largest possible coarse aggregate is an important consideration if optimization of modulus of elasticity, creep, and drying shrinkage are important.

3.1.5 *Fine aggregate*-The grading and particle shape of the fiie aggregate are significant factors in the production of high-strength concrete. Particle shape and surface texture can have as great an effect on mixing water requirements and compressive strength of concrete as do those of coarse aggregate. Fine aggregates of the same grading but with a difference of 1 percent in voids content may result in a 1 gal. per yd^3 difference in water demand. More information can be found in ACI 211.1.

The quantity of paste required per unit volume of a concrete mixture decreases as the relative volume of coarse aggregate versus fine material increases. Because the amount of cementitious material contained in high-strength concrete is large, the volume of fines tends to be high. Consequently, the volume of sand can be kept to the minimum necessary to achieve workability and compactibility. In this manner, it will be possible to produce higher strength concretes for a given cementitious material content.

Fine aggregates with a fineness modulus (FM) in the range of 2.5 to 3.2 are preferable for high-strength concretes. Concrete mixtures made with a fine aggregate that has an FM of less than 2.5 may be "sticky" and result in poor workability and a higher water requirement. It is sometimes possible to blend sands from different sources to improve their grading and their capacity to produce higher strengths. If manufactured sands are used, consideration should be given to a possible increase in water demand for workability. The particle shape and the increased surface area of manufactured sands over natural sands can significantly affect water demand.

3.1.6 *Chemical admixtures*-In the production of concrete, decreasing the *w/(c+p)* by decreasing the water requirement rather than by increasing the total cementitious materials content, will usually produce higher compressive strengths. For this reason, use of chemical admixtures should be considered when producing high-strength concrete (see ACI 212.3R and ASTM C 494). In this guide, chemical admixture dosage rates are based on fluid oz per 100 lb of total cementitious material (oz/cwt). If powdered admixtures are used, dosage rates are on a dry weight basis. The use of chemical admixtures may improve and control the rate of hardening and slump loss, and result in accelerated strength gain, better durability, and improved workability.

High-range water-reducing admixtures (HRWR), also known as superplasticizers, are most effective in concrete mixtures that are rich in cement and other cementitious materials. HRWR help in dispersing cement particles, and they can reduce mixing water requirements by up to 30 percent, thereby increasing concrete compressive strengths.

Generally, high-strength concretes contain both a conventional water-reducing or water-reducing and retarding admixture and an HRWR. The dosage of the admixtures will most likely be different from the manufacturer's recommended dosage. Although only limited information is available, high-strength concrete has also been produced using a combination of chemical admixtures such as a high dosage rate of a normal-set water reducer and a set accelerator. The performance of the admixtures is influenced by the particular cementitious materials used. The optimum dosage of an admixture or combination of admixtures should be determined by trial mixtures using varying amounts of admixtures. The best results are achieved generally when an HRWR is added after the cement has been wetted in the batching and mixing operation.

Air-entraining admixtures are seldom used in high-strength concrete building applications when there are no freeze-thaw concerns other than during the construction period. If entrained air is required because of severe environments, it will reduce significantly the compressive strength of the concrete.

3.2-Water-cementitious material ratio (*w/(c+p)*)

Many researchers have concluded that the single most important variable in achieving high-strength concrete is the water-cement ratio (*w/c*). Since most high-strength concrete mixtures contain other cementitious materials, a *w/(c+p)* ratio must be considered in place of the traditional *w/c*. The *w/(c+p)*, like the *w/c*, should be calculated on a weight basis. The weight of water in HRWR should be included in the *w/(c+p)*.

The relationship between *w/c* and compressive strength, which has been identified in normal strength concretes, has been found to be valid for higher strength concretes as well. The use of chemical admixtures and other cementitious materials has been proven generally essential to producing placeable concrete with a low *w/c*. *w/(c+p)* for high-strength concretes typically have ranged from 0.20 to 0.50.

3.3-Workability

3.3.1 *Introduction*-For the purpose of this guide, workability is that property of freshly mixed concrete that determines the ease with which it can be properly mixed, placed, consolidated, and finished without segregation.

3.3.2 *Slump*-In general, high-strength concretes should be placed at the lowest slump which can be properly handled and consolidated in the field. A slump of 2 to 4 in. provides the required workability for most applications. However, reinforcement spacing and form details should be considered prior to development of concrete mixtures.

Because of a high coarse aggregate and cementitious materials content and low *w/(c+p)*, high-strength concrete can be difficult to place. However, high-strength concrete can be placed at very high slumps with HRWR without segregation problems. Flowing concretes with slumps in excess of 8 in., incorporating HRWR, are very effective in filling the voids between closely spaced reinforcement. In delivery situations where slump loss may be a problem, a placeable slump can be restored successfully by redosing the concrete with HRWR. A second dosage of HRWR results in increased strengths at nearly all test ages. This practice has been advantageous especially in using HRWR for hot-weather concreting.

3.4-Strength measurements

3.4.1 *Test method*-standard ASTM or AASHTO test methods are followed except where changes are indicated by the characteristics of the high-strength concrete (ACI 363R). The potential strength for a given set of materials can be established only if specimens are made and tested under standard conditions. A minimum of two specimens should be tested for each age and test condition.

3.4.2 *Specimen size*-Generally, 6 x 12-in. cylindrical specimens are specified as the standard for strength evaluation of high-strength concrete. However, some 4 x 8-in. cylinders have been used for strength measurements. The specimen size used by the concrete producer to determine mixture proportions should be compatible with the load capacity of the testing machine and consistent with the cylinder size specified by the designer for acceptance. Measurements of strength using 6 x 12-in. cylinders are not interchangeable with those obtained when using 4 x 8-in. cylinders.

3.4.3 *Type of molds*--The type of mold used will have a significant effect on the measured compressive strength. In general, companion specimens cast using steel molds achieve more consistent compressive strengths than those cast using plastic molds. Molds made of cardboard material are not recommended for casting high-strength concrete specimens. Single-use rigid plastic molds have been used successfully on high-strength concrete projects.

Regardless of the type of mold material, it is important that the type used for establishing mixture proportions be the same type as that used for fiial acceptance testing.

3.4.4 *Specimen capping*--Prior to testing a cylinder, the ends usually are capped to provide for a uniform transmission of force from a testing machine platen into the specimen body. Sulfur mortar is the most widely used capping material and, when properly prepared, is economical, convenient, and develops a relatively high strength in a short period of time.

Cap thickness should be as thin as practical, in the range of **1/16 to ⅛ in.** for high-strength concrete specimens. A commercially available high-strength sulfur capping material has been used to determine concrete strengths in excess of 10,000 psi, with cap thicknesses maintained at approximately ⅛ in. When using a sulfur capping material on high-strength concrete specimens, it is important that irregular end conditions are corrected prior to capping. Irregular end conditions and air voids between the cap and the cylinder end surfaces can adversely affect the measured compressive strength. Some concrete technologists prefer to form or grind specimen ends to ASTM C 39 tolerance when compressive strengths are greater than 10,000 psi.

3.4.5 *Testing machines*--Testing machine characteristics, mainly load capacity and stiffness, can have a significant influence on measured strength results. Good test results and minimum variation have been obtained when testing high-strength concrete cylinders using a testing machine with a minimum lateral stiffness of 10^5 lb/in. and a longitudinal stiffness of at least 10^7 lb/in. Testing machines that are laterally flexible can reduce the measured compressive strength of a specimen.

CHAPTER 4-HIGH-STRENGTH CONCRETE MIXTURE PROPORTIONING

4.1-Purpose

This guide procedure for proportioning high-strength concrete mixtures is applicable to normal weight, non-air-entrained concrete having compressive strengths between 6000 and 12,000 psi (f_{cr}'). When proportioning high-strength concrete mixtures, the basic considerations are still to determine the ingredient quantities required to produce a concrete with the desired plastic properties (workability, finishability, etc.) and hardened properties (strength, durability, etc.) at the lowest cost. Proper proportioning is required for all materials used. Because the performance of high-strength concrete is highly dependent on the properties of its individual components, this proportioning procedure is meant to be a reasonable process to produce submittal mixture proportions based on the performance of adjusted laboratory and field trial batches. Guidelines for the adjustment of mixture proportions are provided at the end of this chapter. This procedure further assumes that the properties and characteristics of the materials used in the trial mixtures are adequate to achieve the desired concrete compressive strength. Guidelines for the selections of materials for producing high-strength concrete are provided in ACI 363R.

Table 4.3.1 — Recommended slump for concretes with and without HRWR

Concrete made using HRWR*	
Slump before adding HRWR	1 to 2 in.
Concrete made without HRWR	
Slump	2 to 4 in.

* Adjust slump to that desired in the field through the addition of HRWR.

Before starting the proportioning of high-strength concrete mixtures, the project specifications should be reviewed. The review will establish the design criteria for specified strengths, the age when strengths are to be attained, and other testing acceptance criteria.

4.2-Introduction

The procedure described in ACI 211.1 for proportioning normal strength concrete is similar to that required for high-strength concrete. The procedure consists of a series of steps, which when completed provides a mixture meeting strength and workability requirements based on the combined properties of the individually selected and proportioned components. However, in the development of a high-strength concrete mixture, obtaining the optimum proportions is based on a series of trial batches having different proportions and contents of cementitious materials.

4.3-Mixture proportioning procedure

Completion of the following steps will result in a set of adjusted high-strength concrete laboratory trial proportions. These proportions will then provide the basis for field testing concrete batches from which the optimum mixture proportions may be chosen.

4.3.1 *Step 1-Select slump and required concrete strength* -Recommended values for concrete slump are given in Table 4.3.1. Although high-strength concrete with HRWR has been produced successfully without a measurable initial slump, an initial starting slump of 1 to 2 in. prior to adding HRWR is recommended. This will insure an adequate amount of water for mixing and allow the superplasticizer to be effective.

For high-strength concretes made without HRWR, a recommended slump range of 2 to 4 in. may be chosen according to the type of work to be done. A minimum value of 2 in. of slump is recommended for concrete without HRWR. Concretes with less than 2 in. of slump are difficult to consolidate due to the high coarse aggregate and cementitious materials content.

The required concrete strength to use in the trial mixture procedure should be determined using the guidelines provided in Chapter 2.

4.3.2 *Step 2-Select maximum size of aggregate*-Based on strength requirements, the recommended maximum

Table 4.3.2— Suggested maximum-size coarse aggregate

Required concrete strength, psi	Suggested maximum-size coarse aggregate, in.
<9000	3/4 to 1
>9000	3/8 to 1/2*

* When using HRWR and selected coarse aggregates, concrete compressive strengths in the range of 9000 to 12,000 pi an be attained using larger than recommended nominal maximum-size coarse aggregates of up to 1 in.

Table 4.3.3— Recommended volume of coarse aggregate per unit volume of concrete

Optimum coarse aggregate contents for nominal maximum sizes of aggregates to be used with sand with fineness modulus of 2.5 to 3.2				
Nominal maximum size, in.	3/8	1/2	3/4	1
Fractional volume* of oven-dry rodded coarse aggregate	0.65	0.68	0.72	0.75

* Volumes are based on aggregates in oven-dry rodded condition as described in ASTM C 29 for unit weight of aggregates.

Table 4.3.4 —First estimate of mixing water requirement and air content of fresh concrete based on using a sand with 35 percent voids

	Mixing water, lb/yd³			
	Maximum-size coarse aggregate, in.			
Slump, in.	3/8	1/2	3/4	1
1 to 2	310	295	285	280
2 to 3	320	310	295	290
3 to 4	330	320	305	300
Entrapped air content*	3 (2.5)†	2.5 (2.0)	2 (1.5)	1.5 (1.0)

* Values given must be adjusted for sands with voids other than 35 percent using Eq. 4-3.
† Mixtures made using HRWR.

sixes for coarse aggregates are given in Table 4.3.2. ACI 318 states the maximum size of an aggregate should not exceed one-fifth of the narrowest dimension between sides of forms, one-third of the depth of slabs, nor three-quarters of the minimum clear spacing between individual reinforcing bars, bundles of bars, or prestressing tendons or ducts.

4.3.3 *Step 3-Select optimum coarse aggregate content* -The optimum content of the coarse aggregate depends on its strength potential characteristics and maximum size. The recommended optimum coarse aggregate contents, expressed as a fraction of the dry-rodded unit weight (DRUW), are given in Table 4.3.3 as a function of nominal maximum size.

Once the optimum coarse aggregate content has been chosen from Table 4.3.3, the oven-dry (OD) weight of the coarse aggregate per yd³ of concrete can be calculated using Eq. (4-l)

$$\text{weight of coarse aggregate} = (\text{coarse aggregate factor} \times \text{DRUW}) \times 27 \quad \text{(4-l)}$$

In proportioning normal strength concrete mixtures, the optimum content of coarse aggregate is given as a function of the maximum size and fineness modulus of the fine aggregate. High-strength concrete mixtures, however, have a high content of cementitious material, and thus are not so dependent on the fine aggregate to supply fiies for lubrication and compactibility of the fresh concrete. Therefore, the values given in Table 4.3.3 are recommended for use with sands having fineness modulus values from 2.5 to 3.2.

4.3.4 *Step 4-Estimate mixing water and air contents-* The quantity of water per unit volume of concrete required to produce a given slump is dependent on the maximum size, particle shape, and grading of the aggregate, the quantity of cement, and type of water-reducing admixture used. If an HRWR is used, the water content in this admixture is calculated generally to be a part of the *w/(c+p)*. Table 4.3.4 gives estimates of required mixing water for high-strength concretes made with 3/8 to 1 in. maximum-size aggregates prior to the addition of any chemical admixture. Also given are the corresponding values for entrapped air content. These quantities of mixing water are maximums for reasonably well-shaped, clean, angular coarse aggregates, well-graded within the limits of ASTM C 33. Because particle shape and surface texture of a fine aggregate can significantly influence its voids content, mixing water requirements may be different from the values given.

The values for the required mixing water given in Table 4.3.4 are applicable when a fine aggregate is used that has a void content of 35 percent. The void content of a fine aggregate may be calculated using Eq. (4-2)

$$\textit{Void content, V, \%} = \left(1 - \frac{\textit{Oven-dry rodded unit weight}}{\textit{Bulk specific gravity (dry)} \times 62.4}\right) \times 100 \quad (4\text{-}2)$$

When a fine aggregate with a void content not equal to 35 percent is used, an adjustment must be made to the recommended mixing water content. This adjustment may be calculated using Eq. (4-3)

$$\text{Mixing water adjustment, lbs/yd}^3 = (V - 35) \times 8 \quad (4\text{-}3)$$

Use of Eq. (4-3) results in a water adjustment of 8 lb/yd³ of concrete for each percent of voids deviation from 35 percent.

4.3.5 *Step 5-Select w/(c+p)*-In high-strength concrete mixtures, other cementitious material, such as fly ash, may be used. The *w/(c+p)* is calculated by dividing the weight of the mixing water by the combined weight of the cement and fly ash.

In Tables 4.3.5(a) and (b), recommended maximum *w/(c+p)* are given as a function of maximum-size aggregate

Table 4.3.5(a)— Recommended maximum *w/(c + p)* for concretes made without HRWR

Field strength f_{cr}'*, psi		*w/(c + p)* Maximum-size coarse aggregate, in. 3/8	1/2	3/4	1
7000	28-day	0.42	0.41	0.40	0.39
	56-day	0.46	0.45	0.44	0.43
8000	28-day	0.35	0.34	0.33	0.33
	56-day	0.38	0.37	0.36	0.35
9000	28-day	0.30	0.29	0.29	0.28
	56-day	0.33	0.32	0.31	0.30
10,000	28-day	0.26	0.26	0.25	0.25
	56-day	0.29	0.28	0.27	0.26

* $f_{cr}' = f_c' + 1400$.

Table 4.3.5(b)— Recommended maximum *w/(c + p)* ratio for concretes made with HRWR

Field strength f_{cr}'*, psi		*w/(c + p)* Maximum-size coarse aggregate, in. 3/8	1/2	3/4	1
7000	28-day	0.50	0.48	0.45	0.43
	56-day	0.55	0.52	0.48	0.46
8000	28-day	0.44	0.42	0.40	0.38
	56-day	0.48	0.45	0.42	0.40
9000	28-day	0.38	0.36	0.35	0.34
	56-day	0.42	0.39	0.37	0.36
10,000	28-day	0.33	0.32	0.31	0.30
	56-day	0.37	0.35	0.33	0.32
11,000	28-day	0.30	0.29	0.27	0.27
	56-day	0.33	0.31	0.29	0.29
12,000	28-day	0.27	0.26	0.25	0.25
	56-day	0.30	0.28	0.27	0.26

* $f_{cr}' = f_c' + 1400$.

Note: A comparison of the values contained in Tables 4.3.5(a) and 4.3.5(b) permits, in particular, the following conclusions:

1. For a given water cementitious material ratio, the field strength of concrete is greater with the use of HRWR than without it, and this greater strength is reached within a shorter period of time.

2. With the use of HRWR, a given concrete field strength can be achieved in a given period of time using less cementitious material than would be required when not using HRWR.

to achieve different compressive strengths at either 28 or 56 days. The use of an HRWR generally increases the compressive strength of concrete. The *w/(c +p)* values given in Table 4.3.5(a) are for concretes made without HRWR, and those in Table 4.3.5(b) are for concretes made using an HRWR.

The *w/(c+p)* may be limited further by durability requirements. However, for typical applications, high-strength concrete would not be subjected to severe exposure conditions.

When the cementitious material content from these tables exceed 1000 lb, a more practical mixture may be produced using alternative cementitious materials or proportioning methods.

4.3.6 *Step 6-Calculate content of cementitious material* -The weight of cementitious material required per yd^3 of concrete can be determined by dividing the amount of mixing water per yd^3 of concrete (Step 4) by the *w/(c+p)* ratio (Step 5). However, if the specifications include a minimum limit on the amount of cementitious material per yd^3 of concrete, this must be satisfied. Therefore, the mixture should be proportioned to contain the larger quantity of cementitious material required. When the cementitious material content from the following tables exceeds 1000 lb, a more practical mixture may be produced using alternate cementitious materials or proportioning methods. This process is beyond the scope of this guide.

4.3.7 *Step 7-Proportion basic mixture with no other cementitious material*-To determine optimum mixture proportions, the proportioner needs to prepare several trial mixtures having different fly ash contents. Generally, one trial mixture should be made with portland cement as the only cementitious material. The following steps should be followed to complete the basic mixture proportion.

1. *Cement content*-For this mixture, since no other cementitious material is to be used, the weight of cement equals the weight of cementitious material calculated in Step 6.

2. *Sand content*-After determining the weights per yd^3 of coarse aggregate, the cement and water, and the percentage of air content, the sand content can be calculated to produce 27 ft^3, using the absolute volume method.

4.3.8 *Step 8--Proportion companion mixtures using fly ash*-The use of fly ash in producing high-strength concrete can result in lowered water demand, reduced concrete temperature, and reduced cost. However, due to variations in the chemical properties of fly ash, the strength-gain characteristics of the concrete might be affected. Therefore, it is recommended that at least two different fly ash contents be used for the companion trial mixtures. The following steps should be completed for each companion trial mixture to be proportioned:

1. *Fly ash type*-Due to differing chemical compositions, the water-reducing and strength-gaining characteristics of fly ash will vary with the type used, and its source. Therefore, these characteristics, as well as availability, should be considered when choosing the fly ash to be used.

2. *Fly ash content*-The amount of cement to be replaced by fly ash depends on the type of material to be used. The recommended limits for replacement are given in Table 4.3.6, for the two classes of fly ash. For each companion trial mixture to be designed, a replacement percentage should be chosen from this table.

3. *Fly ash weight*-Once the percentages for replacement have been chosen, the weight of the fly ash to be used for each companion trial mixture can be calculated by multiplying the total weight of cementitious materials (Step 6) by the replacement percentages previously cho-

Table 4.3.6— Recommended values for fly ash replacement of portland cement

Fly ash	Recommended replacement (percent by weight)
Class F	15 to 25
Class C	20 to 35

sen. The remaining weight of cementitious material corresponds to the weight of cement. Therefore, for each mixture, the weight of fly ash plus the weight of cement should equal the weight of cementitious materials calculated in Step 6.

4. *Volume of fly ash*-Due to the differences in bulk specific gravities of portland cement and fly ash, the volume of cementitious materials per **yd^3** will vary with the fly ash content, even though the weight of the cementitious materials remains constant. Therefore, for each mixture, the volume of cementitious materials should be calculated by adding the volume of cement and the volume of fly ash.

5. *Sand content*-Having found the volume of cementitious materials per **yd^3** of concrete, the volumes per **yd^3** of coarse aggregate, water, and entrapped air (Step 7), the sand content of each mixture can be calculated using the absolute volume method.

Using the preceding procedure, the total volume of cement and fly ash plus sand per **yd^3** of concrete is kept constant. Further adjustments in the mixture proportions may be needed due to changes in water demand and other effects of fly ash on the properties of the concrete. These adjustments are determined during trial mixing, as discussed in Section 4.3.10.

4.3.9 *Step 9--Trial mixtures*-For each of the trial mixtures proportioned in Steps 1 through 8, a trial mixture should be produced to determine the workability and strength characteristics of the mixtures. The weights of sand, coarse aggregate, and water must be adjusted to correct for the moisture condition of the aggregates used. Each batch should be such that, after a thorough mixing, a uniform mixture of sufficient size is achieved to fabricate the number of strength specimens required.

4.3.10 *Step l0-Adjust trial mixture proportions*-If the desired properties of the concrete are not obtained, the original trial mixture proportions should be adjusted according to the following guidelines to produce the desired workability.

1. *Initial slump*--If the initial slump of the trial mixture is not within the desired range, the mixing water should be adjusted. The weight of cementitious material in the mixture should be adjusted to maintain the desired *w/(c+p)*. The sand content should then be adjusted to insure proper yield of the concrete.

2. *HRWR dosage rate*-If HRWR is used, different dosage rates should be tried to determine the effect on strength and workability of the concrete mixture. Because of the nature of high-strength concrete mixtures, higher dosage rates than those recommended by the admixture manufacturer may be tolerated without segregation. Also, since the time of addition of the HRWR and concrete temperature have been found to affect the effectiveness of the admixture, its use in laboratory trial mixtures may have to be adjusted for field conditions. In general, it has been found that redosing with HRWR to restore workability results in increased strengths at nearly all test ages.

3. *Coarse aggregate content*-Once the concrete trial mixture has been adjusted to the desired slump, it should be determined if the mixture is too harsh for job placement or finishing requirements. If needed, the coarse aggregate content may be reduced, and the sand content adjusted accordingly to insure proper yield. However, this may increase the water demand of the mixture, thereby increasing the required content of cementitious materials to maintain a given *w/(c+p)*. In addition, a reduction in coarse aggregate content may result in a lower modulus of elasticity of the hardened concrete.

4. *Air content*-If the measured air content differs significantly from the designed proportion calculations, the dosage should be reduced or the sand content should be adjusted to maintain a proper yield.

5. *w/(c+p)*-If the required concrete compressive strength is not attained using the *w/(c+ p)* recommended in Table 4.3.5(a) or (b), additional trial mixtures having lower *w/(c+ p)* should be tested. If this does not result in increased compressive strengths, the adequacy of the materials used should be reviewed.

4.3.11 *Step 11-Select optimum mixture proportions*-Once the trial mixture proportions have been adjusted to produce the desired workability and strength properties, strength specimens should be cast from trial batches made under the expected field conditions according to the ACI 211.1 recommended procedure for making and adjusting trial batches. Practicality of production and quality control procedures have been better evaluated when production-sized trial batches were prepared using the equipment and personnel that were to be used in the actual work. The results of the strength tests should be presented in a way to allow the selection of acceptable proportions for the job, based on strength requirements and cost.

CHAPTER 5-SAMPLE CALCULATIONS

5.1-Introduction

An example is presented here to illustrate the mixture proportioning procedure for high-strength concrete discussed in the preceding chapter. Laboratory trial batch results will depend on the actual materials used. In this example, Type I cement having a bulk specific gravity of 3.15 is used.

5.2-Example

High-strength concrete is required for the columns in the first three floors of a high-rise office building. The specified compressive strength is 9000 psi at 28 days. Due to the close spacing of steel reinforcement in the columns, the largest nominal maximum-size aggregate that can be used is 3/4 in. A natural sand that meets ASTM C 33 limits will be used, which has the following properties: fineness modulus *FM* = 2.90; bulk specific gravity based on oven-dry weight *BSGdry* = 2.59; absorption based on oven-dry weight *Abs* = 1.1 percent; dry-rodded unit weight *DRUW* = 103 lb/ft^3. Also, a HRWR and a set-retarding admixture will be used.

5.2.1 *Step 1-Select slump and required concrete strength*-Since an HRWR is to be used, the concrete will be designed based on a slump of 1 to 2 in. prior to the addition of the HRWR.

The ready-mix producer has no prior history with high-strength concrete, and therefore will select proportions based on laboratory trial mixtures. Using Eq. (2.3), the required average strength used for selection of concrete proportions is

$$f'_{cr} = \frac{(9000 + 1400)}{0.90} = 11{,}556 \; psi, \ldots \; i.e., \; 11{,}600 \; psi$$

5.2.2 *Step 2-Select maximum size of aggregate*–Based on the guidelines in Table 4.3.2, a crushed limestone having a nominal maximum size of 1/2 in. is to be used. Its material properties are as follows: bulk specific gravity at oven-dry, BSG_{dry} = 2.76; absorption at oven-dry, *Abs* = 0.7 percent; dry-rodded unit weight, *DRUW* = 101 lb/ft^3. The grading of the aggregate must comply with ASTM C 33 for size designation No. 7 coarse aggregate.

5.2.3 *Step 3-Select optimum coarse aggregate content*-The optimum coarse aggregate content, selected from Table 4.3.3, is 0.68 per unit volume of concrete. The dry weight of coarse aggregate per yd^3 of concrete W_{dry}, is then

$$(0.68) \times (101) \times (27) = 1854 \text{ lb, using Eq. (4.1)}$$

5.2.4 *Step 4-Estimate mixing water and air contents*-Based on a slump of 1 to 2 in., and 1/2-in. maximum-size coarse aggregate, the first estimate of the required mixing water chosen from Table 4.3.4 is 295 lb/yd^3 of concrete, and the entrapped air content, for mixtures made using HRWR, is 2.0 percent.

However, using Eq. (4-2), the voids content of the sand to be used is

$$\left[1 - \frac{103}{(2.59) \times (62.4)}\right] \times 100 = 36 \; percent$$

The mixing water adjustment, calculated using Eq. (4-3), is

$$(36 - 35) \times 8 = +8 \text{ lb/yd}^3 \text{ of concrete}$$

Therefore, the total mixing water required per yd^3 of concrete is 295 + 8 or 303 lb. This required mixing water includes the retarding admixture, but does not include the water in the HRWR.

5.2.5 *Step 5 - Select w/(c+p)*-For concrete to be made using HRWR and 1/2-in. maximum-size aggregate, and having an average compressive strength based on laboratory trial mixtures of 11,600 psi at 28 days, the required *w/c+p* chosen from Table 4.3.5(b) is interpolated to be 0.31. It should be noted that the compressive strengths listed in Tables 4.3.5(a) and (b) are required average field strengths. Therefore, although the required strength of laboratory trial mixtures is 11,600 psi, the value to be used in the tables is

$$(0.90) \times (11{,}600) = \approx 10{,}400 \text{ psi}$$

5.2.6 *Step 6--Calculate content of cementitious material* --The weight of cementitious material per yd^3 of concrete is

$$\left(\frac{303}{0.31}\right) = 977 \; lb$$

The specifications do not set a minimum for cementitious materials content, so 977 lb/yd^3 of concrete will be used.

5.2.7 *Step 7-Proportion basic mixture with cement only*

1. Cement content per yd^3 = 977 lb.

2. The volumes per yd^3 of all materials except sand are as follows:

Cement = (977)/(3.15 x 62.4) =	4.97 ft^3
Coarse aggregate = (1854)/(2.76 x 62.4) =	10.77 ft^3
Water = (303)/(62.4) =	4.86 ft^3
Air = (0.02) x (27) =	0.54 ft^3
Total volume =	21.14 ft^3

Therefore, the required volume of sand per yd^3 of concrete is (27 - 21.14) = 5.86 ft^3. Converting this to weight of sand, dry, per yd^3 of concrete, the required weight of sand is

$$(5.86) \times (62.4) \times (2.59) = 947 \text{ lb.}$$

Cement	977 lb
Sand, dry	947 lb
Coarse aggregate, dry	1854 lb
Water, including 3 oz/cwt* retarding admixture	303 lb

* Hundred weight of cement.

5.2.8 *Step 8-Proportion companion mixtures using cement and fly ash*

1. An ASTM Class C fly ash is to be used which has a bulk specific gravity of 2.64.

2. The recommended limits for replacement given in Table 4.3.6 for Class C fly ash are from 20 to 35 percent. Four companion mixtures will be proportioned, having fly ash replacement percentages as follows:

Companion mixture #1	20 percent
Companion mixture #2	25 percent
Companion mixture #3	30 percent
Companion mixture #4	35 percent

3. For companion mixture #1, the weight of fly ash per yd^3 of concrete is (0.20) x (977) = 195 lb. therefore the cement is (977) - (195) = 782 lb. The weights of cement and fly ash per yd^3 of concrete for the remaining companion mixes are calculated in a similar manner. The values are as follow:

Companion mixture	Cement, lb	Fly ash, lb	Total, lb
#1	782	195	977
#2	733	244	977
#3	684	293	977
#4	635	342	977

4. For the first companion mixture, the volume of cement per yd^3 of concrete is (782)/(3.15 x 62.4) = 3.98 ft^3, and the fly ash per yd^3 is (195)/(2.64 x 62.4) = 1.18 ft^3. The volume of cement, fly ash, and total cementitious material for each companion mixture are:

Companion mixture	Cement, ft^3	Fly ash, ft^3	Total, ft^3
#1	3.98	1.18	5.16
#1	3.73	1.48	5.21
#3	3.48	1.78	5.26
#4	3.23	2.08	5.31

5. For all of the companion mixtures, the volumes of coarse aggregate, water, and air per yd^3 of concrete are the same as for the basic mixture that contains no other cementitious material. However, the volume of cementitious material varies with each mixture. The required weight of sand per yd^3 of concrete for companion mixture #1 is calculated as follows:

Component	Volume (per cubic yard of concrete. ft^3)
Cementitious material	5.16
Coarse aggregate	10.77
Water (including 2.5 oz/cwt retarding mixture)	486
Air	0.54
Total volume	21.33

The required volume of sand is (27 - 21.33) = 5.67 ft^3. Converting this to the weight of sand (dry) per yd^3 of concrete, the required weight is: (5.67) x (62.4) x (2.59) = 916 lb.

The mixture proportions per yd^3 of concrete for each companion mixture are as follows:

Companion mixture. #1	
Cement	782 lb
Fly ash	195 lb
Sand, dry	916 lb
Coarse aggregate, dry	1854 lb
Water (including 2.5 oz/cwt retarding mixture)	303 lb

Companion mixture #2	
Cement	733 lb
Fly ash	244 lb
Sand, dry	908 lb
Coarse aggregate, dry	1854 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb

Companion mixture #3	
Cement	684 lb
Fly ash	293 lb
Sand, dry	900 lb
Coarse aggregate, dry	1854 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb

Companion mixture #4	
Cement	635 lb
Fly ash	342 lb
Sand, dry	892 lb
Coarse aggregate, dry	1854 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb

As shown in this example, the dosage rate of chemical admixture may or may not need to be adjusted when other cementitious materials are used. There are no existing guidelines to be followed when doing this adjustment other than experience. The proportioner needs to be aware of the possible need for this adjustment. During trial batches, verify proper dosage rates for all chemical admixtures.

5.2.9 *Step 9-Trial mixtures*-Trial mixtures are to be conducted for the basic mixture and each of the four companion mixtures. The sand is found to have 6.4 percent total moisture, and the coarse aggregate is found to have 0.5 percent total moisture, based on dry conditions. Corrections to determine batch weights for the basic mixtures are done as follows: sand, wet = (947) x (1 + 0.064) = 1008 lb; coarse aggregate, wet = (1854) x (1 + 0.005) = 1863 lb; and water, correction = (303) - (947) (0.064 - 0.011) - (1854)(0.005 - 0.007) = 257 lb.

Thus the batch weight of water is corrected to account for the excess moisture contributed by the aggregates, which is the total moisture minus the absorption of the aggregate.

Basic mixture	Dry weights	Batch weights
Cement	977 lb	977 lb
Sand	947 lb	1008 lb
Coarse aggregate	1854 lb	1863 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb	259 lb

Companion mixture #1	Dry weights	Batch weights
Cement	782 lb	782 lb
Fly ash	195 lb	195 lb
Sand	916 lb	975 lb
Coarse aggregate	1854 lb	1863 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb	259 lb

Companion mixture #2	Dry weights	Batch weights
Cement	733 lb	733 lb
Fly ash	244 lb	244 lb
Sand	908 lb	966 lb
Coarse aggregate	1854 lb	1863 lb
Water (including 25 oz/cwt retarding admixture)	303 lb	259 lb

Companion mixture #3	Dry weights	Batch weights
Cement	684 lb	684 lb
Fly ash	293 lb	293 lb
Sand	900 lb	958 lb
Coarse aggregate	1854 lb	1863 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb	259 lb

Companion mixture #4	Dry weights	Batch weights
Cement	635 lb	635 lb
Fly ash	342 lb	342 lb
Sand	892 lb	949 lb
Coarse aggregate	1854 lb	1863 lb
Water (including 2.5 oz/cwt retarding admixture)	303 lb	259 lb

The size of the trial mixture is to be 3.0 ft^3. The reduced batch weights to yield 3.0 ft^3 are as follows:

Mixture	Basic	Comp #1	Comp #2	Comp #3	Comp #4
Cement, lb	108.56	86.89	81.44	76.00	70.56
Fly ash, lb	—	21.67	27.11	32.56	38.00
Sand, lb	112.00	108.33	107.33	106.44	105.44
Coarse aggregate, lb	207.00	207.00	207.00	207.00	207.00
Water, lb	28.56	28.67	28.67	28.78	28.78
Chemical admixtures (included as part of the mixing water)					

5.2.10 *Step 10--Adjust trial mixture proportions*-The batch weights for each trial mixture were adjusted to obtain the desired slump, before and after the addition of the HRWR, and the desired workability. The adjustments to the batch weights for the basic mixture and companion mixture #4 will be shown in detail. Those for the other three companion mixtures will be summarized.

5.2.10.1 *Basic mixture*

1. Although the amount of water required to produce a 1 to 2-in. slump was calculated to be 28.56 lb, it was found that 29.56 lb (including 2.5 oz/cwt retarding admixture) were actually needed to produce the desired slump. The actual batch weights then were:

Cement	108.56 lb
Sand	112.00 lb
Coarse aggregate	207.00 lb
Water	29.56 lb

Correcting these to dry weights gives:

Cement		108.56 lb
Sand, dry	(112.00)/(1.064) =	105.26 lb
Coarse aggregate, dry	(207.00)/(1.005) =	205.97 lb
Batch water	(29.56 + 5.58* − 0.41†) =	34.73 lb

* = Sand moisture correction.
† = C/A moisture correction.

The actual yield of the trial mixture was:

Cement	(108.56)/(3.15 x 62.4) =	0.55 ft^3
Sand	(105.26)/(2.59 x 62.4) =	0.65
Coarse aggregate	(205.97)/(2.76 x 62.4) =	1.20
Water	(34.73)/(62.4) =	0.56
Air	(0.02)(3.0) =	0.06
	Total volume	3.02 ft^3

Adjusting the mixture proportions to yield 27 ft^3 gives:

Cement	971 lb
Sand, dry	941 lb
Coarse aggregate, dry	1841 lb
Water (including 2.5 oz/cwt retarding admixture)	311 lb

The new mixture proportions result in a $w/(c+p)$ of 0.32. To maintain the desired ratio of 0.31, the weight of cement should be increased to (311)/(0.31) = 1003 lb/yd^3 of concrete. The increase in volume due to the adjustment of the weight of cement is (1003 − 971)/(3.15 x 62.4) = 0.16 ft^3, which should be adjusted for by removing an equal volume of sand. The weight of sand to be removed is 0.16 x 2.59 x 62.4 = 26 lb. The resulting adjusted mixture proportions are:

Cement	1003 lb
Sand, dry	915 lb
Coarse aggregate, dry	1841 lb
Water (including 2.5 oz/cwt retarding admixture)	311 lb

2. For placement in the heavily reinforced columns, a "flowing" concrete, having a slump of at least 9 in., is desired. The dosage rate recommended by the manufacturer of the HRWR ranged between 8 and 16 oz/100 lb of cementitious material. In a laboratory having an ambient temperature of 75 F, it was found that adding

HRWR to the adjusted mixture at a dosage rate of 8 oz/cwt produced a slump of 6 in., 11 oz/cwt produced a slump of 10 in., and 16 oz/cwt caused segregation of the fresh concrete. In all cases, a constant dosage rate of retarding admixture (2.5 oz/cwt) was also added to the mixture with the mixing water. The HRWR at a dosage rate of 11 oz/cwt was added approximately 15 min after initial mixing.

3. It was determined that the concrete mixture with a 10-in. slump had adequate workability for proper placement, so no adjustment was necessary to the coarse aggregate content.

4. The air content of the HRWR mixture was measured at 1.8 percent, so no correction was necessary.

5. Note that the addition of the HRWR might require an adjustment in the cementitious content and yield of the mixture to account for the additional volume of admixture. Under normal dosage rates, 10 to 15 oz/cwt, the correction needed is negligible and not shown in this example.

6. The 28-day compressive strength of the basic mixture was found to be 11,750 psi, which satisfied the required laboratory test strength of 11,600 psi.

5.2.10.2 *Companion mixture #4*

1. The actual amount of mixing water required (including 2 oz/cwt retarding admixture) to produce a 1 to 2-in. slump was less than that calculated for this mixture. The actual batch weights were:

Cement	70.56 lb
Fly ash	38.00 lb
Sand	105.44 lb
Coarse aggregate	207.00 lb
Water	27.83 lb

Correcting these by dry weights gives:

Cement	70.56 lb
Fly ash	38.00 lb
Sand, dry	99.10 lb
Coarse aggregate, dry	205.97 lb
Batch water	32.67 lb

The actual yield of the trial mixture was:

Cement	(70.56)/(3.15 x 62.4) =	0.36 ft³
Fly ash	(38.00)/(2.64 x 62.4) =	0.23
Sand	(99.10)/(2.59 x 62.4) =	0.61
Coarse aggregate	(205.97)/(2.76 x 62.4) =	1.20
Water	(32.67)/(62.4) =	0.52
Air	(0.02)(3.0) =	0.06
	Total volume	2.98 ft³

Adjusting the mixture proportions to yield 27 ft^3 gives:

Cement	639 lb
Fly ash	344 lb
Sand, dry	898 lb
Coarse aggregate, dry	1866 lb
Water (including 2.5 oz/cwt retarding admixture)	296 lb

The new mixture proportions result in a *w/(c+p)* of 0.30. The desired ratio was 0.31, so the weight of cementitious material may be reduced. The percentage of fly ash for this mixture is 35 percent, and should be maintained. The new weight of cementitious material is (296)/(0.31) = 955 lb. Of this, 35 percent should be fly ash, giving 334 lb of fly ash and 621 lb of cement. The change in volume due to the reduction in cementitious material is:

$$(639 - 621)/(3.15 \times 62.4) + (344 - 334)/(2.64 \times 62.4) = 0.15\ ft^3$$

Therefore, 0.15 ft^3 of sand should be added, which increases the weight of sand by (0.15)(2.59)(62.4) = 24 lb/yd^3 of concrete. The adjusted mixture proportions are:

Cement	621 lb
Fly ash	334 lb
Sand, dry	922 lb
Coarse aggregate, dry	1866 lb
Water (including 2.5 oz/cwt retarding admixture)	296 lb

2. In adding HRWR to the adjusted mixture to produce a flowing concrete, it was found that 9 oz of HRWR per 100 lb. of cementitious material produced a slump of 9 1/2 in. under laboratory conditions. A retarding admixture (2 oz/cwt) was added to the concrete with mixing water, and the HRWR was added approximately 15 min after initial mixing.

3. The HRWR mixture had adequate workability, so no adjustment to the coarse aggregate content was necessary.

4. The air content of the HRWR mixture was measured at 2.1 percent.

5. The average-28-day compressive strength of specimens cast from the laboratory trial mixture was found to be 11,370 psi.

5.2.10.3 *Summary of trial mixture performance*-The following is a summary of the results of the adjusted laboratory trial mixtures.

Mixture	Basic	C.M.* #1	C.M. #2	C.M. #3	C.M. #4
Cement, lb	1003	782	738	671	621
Fly ash, lb	—	195	246	287	334
Sand, dry, lb	915	916	914	917	922
Coarse aggregate dry, lb	1841	1854	1866	1854	1866
Water, lb	311	303	301	297	296
Slump, in.	1.00	1.25	1.00	1.50	2.00

Retarder, oz/cwt	3.0	2.5	2.5	2.0	2.0
HRWR, oz/cwt	11.0	11.0	10.0	9.5	9.0
Slump, in.	10.0	10.50	9.00	10.25	9.50
28-day psi	11,750	11,500	11,900	11,600	11,370

* C.M. =companion mix.
Note: This table has intentionally omitted the water in HRWR to avoid confusion. Section 3.2 of this guide suggests this be done to properly determine $w/(c+p)$.

5.3.11 *Step 11-Select optimum mixture proportions-* Companion mix (c.m.) #4 was the only trial mixture that was significantly less than the required compressive strength of 11,600 psi at 28 days. Field trial batches were made for all of the others. The mixtures were adjusted to the desired slumps, both before and after addition of the HRWR, and strength specimens were cast. Concrete temperatures were also recorded. The test results are shown below.

Mixture	28-day compressive strength, psi	Concrete temperature, deg F
Basic	10,410	94
C.M. #1	10,570	93
C.M. #2	10,530	89
C.M. #3	10,490	84

Although all mixtures produced the required field strength of 10,400 psi at 28 days, the reduced concrete temperature and cementitious material content of companion mix #3 made it more desirable to the ready-mix producer. As ambient conditions or material properties vary, additional field adjustments may be necessary.

CHAPTER 6-REFERENCES

6.1-Recommended references

The documents of the various standards-producing organizations referred to in this document are listed below with their serial designation.

The preceding publications may be obtained from the following organizations.

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM International
100 Barr Harbor Dr.
West Conshohocken, PA 19428

American Concrete Institute (ACI)

211.1 Standard Practice for Selecting Proportions for Normal, Heavy Weight, and Mass Concrete
212.3R Chemical Admixtures for Concrete
214 Recommended Practice for Evaluation of Strength Test Results of Concrete
226.1R Ground Granulated Blast Furnace Slag As a Cementitious Constituent in Concrete
301 Specifications for Structural Concrete for Buildings
318 Building Code Requirements for Reinforced Concrete
363R State-of-the-Art Report on High-Strength Concrete

American Society for Testing and Materials (ASTM)

C 29 Standard Test Method for Unit Weight and Voids in Aggregates
C 33 Standard Specification for Concrete Aggregates
C 39 Test Method for Cylindrical Strength of Cylindrical Concrete Specimens
C 94 Specification for Ready Mixed Concrete
C 494 Standard Specification for Chemical Admixtures for Concrete
C 618 Standard Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete
C 917 Standard Method of Evaluation of Cement Strength Uniformity from a Single Source

CONVERSION FACTORS

1 in. = 25.4 mm
1 psi = 6.8 kPa
1 lb/in.^{3} = 2.768 x10^{-5} kg/mm^3
1 lb/yd^3 = 0.59 kg/m^3

ACI 211.4R-93 was submitted to letter ballot of the committee and approved in accordance with ACI balloting procedures

Anexo 7. *NTP 339.088*

NORMA TÉCNICA PERUANA

NTP 339.088
2014 (revisada el 2019)

Dirección de Normalización - INACAL
Calle Las Camelias 817, San Isidro (Lima 27)

Lima, Perú

CONCRETO. Agua de mezcla utilizada en la producción de concreto de cemento Pórtland. Requisitos

CONCRETE. Mixing water used in the production of Portland cement concrete. Specifications

Esta Norma Técnica Peruana adoptada por el INACAL está basada en la Norma ASTM 1602/C 1602M:2012 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete, Derecho de autor de ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428, USA. Reimpreso por autorización de ASTM International

2019-06-28
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Precio basado en 14 páginas

I.C.S.: 90.100.30

ESTA NORMA ES RECOMENDABLE

Descriptores: Agua combinada, densidad, aditivos estabilizantes de hidratación, agua de mezcla, agua reciclada

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ÍNDICE

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PRÓLOGO
(de revisión 2019)

A.1 La Norma Técnica Peruana (NTP) **NTP 339.088:2014 CONCRETO. Agua de mezcla utilizada en la producción de concreto de cemento Portland. Requisitos,** 3ª Edición, se encuentra incluida en el Programa de Actualización de Normas Técnicas Peruanas.

A.2 La NTP referida, aprobada mediante resolución N° 0151-2014/CNB-INDECOPI, fue revisada por el Comité Técnico de Normalización (CTN) de Agregados, Concreto, Concreto Armado y Concreto Pretensado, y puesta a consulta pública por un periodo de 30 días calendario. No recibió observaciones por parte de los representantes de los sectores involucrados: producción, consumo y técnico.

A.3 El CTN de Agregados, Concreto, Concreto Armado y Concreto Pretensado, recomendó mantener la vigencia de la NTP y la Dirección de Normalización (DN), procedió a mantener su vigencia, previa revisión final, aprobando la versión revisada, el 28 de junio de 2019.

NOTA: Cabe resaltar que la revisión de la presente NTP se ha realizado con el objetivo de determinar su vigencia, más no su actualización.

A.4 Los métodos de ensayo y de muestreo cambian periódicamente con el avance de la técnica. Por lo cual, recomendamos consultar en el Centro de Información y Documentación del INACAL, la vigencia de los métodos de ensayo y de muestreo citados en esta NTP.

A.5 La presente Norma Técnica Peruana reemplaza a la NTP 339.088:2014 CONCRETO. Agua de mezcla utilizada en la producción de concreto de cemento Portland. Requisitos, 3ª Edición.

B. INSTITUCIONES MIEMBROS DEL CTN DE AGREGADOS, CONCRETO, CONCRETO ARMADO Y CONCRETO PRETENSADO

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PREFACIO

A. RESEÑA HISTÓRICA

A.1 La presente Norma Técnica Peruana fue elaborado por el Comité Técnico de Normalización de Agregados, concreto, hormigón armado y hormigón pretensado, mediante el Sistema 2 u Ordinario, durante los meses de julio a setiembre del 2014, utilizando como antecedente a la norma ASTM 1602/C 1602M:2012 Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.

A.2 El Comité Técnico de Normalización de Agregados, hormigón (concreto), hormigón armado y hormigón pretensado presentó a la Comisión de Normalización y de Fiscalización de Barreras Comerciales no Arancelarias –CNB-, con fecha 2014-10-06, el PNTP 339.088:2014**,** para su revisión y aprobación, siendo sometido a la etapa de discusión pública el 2014-10-31. No habiéndose presentado observaciones fue oficializada como Norma Técnica Peruana **NTP 339.088:2014 CONCRETO. Agua de mezcla utilizada en la producción de concreto de cemento Portland. Requisitos**, 3ª Edición, el 14 de enero de 2015.

A.3 Esta Norma Técnica Peruana reemplaza a la NTP 339.088:2006 y fue tomada en su totalidad de la ASTM 1602/C 1602M:2012. La presente Norma Técnica Peruana presenta cambios editoriales referidos principalmente a terminología empleada propia del idioma español y ha sido estructurada de acuerdo a las Guías Peruanas GP 001-1995 y GP 002:1995.

B. INSTITUCIONES QUE PARTICIPARON EN LA ELABORACIÓN DE LA NORMA TÉCNICA PERUANA

Secretaría	Asociación de Productores de Cemento - ASOCEM
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CONCRETO. Agua de mezcla utilizada en la producción de concreto de cemento Pórtland. Requisitos

1 Objeto

1.1 Esta Norma Técnica Peruana establece los requisitos de composición y performance para el agua utilizada como agua de mezcla en el concreto de cemento Portland. Define las fuentes de agua y estipula los requisitos y las frecuencias de ensayo para la calificación de las fuentes de agua individuales o combinadas.

1.2 Esta Norma Técnica Peruana no tiene como propósito establecer los métodos de almacenamiento, transporte, o mezcla del agua; ni dirigir el desarrollo y mantenimiento de los programas de control de calidad del productor del concreto.

1.3 El texto de esta especificación, referencias, notas y notas al pie de página proporcionan material explicatorio. Estas notas y notas al pie de página (excluyendo las de las tablas y figuras) no deberán ser consideradas como requisitos de esta norma.

1.4 Esta Norma no tiene como propósito lo que concierne a la seguridad, asociada con su uso. Es responsabilidad del usuario de esta norma establecer las medidas de seguridad y salud apropiadas y determinar la aplicabilidad de las limitaciones regulatorias previas a su uso.

2 Referencias normativas

Las siguientes normas contienen disposiciones que al ser citadas en este texto, constituyen requisitos de esta Norma Técnica Peruana. Las ediciones indicadas estaban en vigencia en el momento de esta publicación. Como toda norma está sujeta a revisión, se recomienda a aquellos que realicen acuerdos en base a ellas, que analicen la conveniencia de usar las ediciones recientes de las normas citadas seguidamente. El Organismo Peruano de Normalización posee la información de las Normas Técnicas Peruanas en vigencia en todo momento.

2.1 Normas Técnicas Peruanas

NTP 334.003:2008[1]	CEMENTOS. Procedimiento para la obtención de pastas y morteros de consistencia plástica por mezcla mecánica
NTP 334.051:2006[2]	CEMENTOS. Método para determinar la resistencia a la compresión de morteros de Cemento Portland usando especímenes de 50 mm de lado
NTP 334.086:2008[3]	CEMENTOS. Método para el análisis químico del cemento
NTP 339.033:2009[4]	HORMIGÓN (CONCRETO). Método de ensayo para la elaboración y curado de probetas cilíndricas de concreto en obra
NTP 339.034:2008[5]	HORMIGÓN (CONCRETO). Método de ensayo para el esfuerzo a la compresión de muestras cilíndricas de concreto
NTP 339.082:2011[6]	HORMIGÓN (CONCRETO). Método de ensayo para la determinación del tiempo de fraguado de mezclas por medio de su resistencia a la penetración
NTP 334.088:2006[7]	CEMENTOS. Aditivos químicos en pastas, morteros y hormigón (concreto)

[1] La NTP 334.003:2008 fue dejada sin efecto. La versión vigente a la fecha es la NTP 334.003:2017
[2] La NTP 334.051:2006 fue dejada sin efecto. La versión vigente a la fecha es la NTP 334.051:2013 (revisada el 2018)
[3] La NTP 334.086:2008 fue dejada sin efecto. La versión vigente a la fecha es la NTP 334.086:2017
[4] La NTP 339.033:2009 fue dejada sin efecto. La versión vigente a la fecha es la NTP 334.086:2017
[5] La NTP 339.034:2008 fue dejada sin efecto. La versión vigente a la fecha es la NTP 339.034:2015
[6] La NTP 339.082:2011 fue dejada sin efecto. La versión vigente a la fecha es la NTP 339.082:2017
[7] La NTP 334.088:2006 fue dejada sin efecto. La versión vigente a la fecha es la NTP 334.088:2015

NTP 339.114:1999[8]	HORMIGÓN (CONCRETO). Concreto premezclado
NTP 339.183:2003[9]	HORMIGÓN (CONCRETO). Práctica normalizada para la elaboración y curado de especímenes de hormigón (concreto) en el laboratorio
NTP 339.047:2006[10]	HORMIGÓN (CONCRETO). Definiciones y terminología relativas al hormigón
NTP 400.037:2002[11]	AGREGADOS. Especificaciones normalizadas para agregados en hormigón (concreto

2.2 Otros documentos

ASTM C 1603:2010[12]	Método de ensayo para la medición de sólidos en agua

Norma Técnica E-060 Concreto Armado, Reglamento Nacional de Edificación

3 Campo de aplicación

Esta Norma Técnica Peruana se aplica para la especificación del agua de mezcla utilizada en la producción de concreto de cemento Portland.

[8] La NTP 339.114:1999 fue dejada sin efecto. La versión vigente a la fecha es la NTP 339.114:2016
[9] La NTP 339.183:2003 fue dejada sin efecto. La versión vigente a la fecha es la NTP 339.183:2013 (revisada el 2018)
[10] La NTP 339.047:2006 fue dejada sin efecto. La versión vigente a la fecha es la NTP 339.047:2014
[11] La NTP 400.037:2002 fue dejada sin efecto. La versión vigente a la fecha es la NTP 400.037:2018
[12] La ASTM C1603-2010 fue dejada sin efecto. La versión vigente a la fecha es la ASTM C1603-16

4 Terminología

Para los propósitos de esta Norma Técnica Peruana se aplican las siguientes definiciones, además de las contenidas en la NTP 339.047:

4.1
agua combinada
es la mezcla de dos o más fuentes de agua combinadas entre sí, antes o durante su introducción en la producción del concreto

4.2
aditivos estabilizante de la hidratación
es el conjunto de aditivos retardadores, que cumplen con la NTP 334.088 tipo B o D, que pueden reducir previsiblemente el tiempo de hidratación del cemento y que son utilizados para aplicaciones que requieren la regulación del tiempo de fraguado del concreto premezclado regresado; la reducción del agua de producción del concreto, o para aplicaciones que requieren plazos extendidos de entrega del concreto premezclado

4.3
agua no potable
son fuentes de agua que no son aptas para el consumo humano, o que contienen cantidades de substancias que la decoloran o hacen que tengan un olor o sabor objetable, pero no contienen agua de las operaciones de producción de concreto

4.4
agua potable
agua que es apta para el consumo humano

4.5
agua proveniente de las operaciones de producción de concreto
agua recuperada de los procesos de producción de concreto de cemento Portland, que incluye el agua de lavado del camión mezclador; agua de lluvia colectada en un recipiente en una planta de producción de concreto, agua que contiene ingredientes de concreto

5 Requisitos para el uso

5.1 El agua de mezcla consistirá de:

- agua de la tanda (agua pesada o medida en la planta de dosificación);
- hielo, (cuando se especifica en clima cálido);
- agua adicionada por el operador del camión mezclador, según se especifique;
- humedad libre de los agregados; y
- agua de constitución de los aditivos cuando ésta incrementa la relación agua/materiales cementosos por más de 0,01 .

5.2 Se permitirá el uso de agua potable como agua de mezcla en el concreto sin la realización de ensayos para evaluar su conformidad con los requisitos de esta Norma.

5.3 Se permitirá el uso de agua de mezcla que esté compuesta total o parcialmente de fuentes de agua no potables o provenientes de las operaciones de producción de concreto, en algunas proporciones para alcanzar los límites calificados y cumplir los requisitos de la Tabla 1 . A opción del comprador y cuando sea apropiado para la construcción, serán especificados algunos de los límites opcionales establecidos en la Tabla 2 , al momento de solicitar el concreto en conformidad con la NTP 339.114 .

5.3.1 Las fuentes de agua no potable serán calificadas para su uso en conformidad con el subcapítulo 6.1 . Cuando sea requerido por el comprador, también se aplicarán los requisitos del subcapítulo 6.4 . Cuando la fuente de agua no potable es mezclada con una fuente de agua potable, la calificación del agua de mezcla deberá ser al más alto porcentaje de la fuente no potable en el agua de mezcla combinada prevista durante la producción.

5.3.2 El agua combinada, mezcla de dos o más fuentes, donde una de ellas proviene de la producción de concreto, será calificada para su uso en conformidad con el subcapítulo 6.2 . Cuando sea requerido por el comprador, también se aplicarán los requisitos del subcapítulo 6.4 . El agua combinada será calificada al más alto contenido de sólidos en el agua de mezcla total prevista durante la producción. Se permitirá que el agua de mezcla contenga igual o menos sólidos totales que el nivel calificado por el ensayo.

6 Requisitos y ensayos

6.1 Para fuentes de agua de mezcla no potable (como está definido en el subcapítulo 4.3), propuestas para su uso como agua de mezcla total o como parte del agua de mezcla combinada (como está definido en el subcapítulo 4.1), se aplicará lo siguiente al agua de mezcla combinada total:

6.1.1 El agua será ensayada en conformidad con la Tabla 1 antes del primer uso y a partir de entonces cada tres meses o con mayor frecuencia cuando haya razón para creer que ha ocurrido un cambio en las características de la fuente. Cuando los resultados de cuatro ensayos consecutivos indican conformidad con la Tabla 1 , se permitirá ensayar con una frecuencia menor, pero no menos que un año. Las pruebas se realizarán de conformidad con 6.3 .

6.2 Para fuentes de agua de las operaciones de producción de concreto (como está definido en el subcapítulo 4.5), propuestas para su uso como agua de mezcla total o como parte del agua de mezcla combinada (como está definido en el subcapítulo 4.1), se aplicará lo siguiente al agua de mezcla combinada total:

6.2.1 La densidad de la fuente de agua de las operaciones de producción de concreto premezclado será ensayada por lo menos diariamente en conformidad con el método de ensayo de la norma ASTM C 1603 o monitoreada con un hidrómetro que ha sido verificado en conformidad con el método de ensayo de la norma ASTM C1603 . Los productores que utilicen dispositivos automatizados deberán mantener en la planta de producción, la documentación de los procedimientos y la calibración de los sistemas, según sea necesario (Véase Nota 1).

NOTA 1: Para alcanzar un contenido de sólidos específico, las proporciones de mezcla de las fuentes de agua pueden ser determinadas en conformidad con el Anexo A1 del Método de Ensayo de la norma ASTM C1603 .

6.2.2 El agua combinada será ensayada en conformidad con los requisitos de la Tabla 1, de acuerdo con el párrafo 6.3, al más alto contenido de sólidos previsto para ser utilizada durante la producción, en conformidad con las siguientes frecuencias de ensayo:

6.2.2.1 Cuando la densidad del agua combinada es menor que 1,01 g/mL , el agua deberá ser ensayada antes del primer uso y a partir de entonces cada seis meses. Se permitirá reducir la frecuencia de ensayo una vez cada doce meses cuando los resultados de dos ensayos consecutivos indican conformidad con los requisitos de la Tabla 1 (Véase Nota 2).

NOTA 2: Esta condición tiene la intención de abarcar el uso de agua de lavado clarificada que ha sido pasada a través de un sistema de pozas de decantación.

6.2.2.2 Cuando la densidad del agua combinada está entre 1.01 y 1.03 , el agua será ensayada antes del primer uso y a partir de entonces mensualmente. Se permitirá que la frecuencia de ensayo sea reducida una vez cada tres meses cuando los resultados de cuatro ensayos consecutivos indican conformidad con los requisitos de la Tabla 1 . (Véase Nota 3).

NOTA 3: La densidad del agua de aproximadamente 1,03 representa un contenido de sólidos totales de 50 000 ppm .

6.2.2.3 Cuando la densidad del agua combinada excede a 1,03, el agua será ensayada semanalmente o con mayor frecuencia cuando haya razón para creer que ha ocurrido un cambio en las características del agua para su conformidad con los requisitos de la Tabla 1 . Se permitirá que la frecuencia de ensayo sea reducida una vez cada mes cuando los resultados de dos meses de ensayos consecutivos indican conformidad con los requisitos de la Tabla 1 .

6.2.2.4 Los ensayos para el agua con densidad mayor a 1,05 deberán ser los mismos a los indicados en el subcapítulo 6.2.2.3, sea que el agua incluya o no aditivos estabilizadores de hidratación. (Véase Nota 4).

NOTA 4: La densidad del agua que excede aproximadamente a 1,05, donde los sólidos están esencialmente compuestos de materiales cementosos, puede requerir el uso de aditivos estabilizadores de hidratación para mantener su conformidad con los requisitos de la Tabla 1. El productor debe tener un proceso documentado en el lugar para verificar la efectividad de los aditivos y las dosis empleadas.

6.3 Los ensayos del concreto para verificar el cumplimiento de los requisitos de la Tabla 1 se llevarán a cabo de conformidad con el Anexo C . Un lote de especímenes de concreto preparados con el agua de mezclado a ser calificada se comparará con un lote testigo preparado con agua potable (Véase Nota 5). Se utilizará una de las opciones de 6.3.1, 6.3.2 o 6.3.3:

6.3.1 Usando muestras de lotes de producción

6.3.1.1 Los especímenes de concreto correspondientes a lotes de producción para los ensayos de resistencia, serán elaborados y curados de acuerdo con la NTP 339.033 . Los resultados de las pruebas de resistencia a compresión, de cada lote será el promedio de por lo menos dos muestras estándar elaboradas de una muestra compuesta.

6.3.2 Usando lotes de concreto de laboratorio

6.3.2.1 Lotes de concreto de laboratorio deberá ser preparados de acuerdo con la NTP 339.183 . Las muestras para resistencia a la compresión serán elaboradas y curadas de acuerdo con la NTP 339.183 . Los resultados de las pruebas de resistencia a compresión de cada lote será el promedio de al menos dos muestras estándar

6.3.3 Usando lotes de mortero de laboratorio

6.3.3.1 Para el mortero se utiliza arena que cumpla con la NTP 400.037. Los morteros deberán prepararse de acuerdo con la NTP 334.003 con una parte de cemento Portland y 2,25 partes de arena en masa y una relación agua/materiales cementosos de 0,50 ± 0,02. El tamaño del lote deberá ser de al menos 20 % mayor que la cantidad requerida para especímenes de ensayo de resistencia y ensayos de tiempo de fraguado.

6.3.3.2 Preparar por lo menos tres cubos de mortero de 50 mm por cada lote. Los especímenes de ensayo de resistencia deberán ser curados de acuerdo con el método de ensayo de la NTP 334.051 .

6.3.4 La resistencia de especímenes cilíndricos de concreto deberá ser determinada a los 7 días de conformidad con el método de ensayo descrito en la NTP 339.034 .

6.3.5 La resistencia de los cubos de mortero deberá ser determinada a los 7 días, de acuerdo con el método de ensayo de la norma ASTM C109/C109M .

6.3.6 El tiempo de fraguado deberá ser medido de acuerdo con el método de ensayo de la NTP 339.082 .

6.4 Para los requisitos opcionales en la Tabla 2 , el fabricante deberá mantener la documentación de las concentraciones químicas de cloruros, sulfatos y álcalis en las fuentes de agua no potable o agua de las operaciones de producción de concreto. Estas pruebas se llevarán a cabo antes del primer uso y, posteriormente, una vez cada 6 meses, o más a menudo, o cuando hay razones para creer que se ha producido un cambio en las características de la fuente. A menos que se especifique otra cosa y cuando sea requerido por el comprador, los requisitos de la Tabla 2 se aplicarán al agua combinada según 5.3.1 y 5.3.2 . Esta información se facilitará al comprador a petición (véase Nota 5).

NOTA 5: El muestreo del agua combinada total en su forma final, tanto de la planta de dosificación o de la unidad de transporte, es poco viable. Por lo tanto, para el propósito de ensayo para su conformidad con los requisitos de la Tabla 1 y Tabla 2, es aceptable muestrear, proporcionar y combinar las fuentes individuales de agua para obtener una muestra de ensayo que sea representativa del agua de mezcla combinada real utilizada en la producción. Para concentraciones de cloruros, sulfatos y álcalis, es aceptable llevar a cabo mediciones en la fuente de agua no potable o en el agua de la producción de concreto y en el agua combinada para calcular la concentración.

7 Antecedentes

7.1 NTP 339.088:2006, HORMIGÓN (CONCRETO). Agua de mezcla utilizada en la producción de concreto de cemento Portland. Requisitos

7.2 ASTM C1602/C1602M:2012, Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete

ANEXO A
(NORMATIVO)

Tabla 1 - Requisitos de performance del concreto para el agua de mezcla

	Límites
Resistencia a compresión, % mínimo con relación a la muestra control a 7 días [A]	90
Tiempo de fraguado, desviación respecto al control, horas:minutos [A]	De 1:00 más temprano a 1:30 más tarde

[A] Las comparaciones estarán basadas en proporciones fijas para una mezcla de concreto o mortero. La mezcla de control se hace con el 100 % de agua potable o agua destilada. La mezcla de ensayo se debe realizar con el agua de la mezcla que se está evaluando (Véase Anexo C).

ANEXO B
(NORMATIVO)

Tabla 2 - Límites químicos opcionales para el agua de mezcla combinada[A]

	Límite	Métodos de Ensayo
Concentración máxima en el agua de mezcla combinada, ppm [B]		
A. Cloruro como Cl^-, ppm		
1 En concreto pretensado, tableros de puentes, o designados de otra manera.	500 [C]	NTP 334.086
2 Otros concretos reforzados en ambientes húmedos o que contengan aluminio embebido o metales diversos o con formas metálicas galvanizadas permanentes	1 000 [C]	NTP 334.086
B. Sulfatos como SO_4, ppm	3000	NTP 334.086
C. Álcalis como (Na_2O + 0,658 K_2O), ppm	600	NTP 334.086
D. Sólidos totales por masa, ppm	50 000	ASTM C1603

[A] Los límites de especificación de esta tabla no están prohibidos de ser especificados como elementos individuales o en conjunto de acuerdo con la sección sobre Información de pedido de la NTP 334.114 .
[B] ppm es la abreviación de partes por millón.
[C] Cuando el productor pueda demostrar que estos límites para el agua de mezcla pueden ser excedidos, se regirán los requerimientos para el concreto Norma Técnica E-060 del Reglamento de Edificación. Para condiciones que permiten utilizar cloruro de calcio ($CaCl_2$) como aditivo acelerador, se permitirá que el comprador pueda prescindir de la limitación del cloruro.
[D] Métodos de ensayo NTP 334.086 incluye referencia y métodos de ensayo alternativos para medir la concentración de cloruros, sulfatos, álcalis y en soluciones preparadas a partir de la disolución de materiales de cemento. Utilizar los métodos de ensayo aplicables en la NTP 334.086 para medir estos constituyentes. El laboratorio que realiza estas pruebas no está obligado a cumplir con los requisitos en materia de calificación de la NTP 334.086. Se permiten métodos instrumentales y métodos químicos húmedos alternativos que se señalan en la NTP 334.086 que miden la concentración de estas especies químicas en solución. Cuando se utilizan métodos alternativos, el método de ensayo utilizado se incluirá en el informe.

ANEXO C
(NORMATIVO)

C.1 Comparación entre dos mezclas de concreto o mortero necesaria para la conformidad con la Tabla 1

Introducción

Para cumplir con los requisitos de performance de la Tabla 1 , se requiere de la comparación entre dos mezclas de concreto o mezclas de mortero: una como tanda de control utilizando una fuente de agua potable, y una segunda como tanda de ensayo utilizando la fuente (s) de agua propuesta para su uso. Deberá aplicarse lo siguiente:

C.1.1 La composición en el lote de ensayo del agua que se está calificando para el uso se hará de conformidad con 5.3.1 o 5.3.2 .

C.1.2 La edad de agua en el lote de ensayo que está siendo calificado para el uso deberá estar tan cerca como sea posible a la edad real de agua usada durante la producción real. La edad de agua representa el período de tiempo desde que el agua de las operaciones de producción de concreto contiene al cemento.

C.1.3 Los aditivos incorporadores de aire y reductores de agua son permitidos en las tandas de ensayo y de control. El aditivo incorporador de aire será ajustado para producir el contenido de aire específico con una tolerancia de ± 1,5 % . La dosis del aditivo reductor de agua será la misma en ambas tandas.

C.1.4 Los aditivos estabilizadores de hidratación están permitidos para usarlos en el agua de mezcla para la tanda de ensayo. No están permitidos otros aditivos controladores de fraguado.

C.1.5 El contenido de agua de mezcla en la tanda de ensayo no será menor que el contenido de agua de mezcla en la tanda de control.

C.1.6 Las proporciones de mezcla para el lote de ensayo y de control se conservarán y estarán disponibles bajo pedido.

C.1.7 La temperatura de las muestras de control y de prueba de concreto o mortero que se están comparando, deben estar dentro de ± 3 °C en el momento de la toma de muestras y se deben someter a las mismas condiciones de curado para las probetas de ensayo de resistencia y se deben mantener a la misma temperatura durante la duración del tiempo del ensayo de fraguado.

ANEXO D
(INFORMATIVO)

D.1 Guía para la frecuencia de ensayo con relación a la fuente de agua utilizada en el agua de mezcla

Fuentes de Agua	Densidad del agua combinada (g/mL)	Frecuencia de Ensayo		
		Densidad, ASTM C1603	Tabla 1	Tabla 2
Potable	N/A	N/A	N/A	N/A
No Potable [A]	N/A	N/A	Cada 3 meses; después de 4 ensayos anualmente (6.1.1)	6 meses
Concreto	< 1,01	Diariamente (6.2.1)	Cada 6 meses; después de 2 ensayos anualmente (6.2.2.1)	6 meses
Producción[A]	1,01 – 1,03		Mensualmente; después de 4 ensayos cada 3 meses (6.2.2.2)	
	> 1,03		Semanalmente; después de 8 ensayos mensualmente (6.2.2.3)	

[A] La frecuencia de ensayo se aplica al agua de mezcla combinada cuando está total o parcialmente compuesta de las fuentes listadas como está definido en el capítulo 4 .
N/A: No aplicable.

NORMA TÉCNICA PERUANA | **NTP 400.012 2013 (revisada el 2018)**

Dirección de Normalización - INACAL
Calle Las Camelias 817, San Isidro (Lima 27) Lima, Perú

AGREGADOS. Análisis granulométrico del agregado fino, grueso y global

AGGREGATES. Standard test method for sieve analysis of fine, coarse and global aggregates

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ÍNDICE

PRÓLOGO
(de revisión 2018)

A.1 La Norma Técnica Peruana (NTP) **NTP 400.012:2013 AGREGADOS. Análisis granulométrico del agregado fino, grueso y global,** 3ª Edición, se encuentra incluida en el Programa de Actualización de Normas Técnicas Peruanas.

A.2 La NTP referida, aprobada mediante resolución N° 0006-2013/CNB-INDECOPI, fue revisada por el Comité Técnico de Normalización (CTN) de Agregados, concreto, concreto armado y concreto pretensado, y puesta a consulta pública por un periodo de 30 días calendario. No recibió observaciones por parte de los representantes de los sectores involucrados: producción, consumo y técnico.

A.3 El CTN de Agregados, concreto, concreto armado y concreto pretensado, recomendó mantener la vigencia de la NTP y la Dirección de Normalización (DN), procedió a mantener su vigencia, previa revisión final, aprobando la versión revisada, el 27 de junio de 2018.

NOTA: Cabe resaltar que la revisión de la presente NTP se ha realizado con el objetivo de determinar su vigencia, más no su actualización.

A.4 Los métodos de ensayo y de muestreo cambian periódicamente con el avance de la técnica. Por lo cual, recomendamos consultar en el Centro de Información y Documentación del INACAL, la vigencia de los métodos de ensayo y de muestreo citados en esta NTP.

A.5 La presente Norma Técnica Peruana reemplaza a la NTP 400.012:2013 AGREGADOS. Análisis granulométrico del agregado fino, grueso y global, 3ª Edición.

B. INSTITUCIONES MIEMBROS DEL CTN DE AGREGADOS, CONCRETO, CONCRETO ARMADO Y CONCRETO PRETENSADO

Secretaría	Asociación de Productores de Cemento – ASOCEM
Presidente	Manuel González de la Cotera
Secretario	Juan Avalo Castillo
ENTIDAD	**REPRESENTANTE**
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BASF CONSTRUCTION CHEMICALS PERU S. A.	Katia Rider Perez
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MTC – DIRECCION DE ESTUDIOS ESPECIALES	Segundo Santo Villalobos
MINISTERIO DE VIVIENDA, CONSTRUCCION Y SANEAMIENTO	Carlos Carbajal Catacora
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SIKA PERU S. A.	Carlos Gómez
UNI – Facultad Ingeniería Civil	Ana Victoria Torre
URP – Facultad Ingeniería Civil	Enriqueta Pereyra
UNICON S. A.	José Álvarez Cangahuala
Consultor	Ana Biondi

PREFACIO

A. RESEÑA HISTÓRICA

A.1 La presente Norma Técnica Peruana ha sido elaborada por el Comité Técnico de Normalización de Agregados, concreto, concreto armado y concreto pretensado, mediante el Sistema 2 u Ordinario, durante los meses de enero a agosto de 2012, utilizando como antecedentes

A.2 El Comité Técnico de Normalización de Agregados, concreto, concreto armado y concreto pretensado, presentó a la Comisión de Normalización y Fiscalización de Barreras Comerciales no Arancelarias –CNB-, con fecha 2012-08-29, el PNTP 400.012:2012, para su revisión y aprobación, siendo sometido a la etapa de discusión pública el 2012-11-15. No habiéndose presentado observaciones fue oficializada como Norma Técnica Peruana **NTP 400.012:2013 AGREGADOS. Análisis granulométrico del agregado fino, grueso y global**, 3ª Edición, el 01 de febrero de 2013.

A.3 Esta Norma Técnica Peruana reemplaza a la NTP 400.012:2001. La presente Norma Técnica Peruana presenta cambios editoriales referidos principalmente a la terminología empleada propia del idioma español y ha sido estructurada de acuerdo a las Guías Peruanas GP 001:1995 y GP 002:1995.

B. INSTITUCIONES QUE PARTICIPARON EN LA ELABORACIÓN DE LA NORMA TÉCNICA PERUANA

Secretaría	Asociación de Productores de Cemento - ASOCEM
Presidente	Manuel Gonzales de la Cotera Scheirmüller - ASOCEM
Secretaría	Juan Avalo Castillo
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PREMIX S.A.	Carlos Forero
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SIKA PERÚ S.A.	Patricio Arellano
CONSULTOR	Ana Biondi
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ARPL TECNOLOGÍA INDUSTRIAL S.A.	Wilfredo Quintana
COLEGIO DE INGENIEROS DEL PERÚ - Capitulo de Civiles	Enrique Rivva
PONTIFICIA UNIVERSIDAD CATOLICA	Juan Ginocchio Gladys Villa García
UNIVERSIDAD NACIONAL DE INGENIERÍA	Ana Victoria Torre Rafael Cachay
SENCICO	Vanna Guffanti
CORPORACIÓN ACEROS AREQUIPA S.A.	Víctor Granados Edgar García
QUÍMICA SUIZA S.A.	Milan Pejnovic
UNIVERSIDAD RICARDO PALMA	Enriqueta Pereyra Liliana Chevarría

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AGREGADOS. Análisis granulométrico del agregado fino, grueso y global

1 Objeto

La presente Norma Técnica Peruana establece el método para la determinación de la distribución por tamaño de partículas del agregado fino, grueso y global por tamizado.

Los valores indicados en el SI deben ser considerados como estándares. La ASTM E 11 designa los tamices en pulgadas, para esta Norma Técnica Peruana, se designan en unidades SI exactamente equivalentes.

2 Referencias normativas

Las siguientes normas contienen disposiciones que al ser citadas en este texto constituyen requisitos de esta Norma Técnica Peruana. Las ediciones indicadas estaban en vigencia en el momento de esta publicación. Como toda Norma está sujeta a revisión, se recomienda a aquellos que realicen acuerdos con base en ellas, que analicen la conveniencia de usar las ediciones recientes de las normas citadas seguidamente. El Organismo Peruano de Normalización posee la información de las Normas Técnicas Peruanas en vigencia en todo momento.

2.1 Normas Técnicas Peruanas

NTP 339.047:2006[1]	HORMIGÓN (CONCRETO). Definiciones y terminología relativas al hormigón y agregados
NTP 350.001:1970[2]	TAMICES DE ENSAYO. Requisitos

[1] La NTP 339.047:2006 fue dejada sin efecto. La versión vigente a la fecha es la NTP 339.047:2014

[2] La NTP 350.001:1970 fue dejada sin efecto. La versión vigente a la fecha es la NTP 350.001:1970 (revisada el 2007)

NTP 400.010:2011[3]	AGREGADOS. Extracción y preparación de las muestras
NTP 400.011:2008[4]	AGREGADOS. Definición y clasificación de agregados para uso en morteros y hormigones (concretos)
NTP 400.018:2002[5]	AGREGADOS. Método de ensayo normalizado para determinar materiales más finos que pasan por el tamiz normalizado 75 μm (200) por lavado en agregados
NTP 400.037:2000[6]	AGREGADOS. Especificaciones normalizadas para agregados en hormigón (concreto)
NTP 400.043:2006[7]	AGREGADOS. Práctica normalizada para reducir las muestras de agregados a tamaño de ensayo

2.2 Normas Técnicas de Asociación

ASTM C 637:2009[8]	Especificación para agregados para concreto blindado contra radiación
ASTM C 670:2010[9]	Practica para preparación de los términos precisión y tendencia para métodos de ensayo en materiales de construcción

[3] La NTP 400.010:2011 fue dejada sin efecto. La versión vigente a la fecha es la NTP 400.010:2011 (revisada el 2016).

[4] La NTP 400.011:2008 fue dejada sin efecto. La versión vigente a la fecha es la NTP 400.011:2008 (revisada el 2018).

[5] La NTP 400.018:2002 fue dejada sin efecto. La versión vigente a la fecha es la NTP 400.018:2013.

[6] La NTP 400.037:2000 fue dejada sin efecto. La versión vigente a la fecha es la NTP 400.037:2018.

[7] La NTP 400.043:2006 fue dejada sin efecto. La versión vigente a la fecha es la NTP 400.043:2015.

[8] La ASTM C637:2009 fue dejada sin efecto. La versión vigente a la fecha es la ASTM C637-14.

ASTM E 11-09e[10]	Especificación para tamices de alambre tejido
AASHTO T 27:2011	Método de ensayo para análisis granulométrico de agregados finos y gruesos

3 Campo de aplicación

3.1 Esta Norma Técnica Peruana se aplica para determinar la gradación de materiales propuestos para su uso como agregados o los que están siendo utilizados como

filtro. Los resultados serán utilizados para determinar el cumplimiento de la distribución
del tamaño de partículas con los requisitos que exige la especificación técnica de la obra y proporcionar los datos necesarios para el control de la producción de agregados. Los datos también pueden ser utilizados para correlacionar el esponjamiento y el embalaje.

3.2 La determinación exacta del material más fino que la malla de 75 μm (N° 200) no puede ser obtenida por esta Norma Técnica Peruana. Se utilizará la NTP 400.018.

3.3 Para la determinación de los agregados gruesos consultar los métodos de muestreo y análisis en la ASTM C 637.

4 Definiciones

Para los términos utilizados en esta Norma Técnica Peruana, referirse a la NTP 400.011, NTP 339.047 y NTP 400.037.

[9] La ASTM C670-2010 fue dejada sin efecto. La versión vigente a la fecha es la ASTM C670-15.

[10] La ASTM E11-09e fue dejada sin efecto. La versión vigente a la fecha es la ASTM E11-17.

5 Resumen del método

Una muestra de agregado seco, de masa conocida, es separada a través de una serie de tamices que van progresivamente de una abertura mayor a una menor, para determinar la distribución del tamaño de las partículas.

6 Aparatos

6.1 **Balanzas:** Las balanzas utilizadas en el ensayo de agregado fino, grueso y global deberán tener la siguiente exactitud y aproximación:

6.1.1 Para agregado fino, con aproximación de 0,1 g y exacta a 0,1 g o 0,1 % de la masa de la muestra, cualquiera que sea mayor, dentro del rango de uso.

6.1.2 Para agregado grueso o agregado global, con aproximación y exacta a 0,5 g o 0,1 % de la masa de la muestra, cualquiera que sea mayor, dentro del rango de uso.

6.2 **Tamices:** Los tamices serán montados sobre armaduras construidas de tal manera que se prevea pérdida de material durante el tamizado. Los tamices cumplirán con la NTP 350.001.

NOTA 1: Es recomendable que los tamices montados en marcos mayores que los normalizados de 203,2 mm de diámetro, se usen para ensayos del agregado grueso y del global, para reducir la posibilidad de sobrecarga de los tamices. Véase el apartado 8.3.

6.3 **Agitador mecánico de tamices:** Un agitador mecánico impartirá un movimiento vertical o movimiento lateral al tamiz, causando que las partículas tiendan a saltar y girar presentando así diferentes orientaciones a la superficie del tamizado. La acción del tamizado será tal que el criterio para un adecuado tamizado descrito en el apartado 8.4 esté dentro de un periodo de tiempo razonable.

NOTA 2: El uso del agitador mecánico es recomendado cuando la cantidad de la muestra es de 20 kg o mayor y puede ser utilizado para muestras más pequeñas incluyendo el agregado fino. El tiempo

[illegible]

de muestra; mientras que una gran área del tamiz necesaria para un tamizado práctico del agregado grueso o global de gran tamaño nominal, igualmente podría resultar en la pérdida de una porción de la muestra si se usa para una pequeña muestra de agregado grueso o agregado fino.

6.4 **Horno:** Un horno de medidas apropiadas capaz de mantener una temperatura uniforme de 110 °C ± 5 °C .

7 Muestreo

7.1 Tomar la muestra de agregado de acuerdo a la NTP 400.010. El tamaño de la muestra de campo deberá ser la cantidad indicada en la NTP 400.010 o cuatro veces la cantidad requerida en los apartados 7.4 y 7.5 (excepto con la modificación que se presenta en el apartado 7.6), la que sea mayor.

7.2 Mezclar completamente la muestra y reducirla a la cantidad necesaria para el ensayo utilizando los procedimientos descritos en la práctica normalizada NTP 400.043. La muestra para el ensayo será aproximadamente de la cantidad deseada cuando esté seca y deberá ser el resultado final de la reducción. No se permitirá la reducción a una cantidad exacta predeterminada.

NOTA 3: Cuando el ensayo propuesto sea el de análisis granulométrico, incluyendo la determinación del material más fino que la malla de 75 μm (N° 200), la muestra podrá ser reducida en el campo para evitar el envío de excesiva cantidad de material al laboratorio.

7.3 **Agregado fino:** La cantidad de la muestra de ensayo, luego del secado, será de 300 g mínimo.

7.4 **Agregado grueso:** La cantidad de muestra de ensayo de agregado grueso será conforme a lo indicado en la Tabla A.1 (véase Anexo A).

7.5 **Agregado global:** La cantidad de muestra de ensayo de agregado global será la misma que para la del agregado grueso. Véase el apartado 7.4 y Tabla A.1 (véase Anexo A).

7.6 **Muestras de agregado grueso y agregado global de mayor tamaño:** La cantidad de muestra requerida para agregados con tamaños máximos nominales a 50 mm o mayores debe ser tal como para evitar la reducción de la muestra y ensayada como una unidad; excepto con cuarteador y agitador mecánico de tamices de capacidad suficiente. Cuando no se disponga de estos equipos, en lugar de combinar y mezclar incrementos de muestra para luego reducirla a una muestra de ensayo, como una opción, se puede realizar el tamizado de aproximadamente igual número de incrementos de tal modo que el total de la masa ensayada cumpla con los requisitos del apartado 7.4.

7.7 En el caso que la determinación de la cantidad de material más fino que la malla 75 μm (Nº 200) sea realizada mediante el método descrito en la NTP 400.018, se procederá como sigue:

7.7.1 Para agregados con tamaño máximo nominal de 12,5 mm o menores utilizar la muestra de ensayo que se utiliza en la NTP 400.018 y este método. Primero ensayar la muestra de acuerdo con la NTP 400.018 completando la operación de secado final, luego tamizar la muestra en seco como se estipula en los apartados 8.2 hasta 8.7 de esta Norma Técnica Peruana.

7.7.2 Para agregados con tamaño máximo nominal mayores a 12,5 mm utilizar una muestra de ensayo simple como se describe en el apartado 7.7.1 o una muestra simple separada por el método de ensayo que describe la NTP 400.018.

7.7.3 Cuando la especificación requiera la determinación de la cantidad total de material más fino que la malla de 75 μm (Nº 200) por lavado y secado, utilizar el procedimiento descrito en el apartado 7.7.1.

8 Procedimiento

8.1 Secar la muestra a peso constante a una temperatura de 110 °C ± 5 °C .

NOTA 4: Para ensayos de control, particularmente cuando se deseen resultados rápidos no es necesario secar el agregado grueso para el análisis granulométrico. Los resultados son ligeramente afectados por el contenido de humedad a menos que: (1) el tamaño máximo nominal es menor que 12,5 mm; (2) el agregado grueso contenga apreciable cantidad de material más fino que 4,75 mm (Nº 4); o (3) el agregado grueso es altamente absorbente (ejemplo un agregado ligero). También las muestras pueden ser secadas a una temperatura alta utilizando planchas calientes sin afectar los resultados, manteniendo los escapes de vapor sin generación de presiones suficientes como para fracturar las partículas y, temperaturas que no sean mayores como para causar el rompimiento químico del agregado.

8.2 Se seleccionarán tamaños adecuados de tamices para proporcionar la información requerida por las especificaciones que cubran el material a ser ensayado. El uso de tamices adicionales puede ser necesario para obtener otra información, tal como módulo de fineza o para regular la cantidad de material sobre un tamiz. Encajar los tamices en orden de abertura decreciente desde la tapa hasta el fondo y colocar la muestra sobre el tamiz superior. Agitar los tamices manualmente o por medio de un aparato mecánico por un período suficiente, establecido por tanda o verificado por la medida de la muestra ensayada, para obtener los criterios de suficiencia o tamizado descritos en el apartado 8.4.

8.3 Limitar la cantidad de material sobre el tamiz utilizado de tal manera que todas las partículas tengan la oportunidad de alcanzar la abertura del tamiz un número de veces durante la operación de tamizado. Para tamices con aberturas menores que 4,75 mm (N° 4), la cantidad retenida sobre alguna malla al completar el tamizado no excederá a 7 kg/m^2 de área superficial de tamizado (Nota 5). Para tamices con aberturas de 4,75 mm (N° 4) y mayores, la cantidad retenida en kg no deberá sobrepasar el producto de 2,5 x (abertura del tamiz en mm x (área efectiva de tamizado, m^2). Esta cantidad se muestra en la Tabla A.2 (véase Anexo A) para 5 dimensiones de tamices de uso común. En ningún caso la cantidad retenida será mayor como para causar deformación permanente al tamiz.

8.3.1 Prevenir una sobrecarga de material sobre un tamiz individual por uno de los siguientes procedimientos:

8.3.1.1 Colocar un tamiz adicional con abertura intermedia entre el tamiz que va a ser sobrecargado y el tamiz inmediatamente superior en la disposición original de tamices.

8.3.1.2 Separar la muestra en dos o más porciones, tamizando cada porción individual. Combinar las masas de cada porción retenidas sobre un tamiz especificado antes de calcular el porcentaje de la muestra sobre el tamiz.

8.3.1.3 Utilizar tamices de mayor armazón que provean mayor área de tamizado.

NOTA 5: La cantidad de 7 kg/m^2 a 200 g para los diámetros usuales de tamiz de 203,2 mm (con superficie efectiva de tamizado de 190,5 mm de diámetro).

8.4 Continuar el tamizado por un período suficiente, de tal manera que al final no más del 1 % de la masa del residuo sobre uno de los tamices, pasará a través de él durante 1 min de tamizado manual como sigue: Sostener firmemente el tamiz individual con su tapa y fondo bien ajustado en posición ligeramente inclinada en una mano. Golpear el filo contra el talón de la otra mano con un movimiento hacia arriba y a una velocidad de cerca de 150 veces por min, girando el tamiz un sexto de una revolución por cada 25 golpes. En la determinación de la eficacia del tamizado para medidas mayores de 4,75 mm (N° 4), limitar a una capa simple de partículas sobre el tamiz. Si la medida del tamiz hace impracticable el movimiento de tamizado descrito, utilizar el tamiz de 203 mm de diámetro para verificar la eficiencia del tamizado.

8.5 En el caso de mezclas de agregados gruesos y finos, consultar el apartado 8.3.1 para evitar la sobrecarga de tamices individuales.

8.5.1. Opcionalmente, la porción más fina que la malla de 4,75 mm (N° 4), puede ser reducida utilizando un sacudidor mecánico de acuerdo con el método NTP 400.043. Si se siguió este procedimiento, calcular la masa del incremento de cada medida de la muestra original como sigue:

$$A = \left(\frac{W_1}{W_2}\right)B$$

Donde:

A = masa del incremento de la medida sobre la base de la muestra total.

W_1 = masa de la fracción más fina que la malla de 4,75 mm (N° 4) en la muestra total.

W_2 = masa de la porción reducida de material más fino que la malla de 4,75 mm (N° 4) efectivamente tamizada.

B = masa del incremento en la porción reducida tamizada.

8.6 A no ser que se utilice un sacudidor mecánico, tamizar manualmente las partículas mayores que 75 mm para la determinación de las aberturas menores de tamiz a través de las que cada partícula debe pasar. Empezar con el menor tamiz utilizado. Alternar las partículas, si es necesario, para determinar si pasarán a través de una abertura particular; de cualquier modo no fuerce las partículas a pasar a través del tamiz.

8.7 Determinar la masa de cada incremento de medida sobre una balanza conforme a los requerimientos especificados en el apartado 5.1 aproximando al 0,1 % más cercano de la masa total original de la muestra seca. La masa total de material luego del tamizado deberá ser verificada con la masa de la muestra colocada sobre cada tamiz. Si la cantidad difiere en más de 0,3 % , sobre la masa seca original de la muestra, el resultado no deberá utilizarse para propósitos de aceptación.

8.8 Si la muestra fue previamente ensayada por el método descrito en la NTP 400.018, adicionar la masa del material más fino que la malla de 75 μm (N° 200) determinada por el método de tamizado seco.

9 Cálculo

9.1 Calcular el porcentaje que pasa, los porcentajes totales retenidos, o los porcentajes sobre cada tamiz, aproximando al 0,1 % más cercano de la masa seca inicial de la muestra. Si la misma muestra fue primero ensayada por el método de ensayo que se describe en la NTP 400.018, incluir la masa de material más fino que la malla de 75 μm (N° 200) calculada por el método de lavado y utilizar el total de la masa de la muestra seca previa al lavado descrito en el método de ensayo de la NTP 400.018, como base para calcular todos los porcentajes.

9.1.1 Cuando se ensayan incrementos de la muestra, como se indica en el apartado 7.6, se utilizará el total de la masa de la porción del incremento retenido en cada tamiz, para calcular los porcentajes que se mencionan en el apartado 9.1.

9.2 Cuando se requiera, calcular el módulo de fineza, sumando el porcentaje acumulado retenido de material de cada uno de los siguientes tamices (porcentaje acumulado retenido) y dividir la suma entre 100: 150 μm (N° 100); 300 μm (N° 50); 600 μm (N° 30); 1,18 mm (N° 16); 2,36 mm (N° 8); 4,75 mm (N° 4); 9,5 mm (3/8 de pulgada); 19,0 mm (3/4 de pulgada); 37,5 mm (1 1/2 pulgada) y mayores; incrementando en la relación 2 a 1.

10 Reporte

10.1 Dependiendo de las especificaciones para el uso del material, el reporte incluirá lo siguiente:

10.1.1 Porcentaje total que pasa cada tamiz.

10.1.2 Porcentaje total retenido en cada tamiz.

10.1.3 Porcentaje retenido entre tamices consecutivos.

10.2 Reportar los porcentajes en números enteros, excepto que si el porcentaje que pasa la malla de 75 μm (N° 200) es menor del 10 % , se aproximará al 0,1 % más cercano.

10.3 Reportar el módulo de fineza, cuando se solicite, al 0,01.

11 Precisión y desviación

11.1 **Precisión:** La estimación de la precisión para este método de ensayo se presenta en la Tabla A.3 (véase Anexo A). Los estimados están basados en los resultados obtenidos por "AASHTO Materials Reference Laboratory Proficiency Sample Program" (Programa de Muestreo del Laboratorio de Materiales de Referencia de AASHTO), con ensayos realizados con el método ASTM C 136 y AASHTO T 27.

Los datos se basaron en resultados de 65 a 233 laboratorios que ensayaron en 18 pares de muestras de referencia de agregado grueso y de 74 a 222 laboratorios que ensayaron 17 pares de muestras de referencia de agregado fino (muestras N° 21 al 90), los valores de la tabla se dan para diferentes rangos del porcentaje total del agregado que pasa un tamiz.

11.1.1 Los valores de la precisión para el agregado fino de la Tabla A.3 (véase Anexo A) se realizaron con 500 g de muestra de ensayo. La revisión de este método en

1994 permitió reducir la muestra a un mínimo de 300 g . El análisis de los resultados de muestras de referencia con 300 g y 500 g , las muestras 99 y 100 (las muestras 99 y 100 fueron esencialmente idénticas) produjeron los valores de precisión de la Tabla A.4 (Véase Anexo A), que indican solamente diferencias menores debido al tamaño de muestra.

NOTA 6: Los valores del agregado fino de la Tabla A.3 serán revisados para reflejar la muestra de ensayo de 300 g , cuando se ha ensayado un número suficiente de muestras de referencia utilizando aquel tamaño de muestra que provea datos confiables.

11.2 **Desviación:** Mientras no se acepte un material de referencia adecuado para determinar la desviación en este método de ensayo, no se establecerá la desviación.

12 Antecedente

ASTM C136:2006 Standard test method for sieve analysis of fine and coarse aggregates

ANEXO A

(NORMATIVO)

Tabla A.1 - Cantidad mínima de la muestra de agregado grueso o global

Tamaño Máximo Nominal Aberturas Cuadradas mm (pulg)	Cantidad de la Muestra de Ensayo, Mínimo kg (lb)
9,5 (3/8)	1 (2)
12,5 (½)	2 (4)
19,0 (¾)	5 (11)
25,0 (1)	10 (22)
37,5(1 ½)	15 (33)
50 (2)	20 (44)
63 (2 ½)	35 (77)
75 (3)	60 (130)
90 (3 ½)	100 (220)
100 (4)	150 (330)
125 (5)	300 (660)

Tabla A.2 - Máxima cantidad permitida de material retenido sobre un tamiz, kg

Abertura nominal del Tamiz, mm	DIMENSIÓN NOMINAL DEL TAMIZ [A]				
	203,2 mm diám.[B]	254 mm diám.[B]	304,8 mm diám.[B]	350 por 350 mm	372 por 580 mm
	ÁREA DE TAMIZADO, m^2				
	0,0285	0,0457	0,0670	0,1225	0,2158
125	C	C	C	C	67,4
100	C	C	C	30,6	53,9
90	C	C	15,1	27,6	48,5
75	C	8,6	12,6	23,0	40,5
63	C	7,2	10,6	19,3	34,0
50	3,6	5,7	8,4	15,3	27,0
37,5	2,7	4,3	6,3	11,5	20,2
25,0	1,8	2,9	4,2	7,7	13,5
19,0	1,4	2,2	3,2	5,8	10,2
12,5	0,89	1,4	2,1	3,8	6,7
9,5	0,67	1,1	1,6	2,9	5,1
4,75	0,33	0,54	0,80	1,5	2,6

A Dimensiones del tamiz en pulgadas: Diámetro de 8,0 pulg , diámetro de 10,0 pulg ; diámetro de 12,0 pulg ; de 13,8 pulg x 13,8 pulg (14 pulg x 14 pulg nominal); 14,6 pulg x 22,8 pulg (16 pulg x 24 pulg nominal).

B El área de los tamices circulares se basa sobre su diámetro efectivo 12,7 mm menos que el diámetro nominal, dado que la especificación E 11 permite que la soldadura entre el tamiz y el marco (armazón) sea hasta de 6,35 mm (1/4 pulg) sobre el tamiz. De este modo el diámetro efectivo de tamizado para un tamiz de 203,2 mm (8,0 pulg) es 190,5 mm (7,5 pulg). Los fabricantes de tamices no deben sobrepasar de 6,35 mm (1/4 pulg) de espesor de soldadura sobre el tamiz.

C Los tamices indicados tienen menos de cinco aberturas y no deberán ser utilizados para tamizado, excepto como está previsto en el apartado 8.6.

Tabla A.3 - Precisión

	Porcentaje total de material que pasa		Desviación Típica (1s), %[A]	Rango aceptable de dos resultados (d2s), %[A]
Agregado Grueso[B]				
Precisión de un operador	<100	≥95	0,32	0,9
	<95	≥85	0,81	2,3
	<85	≥80	1,34	3,8
	<80	≥60	2,25	6,4
	<60	≥20	1,32	3,7
	<20	≥15	0,96	2,7
	<15	≥10	1,00	2,8
	<10	≥5	0,75	2,1
	<5	≥2	0,53	1,5
	<2	<0	0,27	0,8
Precisión Multilaboratorio	<100	≥95	0,35	1,0
	<95	≥85	1,37	3,9
	<85	≥80	1,92	5,4
	<80	≥60	2,82	8,0
	<60	≥20	1,97	5,6
	<20	≥15	1,60	4,5
	<15	≥10	1,48	4,2
	<10	≥5	1,22	3,4
	<5	≥2	1,04	3,0
	<2	<0	0,45	1,3
Agregado Fino				
Precisión de un operador	<100	≥95	0,26	0,7
	<95	≥60	0,55	1,6
	<60	≥20	0,83	2,4
	<20	≥15	0,54	1,5
	<15	≥10	0,36	1,0
	<10	≥2	0,37	1,1
	<2	>0	0,14	0,4
Precisión Multilaboratorio	<100	≥95	0,23	0,6
	<95	≥60	0,77	2,2
	<60	≥20	1,41	4,0
	<20	≥15	1,10	3,1
	<15	≥10	0,73	2,1
	<10	≥2	0,65	1,8
	<2	>0	0,31	0,9

[A] Estos números representan, respectivamente, los límites (1s) y (d2s) descritos en la norma ASTM C 670

[B] La estimación de la precisión se basa en agregados de tamaño máximo nominal de 19,0 mm (3/4 pulg)

Tabla A.4 - Precisión para muestras de ensayo de 300 g y 500 g

Muestra de referencia de agregado fino				En el laboratorio		Entre laboratorios	
Resultados de los ensayos	**Cantidad de muestra**	**Número de laboratorios**	**Promedio**	**1s[11]**	**d2s**	**1s**	**d2s[12]**
ASTM C 136/AASHTO T 27							
Material total que pasa el tamiz No. 4 (%)	500 g	285	99,922	0,027	0,066	0,037	0,104
	300 g	276	99,990	0,021	0,060	0,042	0,117
Material total que pasa el tamiz No. 8 (%)	500 g	281	84,10	0,43	1,21	0,63	1,76
	300 g	274	84,32	0,39	1,09	0,69	1,92
Material total que pasa el tamiz No. 16 (%)	500 g	286	70,11	0,53	1,49	0,75	2,10
	300 g	272	70,00	0,62	1,74	0,76	2,12
Material total que pasa el tamiz No. 30 (%)	500 g	287	48,54	0,75	2,10	1,33	3,73
	300 g	276	48,44	0,87	2,44	1,36	3,79
Material total que pasa el tamiz No. 50 (%)	500 g	286	13,52	0,42	1,17	0,98	2,73
	300 g	275	13,51	0,45	1,25	0,99	2,76
Material total que pasa el tamiz No. 100 (%)	500 g	287	2,55	0,15	0,42	0,37	1,03
	300 g	270	2,52	0,18	0,52	0,32	0,80
Material total que pasa el tamiz No. 200 (%)	500 g	278	1,32	0,11	0,32	0,31	0,85
	300 g	266	1,30	0,14	0,39	0,31	0,85

11 Límite con 1 sigma.
12 Límite con 2 sigma.

Anexo 9. *ASTM C 87 - 03*

Designation: C 87 – 03

Standard Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar[1]

This standard is issued under the fixed designation C 87; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope *

1.1 This test method covers the determination of the effect on mortar strength of the organic impurities in fine aggregate, whose presence is indicated using Test Method C 40. Comparison is made between compressive strengths of mortar made with washed and unwashed fine aggregate.

1.2 The SI values shown are to be regarded as the standard. The inch-pound values shown in parentheses are provided for information purposes only.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*(**Warning**—Fresh hydraulic cementitous mixtures are caustic and may cause chemical burns to exposed skin and tissue upon prolonged exposure.)[2]

2. Referenced Documents

2.1 *ASTM Standards:*

C 33 Specification for Concrete Aggregates[3]

C 40 Test Method for Organic Impurities in Fine Aggregates for Concrete[3]

C 109/C 109M Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)[4]

C 128 Test Method for Density, Relative Density, (Specific Gravity), and Absorption of Fine Aggregate[3]

C 150 Specification for Portland Cement[4]

C 230 Specification for Flow Table for Use in Tests of Hydraulic Cement[4]

C 305 Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency[4]

C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[4]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[3]

C 702 Practice for Reducing Samples of Aggregate to Testing Size[3]

D 75 Practice for Sampling Aggregates[5]

D 3665 Practice for Random Sampling of Construction Materials[5]

3. Significance and Use

3.1 This test method is of significance in making a final determination of the acceptability of fine aggregates with respect to the requirements of Specification C 33 concerning organic impurities.

3.2 This test method is applicable to those samples which, when tested in accordance with Test Method C 40, have produced a supernatant liquid with a color darker than that of the reference standard color plate No. 3 or color solution.

4. Basis for Comparison

4.1 The fine aggregate shall be compared in mortar, as described in this test method, with a sample of the same aggregate that has been washed in a 3 % solution of sodium hydroxide followed by thorough rinsing in water. The washing shall be repeated until the supernatant liquid obtained in Test Method C 40 has a color lighter than the reference standard. The washing shall be performed in such a way as to minimize the loss of fines, so that the washed aggregate has a fineness modulus within 0.10 of that of the unwashed aggregate. The prepared aggregate shall be checked with a suitable indicator such as phenolphthalein, pH paper or by using a pH meter to assure that sodium hydroxide has been removed prior to preparation of the mortar.

4.2 Unless otherwise specified or permitted, strength comparisons shall be made at 7 days in accordance with the following conditions:

4.2.1 Mix three batches of mortar with the prepared aggregate washed in sodium hydroxide and three batches with the

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concretes and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

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[2] See section on Safety Precautions, *Manual of Aggregate and Concrete Testing, Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.01.

[5] *Annual Book of ASTM Standards*, Vol 04.03.

***A Summary of Changes section appears at the end of this standard.**

unwashed aggregate on the same day. Mix the batches for the two conditions alternately.

4.2.2 Mold three 50-mm (2-in.) cubes from each batch.

4.2.3 Test the three cubes from each batch at the age specified.

5. Apparatus

5.1 *Flow Table, Flow Mold, and Caliper*, as described in Specification C 230.

5.2 *Tamper, Trowel, Cube Molds, and Testing Machine*, as described in Test Method C 109/C 109M.

5.3 *Mixer, Bowl, and Paddle*, as described in Practice C 305.

5.4 *Curing Apparatus*, as described in Specification C 511.

6. Reagents and Materials

6.1 Portland cement shall be Type I or Type II, meeting the requirements of Specification C 150.

6.2 *Sodium Hydroxide Solution* (3 %)—Dissolve 3 parts by mass of sodium hydroxide (NaOH) in 97 parts water.

7. Sampling

7.1 Fine aggregate for this test shall be obtained from the same sample used for Test Method C 40. Any reduction of samples to obtain test specimens shall be in accordance with Practice C 702.

7.2 Secure an additional field sample if needed from the aggregate supply in accordance with Practice D 75 and Practice D 3665.

8. Temperature and Relative Humidity

8.1 8.1 The temperature of the mixing water, moist cabinet, moist room and storage tank water shall be maintained at 23.0 ± 2.0°C (73.5 ± 3.5°F).

8.2 The relative humidity of the moist cabinet or moist room shall be maintained at not less than 95 %.

9. Preparation of Mortar

9.1 Prepare the mortar in a mechanical mixer (see **Warning** in 9.1.2) in accordance with the procedure for mixing mortars described in Practice C 305, as modified below.

9.1.1 The mortar shall be proportioned to produce a consistency of 100 ±5 as determined by the flow test.

9.1.2 In the event that the fine aggregate being used includes particles so large that the adjustment bracket (as described in Practice C 305) cannot provide adequate clearance, the oversized particles shall be removed by sieving on the 4.75-mm (No. 4) or 2.36-mm (No. 8) sieve. If this procedure is employed, the report shall so state and shall indicate the quantity of material so removed. (**Warning**—The clearances between the paddle and the bowl specified in Practice C 305 are suitable when using the standard mortar made with Ottawa Sand. To permit the mixer to operate freely and to avoid serious damage to the paddle and bowl when coarser aggregates are used, it may be necessary to set the clearance adjustment bracket to provide greater clearances than specified. A clearance of approximately 4.0 mm is required in Practice C 305; a clearance of approximately 5.0 mm has been found to be satisfactory for this method when used with fine aggregate from which the material retained on the 4.75-mm (No. 4) sieve has been removed.)

9.2 Use water and cement in quantities that will yield a water-cement ratio of 0.6 by mass (see Note 1).

NOTE 1—It has been found that 600 g of cement and 360 mL of water will usually be adequate for a 6-cube batch.

9.3 Using fine aggregate that has been brought to a saturated surface dry condition as described in Test Method C 128, prepare a quantity of aggregate that is slightly more than needed to produce a batch of the desired consistency (see Note 2).

NOTE 2—If the absorption has been determined in accordance with Test Method C 128, the aggregate may be prepared for test by adding to a known mass of dry aggregate the amount of water it will absorb, mixing thoroughly, and permitting the aggregate to stand in a covered pan for 30 min before use.

9.4 After placing all the mixing water in the bowl, add the cement to the water. Start the mixer and mix at the slow speed (140 ±5 r/min) for 30 s.

9.5 While still mixing at slow speed over a 30-s period, add a measured quantity of aggregate estimated to provide the proper consistency.

NOTE 3—The quantity of aggregate used may be determined by subtracting from a known quantity of prepared aggregate the mass of the portion remaining after mixing.

9.6 Stop the mixer, change to medium speed (285 ±10 r/min), and mix for 30 s.

9.7 Stop the mixer and let the mortar stand for 1.5 min. During the first 15 s of this interval, quickly scrape down into the batch any mortar that may have collected on the side of the bowl, then for the remainder of this interval, cover the bowl with the lid.

9.8 Finish by mixing for 1 min at medium speed. If the flow appears to be too high additional sand may be added after the first 30 s of this mixing period. If so, stop the mixer briefly, add the sand, and then complete the additional 30 s of mixing.

9.9 In any case requiring a remixing interval, any mortar adhering to the side of the bowl shall be quickly scraped down into the batch with the scraper prior to remixing.

9.10 Make a determination of the flow.

10. Procedure

10.1 *Flow Test*:

10.1.1 Carefully wipe the flow table clean. Dry the surface and place the flow mold at the center. Immediately after completing the mixing operation, place a layer of mortar approximately 25 mm (1 in.) in thickness in the mold and tamp 20 times with the tamper. The tamping pressure shall be just sufficient to ensure uniform filling of the mold. Fill the mold with mortar and tamp as specified for the first layer. Cut off the mortar to a plane surface, flush with the top of the mold, by drawing the straight edge of the trowel (held nearly perpendicular to the mold) with a sawing motion across the top of the mold. Wipe the table top clean and dry, being especially careful to remove any water from around the edge of the flow mold. Lift the mold away from the mortar 1 min after completing the mixing operation. Immediately drop the table through a height of 12.7 mm (0.5 in.) ten times in 6 s. The flow is the resulting increase in average diameter of the mortar specimen, measured on at least four diameters at approximately equal angles, expressed as a percentage of the original diameter.

10.1.2 Should the flow be too great, return the mortar to the mixing vessel, add additional sand, mix for 30 s at medium speed, and make another determination of the flow. If more than two trials must be made to obtain a flow of 100 ±5, consider the mortar as a trial mortar, and prepare a new batch.

10.1.3 If the mortar is too dry, discard the batch.

10.1.4 Determine the quantity of sand used by subtracting the weight of the portion remaining after mixing from the mass of the initial sample.

10.2 *Molding Test Specimens*—Immediately following completion of a flow test that indicates acceptable consistency, return the mortar from the flow table to the mixing bowl, scrape down the bowl, and then remix the entire batch for 15 s at medium speed. Upon completion of mixing, shake the excess mortar from the paddle into the bowl. Place the mortar in cube molds in two layers in accordance with the procedures described in Test Method C 109/C 109M.

10.3 Store the test specimens initially in a moist cabinet or moist room for 24 ± 0.5 h. Additional curing shall be by immersion in saturated lime water.

10.4 Determine compressive strength of the cubes in accordance with Test Method C 109/C 109M.

11. Calculation and Report

11.1 Calculate the compressive strength of each specimen by dividing the maximum load it carried during the test by the cross-sectional area. Average the strengths of the three specimens from each batch. Calculate three strength ratios by dividing the average strength for a batch containing unwashed sand by the average strength for the corresponding (in respective order of mixing) batch containing washed sand.

11.2 Report the average of the three ratios, expressed as a percentage, as the relative strength for the sand under test.

12. Precision and Bias

12.1 The following precision statement is applicable when a test result is the average ratio, as defined by this test method, of three pairs of mortar batch strength tests with all the batches mixed on the same day and tested at the same age.

12.2 The single laboratory coefficient of variation has been determined to be 5.4 % (Note 4). Therefore, results of two properly conducted tests in the same laboratory should not differ from each other by more than 15.3 % (Note 4) of their average. The maximum range (difference between highest and lowest) of the three individual ratios used in calculating the average should not exceed 17 % (Note 5).

NOTE 4—These numbers represent respectively the (1s %) and (d2s %) limits as described in Practice C 670.

NOTE 5—Calculated as described in Practice C 670.

13. Keywords

13.1 aggregate; organic impurities; mortar strength

SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C 87-83 (1995)$^{\epsilon 1}$) that may impact the use of this standard.

(1) Revised Section 1.
(2) Updated Section 2.
(3) Revised 3.2.
(4) Revised Section 4.
(5) Added new 5.4.
(6) Revised 6.2.
(7) Revised 7.1.
(8) Revised Section 8.
(9) Revised Section 9.
(10) Revised Section 10.
(11) Revised Note 5.

Anexo 10. *ASTM D2216 – 19*

Designation: D2216 – 19

Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass[1]

This standard is issued under the fixed designation D2216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover the laboratory determination of the water (moisture) content by mass of soil, rock, and similar materials where the reduction in mass by drying is due to loss of water except as noted in 1.4, 1.5, and 1.8. For simplicity, the word "material" shall refer to soil, rock or aggregate whichever is most applicable.

1.2 Some disciplines, such as soil science, need to determine water content on the basis of volume. Such determinations are beyond the scope of this test method.

1.3 The water content of a material is the ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles, expressed as a percentage.

1.4 The term "solid material" as used in geotechnical engineering is typically assumed to mean naturally occurring mineral particles of soil and rock that are not readily soluble in water. Therefore, the water content of materials containing extraneous matter (such as cement etc.) may require special treatment or a qualified definition of water content. In addition, some organic materials may be decomposed by oven drying at the standard drying temperature for this method (110 ± 5°C). Materials containing gypsum (calcium sulfate dihydrate) or other compounds having significant amounts of hydrated water, may present a special problem as this material slowly dehydrates at the standard drying temperature (110 ± 5°C) and at very low relative humidity, forming a compound (such as calcium sulfate hemihydrate) that is not normally present in natural materials except in some desert soils. In order to reduce the degree of dehydration of gypsum in those materials containing gypsum or to reduce decomposition in highly/fibrous organic soils, it may be desirable to dry the materials at 60°C or in a desiccator at room temperature. When a drying temperature is used which is different from the standard drying temperature as defined by this test method, the resulting water content may be different from the standard water content determined at the standard drying temperature of 110 ± 5°C.

NOTE 1—Test Method D2974 provides an alternate procedure for determining water content of peat materials.

1.5 Materials containing water with substantial amounts of soluble solids (such as salt in the case of marine sediments) when tested by this method will give a mass of solids that includes the previously soluble dissolved solids. These materials require special treatment to remove or account for the presence of precipitated solids in the dry mass of the specimen, or a qualified definition of water content must be used. For example, see Test Method D4542 regarding information on marine sediments.

1.6 This test standard requires several hours for proper drying of the water content specimen. Test Methods D4643, D4944 and D4959 provide less time-consuming processes for determining water content. See Gilbert[2] for details on the background of Test Method D4643.

1.7 Two test methods are provided in this standard. The methods differ in the significant digits reported and the size of the specimen (mass) required. The method to be used may be specified by the requesting authority; otherwise Method A shall be performed.

1.7.1 *Method A*—The water content by mass is recorded to the nearest 1 %. For cases of dispute, Method A is the referee method.

1.7.2 *Method B*—The water content by mass is recorded to the nearest 0.1 %.

1.8 This standard requires the drying of material in an oven. If the material being dried is contaminated with certain chemicals that may react violently or emit hazardous gases when heated, health and safety hazards may exist. Therefore, this standard should not be used in determining the water content of contaminated soils unless adequate health and safety precautions are exercised.

[1] This test method is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity and Density Characteristics of Soils.

Current edition approved March 1, 2019. Published March 2019. Originally approved in 1963. Last previous edition approved in 2010 as D2216–10. DOI: 10.1520/D2216-19.

[2] Gilbert, P.A., "Computer Controlled Microwave Oven System for Rapid Water Content Determination," Tech. Report GL-88–21, Department of the Army, Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, November 1988.

*A Summary of Changes section appears at the end of this standard

1.9 *Units*—The values stated in SI units shall be regarded as standard except the Alternative Sieve Sizes listed in Table 1 are used. No other units of measurement are included in this test method.

1.10 All observed and calculated values shall conform to the guidelines for significant digits and rounding established in Practice D6026, unless superseded by this test method.

1.10.1 This is especially important if the water content will be used to calculate other relationships such as moist mass to dry mass or vice versa, wet unit weight to dry unit weight or vice versa, and total density to dry density or vice versa. For example, if four significant digits are required in any of the above calculations, then the water content must be recorded to the nearest 0.1 %. This occurs since 1 plus the water content (not in percent) will have four significant digits regardless of what the value of the water content is; that is, 1 plus 0.1/100 = 1.001, a value with four significant digits. While, if three significant digits are acceptable, then the water content can be recorded to the nearest 1 %.

1.10.2 If water content data is to be used to calculate other relationships, such as moist or dry mass, wet or dry unit weight or total or dry density, then the specimen mass up to 200 g must be determined using a balance accurate to 0.01 g.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.12 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D2974 Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils

D3740 Practice for Minimum Requirements for Agencies Engaged in Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4220 Practices for Preserving and Transporting Soil Samples

D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

D4542 Test Methods for Pore Water Extraction and Determination of the Soluble Salt Content of Soils by Refractometer

D4643 Test Method for Determination of Water Content of Soil and Rock by Microwave Oven Heating

D4753 Guide for Evaluating, Selecting, and Specifying Balances and Standard Masses for Use in Soil, Rock, and Construction Materials Testing

D4944 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

D4959 Test Method for Determination of Water Content of Soil By Direct Heating

D5079 Practices for Preserving and Transporting Rock Core Samples (Withdrawn 2017)[4]

D6026 Practice for Using Significant Digits in Geotechnical Data

D7263 Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *constant dry mass (of a solid material)*—the state that a water content specimen has attained when further heating results in less than 1 % or 0.1 % additional loss in mass for Method A or B respectively. The time necessary to obtain constant dry mass will vary depending on numerous factors such as the type of material being tested, the size of the specimen and type of oven being used (forced draft or gravity

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[4] The last approved version of this historical standard is referenced on www.astm.org.

TABLE 1 Minimum Requirements for Mass of Test Specimens, and Balance Readability[A]

Maximum Particle Size (100 % Passing)		Method A Water Content Recorded to ±1 %		Method B Water Content Recorded to ±0.1 %	
Sieve Size	Alternative Sieve Size	Minimum Specimen Mass	Balance Readability (g)	Minimum Specimen Mass (g)	Balance Readability (g)
75.0 mm	3 in.	5 kg	10	50 kg	10
37.5 mm	1-½ in.	1 kg	10	10 kg	10
19.0 mm	¾ in.	250 g	0.1	2.5 kg	0.1
9.5 mm	⅜ in.	50 g	0.1	500 g	0.1
4.75 mm	No. 4			100 g	0.01
2.00 mm	No. 10			20 g	0.01

[A] See 1.10.2.

type). The influence of these factors generally can be established by good judgment, and experience with the materials being tested and the apparatus being used.

4. Summary of Test Method

4.1 The mass of a moist test specimen is determined. The specimen is then dried in an oven at a temperature of 110 ± 5°C until a constant mass is achieved. The loss of mass, due to drying, is considered to be water. The water content is calculated using the mass of water to the mass of the dry specimen expressed in percent.

5. Significance and Use

5.1 For many materials, the water content is one of the most significant properties used in establishing a correlation between soil behavior and its index properties.

5.2 The water content of a material is used in expressing the phase relationships of air, water, and solids in a given volume of material.

5.3 In fine-grained soils, the consistency of a given soil type depends on its water content. The water content of a soil, along with its liquid and plastic limits as determined by Test Method D4318, is used to express its relative consistency or liquidity index.

NOTE 2—The quality of the result produced by this standard is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the criteria of Practice D3740 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with Practice D3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D3740 provides a means of evaluating some of those factors.

6. Apparatus

6.1 *Drying Oven*—Vented, thermostatically-controlled, preferably of the forced-draft type and capable of maintaining a uniform temperature of 110 ± 5°C throughout the drying chamber. The oven shall have a means of indicating the oven drying chamber temperature when in operation. This can be accomplished by such means as an electronic display, an analog thermometer, remote temperature recording device or any other means to determine the current drying chamber temperature while in operation.

6.1.1 Ovens in excess of 30 cubic feet shall have the temperature verified for adherence to the temperature requirements in the four quadrants and the center of the oven. Smaller ovens shall have the temperature verified in a single center location. Oven temperature verification shall follow the schedule as outlined in D3740 or following such things as repairs or questionable operation.

6.2 *Balances*—All balances must meet the requirements of Specification D4753 and this section. A Class GP1 balance of 0.01 g readability is required for specimens having a mass of up to 200 g (excluding mass of specimen container) and a Class GP2 balance of 0.1 g readability is required for specimens having a mass over 200 g. If desired, a Class GP1 balance may be used for specimens exceeding 200 g providing the specimen size is within the capacity of the balance. However, the balance used may be controlled by the number of significant digits needed (see 1.10).

6.3 *Specimen Containers*—Suitable containers made of material resistant to corrosion and change in mass upon repeated heating, cooling, exposure to materials of varying pH, and cleaning. Unless a desiccator is used, containers with close-fitting lids shall be used for testing specimens having a mass of 200 g or less; while for specimens having a mass greater than 200 g, containers without lids may be used (see Note 3). One uniquely numbered (identified) container or number-matched container and lid combination as required is needed for each water content determination.

NOTE 3—The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination, and to prevent absorption of moisture from the atmosphere following drying and before final mass determination.

6.4 *Desiccator (Optional)*—A desiccator cabinet or large desiccator jar of suitable size containing silica gel or anhydrous calcium sulfate. It is preferable to use a desiccant that changes color when it needs to be recharged.

NOTE 4—Anhydrous calcium sulfate is sold under the trade name Drierite.

6.5 *Container Handling Apparatus,* heat resistant gloves, tongs, or suitable holder for moving and handling hot containers after drying.

6.6 *Miscellaneous,* knives, spatulas, scoops, quartering cloth, wire saws, etc., as required.

7. Samples

7.1 Soil samples shall be preserved and transported in accordance with Practice D4220 Section 8 Groups B, C, or D soils. Rock samples shall be preserved and transported in accordance with Practice D5079 section 7.5.2.1, Special Care Rock. Keep the samples that are stored prior to testing in non-corrodible airtight containers at a temperature between 3 and 30°C and in an area that is without direct sunlight. Disturbed samples in jars or other containers shall be stored in such a way as to minimize moisture condensation on the insides of the containers.

7.2 The water content determination should be done as soon as practical after sampling, especially if potentially corrodible containers (such as thin-walled steel tubes, paint cans, etc.) or plastic sample bags are used.

8. Test Specimen

8.1 For water contents being determined in conjunction with another ASTM method, the specimen mass requirement stated in that method shall be used if one is provided. If no minimum specimen mass is provided in that method then the values outlined in Table 1 and 1.10.2 shall apply. See Howard[5] for background data for the values listed.

[5] Howard, A. K., "Minimum Test Specimen Mass for Moisture Content Determination," *Geotechnical Testing Journal*, ASTM., Vol. 12, No. 1, March 1989, pp. 39-44.

8.2 The minimum specimen mass of moist material selected to be representative of the total sample is based on visual maximum particle size in the sample and the Method (Method A or B) used to record the data. Minimum specimen mass and balance readability shall be in accordance with Table 1.

8.3 Using a test specimen smaller than the minimum indicated in Table 1 and 8.2 requires discretion, though it may be adequate for the purposes of the test. It shall be noted on the test data forms or test data sheets of any specimen used not meeting these requirements.

8.4 When working with a specimen weighing less than 200 g and containing a relatively large gravel particle, it is appropriate not to include the gravel particle in the test specimen. However, any discarded material shall be described and noted on the test data form/sheet.

8.5 For those samples consisting entirely of intact rock or gravel-size aggregate, the minimum specimen mass shall be 500 g. Representative portions of the sample may be broken into smaller particles. The particle size is dictated by the specimen mass, the container volume and the balance being used to determine constant mass, see 10.4. Specimen masses as small as 200 g may be tested if water contents of only two significant digits are acceptable.

9. Test Specimen Selection

9.1 When the test specimen is a portion of a larger amount of material, the specimen must be selected to be representative of the water condition of the entire sample. The manner in which the test specimen is selected is dependent on the purpose and application of the test, the type of material being tested, the water condition, and the type of sample (from another test, bag, block, etc.).

9.2 For disturbed samples such as trimmings, bag samples, etc; obtain the test specimen by one of the following methods (listed in order of preference):

9.2.1 If the material is such that it can be manipulated and handled without significant moisture loss and segregation, the material shall be mixed thoroughly. Select a representative portion using a scoop of a size that no more than a few scoopfuls are required to obtain the proper size of specimen defined in 8.2. Combine all the portions for the test specimen.

9.2.2 If the material is such that it cannot be thoroughly mixed or mixed and sampled by a scoop, form a stockpile of the material, mixing as much as possible. Take at least five portions of material at random locations using a sampling tube, shovel, scoop, trowel, or similar device appropriate to the maximum particle size present in the material. Combine all the portions for the test specimen.

9.2.3 If the material or conditions are such that a stockpile cannot be formed, take as many portions of the material as practical, using random locations that will best represent the moisture condition. Combine all the portions for the test specimen.

9.3 For intact samples such as block, tube, split barrel, etc, obtain the test specimen by one of the following methods depending on the purpose and potential use of the sample:

9.3.1 Using a knife, wire saw, or other sharp cutting device, trim the outside portion of the sample a sufficient distance to expose the underlaying material to determine if it is layered or if there are exposed anomalies. Trimming the sample in this manner also removes material that may be more dry or more wet than the main portion of the sample. If the existence of layering is questionable, slice the sample in half. If the material is layered, see 9.3.3.

9.3.2 If the material is not layered, obtain the specimen meeting the mass requirements in Table 1 and 8.2 by: *(1)* taking all or one-half of the interval being tested; *(2)* trimming a representative slice from the interval being tested; or *(3)* trimming the exposed surface of one-half or from the interval being tested.

NOTE 5—Migration of moisture in some cohesionless soils may require that the entire sample be tested.

9.3.3 If a layered material (or more than one material type is encountered), select an average specimen, or individual specimens, or both dependent on project goals. Specimens must be properly identified as to location, or what they represent, and appropriate remarks entered on the test data forms or test data sheets.

10. Procedure

10.1 Determine and record the mass of the clean and dry specimen container and its lid, if used, along with its identification number.

10.2 Select representative test specimens in accordance with Section 9.

10.3 Place the moist test specimen in the container and, if used, set the lid securely in position. Determine the mass of the container and moist specimen using a balance (see Table 1 and 8.2) selected on the basis of the specimen mass or required significant digits. Record this value.

NOTE 6—To assist in the oven drying of large test specimens, they should be placed in containers having a large surface area (such as pans) and the material broken up into smaller aggregations.

10.4 Remove the lid (if used) and place the container with the moist specimen in the drying oven. Dry the specimen to a constant mass. Maintain the drying oven at 110 ± 5°C unless otherwise specified (see 1.4). The time required to obtain constant mass will vary depending on the type of material, size of specimen, oven type and capacity, and other factors. The influence of these factors generally can be established by good judgment and experience with the materials being tested and the apparatus being used.

10.4.1 In most cases, drying a test specimen overnight (about 12 to 16 h) is sufficient, especially when using forced draft ovens. In cases where there is doubt concerning the adequacy of drying to a constant dry mass, see 3.2.1 and check for additional loss in mass with additional oven drying over an adequate time period. A minimum time period of two hours shall be used. Increasing the drying time may be necessary with greater specimen mass. A rapid check to see if a relatively large specimen (> than about 100 g of material) is dry; place a small strip of torn paper on top of the material while it is in the oven or just upon removal from the oven. If the paper strip curls the material is **not** dry and requires additional drying time. Specimens of sand may often be dried to constant mass in a period of about 4 h, when a forced-draft oven is used.

10.4.2 Since some dry materials may absorb moisture from other drying specimens that still retain moisture, dried specimens shall be removed before placing moist specimens in the same oven; unless they are being dried for an extended period of time such as overnight.

10.5 After the specimen has dried to constant mass, remove the container from the oven and replace the lid if used or place the specimen in a desiccator. Allow the specimen and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents or heat transmission. Determine the mass of the container and oven-dried specimen using the same type/capacity balance used in 10.3 and record this value. If the possibility exists that the specimen may absorb moisture from the air prior to the determination of its dry mass, tight fitting lids shall be used even after the specimen has been allowed to cool in a desiccator. Good judgment and experience with testing specific soil types may assist in determining if a lid should be used after cooling in a desiccator. Specimens that are allowed to cool with a lid in place shall be weighed with the lid on.

10.5.1 Cooling in a desiccator is acceptable in place of tight fitting lids since it greatly reduces absorption of moisture from the atmosphere during cooling.

10.6 A copy of a sample data sheet is shown in Appendix X1. Any data sheet can be used, provided the form contains all the required data.

11. Calculation

11.1 Calculate the water content of the material as follows:

$$w = [(M_{cms} - M_{cds})/(M_{cds} - M_c)] \times 100 = (M_w/M_s) \times 100 \quad (1)$$

where:

w = water content, %,
M_{cms} = mass of container and moist specimen, g,
M_{cds} = mass of container and oven dry specimen, g,
M_c = mass of container, g,
M_w = mass of water ($M_w = M_{cms} - M_{cds}$), g, and
M_s = mass of oven dry specimen ($M_s = M_{cds} - M_c$), g.

12. Report: Test Data Sheet(s)/Form(s)

12.1 The methodology used to specify how data are recorded on the test data sheet(s)/form(s), as given below, is covered in Practice D6026. These requirements do not consider in situ material variation, use of the data, special purpose studies, or any considerations for the user's objectives. It is common practice to increase or reduce significant digits of reported data commensurate with these considerations. It is beyond the scope of the standard to consider significant digits used in analysis method for engineering design.

12.2 Record as a minimum the following general information (data):

12.2.1 Project information such as project number or identification, the name of the project, the client if applicable.

12.2.2 Person that conducted the test.

12.2.3 Date the test was conducted.

12.2.4 Identification of the sample (material) being tested, such as boring number, sample number, test number, container number etc.

12.2.5 Water content of the specimen to the nearest 1 % for Method A or 0.1 % for Method B, as appropriate based on the minimum mass of the specimen. If this method is used in concert with another method, the water content of the specimen should be reported to the value required by the test method for which the water content is being determined. Refer to Practice D6026 for guidance concerning significant digits, especially if the value obtained from this test method is to be used to calculate other relationships such as unit weight or density. For instance, if it is desired to express dry unit weight, as determined by D7263 to the nearest 0.1 lbf/f^3 (0.02 kN/m^3), it may be necessary to use a balance with a greater readability or use a larger specimen mass to obtain the required significant digits for the mass of water so that the water content can be determined to the required significant digits. Also, the significant digits in Practice D6026 may need to be increased when calculating phase relationships requiring four significant digits.

12.2.6 Indicate if test specimen had a mass less than the minimum required as indicated in Table 1 and 8.2.

12.2.7 Indicate if test specimen contained more than one material type (layered, etc.).

12.2.8 Indicate the drying temperature if different from 110 ± 5°C.

12.2.9 Indicate if any material (size and amount) was excluded from the test specimen.

12.3 When reporting water content in tables, figures, etc., any data not meeting the requirements of this test method shall be noted, such as not meeting the mass, balance, or temperature requirements or a portion of the material is excluded from the test specimen.

13. Precision and Bias

13.1 *Statements on Precision*[6]:

13.1.1 *Precision*—Test data on precision is not presented due to the nature of the soil or rock materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program. Any variation observed in the data is just as likely to be due to specimen variation as to operator or laboratory testing variation.

13.1.2 Subcommittee D18.03 is seeking any data from the users of this test method that might be used to make a limited statement on precision.

13.1.3 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

14. Keywords

14.1 aggregate; consistency; index property; laboratory; moisture analysis; moisture content; soil; water content

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D13-1108.

APPENDIX

(Nonmandatory Information)

X1. WATER CONTENT OF SOIL AND ROCK SAMPLE DATA SHEET

Project Name: ______________ Project Number: ______________ Date:

Test Method: X Method A; ___ Method B

Laboratory Number	04-725-S	04-726-S	04-727-S		
Boring Number	B-1	B-2	B-2		
Field Number	SPT-1	SPT-2	SPT-2a		
Container / Lid Number	725	726	727		
Container Mass, g M_c	770.1	731.7	770.6		
Container+Moist Specimen Mass, g M_{cms}	1895.3	2008.4	1827.9		
Initial Container Dry Specimen Mass, g	1721.4	1872.1	1707.6		
Secondary Container Dry Specimen Mass, g	1721.4	1801.2	1660.8		
Final Container Dry Specimen Mass, g, M_{cds}	1721.4	1801.2	1660.8		
Mass of Water, g, $M_w = M_{cms} - M_{cds}$	173.9	207.2	167.1		
Mass of Solids, g, $M_s = M_{cds} - M_c$	951.3	1069.5	890.2		
Water Content, %, $w = (M_w/M_s) \times 100$	18	19	19		
Unified Soil Classification Group Symbol (Visual)	GC	GC	GC		
Approximate Maximum Particle Size (Visual)					
Oven Temperature if Other Than 110 ± 5°C	—	—	—		

Remarks: ____

Tested By: ______________ Date: ______________ Checked By: ______________

Dry Mass By: ______________ Date: ______________ Spot Checked: ______________

Calculated By: ______________ Date: ______________ Reviewed By: ______________

SUMMARY OF CHANGES

Committee D18 has identified the location of selected changes to these test methods since the last issue, D2216–10, that may impact the use of these test methods. (March 1, 2019)

(1) Added a more detailed description of water content in the Scope.
(2) Included statement for use of water content when used in conjunction with other soil relationships.
(3) Eliminated the reference to E145.
(4) Revised oven requirements in Apparatus Section.
(5) Revised Report Section to conform to D18 SPM.
(6) Incorporated grammatical and spelling revisions.

Anexo 11. *Granulometría de agregado grueso*

2020
...c_Arbulú_j...

Proyecto:	Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2
Solicitante:	Dianelys Holgado Huaco
Tipo de Agregado:	Piedra Chancada
Procedencia:	Cantera de Huambutio
Peso de la muestra:	5423.2 g
Norma:	NTP 400.012
Fecha	25/11/20

GRANULOMETRIA DE AGREGADO GRUESO

TAMIZ #	ABERTURA MALLA (mm)	PESO RETENIDO (g)	PORCENTAJE RETENIDO (%)	PORCENTAJE ACUMULADO RETENIDO (%)	% QUE PASA
1"	25	0	0	0	100
3/4"	19	691.12	12.75	12.75	86.58
1/2"	12.5	1425.24	26.35	39.10	60.90
3/8"	9.50	1130.34	21.14	59.90	42.50
1/4"	6.30	1150.50	21.19	81.20	18.54
4	4.750	365.64	6.49	87.80	13.50
	Fondo	660.40	12.18	100.0	0.00
	Total	5423.2	100.00		

TM	1"
TMN	3/4"
MF	6.60

$$MF = \frac{\Sigma \% \text{ Ret. Acum. En los tamices } (1\,1/2"; 3/4"; 3/8"; \#4; \#8; \#16; \#30; \#50; \#100)}{100}$$

$$MF = \frac{12.75 + 59.94 + 87.82 + 5 \times 100}{100}$$

$$MF = 6.60$$

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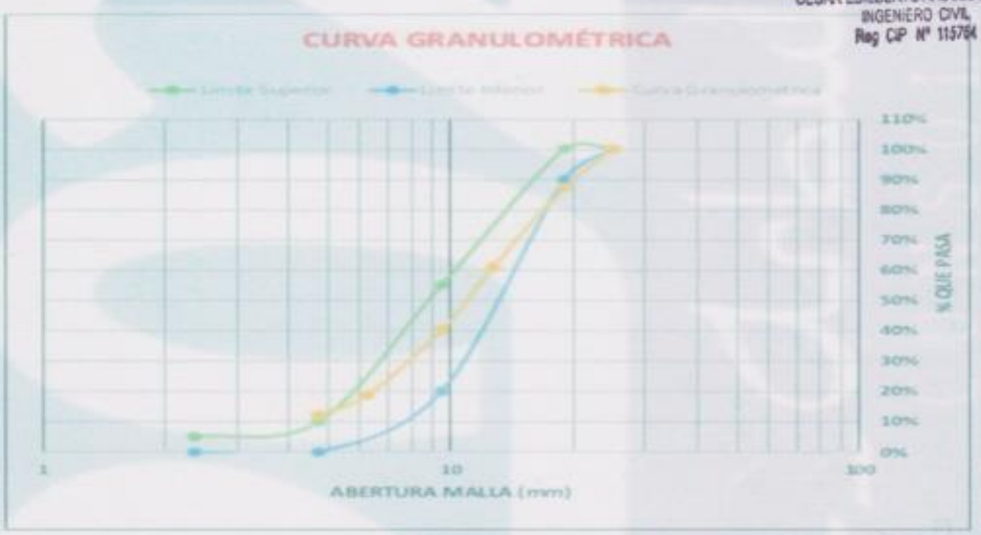

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Anexo 12. *Granulometría de agregado fino*

Proyecto:	Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2
Solicitante:	Dianelys Holgado Huaco
Tipo de Agregado:	Arena Gruesa
Procedencia:	Cantera de Huambutio
Peso de la muestra:	500 g
Norma:	NTP 400.012
Fecha	25/11/20

GRANULOMETRIA DE AGREGADO FINO

TAMIZ #	ABERTURA MALLA (mm)	PESO RETENIDO (g)	PORCENTAJE RETENIDO (%)	PORCENTAJE ACUMULADO RETENIDO (%)	% QUE PASA
3/8"	9.5	0	0	0	100
4	4.75	6.5	1.33	1.33	98.56
8	2.38	56.7	11.37	12.70	85.80
10	2.00	14.8	2.88	15.66	84.34
16	1.18	87.6	16.49	32.24	65.76
20	0.850	61.7	12.34	45.38	54.52
30	0.600	65.9	13.18	58.66	42.14
40	0.425	51.5	11.44	68.06	30.84
50	0.300	44.4	8.76	77.92	22.48
60	0.250	21.3	4.03	82.1	17.90
80	0.180	26.8	5.16	87.46	12.54
100	0.150	15.7	3.13	90.6	8.70
200	0.075	28.8	6.69	96.7	3.20
	Fondo	18.4	3.20	100	0.00
	Total	500	100.00		

MODULO DE FINURA	
Ideal	2.5 - 3.0

TM	3/8"
TMN	#4
MF	2.74

Cálculo de Modulo de Finura (MF):

$$MF = \frac{\sum \% \text{Ret. Acum. En los tamices } [\text{illegible}]}{100}$$

$$MF = \frac{0 + 1.33 + 12.70 + 32.24 + 58.66 + 77.92 + 90.60}{100}$$

$$MF = 2.73$$

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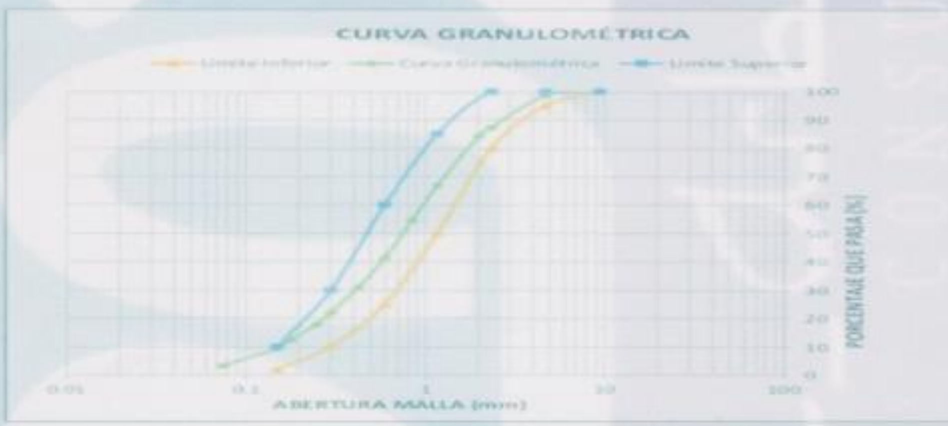

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Anexo 13. *Diseño de mezclas experimental*

Proyecto:	Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2
Solicitante:	Dianelys Holgado Huaco
Fecha	27/11/2020
Procedencia:	Cantera de Huambutío
Cemento:	Cemento Yura Tipo I
Tipo de Aditivo:	plastificante Z
F'c de Diseño:	210 Kg/cm2
Asentamiento:	3"

DISEÑO DE MEZCLAS EXPERIMENTAL

Materia orgánica (g)	Aditivo Plastificante (g)	Agregado Fino (g)	Agregado Grueso (g)	Cemento (g)	Agua (g)	r a/c
0	7.8	497.7	622.1	311	124.4	0.4
0	7.8	544.3	466.6	419.9	124.4	0.3
0	7.8	388.8	575.4	466.6	124.4	0.3
0	7.8	544.3	513.2	311	186.6	0.6
0	7.8	388.8	622.1	357.7	186.6	0.5
0	7.8	435.5	466.6	466.6	186.6	0.4
0	38.9	497.7	466.6	466.6	124.4	0.3
0	38.9	388.8	622.1	419.9	124.4	0.3
0	38.9	544.3	466.6	357.7	186.6	0.5
0	38.9	435.5	622.1	311	186.6	0.6
0	38.9	388.8	513.2	466.6	186.6	0.4
0	38.9	505.4	583.2	311	155.5	0.5
140	7.8	544.3	575.4	311	124.4	0.4
140	7.8	497.7	466.6	466.6	163	0.35
140	7.8	388.8	622.1	419.9	124.4	0.3
140	7.8	544.3	466.6	357.7	186.6	0.5
140	7.8	435.5	622.1	311	186.6	0.6
140	7.8	388.8	513.2	466.6	186.6	0.4
140	38.9	497.7	622.1	311	124.4	0.4
140	38.9	544.3	466.6	419.9	124.4	0.3
140	38.9	388.8	575.4	466.6	124.4	0.3
140	38.9	544.3	513.2	311	186.6	0.6
140	38.9	388.8	622.1	357.7	186.6	0.5
140	38.9	435.5	466.6	466.6	186.6	0.4
46.7	38.9	544.3	575.4	311	124.4	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
0	7.8	497.7	622.1	311	124.4	0.4
0	7.8	544.3	466.6	419.9	124.4	0.3
0	7.8	388.8	575.4	466.6	124.4	0.3
0	7.8	544.3	513.2	311	186.6	0.6
0	7.8	388.8	622.1	357.7	186.6	0.5
0	7.8	435.5	466.6	466.6	186.6	0.4
0	38.9	497.7	466.6	466.6	124.4	0.3
0	38.9	388.8	622.1	419.9	124.4	0.3
0	38.9	544.3	466.6	357.7	186.6	0.5
0	38.9	435.5	622.1	311	186.6	0.6
0	38.9	388.8	513.2	466.6	186.6	0.4
0	38.9	505.4	583.2	311	155.5	0.5
140	7.8	544.3	575.4	311	124.4	0.4
140	7.8	497.7	466.6	466.6	124.4	0.3
140	7.8	388.8	622.1	419.9	124.4	0.3
140	7.8	544.3	466.6	357.7	186.6	0.5
140	7.8	435.5	622.1	311	186.6	0.6
140	7.8	388.8	513.2	466.6	186.6	0.4
140	38.9	497.7	622.1	311	124.4	0.4
140	38.9	544.3	466.6	419.9	124.4	0.3
140	38.9	388.8	575.4	466.6	124.4	0.3
140	38.9	544.3	513.2	311	186.6	0.6
140	38.9	388.8	622.1	357.7	186.6	0.5
140	38.9	435.5	466.6	466.6	186.6	0.4
46.7	38.9	544.3	575.4	311	124.4	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4
46.7	23.3	466.6	544.3	388.8	155.5	0.4

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Proyecto:	Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2
Solicitante:	Dianelys Holgado Huaco

Fecha	27/11/2020	Tipo de Aditivo:	plastificante Z
Procedencia:	Cantera de Huambutio	F'c de Diseño:	210 Kg/cm2
Cemento:	Cemento Yura Tipo I	Asentamiento:	3"

DISEÑO DE MEZCLAS EXPERIMENTAL

N	Run Order	Materia Orgánica (%)	Aditivo Plastificante (%)	Agregado Fino (%)	Agregado Grueso (%)	Cemento (%)	Agua (%)
N 1	50	0	0.5	0.32	0.4	0.2	0.08
N 2	28	0	0.5	0.35	0.3	0.27	0.08
N 3	48	0	0.5	0.25	0.37	0.3	0.08
N 4	9	0	0.5	0.35	0.33	0.2	0.12
N 5	45	0	0.5	0.25	0.4	0.23	0.12
N 6	44	0	0.5	0.28	0.3	0.3	0.12
N 7	46	0	2.5	0.32	0.3	0.3	0.08
N 8	13	0	2.5	0.25	0.4	0.27	0.08
N 9	25	0	2.5	0.35	0.3	0.23	0.12
N 10	33	0	2.5	0.28	0.4	0.2	0.12
N 11	53	0	2.5	0.25	0.33	0.3	0.12
N 12	30	0	2.5	0.325	0.375	0.2	0.10
N 13	6	9	0.5	0.35	0.37	0.2	0.08
N 14	54	9	0.5	0.32	0.3	0.3	0.10
N 15	8	9	0.5	0.25	0.4	0.27	0.08
N 16	16	9	0.5	0.35	0.3	0.23	0.12
N 17	3	9	0.5	0.28	0.4	0.2	0.12
N 18	4	9	0.5	0.25	0.33	0.3	0.12
N 19	15	9	2.5	0.32	0.4	0.2	0.08
N 20	5	9	2.5	0.35	0.3	0.27	0.08
N 21	24	9	2.5	0.25	0.37	0.3	0.08
N 22	58	9	2.5	0.35	0.33	0.2	0.12
N 23	51	9	2.5	0.25	0.4	0.23	0.12
N 24	31	9	2.5	0.28	0.3	0.3	0.12
N 25	49	3	2.5	0.35	0.37	0.2	0.08
N 26	2	3	1.5	0.3	0.35	0.25	0.10
N 27	59	3	1.5	0.3	0.35	0.25	0.10
N 28	37	3	1.5	0.3	0.35	0.25	0.10
N 29	36	3	1.5	0.3	0.35	0.25	0.10
N 30	52	3	1.5	0.3	0.35	0.25	0.10

CESAR EDILBERTO ARBULU JURADO
INGENIERO CIVIL
Reg CIP Nº 115764

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Proyecto:	Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2		
Solicitante:	Dianelys Holgado Huaco		
Fecha	27/11/2020	Tipo de Aditivo:	plastificante Z
Procedencia:	Cantera de Huambutio	F'c de Diseño:	210 Kg/cm2
Cemento:	Cemento Yura Tipo I	Asentamiento:	3"

DISEÑO DE MEZCLAS EXPERIMENTAL

N	Run Order	Materia Orgánica (%)	Aditivo Plastificante (%)	Agregado Fino (%)	Agregado Grueso (%)	Cemento (%)	Agua (%)
N 31	26	0	0.5	0.32	0.4	0.2	0.08
N 32	34	0	0.5	0.35	0.3	0.27	0.08
N 33	18	0	0.5	0.25	0.37	0.3	0.08
N 34	57	0	0.5	0.35	0.33	0.2	0.12
N 35	55	0	0.5	0.25	0.4	0.23	0.12
N 36	35	0	0.5	0.28	0.3	0.3	0.12
N 37	43	0	2.5	0.32	0.3	0.3	0.08
N 38	29	0	2.5	0.25	0.4	0.27	0.08
N 39	38	0	2.5	0.35	0.3	0.23	0.12
N 40	20	0	2.5	0.28	0.4	0.2	0.12
N 41	42	0	2.5	0.25	0.33	0.3	0.12
N 42	40	0	2.5	0.325	0.375	0.2	0.10
N 43	22	9	0.5	0.35	0.37	0.2	0.08
N 44	7	9	0.5	0.32	0.3	0.3	0.08
N 45	12	9	0.5	0.25	0.4	0.27	0.08
N 46	14	9	0.5	0.35	0.3	0.23	0.12
N 47	41	9	0.5	0.28	0.4	0.2	0.12
N 48	56	9	0.5	0.25	0.33	0.3	0.12
N 49	23	9	2.5	0.32	0.4	0.2	0.08
N 50	21	9	2.5	0.35	0.3	0.27	0.08
N 51	27	9	2.5	0.25	0.37	0.3	0.08
N 52	47	9	2.5	0.35	0.33	0.2	0.12
N 53	32	9	2.5	0.25	0.4	0.23	0.12
N 54	19	9	2.5	0.28	0.3	0.3	0.12
N 55	60	3	2.5	0.35	0.37	0.2	0.08
N 56	10	3	1.5	0.3	0.35	0.25	0.10
N 57	39	3	1.5	0.3	0.35	0.25	0.10
N 58	17	3	1.5	0.3	0.35	0.25	0.10
N 59	11	3	1.5	0.3	0.35	0.25	0.10
N 60	1	3	1.5	0.3	0.35	0.25	0.10

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Anexo 14. *Ensayo de compresión a los 28 días*

2020

Proyecto: Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2

Solicitante: Dianelys Holgado Huaco

Fecha: 18/01/2021

Tipo de Aditivo: Z plastificante

Tipo de muestra: Concreto endurecido

F'c de Diseño: 210 Kg/cm2

Presentación: Especimenes paralelepípedos 10x10x5 cm

Asentamiento: 3"

ENSAYO DE COMPRESION A LOS 28 DIAS

N° de Espécimen	Fecha de vaciado	Fecha de rotura	Edad	Ancho (mm)	Profundidad (mm)	Altura (mm)	Volumen cm3	Peso (g)	Densidad cm3/g	Carga (Kg)	F'c (Kg/cm2)
N° 1	22/012/20	18/01/2021	28 días	101.11	100.78	59.84	609.8	1195.8	1.96	2470	40.89
N° 2	22/012/20	18/01/2021	28 días	100.96	100.53	57.9	587.7	1282.9	2.18	3480	59.66
N° 3	22/012/20	18/01/2021	28 días	100.85	101.91	59.3	609.5	1326.3	2.18	3500	58.22
N° 4	22/012/20	18/01/2021	28 días	101.48	100.64	55	561.7	1111.3	1.98	1510	27.17
N° 5	22/012/20	18/01/2021	28 días	101.33	99.43	53.95	543.6	1010.1	1.86	3230	59.64
N° 6	22/012/20	18/01/2021	28 días	101.24	101.88	48.83	503.6	1099.9	2.18	6110	123.21
N° 7	22/012/20	18/01/2021	28 días	101.54	103.13	54.94	575.3	1223.8	2.13	10040	178.58
N° 8	22/012/20	18/01/2021	28 días	100.75	101.02	54.92	559.0	1138.1	2.04	2640	47.65
N° 9	22/012/20	18/01/2021	28 días	100.73	101.16	54.4	554.3	1198.1	2.16	3060	55.72
N° 10	22/012/20	18/01/2021	28 días	100.92	101.25	53.93	551.1	1125.5	2.04	5590	102.54
N° 11	22/012/20	18/01/2021	28 días	100.55	101.01	49.73	505.1	1043.9	2.07	4660	92.98
N° 12	22/012/20	18/01/2021	28 días	100.89	100.67	57.81	587.2	1206.3	2.05	4920	84.45
N° 13	22/012/20	18/01/2021	28 días	100.16	99.82	61.51	615.0	1209	1.97	980	15.93
N° 14	22/012/20	18/01/2021	28 días	100.84	99.98	65.28	658.2	1283.1	1.95	2740	41.80
N° 15	22/012/20	18/01/2021	28 días	100.22	100.6	62.27	627.8	1253.5	2.00	2120	33.91
N° 16	22/012/20	18/01/2021	28 días	100.19	100.88	60.25	609.0	1199.9	1.97	2000	33.02
N° 17	22/012/20	18/01/2021	28 días	102.15	104.02	58.99	626.8	1123.9	1.79	830	13.65
N° 18	22/012/20	18/01/2021	28 días	100.44	100.25	61.87	623.0	1152.4	1.85	2380	38.34
N° 19	22/012/20	18/01/2021	28 días	101.79	102.5	59.46	620.4	1168.1	1.88	580	9.55
N° 20	22/012/20	18/01/2021	28 días	111.76	115.63	46.47	600.5	1088.7	1.81	790	14.95
N° 21	22/012/20	18/01/2021	28 días	100.33	100.43	63.21	636.9	1216.2	1.91	2060	32.47
N° 22	22/012/20	18/01/2021	28 días	100.54	101.41	57.6	587.3	1138.8	1.94	700	12.04
N° 23	22/012/20	18/01/2021	28 días	101.32	105.43	56.42	602.7	1179.8	1.96	1210	20.75
N° 24	22/012/20	18/01/2021	28 días	100.62	100.42	57.99	585.9	1125.9	1.92	2700	46.32
N° 25	22/012/20	18/01/2021	28 días	101.07	100.78	59.94	610.5	1241.1	2.03	3110	51.41
N° 26	22/012/20	18/01/2021	28 días	101.41	100.58	58.67	598.4	1272.4	2.13	5480	92.48
N° 27	22/012/20	18/01/2021	28 días	101.61	101.57	59.39	612.9	1257.2	2.05	4050	67.13
N° 28	22/012/20	18/01/2021	28 días	100.35	100.35	57.46	578.6	1269.8	2.19	8520	147.76
N° 29	22/012/20	18/01/2021	28 días	100.48	100.88	59.17	599.8	1255.8	2.09	4520	75.87
N° 30	22/012/20	18/01/2021	28 días	100.47	102.15	57.66	591.8	1216.3	2.06	5670	97.06

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Proyecto:	Análisis bootstrap del efecto de la contaminación orgánica del agregado, en la resistencia del concreto plastificado 210 kg/cm2
Solicitante:	Dianelys Holgado Huaco
Fecha	18/01/2021
Tipo de Aditivo:	plastificante Z
Tipo de muestra:	Concreto endurecido
F'c de Diseño:	210 Kg/cm2
Presentación:	Especimenes paralelepipedos 10x10x5 cm
Asentamiento:	3"

ENSAYO DE COMPRESION A LOS 28 DIAS

N° de Espécimen	Fecha de vaciado	Fecha de rotura	Edad	Ancho (mm)	Profundidad (mm)	Altura (mm)	Volumen cm3	Peso (g)	Densidad cm3/g	Carga (Kg)	F'c (Kg/cm2)
N° 32	22/012/20	18/01/2021	28 dias	101.54	102.25	54.39	564.7	1157.1	2.05	3960	71.45
N° 33	22/012/20	18/01/2021	28 dias	100.79	100.45	58.98	597.1	1267.3	2.12	2370	39.94
N° 34	22/012/20	18/01/2021	28 dias	101.4	100.93	55.21	565.0	1062.3	1.88	2090	37.42
N° 35	22/012/20	18/01/2021	28 dias	101.14	102.83	53.3	554.3	1075.1	1.94	2300	42.31
N° 36	22/012/20	18/01/2021	28 dias	101.14	101.05	50.21	513.2	1088.9	2.12	5320	104.81
N° 37	22/012/20	18/01/2021	28 dias	101.75	100.71	53.42	547.4	1155.1	2.11	6670	123.34
N° 38	22/012/20	18/01/2021	28 dias	100.5	100.4	58.79	593.2	1259.2	2.12	7820	132.42
N° 39	22/012/20	18/01/2021	28 dias	100.6	100.96	50.6	513.9	1079.2	2.10	4220	82.75
N° 40	22/012/20	18/01/2021	28 dias	104.57	105.01	57.87	635.5	848.1	1.33	760	12.53
N° 41	22/012/20	18/01/2021	28 dias	101.07	101.29	51.62	528.5	1103.9	2.09	9560	183.04
N° 42	22/012/20	18/01/2021	28 dias	102.22	102.25	57.51	601.1	1182.2	1.97	1520	25.85
N° 43	22/012/20	18/01/2021	28 dias	100.15	100.53	62.01	624.3	1207.3	1.93	1400	22.50
N° 44	22/012/20	18/01/2021	28 dias	100.91	99.97	65.5	660.8	1236.8	1.87	2150	32.68
N° 45	22/012/20	18/01/2021	28 dias	100.47	100.41	63.44	640.0	1237.6	1.93	1890	29.66
N° 46	22/012/20	18/01/2021	28 dias	102.08	100.15	60	613.4	1193.1	1.95	3080	50.77
N° 47	22/012/20	18/01/2021	28 dias	101.18	100.39	61.34	623.1	1193.2	1.92	970	15.69
N° 48	22/012/20	18/01/2021	28 dias	102.6	101.86	66	689.8	1223.4	1.77	1910	28.31
N° 49	22/012/20	18/01/2021	28 dias	100.51	100.73	61.17	619.3	1182.1	1.91	2060	33.47
N° 50	22/012/20	18/01/2021	28 dias	101.54	103.22	57.38	601.4	1168.7	1.94	1700	28.94
N° 51	22/012/20	18/01/2021	28 dias	100.28	100.31	59.94	602.9	1126.7	1.87	1210	20.13
N° 52	22/012/20	18/01/2021	28 dias	101.38	101.03	57.32	587.1	1177.3	2.01	1290	22.24
N° 53	22/012/20	18/01/2021	28 dias	100.63	100.77	60.9	617.6	1151	1.86	1470	23.97
N° 54	22/012/20	18/01/2021	28 dias	103.79	102.13	54.84	581.3	1091.5	1.88	1810	32.06
N° 55	22/012/20	18/01/2021	28 dias	101.03	100.3	60.05	608.5	1255.9	2.06	5020	83.04
N° 56	22/012/20	18/01/2021	28 dias	101.32	101.50	57.70	593.4	1172.9	1.98	5290	90.40
N° 57	22/012/20	18/01/2021	28 dias	101.28	101.59	62.03	638.2	1328.4	2.08	5460	86.78
N° 58	22/012/20	18/01/2021	28 dias	100.2	100.66	57.69	581.9	1257.8	2.16	5290	91.30
N° 59	22/012/20	18/01/2021	28 dias	101.2	101.17	58.93	603.3	1272.3	2.11	6980	116.72
N° 60	22/012/20	18/01/2021	28 dias	100.3	100.57	59.76	602.8	1262.1	2.09	4710	78.47

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Anexo 15. *Certificate of compliance*


Nº 200 (13-SEPT-2018)

Testing Equipment for Construction Materials

HUMBOLDT

Certificate of Compliance

to specifications of

ASTM — American Society for Testing and Materials

ANSI — American National Standards Institute

ISO — International Standards Organization

This is to certify that the openings in the wire cloth of this test sieve have been checked through advanced optical technology to ensure conformity to ASTM Specification E-11. The dimensions of the test sieve frame have also been checked with precision gauges to ensure conformity to these same specifications.

Humboldt Mfg. Co. — 1.800.544.7220 • www.humboldtmfg.com • hmc@humboldtmfg.com

LITHO IN U.S.A.

Anexo 16. *Test Sieve certificate of compliance*

ELE
International

TEST SIEVE CERTIFICATE OF COMPLIANCE

P.O. BOX 608
Loveland, CO 80539-0608
In USA 1-800-323-1242
Worldwide (970) 663-9780
Fax: (970) 663-9781
E-mail: soiltest@eleusa.com
Website: www.eleusa.com

Chartmoor Road, Chantwell Business Park
Leighton Buzzard
Bedfordshire, LU7 8WG, England
Phone: +44 1525 249200
Fax: +44 1525 249249
E-mail: ele@eleint.co.uk
http://www.ele.com

This Certificate of Compliance represents ELE's commitment to deliver testing sieves of the highest quality. Every test sieve conforms to the manufacturing requirements of the following specifications:

ASTM E 11	ISO 565 ISO 3310-1	BS 410

Serial Number: 164729087

Anexo 17. *Certificado de calibración CTM 100-2018*

Metrotest E.I.R.L.

LABORATORIO DE METROLOGÍA

CERTIFICADO DE CALIBRACIÓN
CTM-100-2018

Misión:
Prestar servicios con política de mejoramiento continuo y cumplimiento con las normas y especificaciones técnicas requeridas en máquinas y equipos para medición y ensayos.

Visión:
Lograr la confianza de nuestros clientes en el desarrollo de sus empresas a través de nuestros servicios.
Tenemos como objetivo alcanzar el liderazgo en el mercado, y de esta manera obtener para nuestros empleados la consecución de ideales en el plano intelectual y personal, con constante investigación e innovación, en la búsqueda de la máxima exactitud en la medición de ensayos.

Solicitante : **CONSULTORA ITHENDA E.I.R.L.**

Dirección : **AV. MICAELA BASTIDAS NRO. 258 INT. 704 CERCADO DE WANCHAQ - CUSCO - WANCHAQ**

Equipo de Medición : **HORNO ELECTRICO**

Marca : **METROTEST**

Modelo : **MS-H1**

Procedencia : **PERÚ**

Código de Identifica : **NO INDICA**

Número de Serie : **839**

Temperatura de trab : **110 °C ± 10 °C**

Ventilación : **Natural**

Lugar de Calibració : **Lab. Temperatura de Metrotest E.I.R.L.**

Instrumento de Medi :

Nombre	Marca	Modelo	Código de Identificación	Alcance de indicación	División mínima	Tipo de Indicación
Termometro controlador	AUTONICS	TCN4S	NO INDICA	200°C	1°C	Digital

Fecha de Calibració : **2018-03-21**

Fecha de Emisión : **2018-03-21**

Método de Calibración Empleado

La calibración se realizó tomando como referencia el Método de Comparación entre las indicaciones de lectura del termometro controlador del equipo a calibrar con Termometro patrón con 10 termopares utilizando el "Procedimiento de INDECOPI/SNM PC-005 1° Ed. "Procedimiento para la Calibración de Hornos".

Observaciones

- Se colocó una etiqueta con la indicación "CALIBRADO".
- La periodicidad de la calibración depende del uso, mantenimiento y conservación del instrumento.

METROTEST E.I.R.L. LABORATORIO DE METROLOGIA TEMPERATURA

Luiggi Asenjo G.
Jefe de Metrologia

Jr. Aristides Sologuren 484 Dpto. 102 Urb. Parques de Villa Sol - Los Olivos www.metrotesteirl.com / metrotestlogistica@hotmail.com / ventas@metrotesteirl.com
Telf.: 528-7898 Telefax: 528-3324 Entel: 997 045 343 / #962 889 991

Metrotest E.I.R.L.

LABORATORIO DE METROLOGÍA

CERTIFICADO DE CALIBRACION
CTM-100-2018

PATRONES DE REFERENCIA:

Trazabilidad	Patrón utilizado	Certificado de calibración
METROTEST E.I.R.L.	Termometro de indicación Digital con 10 sensores	CTM-001-2018
Patrones de referencia de DM-INACAL	Termometro de indicación digital	LT-539-2017

Condiciones Ambientales:

	Inicial	Final
Temperatura (°C)	19,9	20,3
Humedad (%)	43	45

Resultados de la calibración:

CALIBRACIÓN PARA 110 °C ± 10 °C

TIEMPO (min.)	T ind. (°C) Termómetro del equipo	TEMPERATURA EN LAS POSICIONES DE MEDICION (°C) NIVEL SUPERIOR 1	2	3	4	5	NIVEL INFERIOR 6	7	8	9	10	T prom. (°C)	Tmax-Tmin. (°C)
00	110	111,3	112,2	112,3	110,1	112,1	111,6	111,6	110,6	110,2	112,5	111,5	2,4
02	110	111,3	112,2	112,3	110,1	112,1	111,6	111,6	110,6	110,2	112,5	111,5	2,4
04	110	111,3	112,2	112,3	110,1	112,1	111,6	111,6	110,6	110,2	112,5	111,5	2,4
06	110	111,3	112,2	112,3	110,1	112,2	111,7	111,6	110,7	110,3	112,5	111,5	2,4
08	110	111,4	112,3	112,4	110,1	112,2	111,7	111,7	110,7	110,3	112,6	111,5	2,5
10	110	111,4	112,3	112,4	110,2	112,2	111,7	111,7	110,8	110,4	112,6	111,6	2,4
12	110	111,4	112,3	112,4	110,2	112,2	111,8	111,7	110,8	110,4	112,6	111,6	2,4
14	110	111,4	112,3	112,4	110,2	112,3	111,9	111,7	110,9	110,4	112,6	111,6	2,4
16	110	111,5	112,3	112,4	110,2	112,3	111,9	111,8	110,9	110,5	112,6	111,6	2,4
18	110	111,5	112,4	112,4	110,3	112,4	111,9	111,8	111,0	110,5	112,7	111,7	2,4
20	110	111,5	112,4	112,4	110,3	112,4	111,9	111,8	111,1	110,5	112,7	111,7	2,4
22	110	111,5	112,4	112,4	110,3	112,4	112,0	111,9	111,1	110,5	112,7	111,7	2,4
24	110	111,6	112,4	112,4	110,3	112,4	112,0	111,9	111,1	110,6	112,7	111,7	2,4
26	110	111,6	112,4	112,4	110,4	112,5	112,0	112,0	111,2	110,6	112,7	111,8	2,3
28	110	111,6	112,4	112,4	110,4	112,5	112,0	112,0	111,2	110,6	112,7	111,8	2,3
30	110	111,6	112,4	112,4	110,4	112,5	112,0	112,0	111,2	110,6	112,7	111,8	2,3
32	110	111,6	112,4	112,4	110,4	112,5	112,1	112,0	111,3	110,6	112,7	111,8	2,3
34	110	111,7	112,4	112,4	110,5	112,6	112,1	112,1	111,3	110,7	112,7	111,9	2,2
36	110	111,7	112,4	112,5	110,5	112,6	112,1	112,2	111,3	110,7	112,7	111,9	2,2
38	110	111,7	112,4	112,5	110,5	112,6	112,1	112,2	111,3	110,7	112,7	111,9	2,2
40	110	111,7	112,5	112,5	110,5	112,6	112,1	112,2	111,3	110,7	112,7	111,9	2,2
42	110	111,8	112,5	112,5	110,6	112,6	112,1	112,2	111,3	110,8	112,7	111,9	2,1
44	110	111,8	112,5	112,5	110,6	112,6	112,2	112,2	111,4	110,8	112,7	111,9	2,1
46	110	111,9	112,5	112,6	110,6	112,6	112,2	112,2	111,4	110,8	112,6	111,9	2,0
48	110	111,9	112,5	112,6	110,7	112,6	112,2	112,2	111,4	110,9	112,6	112,0	1,9
50	110	112,0	112,5	112,6	110,7	112,7	112,3	112,2	111,4	110,9	112,6	112,0	2,0
52	110	112,0	112,7	112,6	110,7	112,7	112,3	112,3	111,5	110,9	112,6	112,0	2,0
54	110	112,1	112,5	112,6	110,8	112,7	112,4	112,4	111,5	110,9	112,6	112,1	1,9
56	110	112,1	112,5	112,6	110,8	112,7	112,4	112,4	111,5	111,0	112,5	112,1	1,9
58	110	112,1	112,5	112,6	110,9	112,7	112,4	112,4	111,5	111,0	112,5	112,1	1,8
60	110	112,1	112,5	112,6	110,9	112,7	112,4	112,5	111,5	111,0	112,5	112,1	1,8
T.PROM	110	111,7	112,4	112,5	110,4	112,5	112,0	112,0	111,1	110,6	112,6	111,8	
T.MAX	110	112,1	112,7	112,6	110,9	112,7	112,4	112,5	111,5	111,0	112,7		
T.MIN	110	111,3	112,2	112,3	110,1	112,1	111,6	111,6	110,6	110,2	112,5		
DTT	0,0	0,8	0,5	0,3	0,8	0,6	0,8	0,9	0,9	0,8	0,2		

Metrotest E.I.R.L.

LABORATORIO DE METROLOGÍA

CERTIFICADO DE CALIBRACIÓN
CTM-100-2018

PARÁMETRO	Valor (°C)	Incertidumbre Expandida (°C)
Máxima Temperatura Medida	112,7	0,3
Mínima Temperatura Medida	110,1	0,3
Desviación de Temperatura en el Tiempo	0,9	0,1
Desviación de Temperatura en el Espacio	2,2	0,3
Estabilidad	± 0,45	0,04
Uniformidad	2,5	0,3

T.PROM.: Promedio de la temperatura en una posición de medición durante el tiempo de calibración.
T.prom. : Promedio de la temperatura en las diez posiciones de medición para un istante dado.
T.MAX : Temperatura máxima
T.MIN. : Temperatura mínima
DTT. : Desviación de Temperatura en el tiempo.

Para cada posición de medición su "desviación de temperatura en el tiempo " DTT esta dada por la diferencia entre la máxima y la mínima temperatura registradas en dicha posición
Entre dos posiciones de medición su "desviación de temperatura en el espacio" está dada por la diferencia entre los promedios de temperaturas registradas en ambas posiciones.

Incertidumbre expandida de las indicaciones del termometro propio del medio isotermc **0,5 °C**

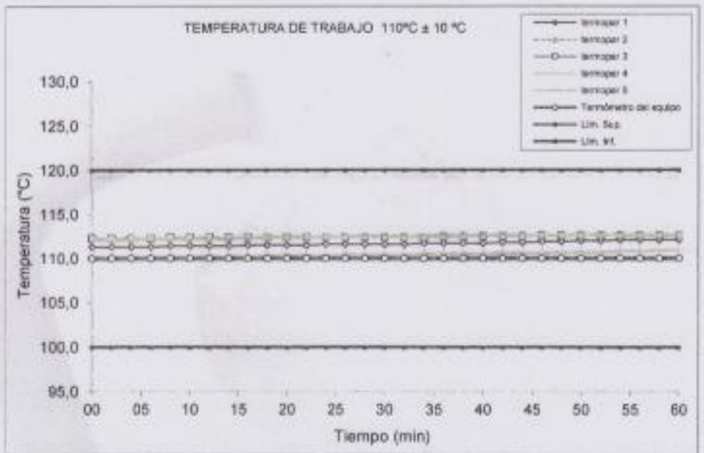
La uniformidad es la máxima diferencia medida de temperatura entre las diferentes posiciones espaciales para un mismo instante de tiempo.

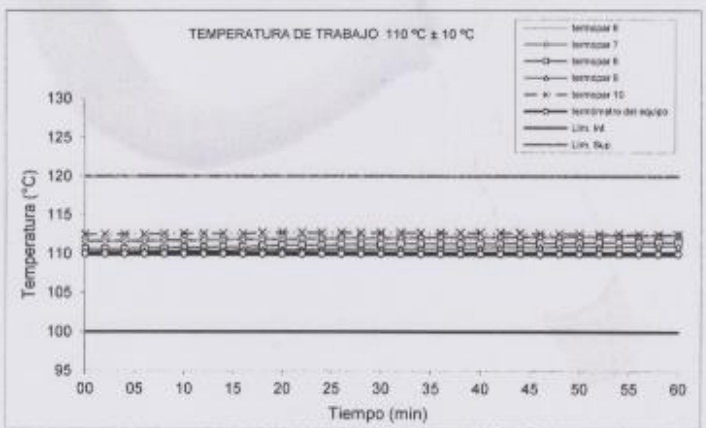
La estabilidad es considerada igual a ±1/2 máx. DTT.

METROTEST E.I.R.L. LABORATORIO DE METROLOGÍA TEMPERATURA

Jr. Arístides Sologuren 484 Dpto. 102 Urb. Parques de Villa Sol - Los Olivos www.metrotesteirl.com / metrotestlogistica@hotmail.com / ventas@metrotesteirl.com
Telf.: 528-7898 Telefax: 528-3324 Entel: 997 045 343 / #962 889 991

CERTIFICADO DE CALIBRACIÓN
CTM-100-2018



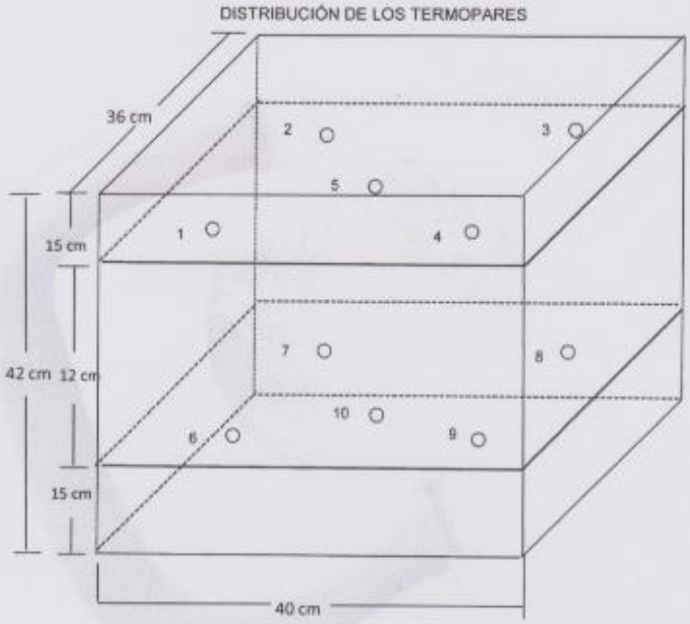


METROTEST E.I.R.L. LABORATORIO DE METROLOGIA TEMPERATURA

Metrotest E.I.R.L.
LABORATORIO DE METROLOGÍA

CERTIFICADO DE CALIBRACIÓN
CTM-100-2018

DISTRIBUCIÓN DE LOS TERMOPARES



Los termopares 5 y 10 estan ubicados en el centro de los planos inferior y superior.
Los termopares del 1 al 4 y del 6 al 10 estan ubicados a 9 cm de las paredes laterales.
Los termopares del 1 al 4 y del 6 al 10 estan ubicados a 10 cm y a 12 cm respectivamente de la parte superior e inferior del horno tal como se muestra en el dibujo.

METROTEST E.I.R.L. LABORATORIO DE METROLOGIA TEMPERATURA

Jr. Aristides Sologuren 484 Dpto. 102 Urb. Parques de Villa Sol - Los Olivos www.metrotesteirl.com / metrotestlogistica@hotmail.com / ventas@metrotesteirl.com
Telf.: 528-7898 Telefax: 528-3324 Entel: 997 045 343 / #962 889 991

Anexo 18. *Certificado Tamiz para ensayo N.º 40*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	426,47	µm
ABERTURA MÁXIMA MAXIMUM APERTURE	439,12	µm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	276,28	µm
MALLA No. MESH No.	40	
SERIE No. SERIAL No.	63845	
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 4,59	µm

FECHA DATE 2018 - 05 - 28 FIRMA SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

ASTM E 11 - 15
BUREAU VERITAS
Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha
Date
2018 - 05 - 28

Instrumento
Instrument
TAMIZ PARA ENSAYO
TEST SIEVE

Fabricante
Manufacturer
PINZUAR LTDA.

Serie No.
Serial No.
63845

Malla No.
Mesh No.
40

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad : Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

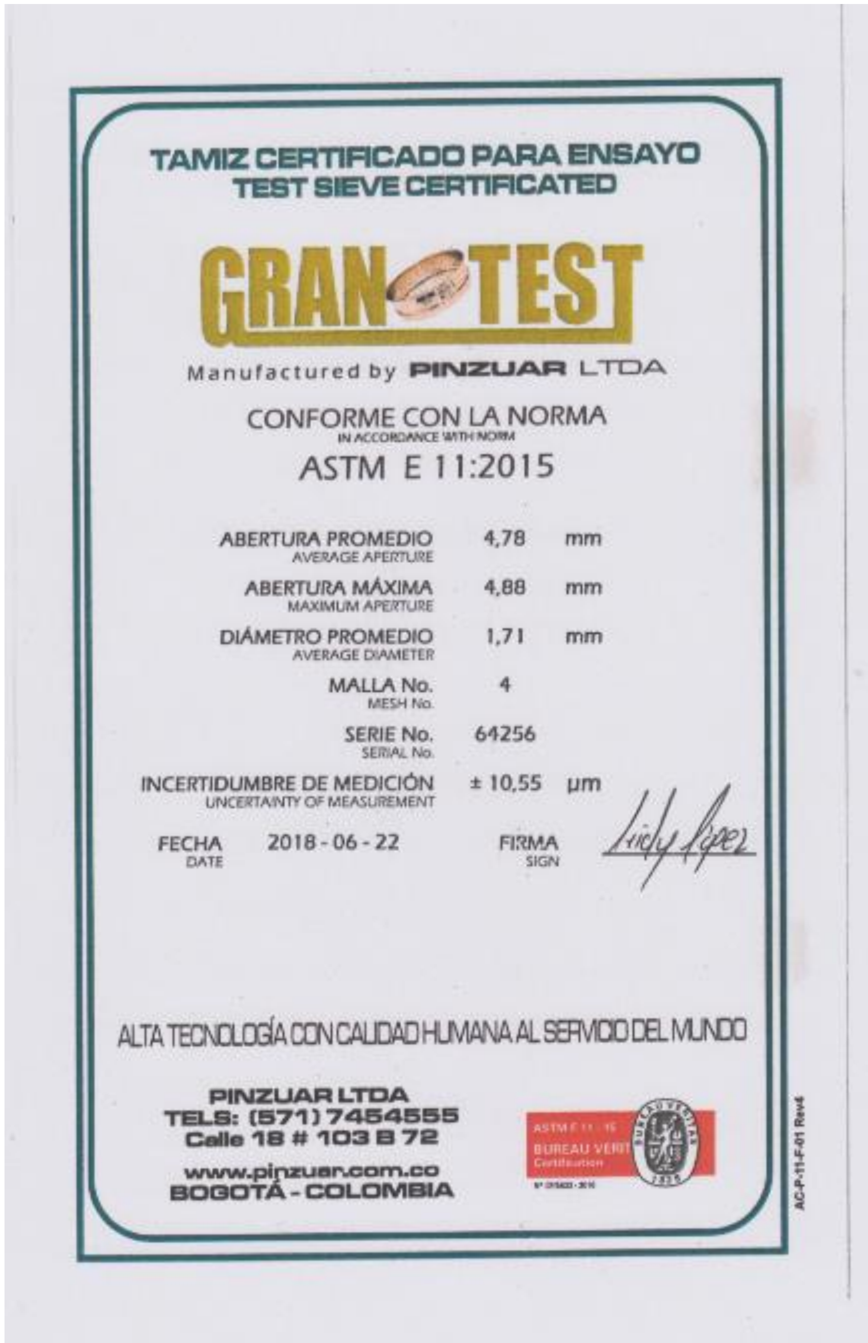
Resultados : Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11-15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 19. *Certificado Tamiz para ensayo N.º 4*



TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	4,78	mm
ABERTURA MÁXIMA MAXIMUM APERTURE	4,88	mm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	1,71	mm
MALLA No. MESH No.	4	
SERIE No. SERIAL No.	64256	
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 10,55	µm

FECHA DATE 2018 - 06 - 22 FIRMA SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
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BOGOTÁ - COLOMBIA

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha Date	**2018 - 06 - 22**
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**64256**
Malla No. Mesh No.	**4**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad : Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados : Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Esta informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 20. *Certificado Tamiz para ensayo N.º 60*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO / AVERAGE APERTURE	250,24	µm
ABERTURA MÁXIMA / MAXIMUM APERTURE	258,66	µm
DIÁMETRO PROMEDIO / AVERAGE DIAMETER	156,66	µm
MALLA No. / MESH No.	60	
SERIE No. / SERIAL No.	59915	
INCERTIDUMBRE DE MEDICIÓN / UNCERTAINTY OF MEASUREMENT	± 3,93	µm

FECHA / DATE 2017 - 09 - 29 FIRMA / SIGN

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PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
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ASTM E 11 - 15
BUREAU VERITAS
Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha Date	**2017 - 09 - 29**
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**59915**
Malla No. Mesh No.	**60**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad: Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados: Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 21. *Certificado Tamiz para ensayo N.º 2*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by **PINZUAR** LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	49,72 mm
ABERTURA MÁXIMA MAXIMUM APERTURE	49,78 mm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	5,00 mm
MALLA No. MESH No.	2"
SERIE No. SERIAL No.	62141
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 10,56 µm

FECHA / DATE: 2016 - 02 - 07   FIRMA / SIGN:

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

ASTM E 11 - 15
BUREAU VERITAS
Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha 2016 - 02 - 07
Date

Instrumento TAMIZ PARA ENSAYO
Instrument TEST SIEVE

Fabricante PINZUAR LTDA.
Manufacturer

Serie No. 62141
Serial No.

Malla No. 2"
Mesh No.

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad : Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados : Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 22. *Certificado Tamiz para ensayo N.º 3/8"*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO / AVERAGE APERTURE	9,49	mm
ABERTURA MÁXIMA / MAXIMUM APERTURE	9,58	mm
DIÁMETRO PROMEDIO / AVERAGE DIAMETER	2,30	mm
MALLA No. / MESH No.	3/8"	
SERIE No. / SERIAL No.	63657	
INCERTIDUMBRE DE MEDICIÓN / UNCERTAINTY OF MEASUREMENT	± 10,55	µm

FECHA / DATE 2018 - 05 - 16 FIRMA / SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

INFORME DE INSPECCIÓN

Fecha Date	**2018 - 05 - 16**
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**63657**
Malla No. Mesh No.	**3/8"**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad: Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados: Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11-15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 23. *Certificado Tamiz para ensayo N.º 20*


TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	851,32	µm
ABERTURA MÁXIMA MAXIMUM APERTURE	882,95	µm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	505,21	µm
MALLA No. MESH No.	20	
SERIE No. SERIAL No.	64609	
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 10,93	µm

FECHA / DATE: 2018 - 07 - 18   FIRMA / SIGN:

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

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TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

BUREAU VERITAS Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha Date	2018 - 07 - 18
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**64609**
Malla No. Mesh No.	**20**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad : Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados : Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 24. *Certificado Tamiz para ensayo N.º 3”*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	74,67	mm
ABERTURA MÁXIMA MAXIMUM APERTURE	75,05	mm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	6,32	mm
MALLA No. MESH No.	3"	
SERIE No. SERIAL No.	61917	
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 10,57	µm

FECHA
DATE
2018 - 01 - 26

FIRMA
SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

BUREAU VERITAS Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha Date	**2018 - 01 - 26**
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**61917**
Malla No. Mesh No.	**3"**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad : Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados : Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 25. *Certificado Tamiz para ensayo N.º 3/4"*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by **PINZUAR** LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO / AVERAGE APERTURE	19,05	mm
ABERTURA MÁXIMA / MAXIMUM APERTURE	19,16	mm
DIÁMETRO PROMEDIO / AVERAGE DIAMETER	3,02	mm
MALLA No. / MESH No.	¾"	
SERIE No. / SERIAL No.	63968	
INCERTIDUMBRE DE MEDICIÓN / UNCERTAINTY OF MEASUREMENT	± 10,55	µm

FECHA / DATE 2018 - 06 - 07 FIRMA / SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha
Date — **2018 - 06 - 07**

Instrumento
Instrument — **TAMIZ PARA ENSAYO**
TEST SIEVE

Fabricante
Manufacturer — **PINZUAR LTDA.**

Serie No.
Serial No. — **63968**

Malla No.
Mesh No. — **¾"**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad: Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados: Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 26. *Certificado Tamiz para ensayo N.º 1”*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	25,03	mm
ABERTURA MÁXIMA MAXIMUM APERTURE	25,68	mm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	3,59	mm
MALLA No. MESH No.	1"	
SERIE No. SERIAL No.	59758	
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 10,56	µm

FECHA
DATE
2017 - 09 - 26

FIRMA
SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
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Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha Date	**2017 - 09 - 26**
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**59758**
Malla No. Mesh No.	**1"**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad: Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados: Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 - 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 - 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 dé la Norma ASTM E 11-15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 27. *Certificado Tamiz para ensayo N.º1 1/2"*

TAMIZ CERTIFICADO PARA ENSAYO
TEST SIEVE CERTIFICATED

GRAN TEST

Manufactured by PINZUAR LTDA

CONFORME CON LA NORMA
IN ACCORDANCE WITH NORM
ASTM E 11:2015

ABERTURA PROMEDIO AVERAGE APERTURE	37,64	mm
ABERTURA MÁXIMA MAXIMUM APERTURE	37,98	mm
DIÁMETRO PROMEDIO AVERAGE DIAMETER	4,53	mm
MALLA No. MESH No.	1 ½"	
SERIE No. SERIAL No.	63816	
INCERTIDUMBRE DE MEDICIÓN UNCERTAINTY OF MEASUREMENT	± 10,56	µm

FECHA / DATE 2018 - 05 - 25   FIRMA / SIGN

ALTA TECNOLOGÍA CON CALIDAD HUMANA AL SERVICIO DEL MUNDO

PINZUAR LTDA
TELS: (571) 7454555
Calle 18 # 103 B 72
www.pinzuar.com.co
BOGOTÁ - COLOMBIA

ASTM E 11 : 15
BUREAU VERITAS
Certification

AC-P-11-F-01 Rev4

INFORME DE INSPECCIÓN

Fecha Date	**2018 - 05 - 25**
Instrumento Instrument	**TAMIZ PARA ENSAYO** TEST SIEVE
Fabricante Manufacturer	**PINZUAR LTDA.**
Serie No. Serial No.	**63816**
Malla No. Mesh No.	**1 ½"**

NORMA DE ENSAYO: ASTM E 11-15

Trazabilidad : Sus especificaciones se han verificado en el laboratorio de Control de calidad de Pinzuar Ltda. Por medio de instrumentos de medición calibrados con trazabilidad al sistema internacional de unidades (SI).

Resultados : Las dimensiones del marco fueron evaluadas de acuerdo al numeral 6.3 de la Norma ASTM E 11 – 15. La abertura de la malla cumple con lo establecido en el numeral 6,1 de la Norma ASTM E 11 – 15. El diámetro del alambre cumple con lo establecido en el numeral 6,2 de la Norma ASTM E 11–15.

PINZUAR LTDA

Este informe expresa fielmente el resultado de las mediciones realizadas y se refiere al momento y condiciones en que se realizaron.

El laboratorio no se responsabiliza de los perjuicios que puedan derivarse del uso inadecuado del instrumento.

Anexo 28. *Certificado de calibración prensa hidráulica para rotura de concreto*

Arsou Group
Laboratorio de Metrología

CERTIFICADO DE CALIBRACIÓN
N° 1425-145-2020

Fecha de emisión	2020/12/30
Solicitante	**CÉSAR EDILBERTO ARBULÚ JURADO**
Dirección	AV. MICAELA BASTIDAS 258- WANCHAQ - CUZCO-PERU
Instrumento de medición	**PRENSA HIDRAULICA PARA ROTURA DE CONCRETO**
Identificación	1425-145-2020
Marca	ARSOU
Modelo	PR701
Serie	2138
Capacidad	120000KG
Indicador	DIGITAL
Bomba	MANUAL
Procedencia	PERÚ
Ubicación	Laboratorio de Suelos y Concreto
Lugar de calibración	Laboratorio de ARSOU GROUP SAC
Fecha de calibración	2020/12/30

Método/Procedimiento de calibración

El procedimiento toma como referencia a la norma ISO 7500-1 "Metallic materials - Verification of static uniaxial testing machines", Se aplicaron dos series de carga al Sistema Digital mediante la misma prensa. En cada serie se registraron las lecturas de las cargas.

Este certificado de calibración documenta la trazabilidad a patrones nacionales o internacionales, que realizan las unidades de medida de acuerdo con el Sistema Internacional de Unidades (SI)

Los resultados son válidos en el momento de la calibración. Al solicitante le corresponde disponer en su momento recalibrar sus instrumentos a intervalos regulares, los cuales deben ser establecidos sobre la base de las características propias del instrumento, sus condiciones de uso, el mantenimiento realizado y conservación del instrumento de medición o de acuerdo a reglamentaciones vigentes.

ARSOU GROUP S.A.C. no se responsabiliza de los perjuicios que pueda ocasionar el uso inadecuado de este instrumento después de su calibración, ni de una incorrecta interpretación de los resultados de la calibración declarados en este documento.

Arsou Group S.A.C Laboratorio de Metrología

ARSOU GROUP S.A.C
Ing. Hugo Luis Arévalo Carnica
METROLOGÍA

ARSOU GROUP S.A.C.
Asoc. Viv. Las Flores de San Diego Mz C Lote 01, San Martin de Porres, Lima, Perú
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ventas@arsougroup.com
www.arsougroup.com

CERTIFICADO DE CALIBRACIÓN
N° 1425-145-2020

Arsou Group
Laboratorio de Metrología

Patrones e Instrumentos auxiliares

Trazabilidad	Patrón Utilizado	Certificado de Calibración
Patrones de referencia de PUCP	Celda de Carga de 100 TN	192-19 con trazabilidad INF-LE 250-18.

Condiciones ambientales durante la calibración

Temperatura Ambiental	Inicial: 20,3 ºc	Final: 20,5 ºC
Humedad Relativa	Inicial: 63 %hr	Final: 65 %hr
Presión Atmosférica	Inicial: 1015 mbar	Final: 1015 mbar

Resultados

TABLA N° 01
CALIBRACION DE PRENSA HIDRAULICA PARA CONCRETO

SISTEMA DIGITAL "A" KG	SERIES DE VERIFICACIÓN PATRON (Kg)				PROMEDIO "B" kg	ERROR Ep %	RPTBLD Rp %
	SERIE (1) kg	SERIE (2) kg	ERROR %	ERROR (2) %			
10000	10001.4	10000.9	0.0	0.0	10001.2	0.0115	0.00
20000	19999.0	19999.5	0.0	0.0	19999.3	0.00	0.00
30000	30000.0	29999.8	0.0	0.0	29999.9	0.00	0.00
40000	40000.5	39999.4	0.0	0.0	40000.0	0.00	0.00
50000	50000.0	50000.0	0.0	0.0	50000.0	0.00	0.00
60000	60000.4	59999.4	0.0	0.0	59999.9	0.00	0.00
70000	69998.8	69999.4	0.0	0.0	69999.1	0.00	0.00
80000	80000.0	79999.5	0.0	0.0	79999.8	0.00	0.00

NOTAS SOBRE CALIBRACION

1. - La Calibración se hizo según el Método C de la norma ISO 7500-1
2.- Ep y Rp son el Error Porcentual y la Repetibilidad definidos en la citada Norma:
Ep = ((A-B) / B)* 100 Rp = Error(2) - Error(1)
3. - La norma exige que Ep y Rp no excedan el +/- 1.0 %
4. - Incertidumbre expandida del Error (Ep) = 0,35 % (1,73 kg)

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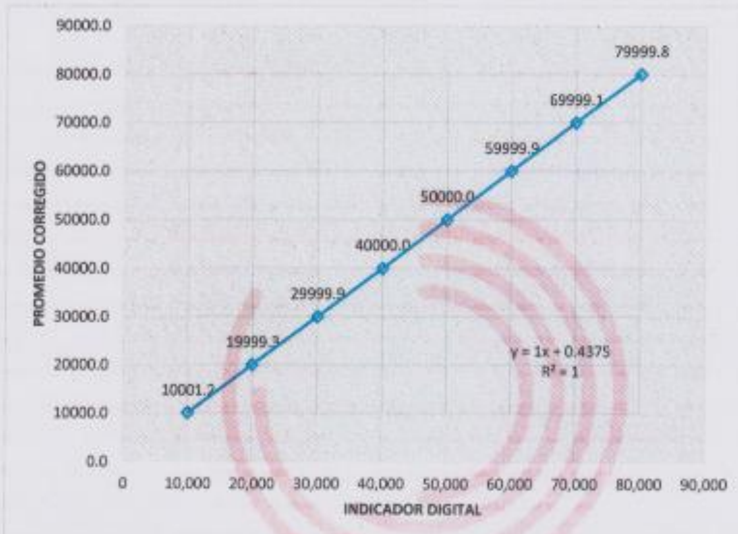
Arsou Group

Laboratorio de Metrología

Gráfica (Coeficiente de correlación y Ecuación de Ajuste

GRAFICO N° 01



Ecuación de ajuste:

Donde: $y = 1x + 0,4375$

Coeficiente Correlación $R^2 = 1$

X : Lectura de la pantalla (kg)

Y : fuerza promedio (kg)

Observaciones

1. Antes de la calibración no se realizó ningún tipo de ajuste.

2. La incertidumbre de la medición ha sido calculada para un nivel de confianza de aproximadamente del 95 % con un factor de cobertura k=2 .

3. (*) Codigo indicado en una etiqueta adherida al instrumento.

4. Con fines de identificación se colocó una etiqueta autoadhesiva con la indicación "CALIBRADO"

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Anexo 29. *Ficha técnica de la materia orgánica*

Abono natural Compost x 5kg
4Estaciones 105943

FICHA TÉCNICA

Características *Es un abono 100% orgánico que contiene todos los nutrientes para el desarrollo óptimo de la planta.*	***Garantía*** *1 Año*
Modelo *Compost*	***Tipo de Producto*** *Abono*
Número de piezas *1*	***Composición/Origen*** *Vegetal*
Marca *4Estaciones*	***Contenido*** *5 kg*
Presentación *Bolsa*	***¿Dónde usarlo?*** *En maceteros y jardinería*