UNIVERSIDAD AUTONOMA DE NUEVO LEON

FACULTAD DE INGENIERIA CIVIL

RESISTENCIA A LA ABRASION DE CONCRETOS PARA PAVIMENTOS

TESIS

QUE PARA OBTENER EL TITULO DE:

INGENIERO CIVIL

PRESENTA:

RÁQUEL SAENZ MICHEL

MONTERREY, N. L. OCTUBRE DE 1999

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Comisión de Exámenes Profesionales
Facultad de Ingeniería Civil de la U.A.N.L.

Asunto:

Petición de aprobación de Tesis para presentar mi examen profesional y obtener mi Titulo de Ingeniero Civil en la U.A.N.L.

Por medio de la presente pongo a su consideración el titulo de mi tesis para presentar examen profesional en la Licenciatura de Ingeniería Civil de la Universidad Autónoma de nuevo León.

Siendo el titulo:
Resistencia a la Abrasión de Concretos para Pavimentos.

Los objetivos de la investigación son los siguientes.

- Determinar el grado de abrasabilidad y resistencia a la compresión de concretos para pavimentos de carreteras fabricados con Cemento Portland Tipo I, agregado calizo, aditivo SRA y sin aditivo SRA para los concretos de referencia.

- Comparar el grado de abrasabilidad de los concretos sin aditivo respecto a los concretos con aditivo para las diferentes relaciones agua-cementante.

Por último, hago de su conocimiento que para el desarrollo de esta investigación he recibido la asesoría de el Dr. Raymundo Rivera Villarreal, por lo cual solicito se me asigne como asesor oficial.

Sin mas por el momento y esperando obtener la aprobación del Titulo para tesis, me despido de ustedes.

Raquel Sáenz Michel
Matrícula 794208

San Nicolas de los Garza, N.L., a 26 de Abril de 1999.

Adriana
26-IV-99

Universidad Autónoma de Nuevo León
Facultad de Ingeniería Civil

DR. RAYMUNDO RIVERA VILLARREAL.
P r e s e n t e .-

Por medio de la presente me permito comunicar a Usted que ha sido designado por esta Secretaría como Asesor de la Tésis **"RESISTENCIA A LA ABRASION DE CONCRETOS PARA PAVIMENTOS"** la cual desarrollará la **SRITA. RAQUEL SAENZ MICHEL** como opción para obtener el Título de Ingeniero Civil.

Mucho agradeceré los comentarios que sobre el alcance de la misma Usted considere.

Sin otro asunto por el momento y en espera de contar con su participación, quedo de Usted.

A T E N T A M E N T E
"ALERE FLAMMAM VERITATIS"
Cd. Universitaria a 27 de Abril de 1999.

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Secretario Académico
Facultad de Ingeniería Civil
Presente.

Con relación a la Tesis "Resistencia a la Abrasión de Concretos para Pavimentos" para obtener el grado de Ingeniero Civil de la Srita. Raquel Sáenz Michel, en su oficio de fecha 27 de abril de 1999, en donde se me designa como asesor de esta tesis, me permito comunicarle que esta Tesis es de **Investigación** y la ha estado elaborando la Srita. Sáenz Michel en este Departamento. Los resultados que se han venido obteniendo son de **gran interés** ya que para una misma relación agua-cemento y misma consistencia, se logra aumentar la resistencia del concreto a la Abrasión cuando se utiliza un Aditivo Superfluidizante como el utilizado en el proyecto.

Atentamente
"ALERE FLAMMAM VERITATIS"
Ciudad Universitaria, a 4 de mayo de 1999

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Por su asesoría para la realización de esta tesis y por mostrarme siempre su apoyo, agradezco muy especialmente al Profr. Raymundo Rivera Villarreal y al personal que labora en el Departamento de Tecnología del Concreto de la Facultad de Ingeniería Civil de la U. A. N. L.

R. S. M.

Dedico esta tesis a mis padres José S. Sáenz Núñez y Eufemia Michel de Sáenz por su gran apoyo durante toda mi carrera, y a Saúl Castillo Muñoz por mostrarme siempre su apoyo y comprensión.

R. S. M.

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Resumen:

Esta investigación consistió en evaluar la resistencia a la abrasión de concretos para pavimentos de carreteras fabricados con agregado calizo, cemento Portland y aditivo Super Reductor de Agua (SRA).

Los concretos fueron fabricados con relaciones agua-cementante de 0.35, 0 40 y 0 45 sin suplementos cementantes ni aditivo para los concretos de referencia y concretos con aditivo *SRA* para una misma consistencia. En el caso de utilizar aditivo para cada relación agua-cementante se redujo el consumo de agua y de cemento para mantener la misma consistencia. La fabricación se realizó en laboratorio a una temperatura de $23\pm1.5^{0}C$ y se curaron bajo condiciones estándar a 3 y 28 días. Los concretos fueron ensayados a la abrasión a los 3 y 28 días en el aparato de abrasión (taladro de presion) una serie en condición seca y otra serie en condición húmeda. La determinación del desgaste se hizo mediante la medición de la pérdida de peso sufrida por el espécimen debido a la acción de presión-rotación-fricción del equipo sobre la superficie del concreto.

Los resultados muestran que los concretos fabricados con aditivo *SRA* presentaron mayor resistencia a la abrasión que los concretos de referencia fabricados sin aditivo, ambos con la misma relación agua-cementante y la misma consistencia.

También se encontró que para un mismo concreto ensayado en condición seca presenta una mayor resistencia a la abrasión que ensayado bajo condición húmeda. Además se observó como era de esperarse que los concretos con menor relación agua-cementante mostraron mayor resistencia a la abrasión.

Objetivos:

- Determinar el grado de abrasabilidad y resistencia a la compresión de concretos para pavimentos de carreteras fabricados con Cemento Portland Tipo I, agregado calizo, aditivo SRA y sin aditivo SRA para los concretos de referencia.

- Comparar el grado de abrasabilidad de los concretos sin aditivo respecto a los concretos con aditivo para las diferentes relaciones agua-cementante.

Todos los concretos se fabricaron para relaciones agua-cementante de 0.35, 0.40 y 0.45 curándose a los 3 y 28 días bajo condiciones estándar. Así mismo se determino el grado de abrasabilidad bajo condiciones tanto secas como húmedas a 3 y 28 días de edad.

Introducción

La abrasión se define como el desprendimiento de partículas al raspar, deslizar o recorrer objetos sobre una superficie. Este fenómeno puede observarse en pavimentos, pisos, canales y otras superficies donde la fuerza de fricción aparece debido al desplazamiento o arrastre de objetos en la superficie.(1)

Para poder estudiar la problemática de la abrasión en el concreto es necesario tomar en cuenta una serie de condiciones bajo la cual estará sujeto, como lo son. el tipo de tráfico, frecuencia, carga de las llantas, tipo de rueda, velocidad de escurrimiento (en el caso de canales), etc.(2) Esto sin descartar otros aspectos como el acabado dado a la superficie, procedimiento de curado, propiedades de los materiales utilizados, *el uso de aditivos especiales para concretos entre otros.*(3)

En general, la abrasión sufrida en el concreto es en su mayoría consecuencia de la menor resistencia a esta acción de la pasta endurecida.(4) Para desarrollar concreto con mayor resistencia a la abrasión, es necesario mejorar sus propiedades, esto se podría lograr haciendo uso de aditivos, los cuales permiten lograr una mejor compactación, facilitar el acabado y usar relaciones agua-cementante bajas, con las cuales se ha encontrado que la acción de la abrasión es menor.(5)

Payne y Dransfield reportaron que la resistencia a la abrasión es inversamente proporcional a la relación agua-cemento, y es afectada por los procedimientos de curado. Consecuentemente, ellos concluyeron que *el uso de un aditivo* para reducir la relacion agua-cemento incrementa la resistencia a la abrasión substancialmente, de este modo reduciendo la influencia de las condiciones de curado en esta propiedad (6)

Se sabe que la resistencia a la compresión es el factor mas determinante en la resistencia a la abrasión del concreto. Siendo la resistencia a la abrasión del concreto fuertemente influenciada por la resistencia abrasiva de sus componentes, como lo son el agregado grueso y el mortero. Generalmente los concretos fabricados con agregados muy resistentes muestran una resistencia a la abrasión mayor que concretos fabricados con agregados menos resistentes.(4) Así mismo, se debe considerar la adherencia de los agregados con la pasta de cementante, ya que se ha encontrado que concretos fabricados con agregados muy resistentes, pero con escasa adherencia, muestran menor resistencia a la abrasion que concretos fabricados con agregados menos resistentes pero con buena adherencia.(5)

Hay varios tipos de métodos estándar de pruebas de abrasión publicados por la American Society for Testing and Materials (ASTM). Se esta de acuerdo que los métodos de prueba son usados para la evaluación de la calidad relativa y no intentan medir la vida esperada de una superficie.(7)

Justificación de la investigación.

Anterior a la investigación que se describirá, tenemos la investigación realizada por el Ing. Richard González Ríos quien trató el tema de Resistencia del Concreto al Rodamiento Abrasivo Mediante el Uso de Aditivo, fabricando concretos fluidos, que son usados en pisos industriales principalmente.

Partiendo de esto último y de la poca información acerca de la resistencia a la abrasión en concreto mediante el uso de aditivos se inició la investigación sobre RESISTENCIA A LA ABRASIÓN DE CONCRETOS PARA PAVIMENTOS, fabricando concretos plásticos para pavimentos en carreteras.

En México, a diferencia de algunos otros países, el uso de pavimentos de concreto hidráulico inició hace pocos años, ya que durante décadas se han venido construyendo carreteras de pavimentos asfálticos, puesto que México es un país productor de petróleo.

Por esto la empresa privada y asociaciones dedicadas a la investigación, se han dado a la tarea de promover la tecnología para la construcción de pavimentos de concreto hidráulico, sin embargo poco se ha hablado acerca de las características que debe tener la superficie del pavimento para lograr mejores superficies de rodamiento y mayor seguridad.

La resistencia a la abrasión es una de las características principal a considerar en los pavimentos de concreto hidráulico, ya que sufren un desgaste por la fuerza de fricción debido al desplazamiento de vehículos.

Por esto cuando el concreto será expuesto a la acción abrasiva, es común el uso de tratamientos especiales con los cuales se produce una resistencia a la abrasión sobre la capa superficial del concreto, los cuales finalmente se traducen en un mayor costo. En si las carreteras de concreto hidráulico representan un costo adicional, pero que finalmente se compensa con los ahorros derivados de la disminución en los gastos de mantenimiento. Esta investigación busca aumentar la resistencia a la abrasión del concreto sin el uso de esos costosos y arduos tratamientos.

Metodología

I. Determinar el agua de reacción para las relaciones agua-cementante 0.35, 0.40 y 0.45 de los concretos de referencia, partiendo del valor propuesto en la tabla del ACI-211, para obtener un revenimiento final de 8-10 cm.

II. Determinar el agua de reacción para las relaciones agua-cementante 0.35, 0.40 y 0.45 de los concretos con aditivo, partiendo del valor propuesto en la tabla del ACI-211 y considerando el aditivo como agua de reacción, para obtener un revenimiento inicial de 3-5 cm y revenimiento final de 8-10 cm.

III. Determinación del grado de abrasabilidad bajo condición seca de:
1.- Concreto con aditivo SRA ACON SF 1040, para las tres relaciones agua-cementante y las dos edades de curado.
2.- Concreto sin aditivo, para las tres relaciones agua-cementante y las dos edades de curado.

IV. Determinación del grado de abrasabilidad bajo condición humeda de:
1.- Concreto con aditivo SRA ACON SF 1040, para las tres relaciones agua-cementante y las dos edades de curado.
2.- Concreto sin aditivo, para las tres relaciones agua-cementante y las dos edades de curado.

V. Determinación de la resistencia a la compresión de:
1.- Concreto con aditivo SRA ACON SF 1040, para las tres relaciones agua-cementante y las dos edades de curado.
2.- Concreto sin aditivo, para las tres relaciones agua-cementante y las dos edades de curado.

Características afines de los concretos.

Los concretos fueron fabricados con Cemento Monterrey Portland Tipo I, agregado calizo de la región con un tamaño máximo de 20 mm y un Aditivo Super Reductor de Agua ACON SF 1040 en los concretos con aditivo. La granulometría utilizada para los agregados fue la especificada en ASTM C-33, para el agregado grueso se utilizó la media de la No. 67 y para el agregado fino la media indicada en el punto 6.1 de dicha norma, ambas granulometrias fueron preparadas para evitar variación de mezcla a mezcla.

Los agregados se prepararon mediante cribado a través de las diferentes mallas especificadas para obtener la misma granulometría en cada mezcla.

Las mezclas se hicieron en una revolvedora de laboratorio de 30 L de capacidad, la cual se puede apreciar en la fotografía No. 1.

Las condiciones del medio ambiente en el laboratorio donde se fabricaron los concretos fueron de 23±1.5 ^{0}C con una humedad relativa mayor del 50 %.

Datos físicos de los materiales.

Materiales	Densidad (kg/m^3)	PVSS (kg/m^3)	PVVS (kg/m^3)	Abs. %	H.O.	M.F.
Cemento	3100					
Ag. Grueso	2740	1565	1675	0.45	0	
Ag. Fino	2620			1.55	0	2.76
Aditivo	1100					

Granulometría.

Agregado Grueso:

Como ya se mencionó la granulometría utilizada fue la especificada en la norma ASTM C-33, la No. 67, escogiéndose la media de dicha curva granulométrica.

Tamaño No.	1" (25mm)	¾" (19mm)	½" (12.5mm)	3/8" (9.5mm)	No. 4 (4.75mm)	No. 8 (2.36mm)
67	100	90-100	85-67	20-55	0-10	0-5
Media	100	95	76	37.5	5	2.5

Agregado Fino:

Para el agregado fino se utilizó la especificada en el punto 6.1 de la norma ASTM C-33, escogiéndose la media de dicha granulometría.

Malla No.	% que pasa	Media (% que pasa)	Ret. acumulado %	Ret. Individual %
3/8"	100	100	0	0
No. 4	95-100	97.5	2.5	2.5
No. 8	80-100	90	10	7.5
No. 16	50-85	67.5	32.5	22.5
No. 30	25-60	42.5	57.5	25
No. 50	10-30	20	80	22.5
No. 100	2-10	6	94	14
Pasa 100		0	100	6

Módulo de finura.

Malla No.	% finos que pasan	% retenido acumulado
3/8"	100	0
No. 4	97.5	2.5
No. 8	90	10
No. 16	67.5	32.5
No. 30	42.5	57.5
No. 50	20	80
No. 100	6	94
suma		276

Módulo de finura = sumatoria % retenido acumulado / 100
Módulo de finura = 276/100
Módulo de finura = 2.76

Composición química del cemento Portland I

Compuestos potenciales del cemento	Símbolo	Porcentaje
Silicato Tricálcico	C_3S	40.2
Silicato Dicálcico	C_2S	34.4
Aluminato Tricálcico	C_3A	8.9
Aluminato Ferrito Tetracálcico	C_4AF	6.5

Composición química del cemento Portland I.

Elemento	Símbolo	Porcentaje
Oxido de Silicio	SiO_2	22.55
Oxido de Aluminio	Al_2O_3	4.72
Oxido de Fierro	Fe_2O_3	2.14
Oxido de Calcio	CaO	62.57
Oxido de Magnesio	MgO	1.49
Trióxido de Azufre	SO_3	2.95
Oxido de Sodio	Na_2O	0.53
Oxido de Potasio	K_2O	0.22
Pentoxido de Fósforo	P_2O_5	0.08
Oxido de Titanio	TiO_2	0.26
Trióxido de Manganeso	Mn_2O_3	0.04
Pérdida por calcinación	P * C	2.33

Proporcionamientos para el concreto de referencia sin aditivo.

Proporcionamiento No. 1
Relación A/C = 0.35

Datos para determinar el proporcionamiento:

- Basándonos en la tabla del ACI-211 el porcentaje de aire atrapado para un revenimiento de 10 cm es de 2%.
- De la misma tabla del ACI-211, tenemos que para un tamaño máximo de agregado de 20 mm y el revenimiento buscado de 10 cm se requieren 205 L de agua por metro cúbico de concreto.
- Según la tabla del ACI-211, el volumen de agregado grueso requerido es de 0 624 para un tamaño máximo de agregado de 20 mm y un módulo de finura 2.76.

Proporcionamiento:

Material	Mat. secos sin incluir agua de Abs. (kg/m^3)	Vol. Abs. m^3/m^3 de concreto	Humedad de secos a S.S.S (kg/m^3)	Materiales secos incluyendo agua de Abs. (kg/m^3)	Kg/23 L de concreto
Agua Reacc.	205	205/1000 = 0.205		205	
Agua total				205 + 13 =218	5.01
Cemento	205/0.35 = 585.7	585.7/3100 = 0.189		585.7	13.47
Ag. Grueso	1675 * 0.624 = 1045.2	1045.2/2740 = 0.381	1045.2*0.0045 = 4.7	1045.2	24.04
Ag Fino	0.205 *2620 = 537.1	0.205	537.1 * 0.0155 – 8.3	537.1	12.35
Aire 2%		0.02			
Suma		1.00			
Agua Abs.			13		

Propiedades físicas del concreto fresco

Revenimiento 10 cm
Aire medido 1.3%
Temperatura del concreto 27^{0}C

Proporcionamiento No. 2
Relación A/C = 0.40

Datos para determinar el proporcionamiento:

- Basándonos en la tabla del ACI-211 el porcentaje de aire atrapado para un revenimiento de 10 cm es de 2%.
- De la misma tabla del ACI-211, tenemos que para un tamaño máximo de agregado de 20 mm y el revenimiento buscado de 10 cm se requieren 205 L de agua por metro cúbico de concreto.
- Según la tabla del ACI-211, el volumen de agregado grueso requerido es de 0.624 para un tamaño máximo de agregado de 20 mm y un módulo de finura 2.76.

Proporcionamiento:

Material	Mat. secos sin incluir agua de Abs. (kg/m³)	Vol. Abs. m³/m³ de concreto	Humedad de secos a S.S.S (kg/m³)	Materiales secos incluyendo agua de Abs. (kg/m³)	Kg/23 L de concreto
Agua Reacc.	180	180/1000 = 0.180		180	
Agua total				180 + 15.82 =195.82	4 5
Cemento	180/0 40 = 450	450/3100 = 0 145		450	10 35
Ag. Grueso	1675 * 0.624 = 1045.2	1045.2/2740 = 0.381	1045.2*0.0045 = 4.7	1045 2	24 04
Ag. Fino	0 274 *2620 = 717.8	0.274	717.8 * 0.0155 = 11 12	717.8	16.51
Aire 2%		0.02			
Suma		1.00			
Agua Abs.			15.82		

Propiedades físicas del concreto fresco

Revenimiento 10 cm
Aire medido 1.6%
Temperatura del concreto 26°C

Proporcionamiento No. 3
Relación A/C = 0.45

Datos para determinar el proporcionamiento:

- Basándonos en la tabla del ACI-211 el porcentaje de aire atrapado para un revenimiento de 10 cm es de 2%.
- De la misma tabla del ACI-211, tenemos que para un tamaño máximo de agregado de 20 mm y el revenimiento buscado de 10 cm se requieren 205 L de agua por metro cubico de concreto.
- Según la tabla del ACI-211, el volumen de agregado grueso requerido es de 0.624 para un tamaño máximo de agregado de 20 mm y un módulo de finura 2 76.

Proporcionamiento:

Material	Mat. secos sin incluir agua de Abs. (kg/m³)	Vol. Abs. m³/m³ de concreto	Humedad de secos a S.S.S (kg/m³)	Materiales secos incluyendo agua de Abs. (kg/m³)	Kg/23 L de concreto
Agua Reacc.	170	170/1000 = 0 170		170	
Agua total				170 + 17.2 – 187 2	4.3
Cemento	170/0.45 = 377.7	377 7/3100 = 0 122		377 7	8.6
Ag. Grueso	1675 * 0.624 = 1045.2	1045.2/2740 = 0.381	1045 2*0 0045 = 4.7	1045 2	24.04
Ag Fino	0.307 *2620 = 804.3	0.307	804.3 * 0.0155 = 12.5	804 3	18 5
Aire 2%		0.02			
Suma		1 00			
Agua Abs.			17.2		

Propiedades físicas del concreto fresco

Revenimiento 10 cm
Aire medido 1.5%
Temperatura del concreto 27^0C

Procedimiento de fabricación del Concreto de Referencia.

1. Se colocan los agregados dentro de la revolvedora y se añade el agua de absorción.

2. Se mezcla durante un minuto para homogeneizar los agregados y que estos tomen su correspondiente agua de absorción.

3. Se añade el cemento y el agua de reacción.

4. Se mezcla durante tres minutos.

5. Se deja reposar un periodo de tres minutos tapando la boca de entrada de la revolvedora con una franela, para evitar la evaporación del agua.

6. Se mezcla nuevamente durante dos minutos.

7. Se mide el revenimiento.

8. Se mide el contenido de aire.

9. Y por último se vacía el concreto en los moldes correspondientes para los especímenes de resistencia a la compresión y resistencia a la abrasión.

Proporcionamientos para el concreto utilizando un aditivo superfluidificante.

Proporcionamiento No. 4
Relación A/C = 0.35

Datos para determinar el proporcionamiento:

- Basándonos en la tabla del ACI-211 el porcentaje de aire atrapado para un revenimiento de 5 cm es de 2%.
- De la misma tabla del ACI-211, tenemos que para un tamaño máximo de agregado de 20 mm y el revenimiento buscado de 5 cm se requieren 190L de agua por metro cúbico de concreto.
- Según la tabla del ACI-211, el volumen de agregado grueso requerido es de 0.624 para un tamaño máximo de agregado de 20 mm y un módulo de finura 2.76.

Proporcionamiento:

Material	Mat. secos sin incluir agua de Abs. (kg/m^3)	Vol. Abs. m^3/m^3 de concreto	Humedad de secos a S.S.S (kg/m^3)	Materiales secos incluyendo agua de Abs. (kg/m^3)	Kg/23 L de concreto
Agua Reacc.	180 – 2.6 =177.4	177/1000 = 0 177		177.4	
Agua total				177 4 +15 = 192 4	4 4
Cemento	180/0.35 = 514 3	514.3/3100 = 0 166		514 3	11 8
Ag. Grueso	1675 * 0.624 = 1045 2	1045.2/2740 = 0.381	1045.2*0.0045 = 4 7	1045 2	24 04
Ag Fino	0.254 *2620 = 665 5	0.254	665 5 * 0 0155 – 10.3	665.5	15 3
Aditivo	2.6	2.6/1100 = 0.002		2.6	0.06
Aire 2%		0.02			
Suma		1.00			
Agua Abs.			15 0		

Propiedades físicas del concreto fresco

Revenimiento inicial 3 cm
Revenimiento final 10 cm
Aire medido 2.0%
Temperatura del concreto 23^{0}C

Proporcionamiento No. 5
Relación A/C = 0.40

Datos para determinar el proporcionamiento:

- Basándonos en la tabla del ACI-211 el porcentaje de aire atrapado para un revenimiento de 5 cm es de 2%.
- De la misma tabla del ACI-211, tenemos que para un tamaño máximo de agregado de 20 mm y el revenimiento buscado de 5 cm se requieren 190L de agua por metro cúbico de concreto.
- Según la tabla del ACI-211, el volumen de agregado grueso requerido es de 0 624 para un tamaño máximo de agregado de 20 mm y un módulo de finura 2.76.

Proporcionamiento:

Material	Mat. secos sin incluir agua de Abs. (kg/m^3)	Vol. Abs. m^3/m^3 de concreto	Humedad de secos a S.S.S (kg/m^3)	Materiales secos incluyendo agua de Abs. (kg/m^3)	Kg/23 L de concreto
Agua Reacc.	170 – 2.1 = 167.9	167.9/1000 = 0.168		167 9	
Agua total				167.9 + 16 6 = 184 5	4.2
Cemento	170/0.40 = 425	425/3100 = 0.137		425	9.8
Ag. Grueso	1675 * 0.624 – 1045 2	1045 2/2740 – 0.381	1045.2*0 0045 = 4.7	1045 2	24 04
Ag. Fino	0.292 *2620 – 765 04	0.292	765 * 0 0155 = 11 9	765	17 6
Aditivo	2.1	2.1/1100 = 0.002		2.1	0 05
Aire 2%		0.02			
Suma		1.00			
Agua Abs.			16 6		

Propiedades físicas del concreto fresco

Revenimiento inicial 3.5 cm
Revenimiento final 10 cm
Aire medido 1.0%
Temperatura del concreto 25^{0}C

Proporcionamiento No. 6
Relación A/C = 0.45

Datos para determinar el proporcionamiento:

- Basándonos en la tabla del ACI-211 el porcentaje de aire atrapado para un revenimiento de 5 cm es de 2%.
- De la misma tabla del ACI-211, tenemos que para un tamaño máximo de agregado de 20 mm y el revenimiento buscado de 5 cm se requieren 190L de agua por metro cubico de concreto.
- Segun la tabla del ACI-211, el volumen de agregado grueso requerido es de 0.624 para un tamaño máximo de agregado de 20 mm y un modulo de finura 2 76.

Proporcionamiento:

Material	Mat. secos sin incluir agua de Abs. (kg/m^3)	Vol. Abs. m^3/m^3 de concreto	Humedad de secos a S.S.S (kg/m^3)	Materiales secos incluyendo agua de Abs. (kg/m^3)	Kg/23 L de concreto
Agua Reacc.	160 – 1.8 = 158.2	158.2/1000 = 0.158		158.2	
Agua total				158.2 + 17 8 – 176	4.0
Cemento	160/0.45 = 355 6	355.6/3100 = 0.115		355 6	8 18
Ag. Grueso	1675 * 0 624 = 1045 2	1045 2/2740 = 0.381	1045.2*0.0045 – 4.7	1045 2	24 04
Ag. Fino	0.324 *2620 = 850	0 324	850 * 0.0155 – 13.1	850	19.55
Aditivo	1.8	1.8/1100 = 0 0016		1 8	0 04
Aire 2%		0.02			
Suma		1 00			
Agua Abs.			17.8		

Propiedades físicas del concreto fresco

Revenimiento inicial 3 cm
Revenimiento final 9 cm
Aire medido 1.4%
Temperatura del concreto 24^{0}C

Procedimiento de fabricación del concreto con aditivo.

1. Se colocan los agregados dentro de la revolvedora y se añade el agua de absorción.
2. Se mezcla durante un minuto para homogeneizar los agregados y que estos tomen su agua de absorción.
3. Se añade el cemento y el agua de reacción.
4. Se mezcla durante tres minutos.
5. Se deja reposar un período de tres minutos tapando la boca de entrada de la revolvedora con una franela, para evitar la evaporación del agua.
6. Se mezcla nuevamente durante dos minutos.
7. Se mide el revenimiento y se regresa a la revolvedora este concreto.
8. Se añade el aditivo SRA y se remezcla aproximadamente un minuto.
9. Por último se mide el revenimiento final.
10. Y se vacía el concreto en los moldes correspondientes para los especímenes de resistencia a la compresión y resistencia a la abrasión.

Resumen de proporcionamientos

	CONCRETO DE REFERENCIA			CONCRETO CON ADITIVO		
PROPORCIONAMIENTO (Kg/m³)						
AGUA REACCION *	205.0	180.0	170.0	180.0	170.0	160.0
AGUA ABSORCIÓN	13 0	15.8	17.2	15 0	16 6	17.8
CEMENTO PORTLAND I	585 7	450 0	377 7	514 3	425.0	355 6
AGREGADO GRUESO	1045 2	1045.2	1045.2	1045 2	1045.2	1045 2
AAGREGADO FINO	537 7	717.9	804 3	665.5	765.0	850 0
ADITIVO DOSIFICAIÓN (ml/kg)				5 0	5 0	5.0
ADITIVO CONSUMO (L/m³)				2 6	2.1	1 8
PROPIEDADES FÍSICAS DEL CONCRETO FRESCO						
REL A/C EN PESO	0 35	0 40	0 45	0.35	0 40	0 45
AIRE (%)	1 3	1.6	1 5	2.0	1.0	1 4
TEMP DEL CONCRETO FRESCO (C)	27	26	27	23	25	24
REVENIMIENTO (cm) INICIA	10	10	10	3	3.5	3
REVENIMIENTO (cm) FINAL	*	*	*	10	10	9
PROPIEDADES DEL CONCRETO ENDURECIDO						
RESISTENCIA A LA COMPRESIÓN EN (Mpa) 3 DIAS	34 9	32.8	28 2	35.6	33.7	28.2
RESISTENCIA A LA COMPRESIÓN EN (Mpa) 28 DIAS	49 8	48.0	42.7	50 1	48.8	42.3

SEGUN EL ACI 211. EL CONSUMO DE ADITIVO SE CONSIDERA COMO AGUA DE REACCIÓN *

Procedimiento de fabricación de los especímenes.

- Especimenes para determinar la resistencia a la abrasión.

  El concreto fue vaciado en moldes de madera de 43 x 63 x 8 cm de peralte y *vibrado* de acuerdo a la norma ASTM C-192, *el acabado de la superficie fue liso* utilizando una llana. Los prismas fueron desmoldados a las 24 h para ser curados bajo condiciones estándar a 3 y 28 días. Posteriormente días antes de cumplir la edad de curado se extrajeron de los prismas especimenes cilíndricos de 15 cm de diámetro y 8 cm de altura para ser ensayados a la abrasión. Los moldes de madera y el equipo de vibrado pueden apreciarse en la fotografía No. 2.

- Especimenes para determinar la resistencia a la compresión.

Los especímenes para determinar la resistencia a la compresión a los 3 y 28 días se fabricaron en moldes cilíndricos de 10 cm de diámetro y 20 cm de altura, de acuerdo a la norma ASTM C-192. Los moldes y el equipo de fabricación pueden verse en la fotografía No. 3.

Descripción y operación del equipo de abrasión.

Aparatos.

Dispositivo de abrasión.

Es un taladro de presión ó dispositivo similar con una porta broca en la cual embona un cortador rotatorio que gira con una velocidad de 200 rev/min y una fuerza excéntrica de 10 kg sobre la superficie del espécimen. Fotografía No. 4 muestra el taladro de presión. Ver figura No. 1 ilustra los detalles del taladro de presión.

La dificultad de mantener una carga constante de abrasión cortante cuando usamos la palanca, mecanismo y el sistema de giro del taladro de presión a sido eliminado por la colocación de una carga directa sobre el vástago que toma el cortante. La máquina consiste esencialmente en un marco que soporta el motor, la polea y el vástago. Un sujetador esta construido en la base para sostener el espécimen.

La carga sobre el vástago puede ser de 10 kg cuando el ciclo de abrasión es normal ó de 20 kg cuando el ciclo de abrasión es severo, la fotografía 2 muestra el peso sobre el vástago, que proporciona la fuerza excéntrica.

Cortador rotatorio.

Esta formado por ruedas abrasivas montadas. Figura No. 2 muestra los detalles del cortador rotatorio. Las roldanas deben de ser de diámetro menor que las ruedas abrasivas antes y después de la prueba. El diámetro de las roldanas debe mantenerse menor que el diámetro de las ruedas abrasivas durante la prueba. Las ruedas abrasivas deben cambiarse periódicamente, preferentemente después de cada 90 minutos de uso. La fotografía 6 ilustra el Cortador Rotatorio, así como el molde donde es colocado el espécimen.

Ensayes de abrasión en especímenes secos.

a) Preparación de los especímenes.

Al cumplirse la edad de curado se sacaron los especímenes del cuarto de curado y se colocaron en el horno a temperatura constante de 50^0C durante 24 h. aproximadamente, ya secos los especímenes se aclimataban al medio ambiente para posteriormente ser ensayados.

b) Procedimiento de ensaye de acuerdo a la norma ASTM C 944-90 "Método estándar para determinar la resistencia a la abrasión de concreto o superficies de mortero según el método Rotación – Cortante".

1. Determinar la masa del espécimen con aproximación de 0.1 gr
2. Se coloca el espécimen perpendicular al aparato de abrasión.
3. Montar el aparato de rotación cortante en el aparato de abrasión.
4. Encender el motor a una velocidad baja hasta que se tenga contacto con la superficie del espécimen.
5. Se continua la abrasión con una carga constante de 20 kg en el espécimen por dos minutos después del contacto entre el cortador y la superficie. Al final de cada dos minutos de periodo de abrasión, remover el espécimen de prueba del aparato de abrasión y limpiar la superficie con una brocha, despues se sopla la superficie con aire.
6. Determinar la masa del espécimen con una aproximación de 0.1 gr.

El método establece que se deben tener tres periodos de prueba en diferentes partes de un concreto o mortero representativo, por lo cual se ensayaron tres especímenes en cada caso de prueba. Ver Fotografía 4 donde se muestran los especímenes del ensaye de abrasión

La abrasión se interpreta como promedio de la pérdida en gramos de los tres especímenes.

Los resultados obtenidos en los ensayes bajo condición seca se encuentran en las siguientes tablas:

Tabla No. 1 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición seca a los 3 días de curado
Tabla No. 2 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición seca a los 3 días de curado.
Tabla No. 3 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición seca a los 28 días de curado.
Tabla No. 4 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición seca a los 28 días de curado.

Ensayes de abrasión en especímenes húmedos.

a) Preparación de los especímenes.

Al cumplirse la edad de curado se sacaron los especímenes del cuarto de curado y se dejaron al medio ambiente hasta lograr la condición Saturados Superficialmente Secos.

c) Procedimiento de ensaye de acuerdo a la norma ASTM C 944-90 "Método estándar para determinar la resistencia a la abrasión de concreto o superficies de mortero según el método Rotación – Cortante".

1. Determinar la masa del espécimen con aproximación de 0.1 gr
2. Se coloca el espécimen perpendicular al aparato de abrasión.
3. Montar el aparato de rotación cortante en el aparato de abrasión.
4. Encender el motor a una velocidad baja hasta que se tenga contacto con la superficie del espécimen.
5. Se continua la abrasión con una carga constante de 20 kg en el espécimen por dos minutos después del contacto entre el cortador y la superficie. Al final de cada dos minutos de periodo de abrasión, remover el espécimen de prueba del aparato de abrasión y limpiar la superficie con una brocha, después se limpia la superficie con aire.
6. Determinar la masa del espécimen con una aproximación de 0.1 gr.

El método establece que se deben tener tres periodos de prueba en diferentes partes de un concreto o mortero representativo, por lo cual se ensayaron tres especímenes en cada caso de prueba.

La abrasión se interpreta como promedio de la pérdida en gramos de los tres especímenes.

Los resultados obtenidos en los ensayes bajo condición húmeda se encuentran en las siguientes tablas:

Tabla No. 5 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición húmeda a los 3 días de curado.
Tabla No. 6 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición húmeda a los 3 días de curado.
Tabla No. 7 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición húmeda a los 28 dias de curado.
Tabla No. 8 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición húmeda a los 28 días de curado.

Ensayes de compresión.

La resistencia a la compresión se determinó en los concretos de referencia y en los concretos con aditivo para cada relación agua – cementante, para comparar estos resultados con los de la resistencia a la abrasión.

Los ensayes a compresión se realizaron en una máquina universal TINIUS OLSEN en forma manual con una velocidad de aplicación de carga entre 0.14 y 0.34 Mpa/s de acuerdo a lo especificado en la norma ASTM C-39. La máquina universal puede verse en la fotografía No. 8.

Los resultados pueden apreciarse en las siguientes tablas:

Tabla No. 9 Resistencia a la compresión del concreto de referencia a los 3 días de curado.
Tabla No. 10 Resistencia a la compresión del concreto de referencia a los 28 días de curado.
Tabla No. 11 Resistencia a la compresión del concreto con aditivo a los 3 días de curado.
Tabla No. 12 Resistencia a la compresión del concreto con aditivo a los 28 días de curado.

Resultados

Tabla No. 1 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición seca a los 3 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1 2 3	3152.8 3055.5 3142.0	3149 6 3052.9 3140 0	2.6
0.40	1 2 3	3198.6 3130.8 3181.9	3196.4 3128 3 3178.0	2 9
0.45	1 2 3	3152.3 3194.5 3197.8	3148 8 3190.6 3194.5	3.6

Tabla No. 2 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición seca a los 3 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1 2 3	2936.0 3005.5 2961.6	2933.0 3002.6 2958.2	3.1
0.40	1 2 3	3153.3 3236.9 3232.8	3149 9 3232 9 3229.2	3 7
0.45	1 2 3	3172.5 3239 3 3274 9	3169 0 3235 1 3270 5	4 0

Tabla No. 3 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición seca a los 28 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1 2 3	3216.8 3244.3 3258.3	3215 4 3242.2 3256.5	1.8
0.40	1 2 3	3204.0 3214.1 3164.8	3202 3 3211.9 3162.5	2.1
0.45	1 2 3	3192.4 3247.3 3233.4	3188.7 3244.4 3230.3	3.2

Tabla No. 4 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición seca a los 28 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1 2 3	3153.5 3217.8 3217.1	3151.5 3214.8 3214.9	2.4
0 40	1 2 3	3256.3 3206 6 3185.0	3252.8 3203.7 3181.0	3.5
0 45	1 2 3	3258 6 3231 1 3205 2	3255 4 3227.3 3201.3	3 6

Tabla No. 5 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición húmeda a los 3 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1 2 3	3180.8 3155.3 3223.5	3175.9 3148.1 3218.6	5.7
0.40	1 2 3	3281.8 3151.7 3261.0	3275.8 3145.6 3255.5	5.9
0.45	1 2 3	3265.0 3257.0 3273.0	3258.0 3250.0 3266.2	6.9

Tabla No. 6 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición humeda a los 3 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1 2 3	3166.8 3179.8 3135.1	3160.5 3173.9 3127.5	6.6
0.40	1 2 3	3263.4 3235.4 3239.9	3255.8 3228.1 3232.7	7.4
0.45	1 2 3	3261.6 3278.5 3247.5	3253.7 3270.6 3239.2	8.0

Tabla No. 7 Resultados de ensayes de abrasión realizados en el concreto con aditivo bajo la condición húmeda a los 28 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1	3225.9	3221.0	4.7
	2	3205.8	3201.3	
	3	3201.8	3197.0	
0.40	1	3257.0	3252.0	4.9
	2	3254.3	3249.6	
	3	3288.2	3283.3	
0.45	1	3209.1	3203.1	6 3
	2	3194.3	3187.7	
	3	3269.0	3262.8	

Tabla No. 8 Resultados de ensayes de abrasión realizados en el concreto de referencia bajo la condición húmeda a los 28 días de curado, expresado en gr.

Relación A/C	Muestra No.	Peso inicial	Peso final	Pérdida promedio
0.35	1	3234 2	3228 6	5 1
	2	3149 2	3144 0	
	3	3265.8	3261 3	
0.40	1	3277 6	3271 2	6 2
	2	3274 6	3268 0	
	3	3281.0	3275 4	
0.45	1	3334.7	3328 3	6 6
	2	3333.2	3326.3	
	3	3340.3	3333.7	

Tabla No. 9 Resistenca a la compresión del concreto de refrencia a los 3 días de curado.

Relación A/C	Espécimen No.	Diámetro (cm)	Carga (kg)	Resistencia (kg/cm²)	Resistencia (Mpa)	Promedio (Mpa)
0.35	1	10.1	25806	322	31.6	34.9
	2	10.0	29700	378	37.1	
	3	10.0	28764	366	35.9	
0.40	1	10.0	27415	349	34.2	32.8
	2	10.0	26094	332	32.6	
	3	10.1	25901	323	31.7	
0.45	1	10.0	21685	276	27.1	28.2
	2	10.0	23305	297	29.1	
	3	10.1	23198	290	28.4	

Tabla No. 10 Resistenca a la compresión del concreto de refrencia a los 28 días de curado.

Relación A/C	Espécimen No.	Diámetro (cm)	Carga (kg)	Resistencia (kg/cm²)	Resistencia (Mpa)	Promedio (Mpa)
0.35	1	10.1	40764	514	50.4	49.8
	2	10.1	40554	506	49.6	
	3	10.1	40350	504	49.4	
0.40	1	10.1	38080	475	46.6	48.0
	2	10.1	37750	471	46.2	
	3	10.0	41076	523	51.3	
0.45	1	10.1	33821	422	41.4	42.7
	2	10.1	35247	440	43.1	
	3	10.1	35556	444	43.5	

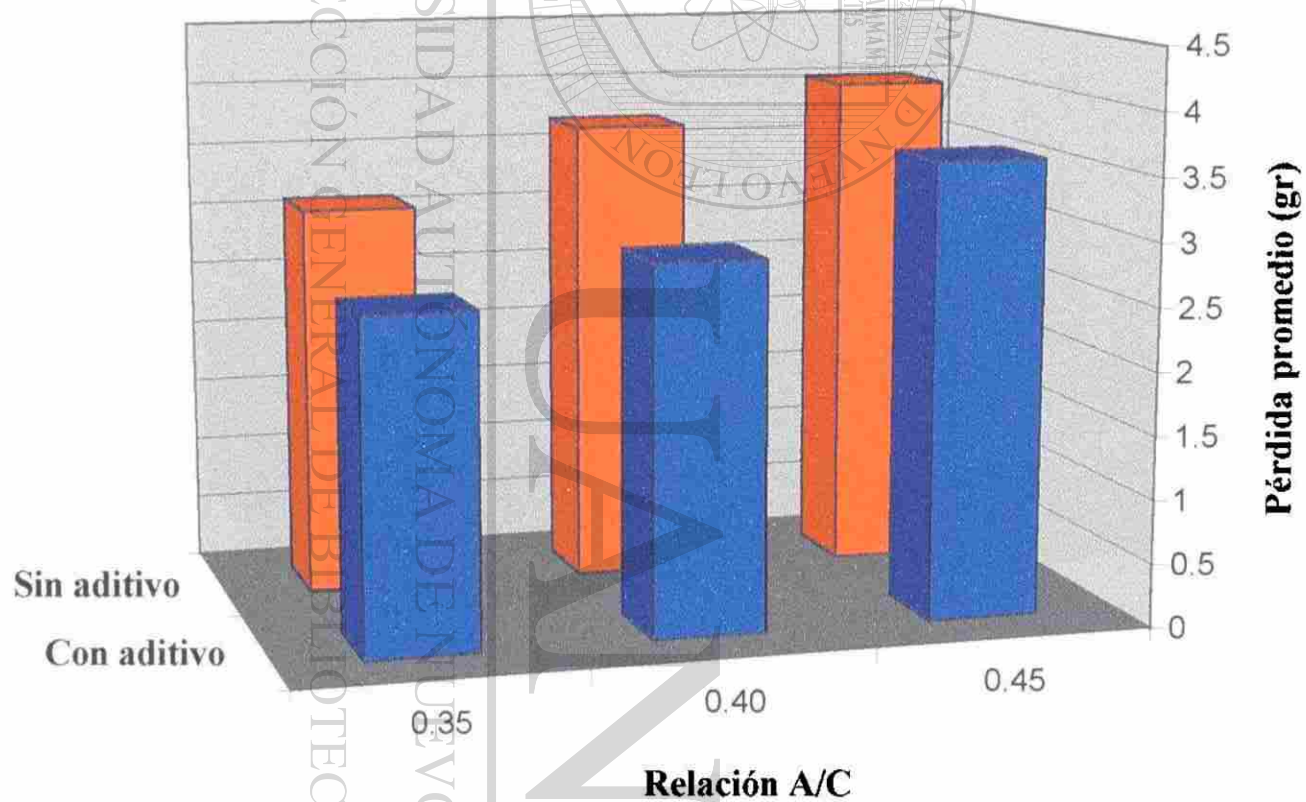
Tabla No. 11 Resistenca a la compresión del concreto con aditivo a los 3 días de curado.

Relación A/C	Espécimen No.	Diámetro (cm)	Carga (kg)	Resistencia (kg/cm²)	(Mpa)	Promedio (Mpa)
0.35	1	10.0	29500	376	36.8	35 6
	2	10.0	28250	360	35.3	
	3	10.1	28300	353	34 6	
0.40	1	10.2	26289	322	31.5	33 7
	2	10.2	31191	382	37 4	
	3	10.2	26770	329	32.2	
0.45	1	10.2	23841	295	28.9	28 2
	2	10.2	23161	286	28 1	
	3	10.2	22871	282	27.6	

Tabla No. 12 Resistenca a la compresión del concreto con aditivo a los 28 días de curado.

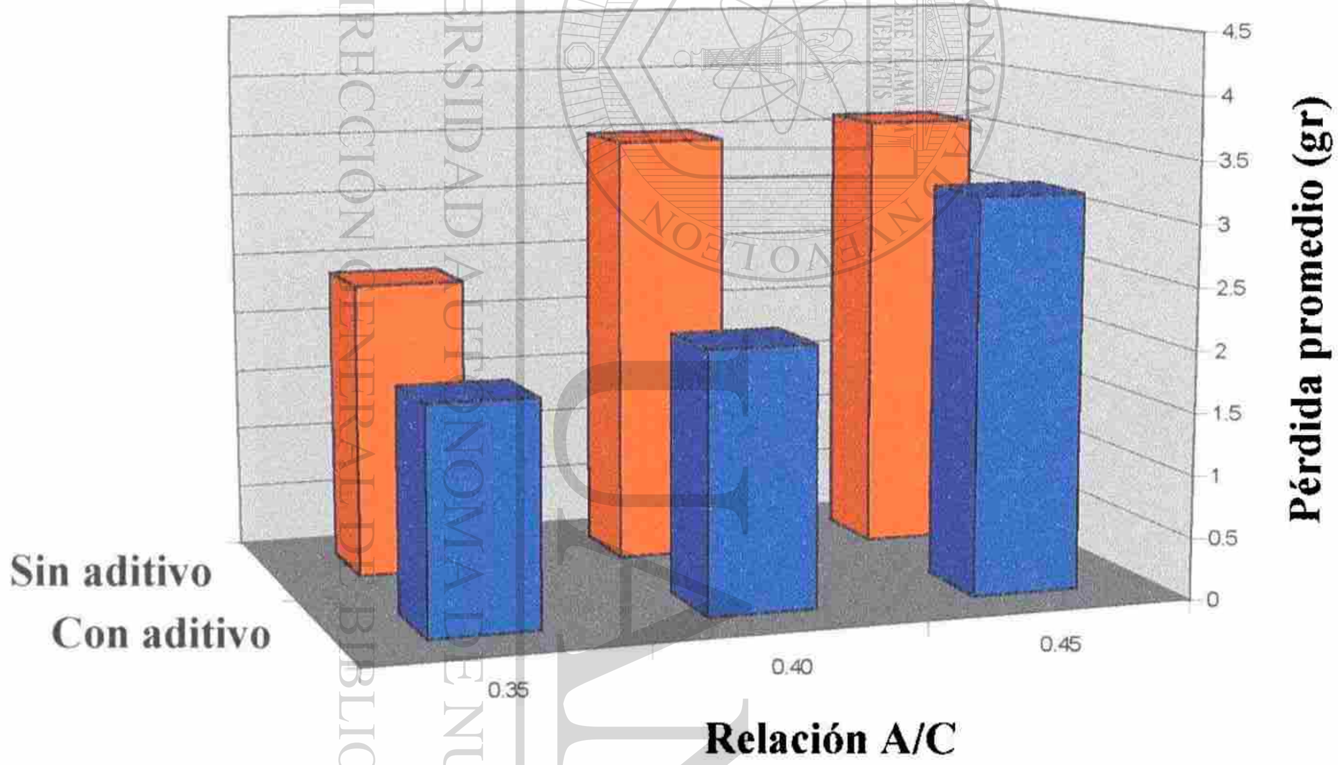
Relación A/C	Espécimen No.	Diámetro (cm)	Carga (kg)	Resistencia (kg/cm²)	(Mpa)	Promedio (Mpa)
0.35	1	10.1	40787	509	49 9	50 1
	2	10.1	41700	520	51 0	
	3	10.1	40256	502	49 3	
0.40	1	10.0	38180	486	47 7	48 8
	2	10.0	38750	493	48.4	
	3	10.1	41076	513	50 3	
0.45	1	10 0	34145	435	42 6	42.3
	2	10.0	34360	437	42 9	
	3	10 1	33864	423	41 4	

Gráficas



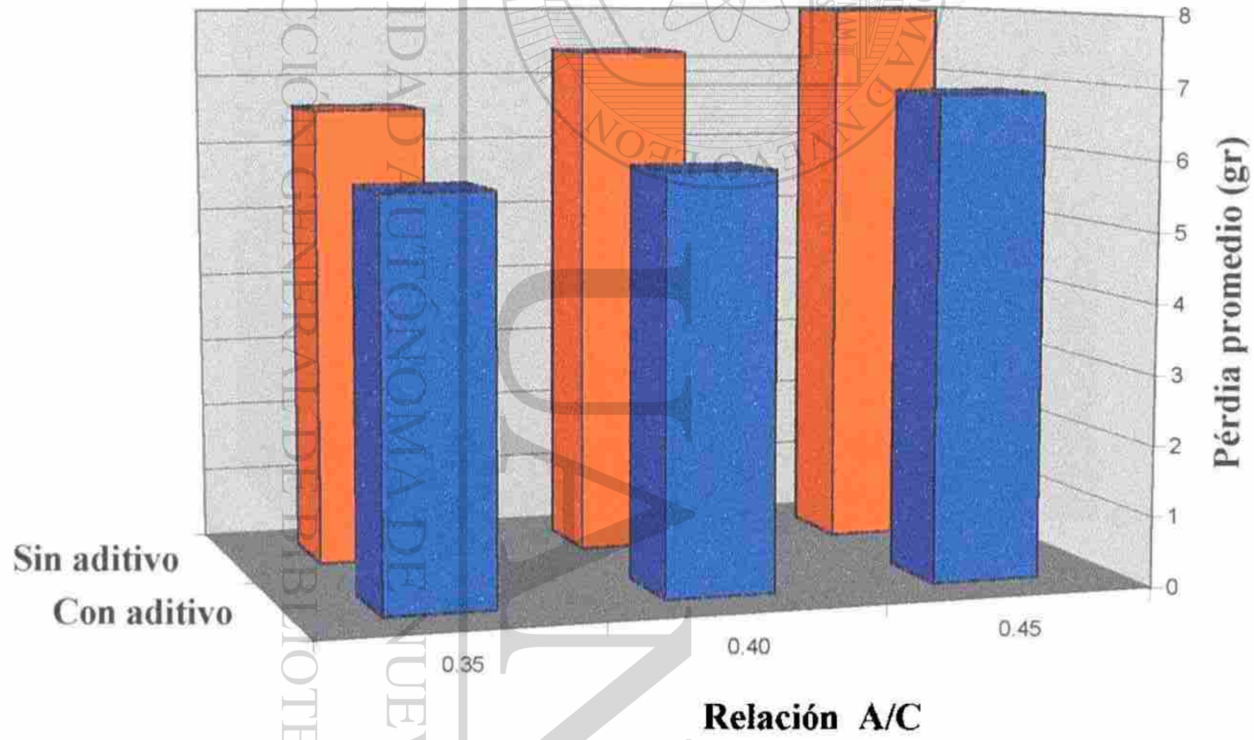
GRAFICA No. 1

Pérdida promedio en concreto sin aditivo y con aditivo, curados a 3 días y ensayados bajo condiciones seca.



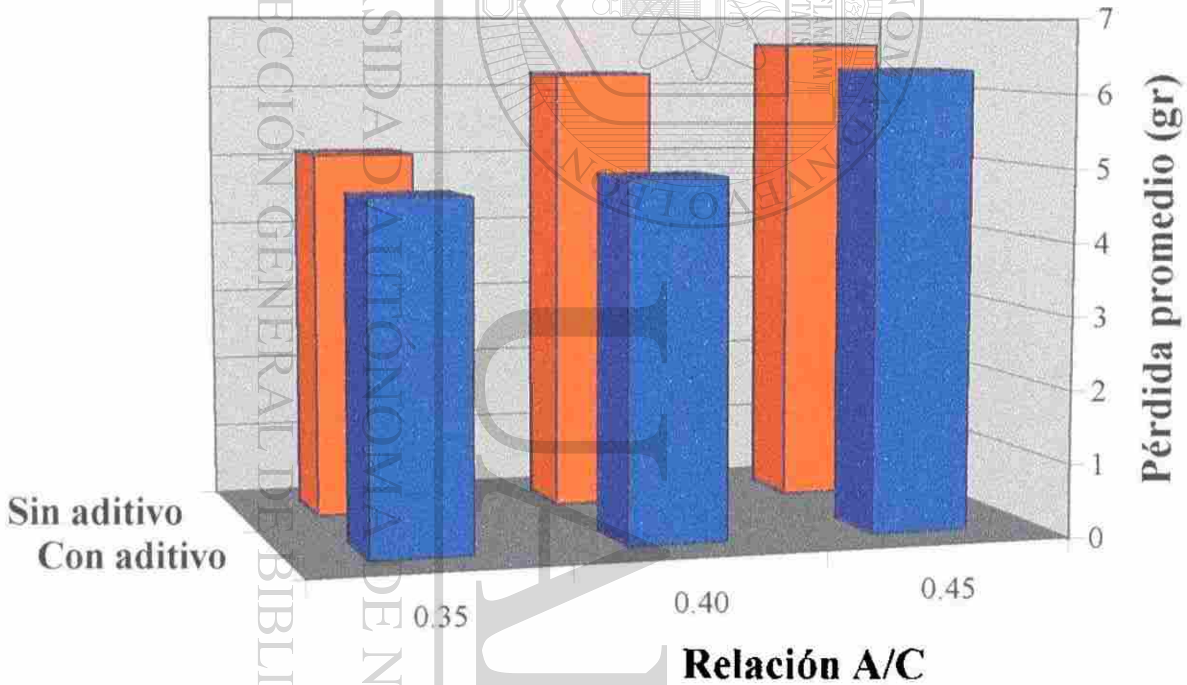
GRAFICA No. 2

Pérdida promedio en concreto sin aditivo y con aditivo, curados a 28 días y ensayados bajo condición seca.



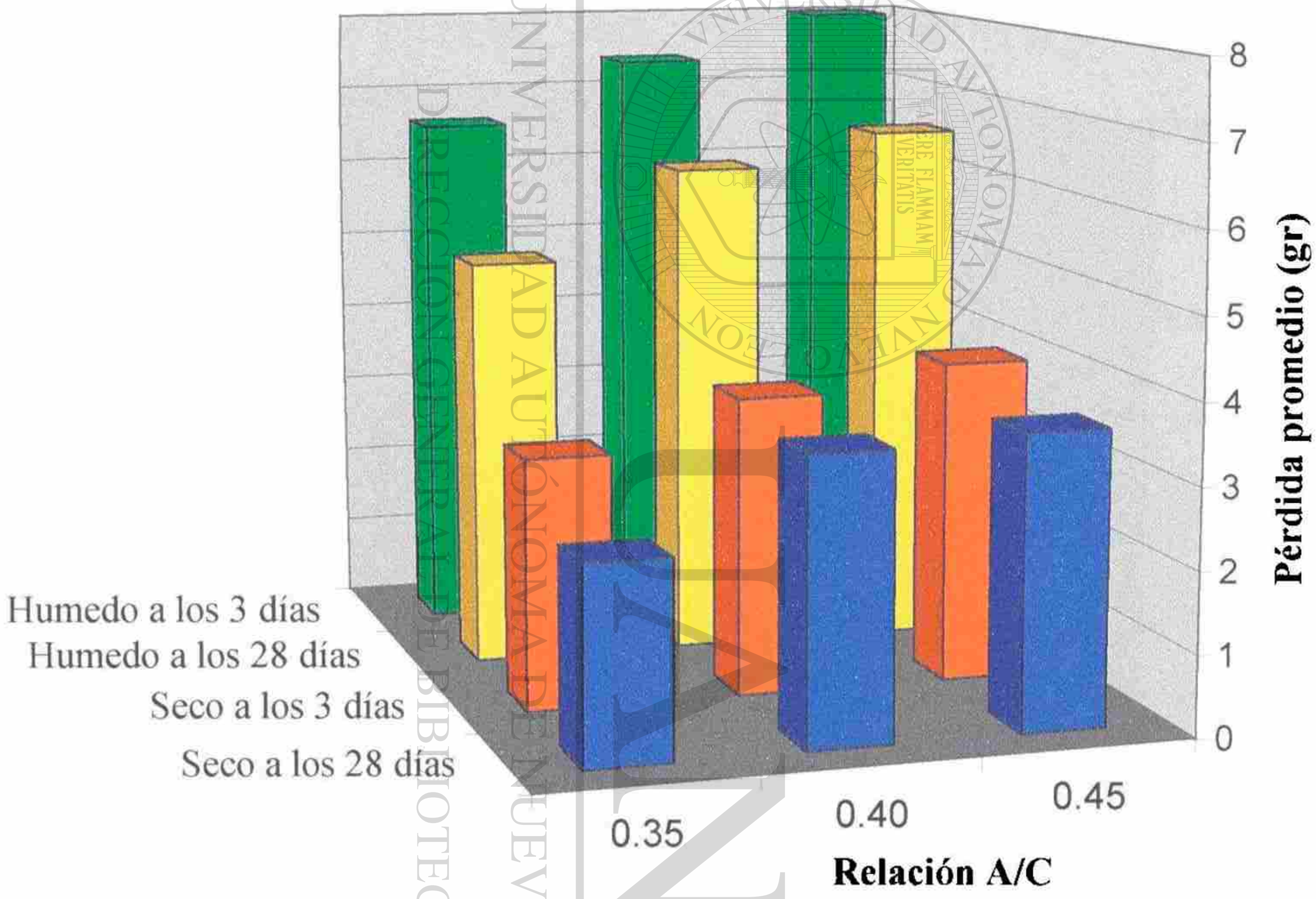
GRAFICA No. 3

Perdida promedio en concreto sin aditivo y con aditivo, curados 3 días y ensayados bajo condición humeda.



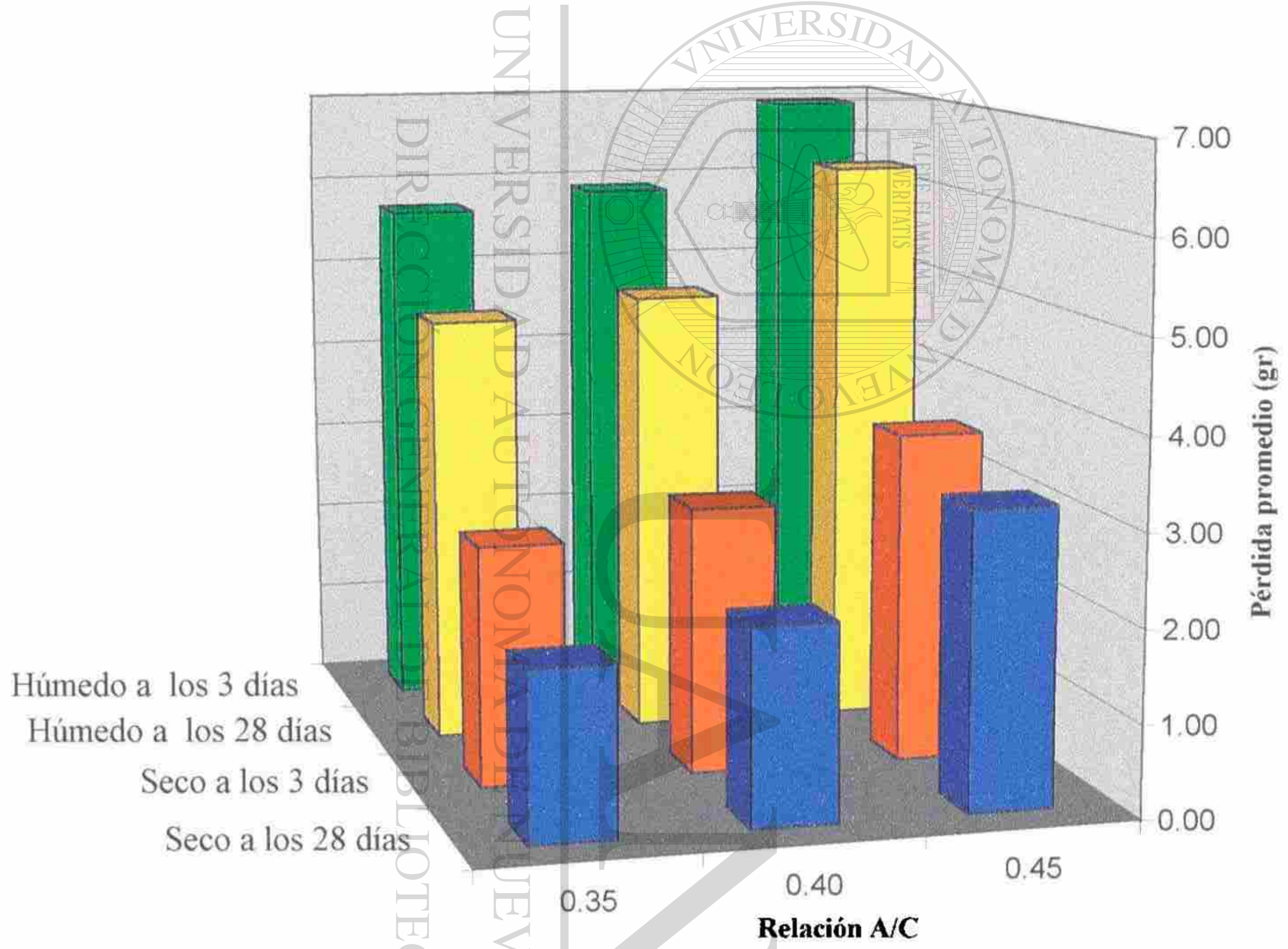
GRAFICA No. 4

Pérdida promedio en concreto sin aditivo y con aditivo, curados 28 días y ensayados bajo condición húmeda.



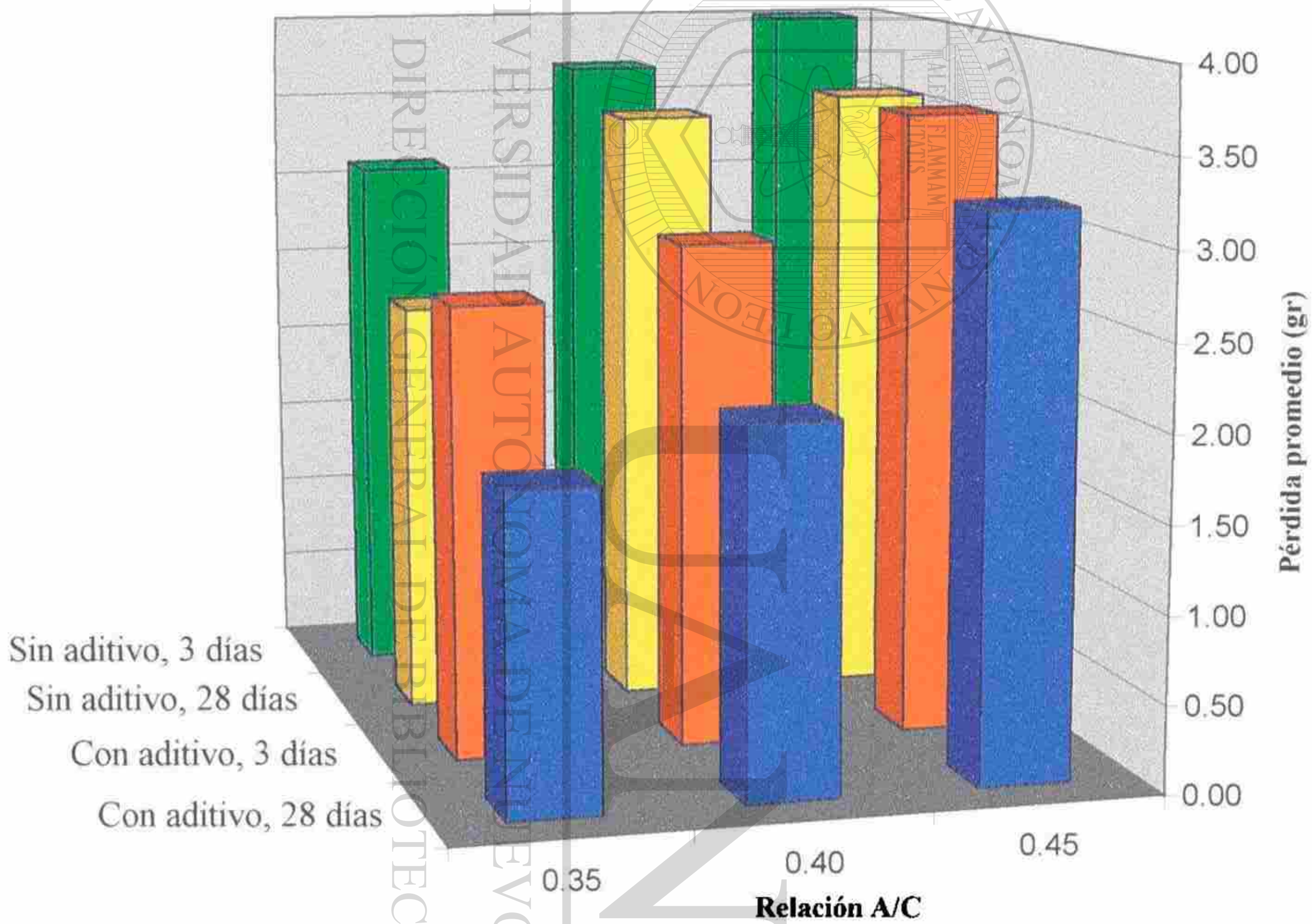
GRAFICA No. 5

Comparación entre pérdidas promedio sufridas en el Concreto *Sin Aditivo*, ensayado bajo condición seca y húmeda a los 3 y 28 días de curado.



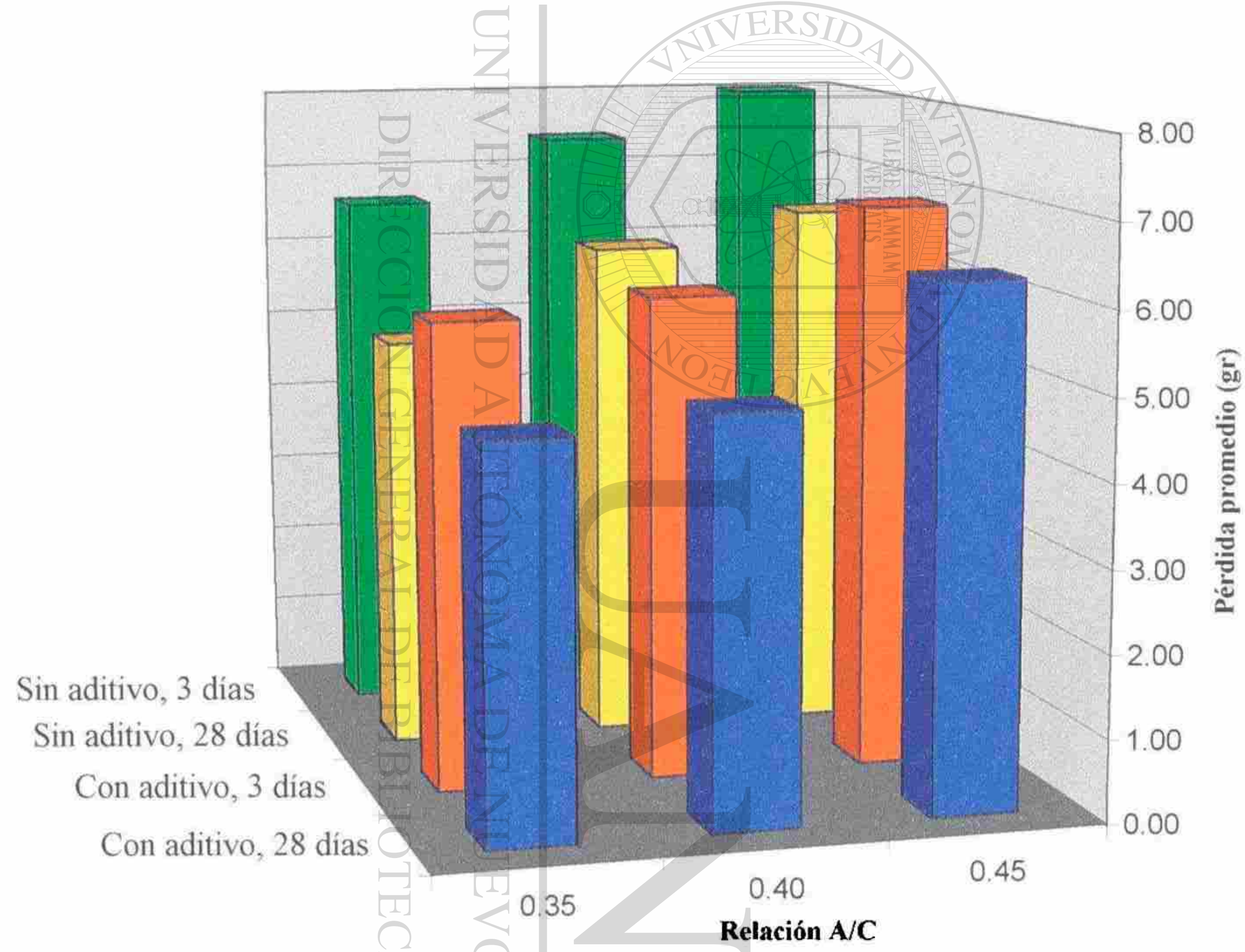
GRAFICA No. 6

Comparación entre las pérdidas promedio sufridas en el Concreto *Con Aditivo*, ensayado bajo condición seca y húmeda a los 3 y 28 días de curado.



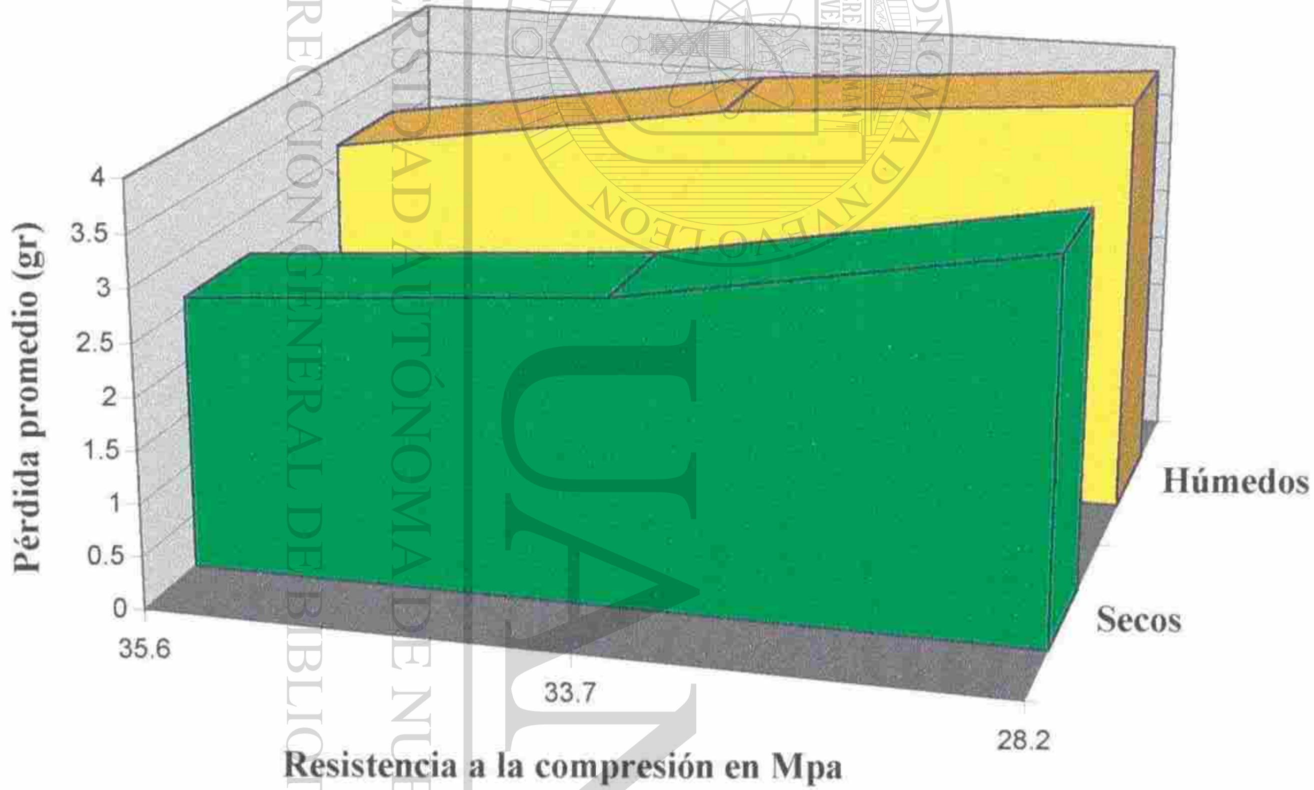
GRAFICA No. 7

Comparación entre las pérdidas promedio sufridas en el Concreto Con Aditivo y Sin Aditivo, ensayados bajo condición *seca* a los 3 y 28 días de curado.



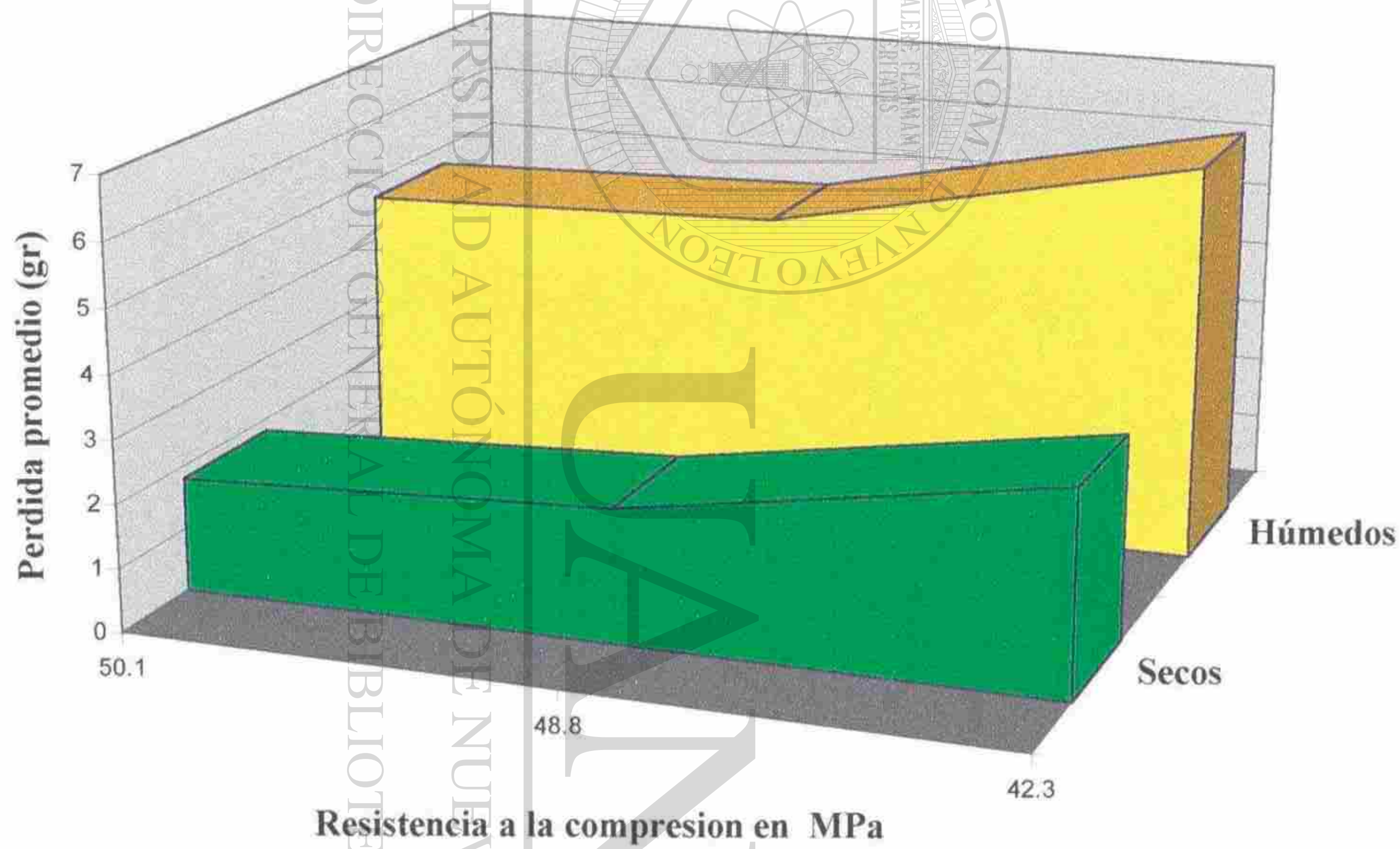
GRAFICA No. 8

Comparación entre las pérdidas promedio sufridas en el Concreto Con Aditivo y Sin Aditivo, ensayados bajo condición *húmeda* a los 3 y 28 días de curado.



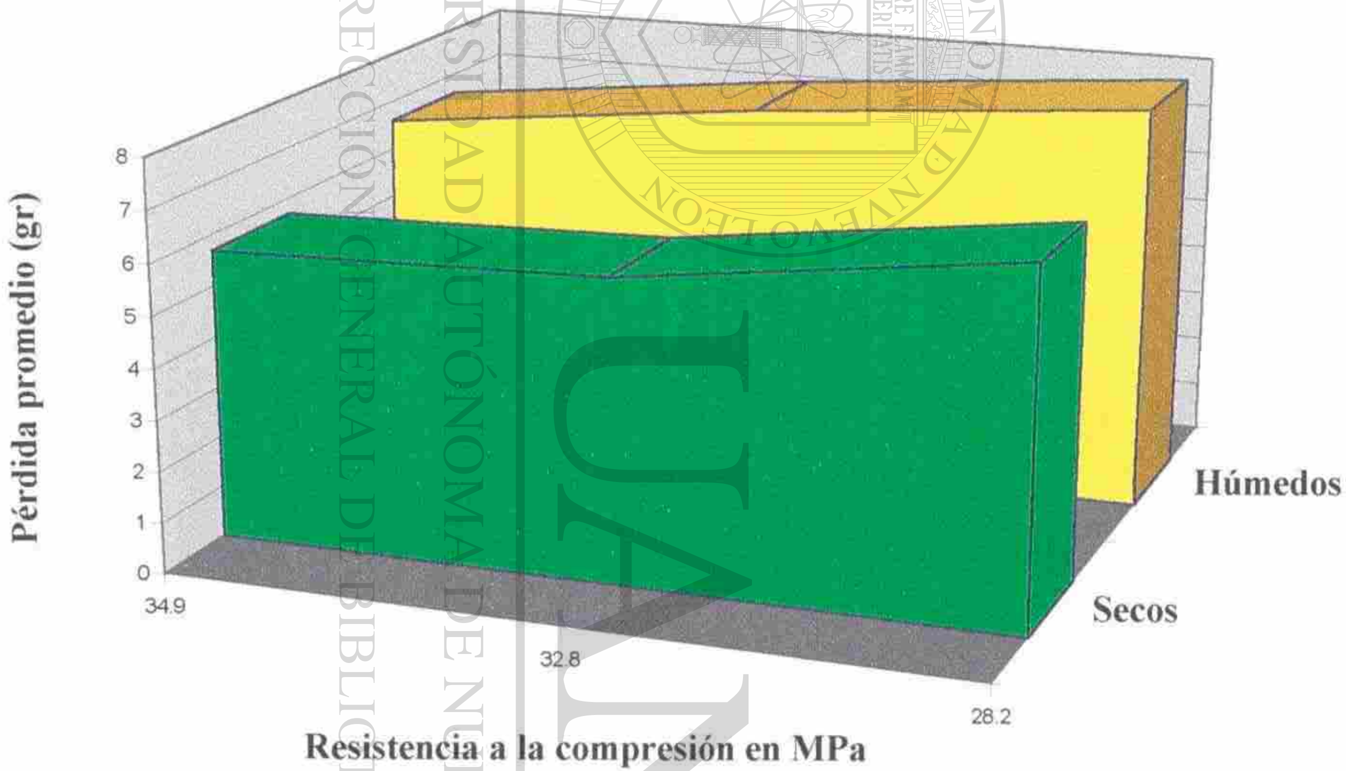
GRAFICA No. 9

Resistencia a la compresión VS pérdida promedio en el concreto *con aditivo*, curado a 3 días.

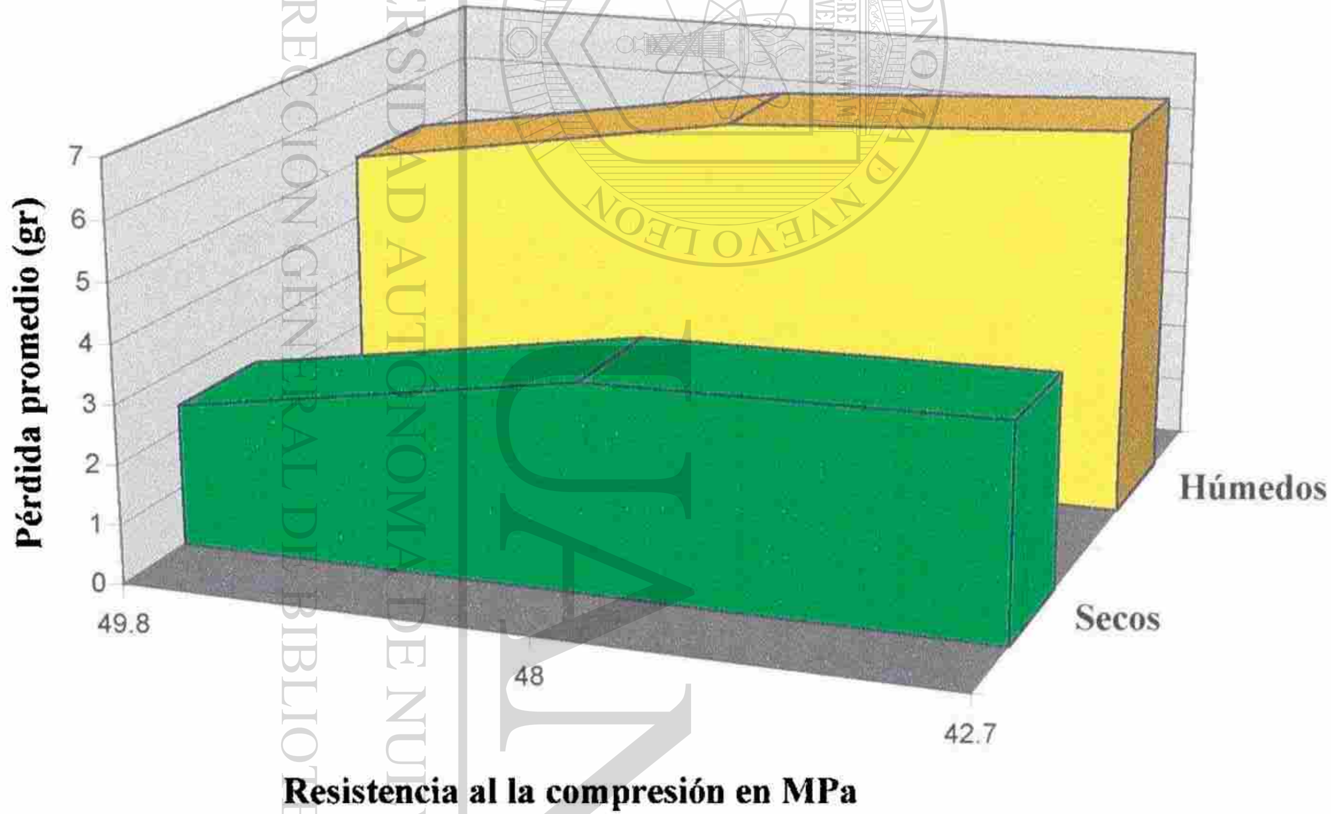


GRAFICA No. 10

Resistencia a la compresión VS pérdida promedio en el concreto *con aditivo*, curado a 28 días.

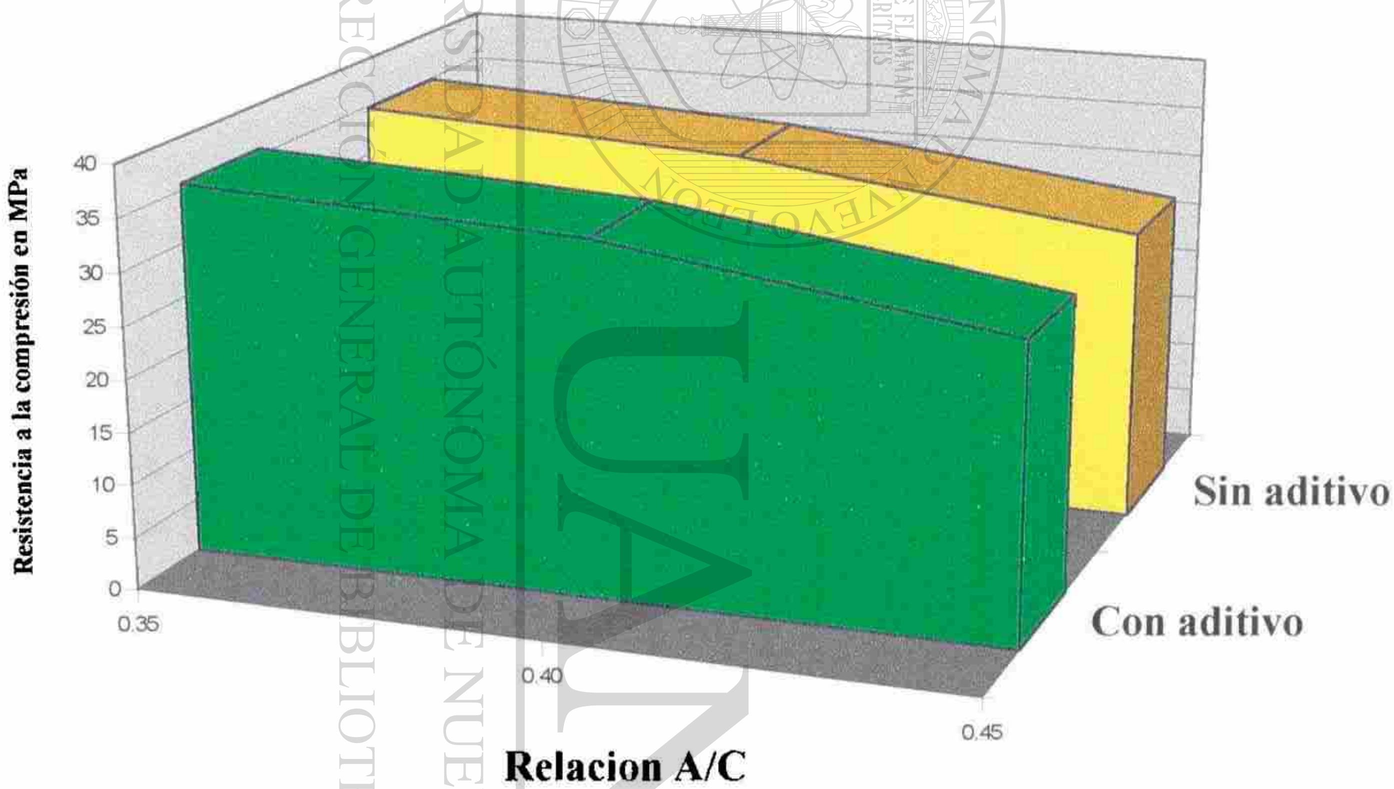


GRAFICA No. 11
Resistencia a la compresión VS pérdida promedio en el concreto *sin aditivo*, curado a 3 días.



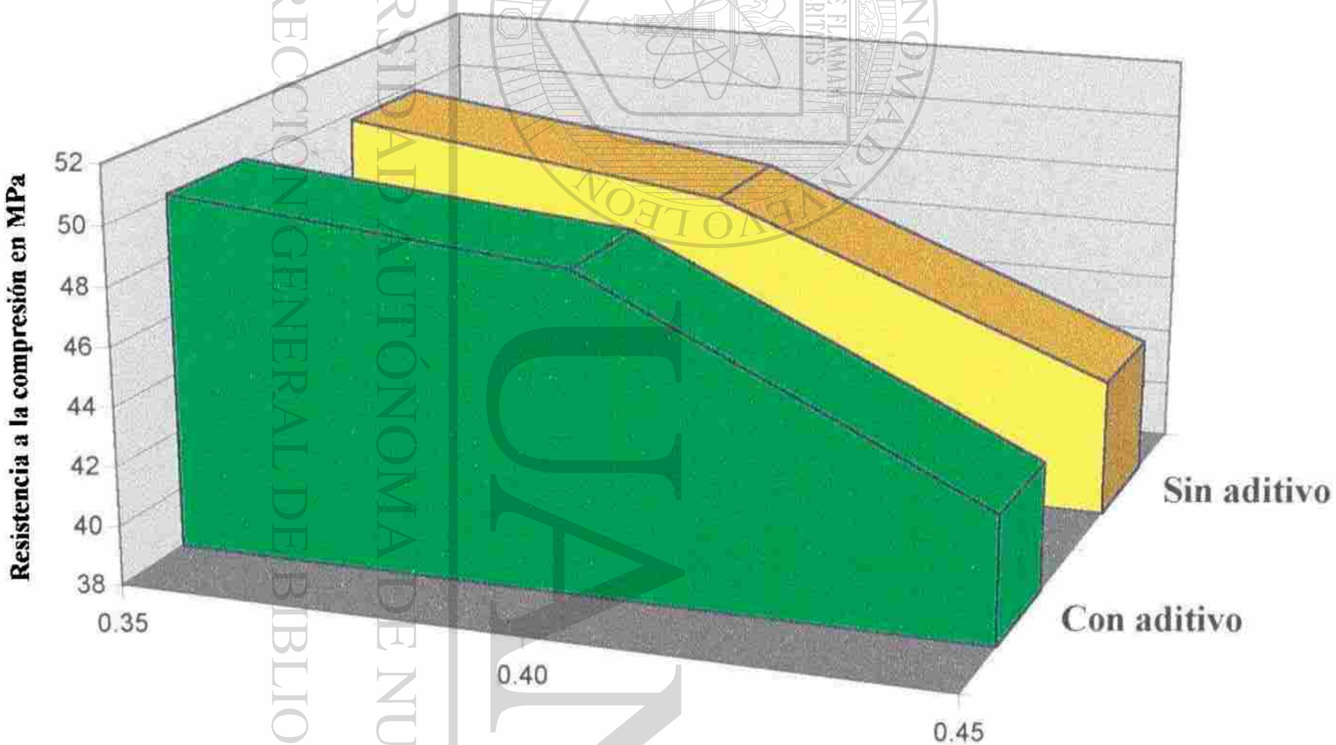
GRAFICA No. 12

Resistencia a la compresión VS pérdida promedio en el concreto *sin aditivo*, curado a 28 días.



GRAFICA No. 13

Resistencia a la compresión en los concretos con y sin aditivo a los 3 días de curado.



Relación A/C

GRAFICA No. 14

Resistencia a la compresión en los concretos con y sin aditivo a los 28 días de curado.

Figuras

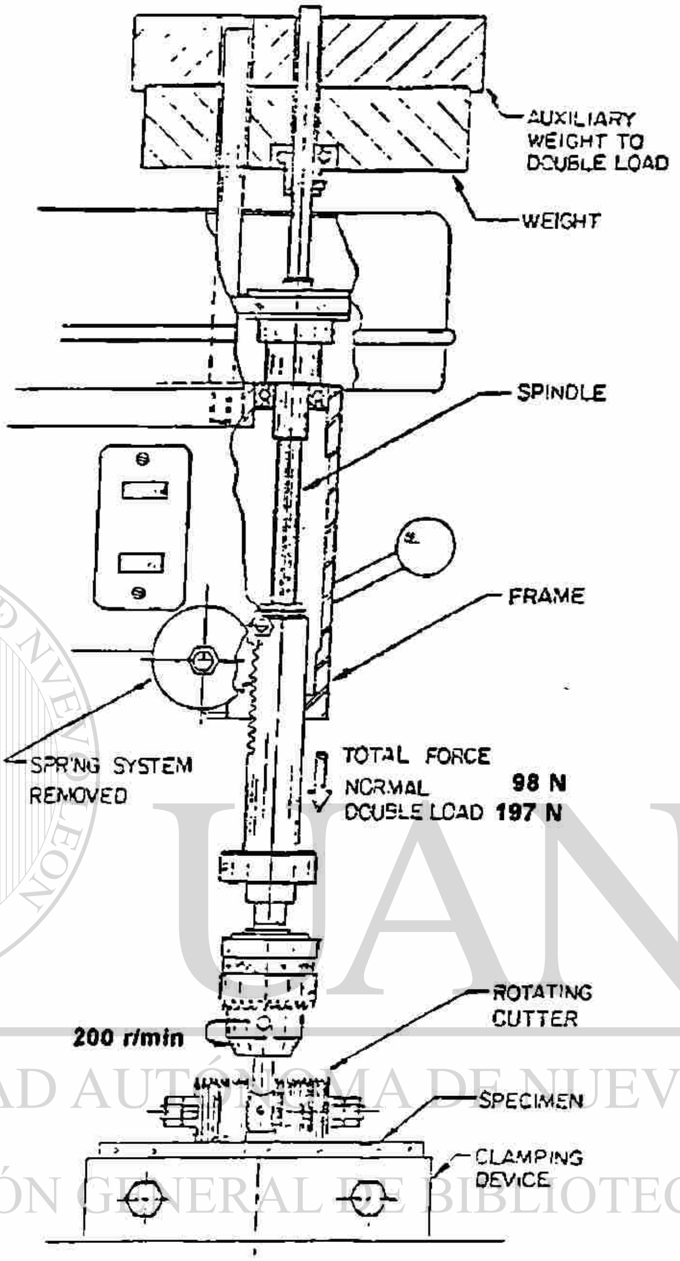


FIGURA 1
Detalles del Taladro de Presión

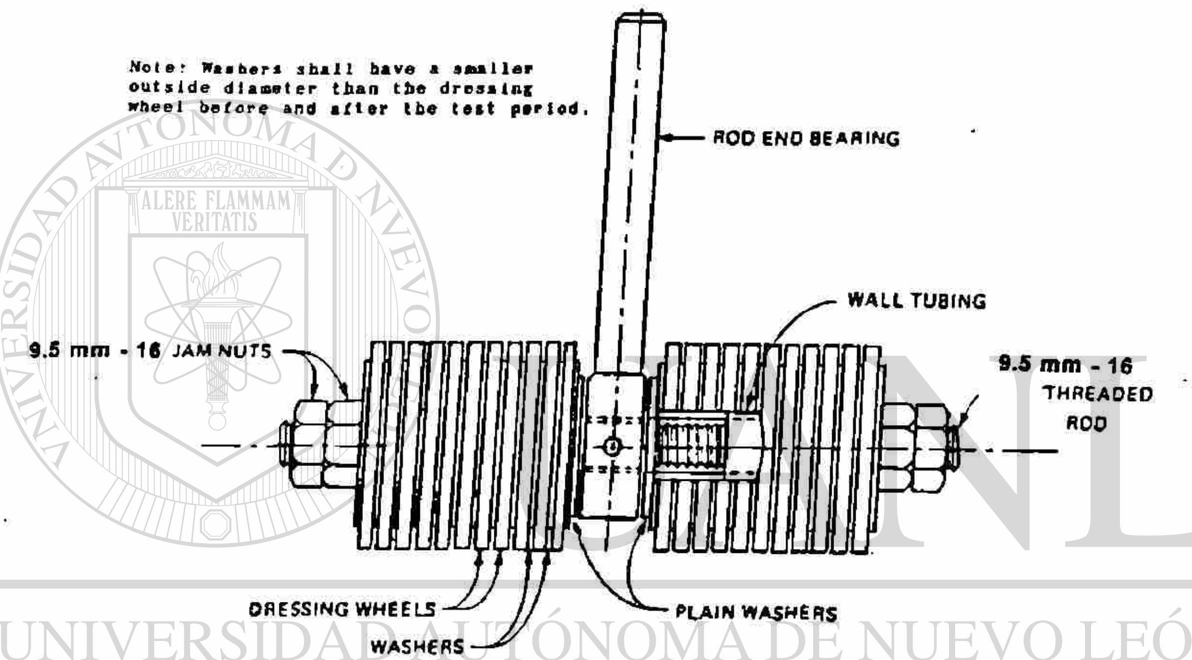
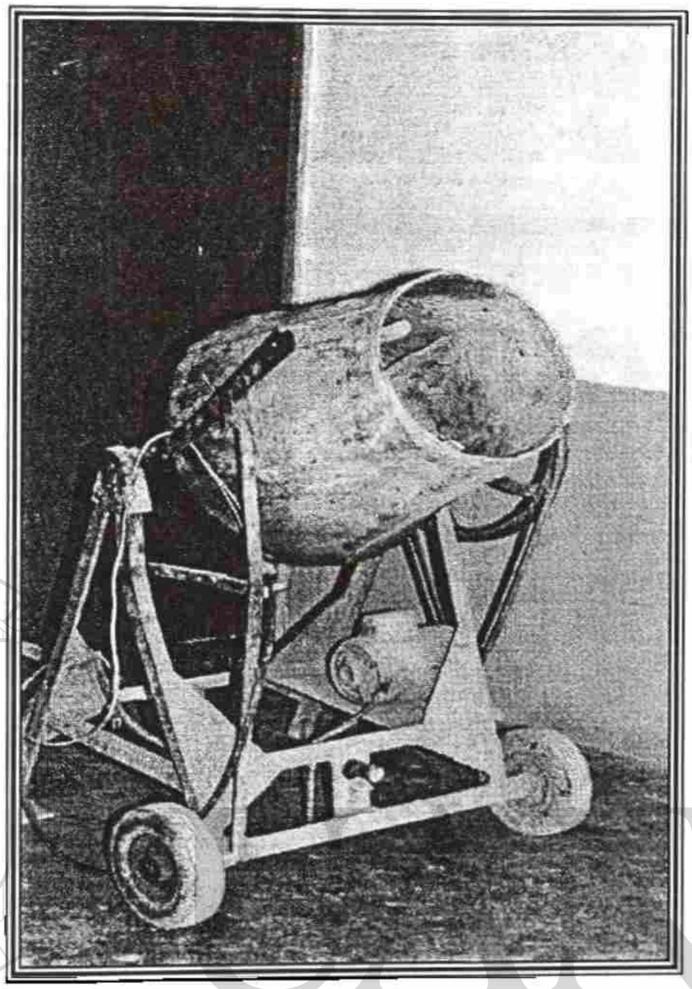


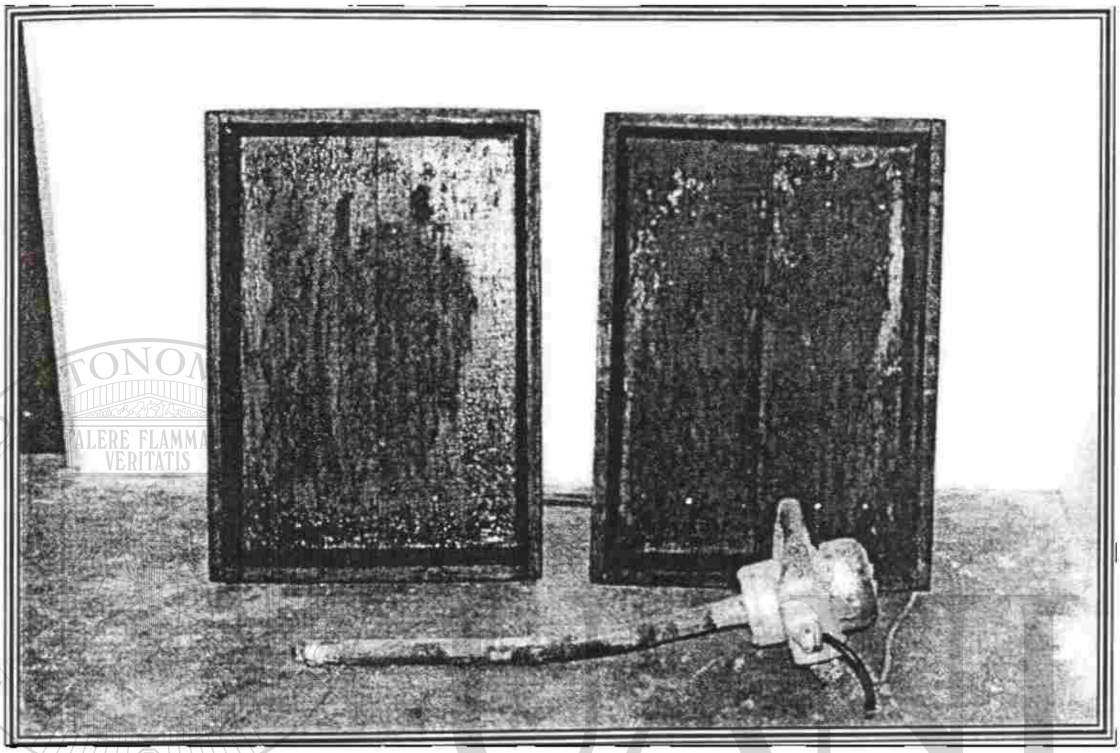
FIGURA 2

Detalles del Cortador Rotatorio

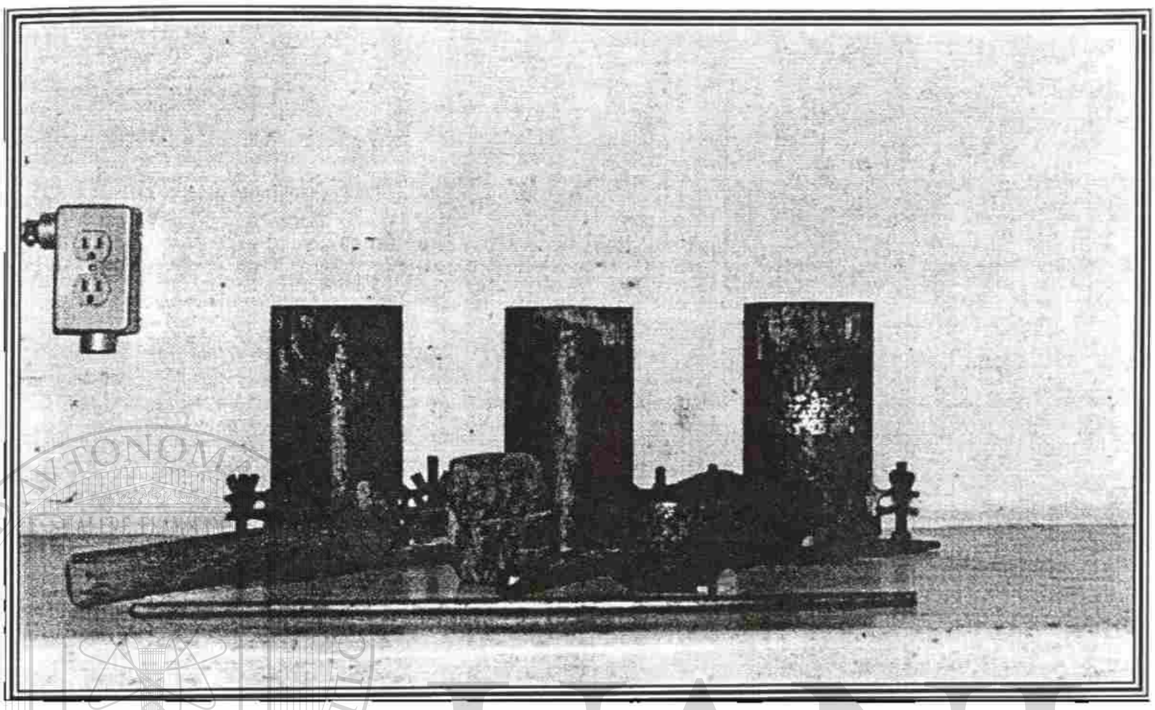
Fotografías



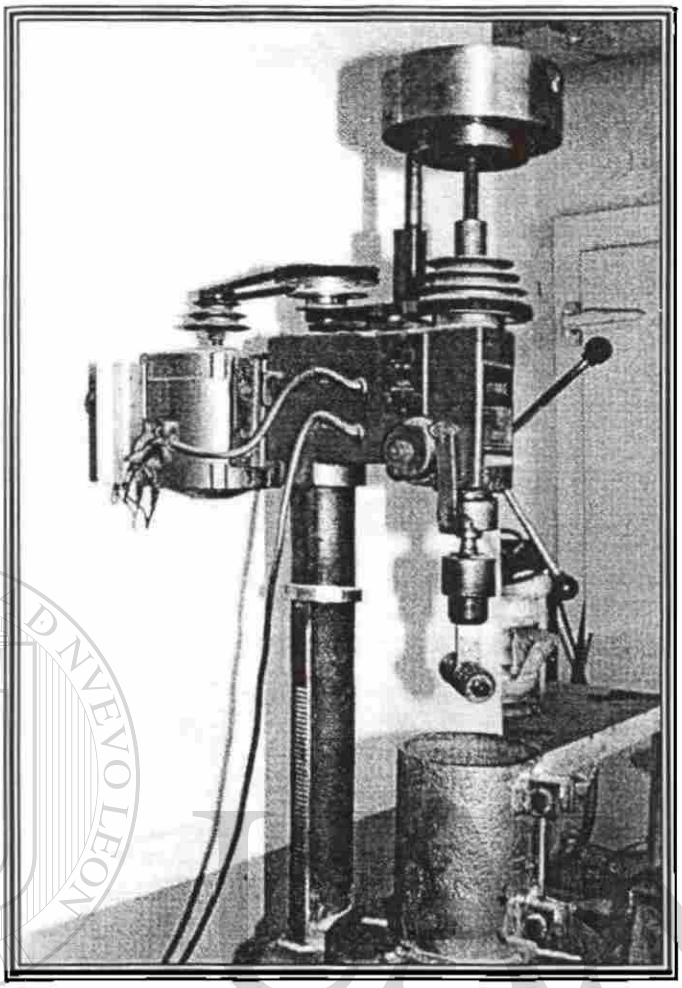
Fotografía Nº 1.- Revolvedora de 30 L de capacidad.



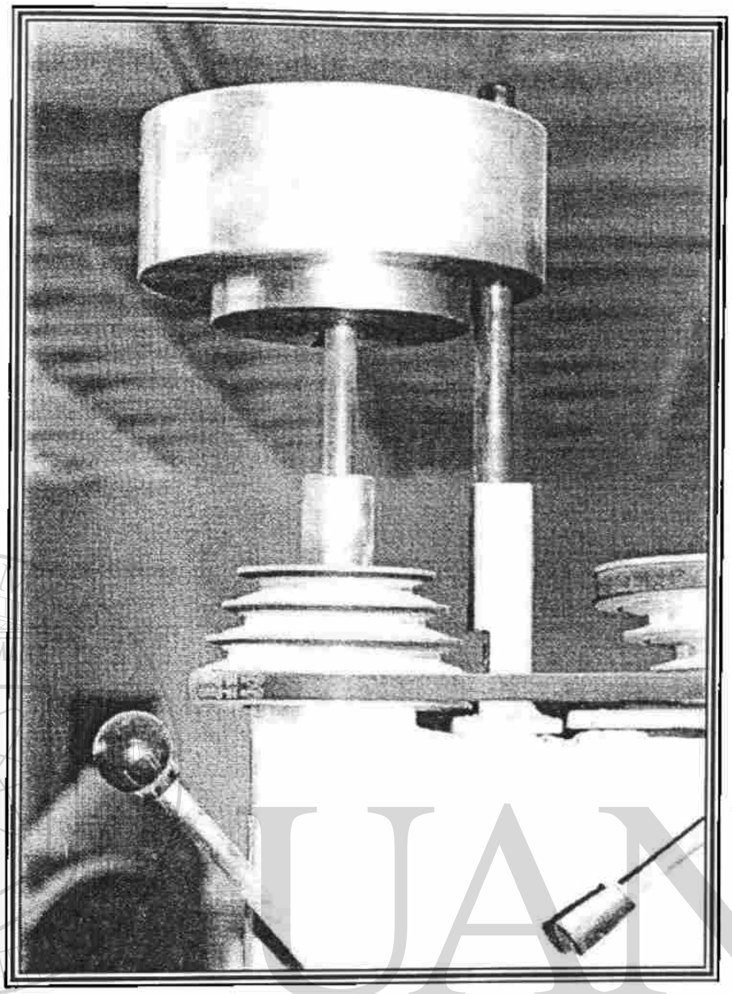
Fotografía Nº 2. Moldes de madera y equipo de vibrado



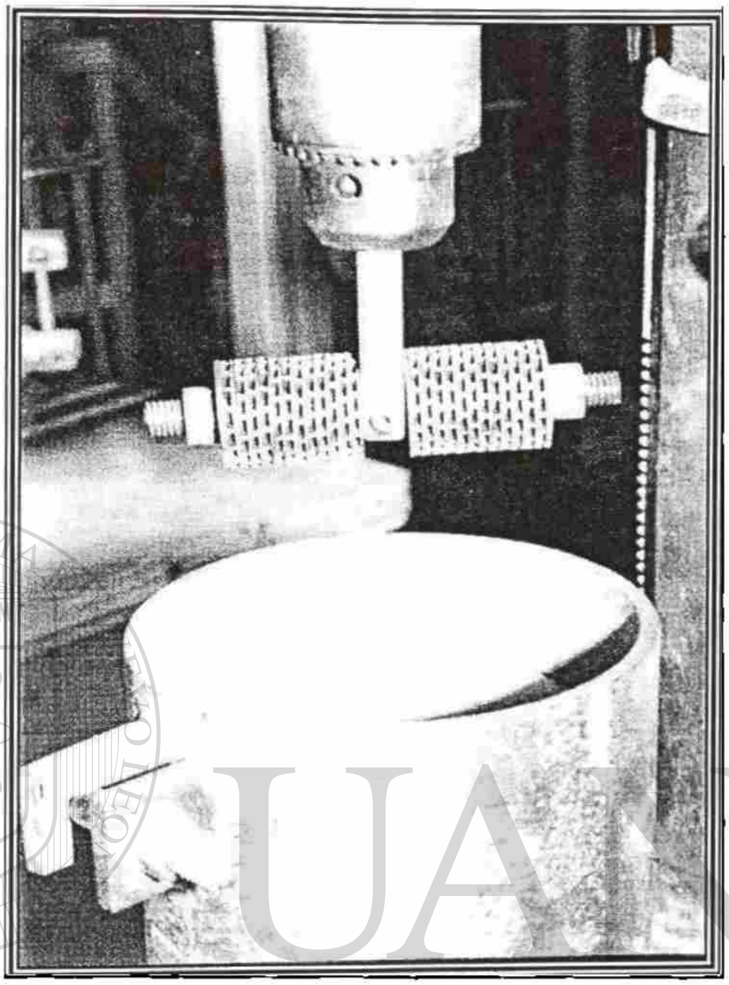
Fotografía Nº 3.- Moldes y equipo para la fabricación de especímenes.



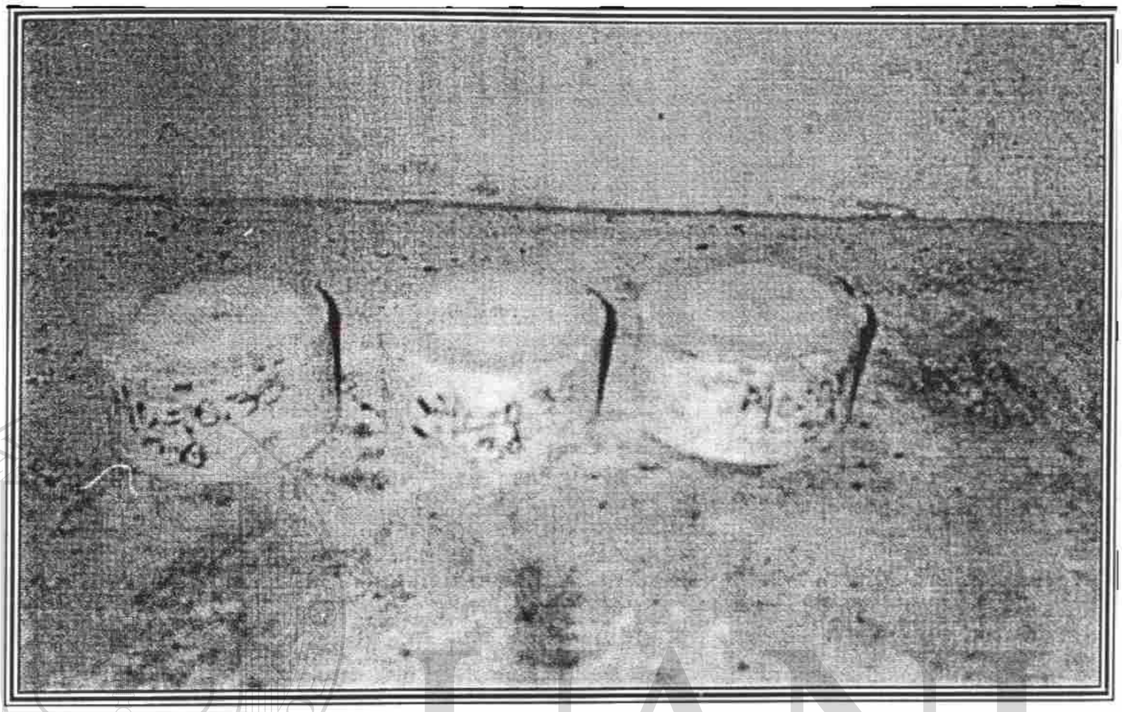
Fotografía Nº4 .- Taladro de presión.



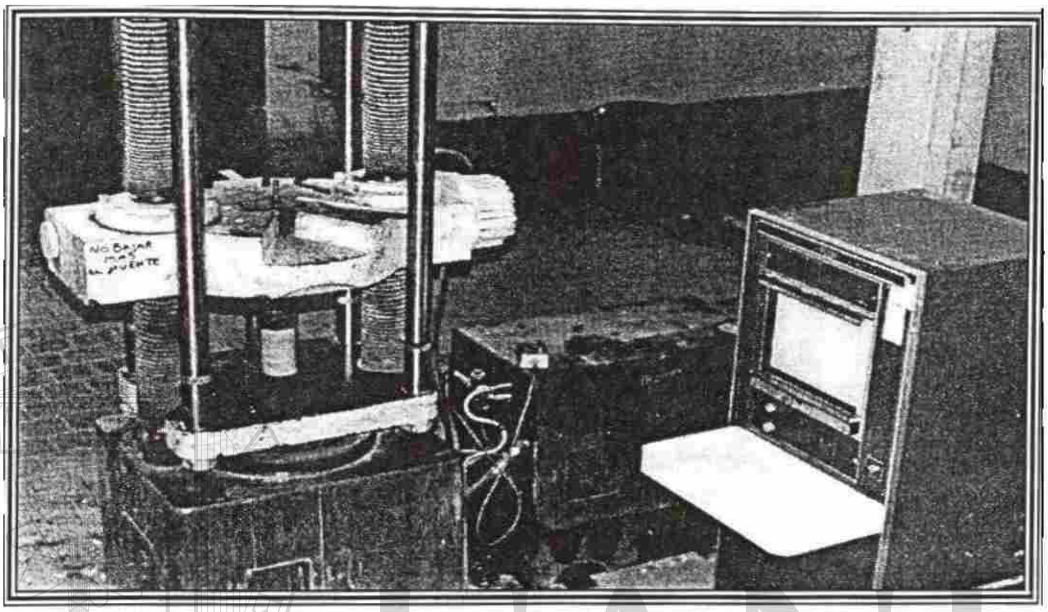
Fotografía Nº5 .- Peso sobre el vástago que proporciona la fuerza excéntrica.



Fotografía Nº 6.- Cortador rotatorio y molde donde se coloca el espécimen.



Fotografía Nº 7. - Especímenes después de haber sido enrayados a la abrasión.



Fotografía Nº 8. - Máquina Universal

Discusiones y comentarios.

Influencia del aditivo superfluidificante.

La gráfica No. 7 muestra que, los concretos sin el uso de aditivo superfluidificante (SF) presentan menor resistencia a la abrasión que los concretos similares fabricados con este aditivo para la misma relación agua – cementante e igual consistencia, ambos ensayados bajo condición seca Lo mismo podemos observar en la gráfica No. 8 que fueron ensayados bajo condición húmeda.

En cuanto a la resistencia a la compresión se puede observar en las gráficas No. 13 y 14, que dado a que se utiliza la misma relación agua – cementante, hubo una ligera variación en la resistencia a la compresión observándose poco aumento de la resistencia de los concretos usando aditivo (SF) respecto a los concretos fabricados sin aditivo (SF).

El uso de un aditivo superfludificante nos permite reducir el consumo de cemento y agua hasta un 12 %, manteniendo la misma relación agua – cementante y la misma consistencia y por lo tanto minimizando posibles agrietamientos por retracción plástica y por secado. Lo anterior se traduce en una reducción de costos de producción así como ahorros derivados de la disminución en los gastos por mantenimiento.

Por consiguiente, podemos tener concretos con la misma resistencia a la compresión, pero con el uso de un aditivo SF podemos aumentar su resistencia a la abrasión, y además como ya se mencionó podemos disminuir los consumos de cemento y una economía adicional al no necesitar tratamientos superficiales adicionales para lograr la misma resistencia a la abrasión.

Conclusiones.

1. Los concretos fabricados con aditivo SF proporcionan mayor resistencia a la abrasión que los concretos fabricados sin aditivo SF.

2. El uso de un aditivo SF además de proporcionar mayor resistencia a la abrasión, nos permite disminuir los consumos de cemento, traduciéndose en un menor costo, así como mantener la trabajabilidad.

3. El concreto con aditivo SF a los 28 días en condición seca presenta mayor resistencia a la abrasión que el concreto sin aditivo SF, variando de un 11 a 24 % al disminuir la relación agua – cementante de 0.45 a 0.35.

4. Como era de esperarse al disminuir la relación agua – cementante en el concreto la resistencia a la abrasión aumenta, en mayor grado al utilizar el aditivo SF.

5. Los concretos sometidos a la acción abrasiva bajo condición seca presentaron mayor resistencia que los concretos ensayados bajo condición húmeda.

Bibliografía.

1. Webster's Dictionary, pg-1, 1994
2. Odd E. Gjorv, Torger Bearland and Heinrich R. Ronning; "Abrasion Resistance of High Strenght Concrete Pavements", ACI Copilation, pg 73-76.
3. Profr Joseph Cabrera, Civil Engineering Materials Unit in the University of Leeds, United Kingdom; Review of current relevant literature on abrasion for input on guide to durable concrete ACI 201.2R (American Concrete Institute 201 2R) Chapter 3 "Abrasion".
4. Taurun R Naik, Shiw S. Singh and Mohammad M Hossain; "Abrasion Resistance of High-Strenght Concrete made with Class C Flay Ash "ACI Materials Journal, November-December 1995, pg 649-659.
5. Ing. Hector Guajardo Berlanga; Tesis "Resistencia al rodamiento abrasivo de pastas, morteros y concretos", U.A.N.L. Septiembre 1995.
6. Payne, J. C.; Dransfield, J. M.- "The Influence of Admixtures and Concrete Society, London, Dec 1985, pg 89-105.
7. Nader Ghafoori and Beny M. Sukandar, "Resistencia a la Abrasión de Bloques de Concreto para Pavimentos". ACI Materials Journal, V. 92, No. 1, Jan-Feb. 1995 pg 25-36.

Apéndice

Designation: C 33 – 93

Standard Specification for Concrete Aggregates[1]

This standard is issued under the fixed designation C 33; 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 specification has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This specification defines the requirements for grading and quality of fine and coarse aggregate (other than lightweight or heavyweight aggregate) for use in concrete.[2]

1.2 This specification may be used by a contractor, concrete supplier, or other purchaser as part of the purchase document describing the material to be furnished.

NOTE 1—This specification is regarded as adequate to ensure satisfactory materials for most concrete. It is recognized that, for certain work or in certain regions, it may be either more or less restrictive than needed. For example, where aesthetics are important, more restrictive limits may be considered regarding impurities that would stain the concrete surface. The specifier should ascertain that aggregates specified are or can be made available in the area of the work, with regard to grading, physical, or chemical properties, or combination thereof.

1.3 This specification may also be referenced in project specifications to define the quality of aggregate, the nominal maximum size of the aggregate, and other specific grading requirements. Those responsible for selecting the proportions for the concrete mixture shall have the responsibility of determining the proportions of fine and coarse aggregate and the addition of blending aggregate sizes if required or approved.

1.4 *Units of Measurement:*

1.4.1 With regard to sieve sizes and the size of aggregate as determined by the use of testing sieves, the values in inch-pound units are shown for the convenience of the user; however, the standard sieve designation shown in parentheses is the standard value as stated in Specification E 11.

1.4.2 With regard to other units of measure, the values stated in inch-pound units are to be regarded as standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 29/C 29M Test Method for Unit Weight and Voids in Aggregate[3]

C 40 Test Method for Organic Impurities in Fine Aggregates for Concrete[3]

C 87 Test Method for Effect of Organic Impurities in Fine Aggregate on Strength of Mortar[3]

C 88 Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate[3]

C 117 Test Method for Materials Finer than 75-μm (No. 200) Sieve in Mineral Aggregates by Washing[3]

C 123 Test Method for Lightweight Particles in Aggregate[3]

C 125 Terminology Relating to Concrete and Concrete Aggregates[3]

C 131 Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[3]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregates[3]

C 142 Test Method for Clay Lumps and Friable Particles in Aggregates[3]

C 227 Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)[3]

C 289 Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)[3]

C 295 Guide for Petrographic Examination of Aggregates for Concrete[3]

C 330 Specification for Lightweight Aggregates for Structural Concrete[3]

C 331 Specification for Lightweight Aggregates for Concrete Masonry Units[3]

C 332 Specification for Lightweight Aggregates for Insulating Concrete[3]

C 342 Test Method for Potential Volume Change of Cement-Aggregate Combinations[3]

C 535 Test Method for Resistance to Degradation of Large-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine[3]

C 586 Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)[3]

C 637 Specification for Aggregates for Radiation-Shielding Concrete[3]

C 638 Descriptive Nomenclature of Constituents of Aggregates for Radiation-Shielding Concrete[3]

C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing[3]

D 75 Practice for Sampling Aggregates[4]

D 3665 Practice for Random Sampling of Construction Materials[4]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[5]

[1] This specification is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.20 on Normal Weight Aggregates.

Current edition approved Oct. 15, 1993. Published December 1993. Originally published as C 33 – 21 T. Last previous edition C 33 – 92a.

[2] For lightweight aggregates, see Specifications C 331, C 332, and C 330; for heavyweight aggregates see Specification C 637 and Descriptive Nomenclature C 638.

[3] *Annual Book of ASTM Standards*, Vol 04.02.

[4] *Annual Book of ASTM Standards*, Vol 04.03.

[5] *Annual Book of ASTM Standards*, Vol 14.02

TABLE 2 Grading Requirements for Coarse Aggregates

Size Number	Nominal Size (Sieves with Square Openings)	Amounts Finer than Each Laboratory Sieve (Square-Openings), Weight Percent												
		4 in (100 mm)	3½ in. (90 mm)	3 in. (75 mm)	2½ in. (63 mm)	2 in. (50 mm)	1½ in. (37.5 mm)	1 in. (25.0 mm)	¾ in. (19.0 mm)	½ in. (12.5 mm)	⅜ in (9.5 mm)	No. 4 (4 75 mm)	No. 8 (2.36 mm)	No 16 (1 18 mm)
1	3½ to 1½ in (90 to 37 5 mm)	100	90 to 100	.	25 to 60	..	0 to 15	...	0 to 5	...	..	.	..	.
2	2½ to 1½ in. (63 to 37 5 mm)		...	100	90 to 100	35 to 70	0 to 15	...	0 to 5	...	...	...	..	.
3	2 to 1 in (50 to 25.0 mm)		..	..	100	90 to 100	35 to 70	0 to 15	...	0 to 5	.	..	..	..
357	2 in to No. 4 (50 to 4 75 mm)	..	..	.	100	95 to 100	... 35	35 to 70	...	10 to 30	..	0 to 5	..	..
4	1½ to ¾ in (37 5 to 19 0 mm)		..	..		100	90 to 100	20 to 55	0 to 15	...	0 to 5	..	..	.
467	1½ in. to No. 4 (37 5 to 4 75 mm)	...	..	...	...	100	95 to 100	...	35 to 70	...	10 to 30	0 to 5	...	.
5	1 to ½ in. (25 0 to 12 5 mm)	...	...	..		..	100	90 to 100	20 to 55	0 to 10	0 to 5	..	...	.
56	1 to ⅜ in. (25 0 to 9.5 mm)	...	...	..	..	...	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	...	...
57	1 in. to No 4 (25 0 to 4 75 mm)	...	..	...	.	...	100	95 to 100	...	25 to 60	...	0 to 10	0 to 5	..
6	¾ to ⅜ in. (19 0 to 9.5 mm)	...	.	...	..	...	..	100	90 to 100	20 to 55	0 to 15	0 to 5	...	.
67	¾ in to No. 4 (19 0 to 4 75 mm)	...	...	...	..	..	..	100	90 to 100	...	20 to 55	0 to 10	0 to 5	...
7	½ in to No 4 (12.5 to 4.75 mm)	...	..	...	..	...	..	...	100	90 to 100	40 to 70	0 to 15	0 to 5	..
8	⅜ in to No 8 (9.5 to 2.36 mm)	...	...	...	..	...	...	...	...	100	85 to 100	10 to 30	0 to 10	0 to 5

6.3 The fine aggregate shall have not more than 45 % passing any sieve and retained on the next consecutive sieve of those shown in 6.1, and its fineness modulus shall be not less than 2.3 nor more than 3.1.

6.4 Fine aggregate failing to meet the sieve analysis and fineness modulus requirements of 6.1, 6.2, or 6.3, may be accepted provided that concrete made with similar fine aggregate from the same source has an acceptable performance record in similar concrete construction; or, in the absence of a demonstrable service record, provided that it is demonstrated that concrete of the class specified, made with the fine aggregate under consideration, will have relevant properties at least equal to those of concrete made with the same ingredients, with the exception that a reference fine aggregate be used which is selected from a source having an acceptable performance record in similar concrete construction.

NOTE 3—Fine aggregate that conforms to the grading requirements of a specification, prepared by another organization such as a state transportation agency, which is in general use in the area, should be considered as having a satisfactory service record with regard to those concrete properties affected by grading.

NOTE 4—Relevant properties are those properties of the concrete which are important to the particular application being considered. STP 169B[6] provides a discussion of important concrete properties.

6.5 For continuing shipments of fine aggregate from a given source, the fineness modulus shall not vary more than 0.20 from the base fineness modulus. The base fineness modulus shall be that value that is typical of the source. If necessary, the base fineness modulus may be changed when approved by the purchaser.

NOTE 5—The base fineness modulus should be determined from previous tests, or if no previous tests exist, from the average of the fineness modulus values for the first ten samples (or all preceding samples if less than ten) on the order. The proportioning of a concrete mixture may be dependent on the base fineness modulus of the fine aggregate to be used. Therefore, when it appears that the base fineness modulus is considerably different from the value used in the concrete mixture, a suitable adjustment in the mixture may be necessary.

7. Deleterious Substances

7.1 The amount of deleterious substances in fine aggregate shall not exceed the limits prescribed in Table 1.

7.2 *Organic Impurities:*

7.2.1 Fine aggregate shall be free of injurious amounts of organic impurities. Except as herein provided, aggregates subjected to the test for organic impurities and producing a color darker than the standard shall be rejected.

7.2.2 A fine aggregate failing in the test may be used, provided that the discoloration is due principally to the presence of small quantities of coal, lignite, or similar discrete particles.

7.2.3 A fine aggregate failing in the test may be used, provided that, when tested for the effect of organic impurities on strength of mortar, the relative strength at 7 days, calculated in accordance with Test Method C 87, is not less than 95 %.

7.3 Fine aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete, except that if such materials are present in injurious amounts, the fine aggregate may be used with a cement containing less than 0.60 % alkalies calculated as sodium oxide equivalent ($Na_2O + 0.658K_2O$) or with the

[6] *Significance of Tests and Properties of Concrete and Concrete Making Materials STP 169B*, ASTM, 1978

TABLE 3 Limits for Deleterious Substances and Physical Property Requirements of Coarse Aggregate for Concrete

NOTE—See Fig. 1 for the location of the weathering regions and Note 10 for guidance in using the map. The weathering regions are defined as follows:

(S) Severe Weathering Region—A cold climate where concrete is exposed to deicing chemicals or other aggressive agents, or where concrete may become saturated by continued contact with moisture or free water prior to repeated freezing and thawing.

(M) Moderate Weathering Region—A climate where occasional freezing is expected, but where concrete in outdoor service will not be continually exposed to freezing and thawing in the presence of moisture or to deicing chemicals.

(N) Negligible Weathering Region—A climate where concrete is rarely exposed to freezing in the presence of moisture

Class Designation	Type or Location of Concrete Construction	Maximum Allowable, %						
		Clay Lumps and Friable Particles	Chert[C] (Less Than 2.40 sp gr SSD)	Sum of Clay Lumps, Friable Particles, and Chert (Less Than 2.40 sp gr SSD)[C]	Material Finer Than No. 200 (75-μm) Sieve	Coal and Lignite	Abrasion[A]	Magnesium Sulfate Soundness (5 cycles)[B]
		Severe Weathering Regions						
1S	Footings, foundations, columns and beams not exposed to the weather, interior floor slabs to be given coverings	10.0	...	...	1.0[D]	1.0	50	...
2S	Interior floors without coverings	5.0	...	...	1.0[D]	0.5	50	...
3S	Foundation walls above grade, retaining walls, abutments, piers, girders, and beams exposed to the weather	5.0	5.0	7.0	1.0[D]	0.5	50	18
4S	Pavements, bridge decks, driveways and curbs, walks, patios, garage floors, exposed floors and porches, or waterfront structures, subject to frequent wetting	3.0	5.0	5.0	1.0[D]	0.5	50	18
5S	Exposed architectural concrete	2.0	3.0	3.0	1.0[D]	0.5	50	18
		Moderate Weathering Regions						
1M	Footings, foundations, columns, and beams not exposed to the weather, interior floor slabs to be given coverings	10.0	...	...	1.0[D]	1.0	50	...
2M	Interior floors without coverings	5.0	...	...	1.0[D]	0.5	50	...
3M	Foundation walls above grade, retaining walls, abutments, piers, girders, and beams exposed to the weather	5.0	8.0	10.0	1.0[D]	0.5	50	18
4M	Pavements, bridge decks, driveways and curbs, walks, patios, garage floors, exposed floors and porches, or waterfront structures subject to frequent wetting	5.0	5.0	7.0	1.0[D]	0.5	50	18
5M	Exposed architectural concrete	3.0	3.0	5.0	1.0[D]	0.5	50	18
		Negligible Weathering Regions						
1N	Slabs subject to traffic abrasion, bridge decks, floors, sidewalks, pavements	5.0	...	...	1.0[D]	0.5	50	...
2N	All other classes of concrete	10.0	...	...	1.0[D]	1.0	50	...

[A] Crushed air-cooled blast-furnace slag is excluded from the abrasion requirements. The rodded or jigged unit weight of crushed air-cooled blast-furnace slag shall be not less than 70 lb/ft^3 (1120 kg/m^3). The grading of slag used in the unit weight test shall conform to the grading to be used in the concrete. Abrasion loss of gravel, crushed gravel, or crushed stone shall be determined on the test size or sizes most nearly corresponding to the grading or gradings to be used in the concrete. When more than one grading is to be used, the limit on abrasion loss shall apply to each.

[B] The allowable limits for soundness shall be 12 % if sodium sulfate is used.

[C] These limitations apply only to aggregates in which chert appears as an impurity. They are not applicable to gravels that are predominantly chert. Limitations on soundness of such aggregates must be based on service records in the environment in which they are used.

[D] This percentage may be increased under either of the following conditions: (1) if the material finer than the No. 200 (75-μm) sieve is essentially free of clay or shale the percentage may be increased to 1.5, or (2) if the source of the fine aggregate to be used in the concrete is known to contain less than the specified maximum amount passing the No. 200 (75-μm) sieve (Table 1) the percentage limit (L) on the amount in the coarse aggregate may be increased to $L = 1 + [(P)/(100 - P)] (T - A)$, where P = percentage of sand in the concrete as a percent of total aggregate, T = the Table 1 limit for the amount permitted in the fine aggregate, and A = the actual amount in the fine aggregate. (This provides a weighted calculation designed to limit the maximum mass of material passing the No. 200 (75-μm) sieve in the concrete to that which would be obtained if both the fine and coarse aggregate were supplied at the maximum tabulated percentage for each of these ingredients.)

addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.)

8. Soundness

8.1 Except as provided in 8.2 and 8.3, fine aggregate subjected to five cycles of the soundness test shall have a weighted average loss not greater than 10 % when sodium sulfate is used or 15 % when magnesium sulfate is used.

8.2 Fine aggregate failing to meet the requirements of 8.1 may be accepted, provided that concrete of comparable properties, made from similar aggregate from the same source, has given satisfactory service when exposed to weathering similar to that to be encountered.

8.3 Fine aggregate not having a demonstrable service record and failing to meet the requirements of 8.1 may be accepted, provided it gives satisfactory results in concrete subjected to freezing and thawing tests (see Test Method C 666).

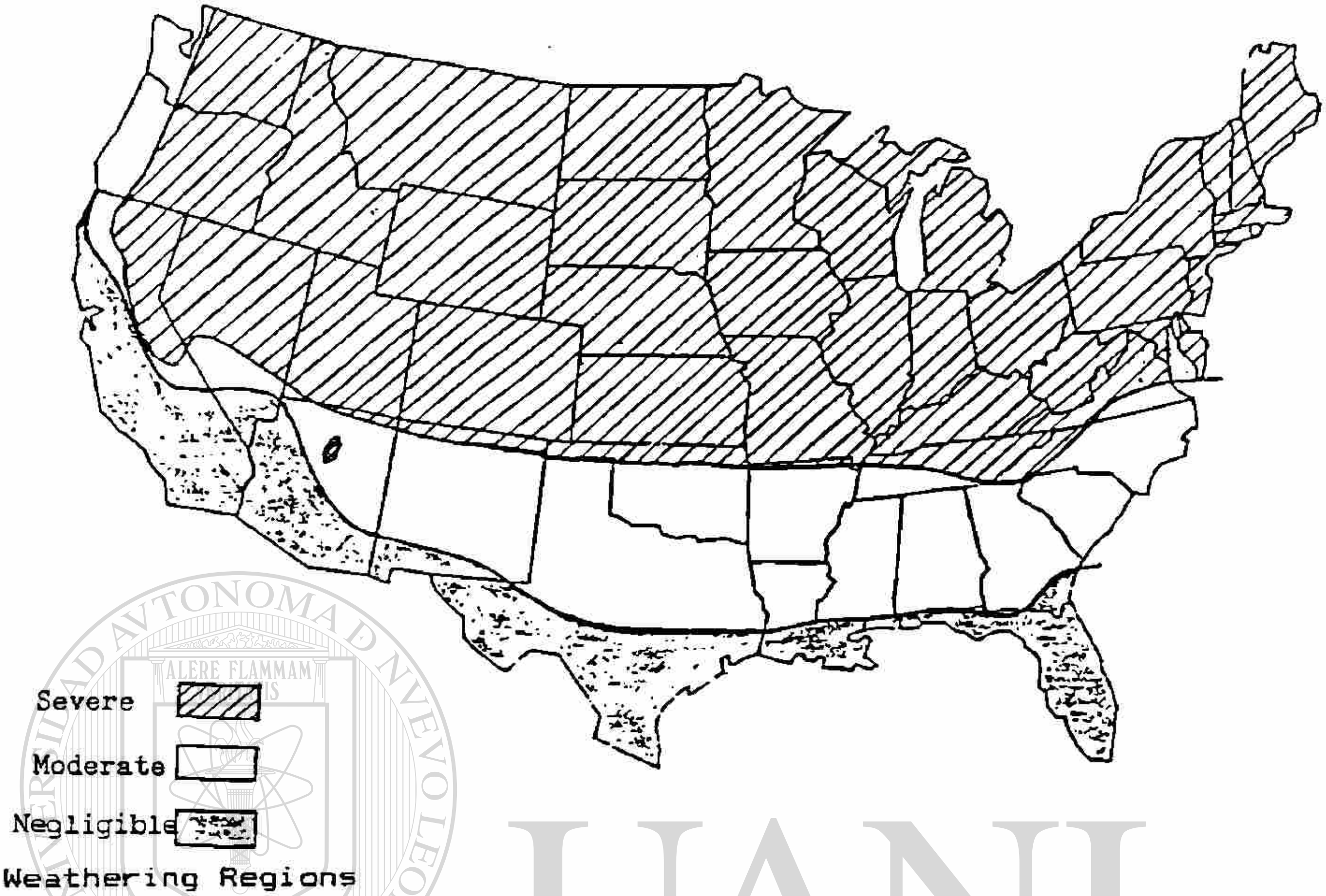


FIG. 1 Location of Weathering Regions

COARSE AGGREGATE

9. General Characteristics

9.1 Coarse aggregate shall consist of gravel, crushed gravel, crushed stone, air-cooled blast furnace slag, or crushed hydraulic-cement concrete, or a combination thereof, conforming to the requirements of this specification.

NOTE 6—Although crushed hydraulic-cement concrete has been used as an aggregate with reported satisfactory results, its use may require some additional precautions. Mixing water requirements may be increased because of the harshness of the aggregate. Partially deteriorated concrete, used as aggregate, may reduce freeze-thaw resistance, affect air void properties or degrade during handling, mixing, or placing. Crushed concrete may have constituents that would be susceptible to alkali-aggregate reactivity or sulfate attack in the new concrete or may bring sulfates, chlorides, or organic material to the new concrete in its pore structure.

10. Grading

10.1 Coarse aggregates shall conform to the requirements prescribed in Table 2 for the size number specified.

NOTE 7—The ranges shown in Table 2 are by necessity very wide in order to accommodate nationwide conditions. For quality control of any specific operation, a producer should develop an average gradation for the particular source and production facilities, and control the gradation within reasonable tolerances from this average. Where coarse aggregate sizes numbers 357 or 467 are used, the aggregate should be furnished in at least two separate sizes.

11. Deleterious Substances

11.1 Except for the provisions of 11.3, the limits given in Table 3 shall apply for the class of coarse aggregate designated in the purchase order or other document (Notes 8 and 9). If the class is not specified, the requirements for Class 3S, 3M, or 1N shall apply in the severe, moderate, and negligible weathering regions, respectively (see Table 3 and Fig. 1).

NOTE 8—The specifier of the aggregate should designate the class of coarse aggregate to be used in the work, based on weathering severity, abrasion, and other factors of exposure. (See Table 3 and Fig. 1.) The limits for coarse aggregate corresponding to each class designation are expected to ensure satisfactory performance in concrete for the respective type and location of construction. Selecting a class with unduly restrictive limits may result in unnecessary cost if materials meeting those requirements are not locally available. Selecting a class with lenient limits may result in unsatisfactory performance and premature deterioration of the concrete. While concrete in different parts of a single structure may be adequately made with different classes of coarse aggregate, the specifier may wish to require the coarse aggregate for all concrete to conform to the same more restrictive class to reduce the chance of furnishing concrete with the wrong class of aggregate, especially on smaller projects.

NOTE 9—For coarse aggregate in concrete exposed to weathering, the map with the weathering regions shown in Fig. 1 is intended to serve only as a guide to probable weathering severity. Those undertaking construction, especially near the boundaries of weathering regions, should consult local weather bureau records for amount of winter precipitation and number of freeze-thaw cycles to be expected, for determining the weathering severity for establishing test requirements of the coarse aggregate. For construction at altitudes exceeding 5000 ft

(1520 m) above sea level, the likelihood of more severe weathering than indicated by the map should be considered. In arid areas, severity of weathering may be less than that indicated. In either case, the definitions of weathering severity in Table 3 would govern. If there is doubt in choosing between two regions, select the more severe weathering region.

11.2 Coarse aggregate for use in concrete that will be subject to wetting, extended exposure to humid atmosphere, or contact with moist ground shall not contain any materials that are deleteriously reactive with the alkalies in the cement in an amount sufficient to cause excessive expansion of mortar or concrete except that if such materials are present in injurious amounts, the coarse aggregate may be used with a cement containing less than 0.60 % alkalies calculated as sodium oxide equivalent (Na_2O + $0.658K_2O$) or with the addition of a material that has been shown to prevent harmful expansion due to the alkali-aggregate reaction. (See Appendix X1.).

11.3 Coarse aggregate having test results exceeding the limits specified in Table 3 may be accepted provided that concrete made with similar aggregate from the same source has given satisfactory service when exposed in a similar manner to that to be encountered; or, in the absence of a demonstrable service record, provided that the aggregate produces concrete having satisfactory relevant properties (see Note 4).

METHODS OF SAMPLING AND TESTING

12. Methods of Sampling and Testing

12.1 Sample and test the aggregates in accordance with the following methods, except as otherwise provided in this specification. Make the required tests on test specimens that comply with requirements of the designated test methods. The same test specimen may be used for sieve analysis and for determination of material finer than the No. 200 (75-µm) sieve. Separated sizes from the sieve analysis may be used in preparation of samples for soundness or abrasion tests. For determination of all other tests and for evaluation of potential alkali reactivity where required, use independent test specimens.

12.1.1 *Sampling*—Practice D 75 and Practice D 3665.

12.1.2 *Grading and Fineness Modulus*—Test Method C 136.

12.1.3 *Amount of Material Finer than No. 200 (75-µm) Sieve*—Test Method C 117.

12.1.4 *Organic Impurities*—Test Method C 40.

12.1.5 *Effect of Organic Impurities on Strength*—Test Method C 87.

12.1.6 *Soundness*—Test Method C 88.

12.1.7 *Clay Lumps and Friable Particles*—Test Method C 142.

12.1.8 *Coal and Lignite*—Test Method C 123, using a liquid of 2.0 specific gravity to remove the particles of coal and lignite. Only material that is brownish-black, or black, shall be considered coal or lignite. Coke shall not be classed as coal or lignite.

12.1.9 *Weight of Slag*—Test Method C 29.

12.1.10 *Abrasion of Coarse Aggregate*—Test Method C 131 or Test Method C 535.

12.1.11 *Reactive Aggregates*—See Appendix X1.

12.1.12 *Freezing and Thawing*—Procedures for making freezing and thawing tests of concrete are described in Test Method C 666.

12.1.13 *Chert*—Test Method C 123 is used to identify particles in a sample of coarse aggregate lighter than 2.40 specific gravity, and Practice C 295 to identify which of the particles in the light fraction are chert.

13. Keywords

13.1 aggregates; coarse aggregate; concrete aggregates; fine aggregate

APPENDIX

(Nonmandatory Information)

X1. METHODS FOR EVALUATING POTENTIAL REACTIVITY OF AN AGGREGATE

X1.1 A number of methods for detecting potential reactivity have been proposed. However, they do not provide quantitative information on the degree of reactivity to be expected or tolerated in service. Therefore, evaluation of potential reactivity of an aggregate should be based upon judgment and on the interpretation of test data and examination of concrete structures containing a combination of fine and coarse aggregates and cements for use in the new work. Results of the following tests may assist in making the evaluation:

X1.1.1 *Practice C 295*—Certain materials are known to be reactive with the alkalies in cements. These include the following forms of silica: opal, chalcedony, tridymite, and cristobalite; intermediate to acid (silica-rich) volcanic glass such as is likely to occur in rhyolite, andesite, or dacite; certain zeolites such as heulandite; and certain constituents of some phyllites. Determination of the presence and quantities of these materials by petrographic examination is helpful in evaluating potential alkali reactivity. Some of these materials render an aggregate deleteriously reactive when present in quantities as little as 1.0 % or even less.

X1.1.2 *Test Method C 289*—In this test method, aggregates represented by points lying to the right of the solid line of Fig. 2 of Test Method C 289 usually should be considered potentially reactive.

X1.1.2.1 If R_c exceeds 70, the aggregate is considered potentially reactive if S_c is greater than R_c.

X1.1.2.2 If R_c is less than 70, the aggregate is considered potentially reactive if S_c is greater than 35 + (R_c 2).

X1.1.2.3 These criteria conform to the solid line curve given in Fig. 2 of Test Method C 289. The test can be made quickly and, while not completely reliable in all cases, provides helpful information, especially where results of the more time-consuming tests are not available.

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X1.1.3 *Test Method C 227*—The results of this test method when made with a high-alkali cement, furnish information on the likelihood of harmful reactions occurring. The alkali content of the cement should be substantially above 0.6 %, and preferably above 0.8 %, expressed as sodium oxide. Combinations of aggregate and cement that have produced excessive expansions in this test usually should be considered potentially reactive. While the line of demarcation between nonreactive and reactive combinations is not clearly defined, expansion is generally considered to be excessive if it exceeds 0.05 % at 3 months or 0.10 % at 6 months. Expansions greater than 0.05 % at 3 months should not be considered excessive where the 6-month expansion remains below 0.10 %. Data for the 3-month tests should be considered only when 6-month results are not available.

X1.1.4 *Test Method C 342*—This test method is intended primarily for research concerning the potential expansion of cement-aggregate combinations subjected to variations of temperature and water saturation during storage under prescribed conditions of test. Its use is mainly by those interested in research on aggregates that are found in parts of Kansas, Nebraska, Iowa and possibly other adjoining areas.

X1.1.4.1 In addition to its usefulness in research, this test method has been found useful in the selection of aggregates of the so-called "sand-gravel" type found mainly in some parts of Kansas, Nebraska and Iowa, which contain very little coarse material; generally 5 to 15 % retained on the No. 4 (4.75-mm) sieve. Much work has been done on the problems of using these aggregates successfully in concrete and is reported in summary in the "Final Report of Cooperative Tests of Proposed Tentative Method of Test for Potential Volume Change of Cement-Aggregate Combinations," Appendix to Committee C-9 Report, Proceedings, ASTM, Volume 54, 1954, p. 356. It indicates that cement-aggregate combinations tested by this procedure in which expansion equals or exceeds 0.200 % at an age of 1 year may be considered unsatisfactory for use in concrete exposed to wide variations of temperature and degree of saturation with water. In that geographical region, the problem has been reduced through the use of partial replacement of the "sand-gravel" with limestone coarse aggregate.

X1.1.5 *Potential Reactivity of Carbonate Aggregates*—The reaction of the dolomite in certain carbonate rocks with alkalies in portland cement paste has been found to be associated with deleterious expansion of concrete containing such rocks as coarse aggregate. Carbonate rocks capable of such reaction possess a characteristic texture and composition. The characteristic texture is that in which relatively large crystals of dolomite are scattered in a finer-grained matrix of calcite and clay. The characteristic composition is that in which the carbonate portion consists of substantial amounts of both dolomite and calcite, and the acid-insoluble residue contains a significant amount of clay. Except in certain areas, such rocks are of relatively infrequent occurrence and seldom make up a significant proportion of the material present in a deposit of rock being considered for use in making aggregate for concrete. Test Method C 586 has been successfully used in (*1*) research and (*2*) preliminary screening of aggregate sources to indicate the presence of material with a potential for deleterious expansions when used in concrete.

Designation: C 39 – 96

Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens[1]

This standard is issued under the fixed designation C 39; 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 test method has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This test method covers determination of compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. It is limited to concrete having a unit weight in excess of 50 lb/ft^3 (800 kg/m^3).

1.2 The values stated in inch-pound units are to be regarded as the standard.

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.*

1.4 The text of this standard references notes which provide explanatory material. These notes shall not be considered as requirements of the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 873 Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds[2]

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[2]

C 1231 Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders[2]

E 4 Practices for Force Verification of Testing Machines[3]

E 74 Practice for Calibration of Force-Measuring Instruments for Verifying the Load Indication of Testing Machines[3]

Manual of Aggregate and Concrete Testing[2]

2.2 *American Concrete Institute:*

CP-16 Concrete Laboratory Testing Technician, Grade I.[4]

3. Summary of Test Method

3.1 This test method consists of applying a compressive axial load to molded cylinders or cores at a rate which is within a prescribed range until failure occurs. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen.

4. Significance and Use

4.1 Care must be exercised in the interpretation of the significance of compressive strength determinations by this test method since strength is not a fundamental or intrinsic property of concrete made from given materials. Values obtained will depend on the size and shape of the specimen, batching, mixing procedures, the methods of sampling, molding, and fabrication and the age, temperature, and moisture conditions during curing.

4.2 This test method is used to determine compressive strength of cylindrical specimens prepared and cured in accordance with Practices C 31, C 192, C 617 and C 1231 and Test Methods C 42 and C 873.

4.3 The results of this test method are used as a basis for quality control of concrete proportioning, mixing, and placing operations; determination of compliance with specifications; control for evaluating effectiveness of admixtures and similar uses.

4.4 The individual who tests concrete cylinders for acceptance testing shall have demonstrated a knowledge and ability to perform the test procedure equivalent to the minimum guidelines for certification of Concrete Laboratory Technician, Level I, in accordance with ACI CP-16.

NOTE 1—The testing laboratory performing this test method should be evaluated in accordance with Practice C 1077.

5. Apparatus

5.1 *Testing Machine*—The testing machine shall be of a type having sufficient capacity and capable of providing the rates of loading prescribed in 7.5.

5.1.1 Verification of calibration of the testing machines in accordance with Practices E 4 is required under the following conditions:

5.1.1.1 After an elapsed interval since the previous verifi-

[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing Concrete for Strength.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

[4] Available from American Concrete Institute, P.O. Box 19150, Detroit, MI 48219-0150.

cation of 18 months maximum, but preferably after an interval of 12 months,

5.1.1.2 On original installation or relocation of the machine,

5.1.1.3 Immediately after making repairs or adjustments that affect the operation of the force applying system of the machine or the values displayed on the load indicating system, except for zero adjustments that compensate for the mass of bearing blocks, or specimen, or both, or

5.1.1.4 Whenever there is reason to doubt the accuracy of the results, without regard to the time interval since the last verification.

5.1.2 *Design*—The design of the machine must include the following features:

5.1.2.1 The machine must be power operated and must apply the load continuously rather than intermittently, and without shock. If it has only one loading rate (meeting the requirements of 7.5), it must be provided with a supplemental means for loading at a rate suitable for verification. This supplemental means of loading may be power or hand operated.

NOTE 2—High-strength concrete cylinders rupture more intensely than normal strength cylinders. As a safety precaution, it is recommended that the testing machines should be equipped with protective fragment guards.

5.1.2.2 The space provided for test specimens shall be large enough to accommodate, in a readable position, an elastic calibration device which is of sufficient capacity to cover the potential loading range of the testing machine and which complies with the requirements of Practice E 74.

NOTE 3—The types of elastic calibration devices most generally available and most commonly used for this purpose are the circular proving ring or load cell.

5.1.3 *Accuracy*—The accuracy of the testing machine shall be in accordance with the following provisions:

5.1.3.1 The percentage of error for the loads within the proposed range of use of the testing machine shall not exceed ±1.0 % of the indicated load.

5.1.3.2 The accuracy of the testing machine shall be verified by applying five test loads in four approximately equal increments in ascending order. The difference between any two successive test loads shall not exceed one third of the difference between the maximum and minimum test loads.

5.1.3.3 The test load as indicated by the testing machine and the applied load computed from the readings of the verification device shall be recorded at each test point. Calculate the error, E, and the percentage of error, E_p, for each point from these data as follows:

$$E = A - B$$
$$E_p = 100(A - B)/B$$

where:

A = load, lbf (or N) indicated by the machine being verified, and

B = applied load, lbf (or N) as determined by the calibrating device.

5.1.3.4 The report on the verification of a testing machine shall state within what loading range it was found to conform to specification requirements rather than reporting a blanket acceptance or rejection. In no case shall the loading range be stated as including loads below the value which is 100 time the smallest change of load estimable on the load-indicatin mechanism of the testing machine or loads within tha portion of the range below 10 % of the maximum rang capacity.

5.1.3.5 In no case shall the loading range be stated a including loads outside the range of loads applied during th verification test.

5.1.3.6 The indicated load of a testing machine shall no be corrected either by calculation or by the use of calibration diagram to obtain values within the requirec permissible variation.

5.2 The testing machine shall be equipped with two steel bearing blocks with hardened faces (Note 4), one of which is a spherically seated block that will bear on the upper surface of the specimen, and the other a solid block on which the specimen shall rest. Bearing faces of the blocks shall have a minimum dimension at least 3 % greater than the diameter of the specimen to be tested. Except for the concentric circles described below, the bearing faces shall not depart from a plane by more than 0.001 in. (0.025 mm) in any 6 in. (152 mm) of blocks 6 in. in diameter or larger, or by more than 0.001 in. in the diameter of any smaller block; and new blocks shall be manufactured within one half of this tolerance. When the diameter of the bearing face of the spherically seated block exceeds the diameter of the specimen by more than ½ in. (13 mm), concentric circles not more than 1/32 in. (0.8 mm) deep and not more than 3/64 in. (1.2 mm) wide shall be inscribed to facilitate proper centering.

NOTE 4—It is desirable that the bearing faces of blocks used for compression testing of concrete have a Rockwell hardness of not less than 55 HRC.

5.2.1 Bottom bearing blocks shall conform to the following requirements:

5.2.1.1 The bottom bearing block is specified for the purpose of providing a readily machinable surface for maintenance of the specified surface conditions (Note 5). The top and bottom surfaces shall be parallel to each other. If the testing machine is so designed that the platen itself is readily maintained in the specified surface condition, a bottom block is not required. Its least horizontal dimension shall be at least 3 % greater than the diameter of the specimen to be tested. Concentric circles as described in 5.2 are optional on the bottom block.

NOTE 5—The block may be fastened to the platen of the testing machine.

5.2.1.2 Final centering must be made with reference to the upper spherical block. When the lower bearing block is used to assist in centering the specimen, the center of the concentric rings, when provided, or the center of the block itself must be directly below the center of the spherical head. Provision shall be made on the platen of the machine to assure such a position.

5.2.1.3 The bottom bearing block shall be at least 1 in. (25 mm) thick when new, and at least 0.9 in. (22.5 mm) thick after any resurfacing operations.

5.2.2 The spherically seated bearing block shall conform to the following requirements:

5.2.2.1 The maximum diameter of the bearing face of the

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suspended spherically seated block shall not exceed the values given below:

Diameter of Test Specimens, in. (mm)	Maximum Diameter of Bearing Face, in. (mm)
2 (51)	4 (102)
3 (76)	5 (127)
4 (102)	6½ (165)
6 (152)	10 (254)
8 (203)	11 (279)

NOTE 6—Square bearing faces are permissible, provided the diameter of the largest possible inscribed circle does not exceed the above diameter.

5.2.2.2 The center of the sphere shall coincide with the surface of the bearing face within a tolerance of ±5 % of the radius of the sphere. The diameter of the sphere shall be at least 75 % of the diameter of the specimen to be tested.

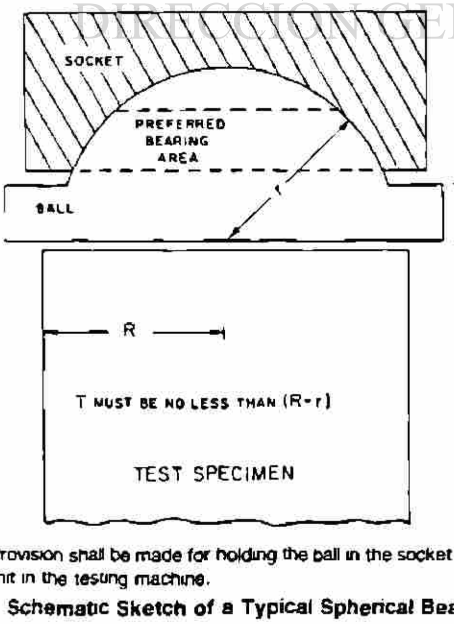
5.2.2.3 The ball and the socket must be so designed by the manufacturer that the steel in the contact area does not permanently deform under repeated use, with loads up to 12 000 psi (82.7 MPa) on the test specimen.

NOTE 7—The preferred contact area is in the form of a ring (described as preferred "bearing" area) as shown on Fig. 1.

5.2.2.4 The curved surfaces of the socket and of the spherical portion shall be kept clean and shall be lubricated with a petroleum-type oil such as conventional motor oil, not with a pressure type grease. After contacting the specimen and application of small initial load, further tilting of the spherically seated block is not intended and is undesirable.

5.2.2.5 If the radius of the sphere is smaller than the radius of the largest specimen to be tested, the portion of the bearing face extending beyond the sphere shall have a thickness not less than the difference between the radius of the sphere and radius of the specimen. The least dimension of the bearing face shall be at least as great as the diameter of the sphere (see Fig. 1).

5.2.2.6 The movable portion of the bearing block shall be held closely in the spherical seat, but the design shall be such that the bearing face can be rotated freely and tilted at least 4° in any direction.



NOTE—Provision shall be made for holding the ball in the socket and for holding the entire unit in the testing machine.

FIG. 1 Schematic Sketch of a Typical Spherical Bearing Block

5.3 *Load Indication:*

5.3.1 If the load of a compression machine used in concrete testing is registered on a dial, the dial shall be provided with a graduated scale that is readable to at least the nearest 0.1 % of the full scale load (Note 8). The dial shall be readable within 1 % of the indicated load at any given load level within the loading range. In no case shall the loading range of a dial be considered to include loads below the value that is 100 times the smallest change of load that can be read on the scale. The scale shall be provided with a graduation line equal to zero and so numbered. The dial pointer shall be of sufficient length to reach the graduation marks; the width of the end of the pointer shall not exceed the clear distance between the smallest graduations. Each dial shall be equipped with a zero adjustment located outside the dialcase and easily accessible from the front of the machine while observing the zero mark and dial pointer. Each dial shall be equipped with a suitable device that at all times until reset, will indicate to within 1 % accuracy the maximum load applied to the specimen.

NOTE 8—Readability is considered to be 1/50 in. (0.5 mm) along the arc described by the end of the pointer. Also, one half of a scale interval is readable with reasonable certainty when the spacing on the load indicating mechanism is between 1/25 in. (1 mm) and 1/16 in. (1.6 mm). When the spacing is between 1/16 in. and 1/8 in. (3.2 mm), one third of a scale interval is readable with reasonable certainty. When the spacing is 1/8 in. or more, one fourth of a scale interval is readable with reasonable certainty.

5.3.2 If the testing machine load is indicated in digital form, the numerical display must be large enough to be easily read. The numerical increment must be equal to or less than 0.10 % of the full scale load of a given loading range. In no case shall the verified loading range include loads less than the minimum numerical increment multiplied by 100. The accuracy of the indicated load must be within 1.0 % for any value displayed within the verified loading range. Provision must be made for adjusting to indicate true zero at zero load. There shall be provided a maximum load indicator that at all times until reset will indicate within 1 % system accuracy the maximum load applied to the specimen.

6. Specimens

6.1 Specimens shall not be tested if any individual diameter of a cylinder differs from any other diameter of the same cylinder by more than 2 %.

NOTE 9—This may occur when single use molds are damaged or deformed during shipment, when flexible single use molds are deformed during molding or when a core drill deflects or shifts during drilling.

6.2 Neither end of compressive test specimens when tested shall depart from perpendicularity to the axis by more than 0.5° (approximately equivalent to 1/8 in. in 12 in. (3 mm in 300 mm)). The ends of compression test specimens that are not plane within 0.002 in. (0.050 mm) shall be sawed or ground to meet that tolerance, or capped in accordance with either Practice C 617 or Practice C 1231. The diameter used for calculating the cross-sectional area of the test specimen shall be determined to the nearest 0.01 in. (0.25 mm) by averaging two diameters measured at right angles to each other at about midheight of the specimen.

6.3 The number of individual cylinders measured for determination of average diameter may be reduced to one for each ten specimens or three specimens per day, whichever is greater, if all cylinders are known to have been made from a single lot of reusable or single-use molds which consistently produce specimens with average diameters within a range of 0.02 in. (0.51 mm). When the average diameters do not fall within the range of 0.02 in. or when the cylinders are not made from a single lot of molds, each cylinder tested must be measured and the value used in calculation of the unit compressive strength of that specimen. When the diameters are measured at the reduced frequency, the cross-sectional areas of all cylinders tested on that day shall be computed from the average of the diameters of the three or more cylinders representing the group tested that day.

6.4 The length shall be measured to the nearest 0.05 *D* when the length to diameter ratio is less than 1.8, or more than 2.2, or when the volume of the cylinder is determined from measured dimensions.

7. Procedure

7.1 Compression tests of moist-cured specimens shall be made as soon as practicable after removal from moist storage.

7.2 Test specimens shall be kept moist by any convenient method during the period between removal from moist storage and testing. They shall be tested in the moist condition.

7.3 All test specimens for a given test age shall be broken within the permissible time tolerances prescribed as follows:

Test Age	Permissible Tolerance
24 h	± 0.5 h or 2.1 %
3 days	2 h or 2.8 %
7 days	6 h or 3.6 %
28 days	20 h or 3.0 %
90 days	2 days 2.2 %

7.4 *Placing the Specimen*—Place the plain (lower) bearing block, with its hardened face up, on the table or platen of the testing machine directly under the spherically seated (upper) bearing block. Wipe clean the bearing faces of the upper and lower bearing blocks and of the test specimen and place the test specimen on the lower bearing block. Carefully align the axis of the specimen with the center of thrust of the spherically seated block.

7.4.1 *Zero Verification and Block Seating*—Prior to testing the specimen, verify that the load indicator is set to zero. In cases where the indicator is not properly set to zero, adjust the indicator (Note 10). As the spherically seated block is brought to bear on the specimen, rotate its movable portion gently by hand so that uniform seating is obtained.

NOTE 10—The technique used to verify and adjust load indicator to zero will vary depending on the machine manufacturer. Consult your owner's manual or compression machine calibrator for the proper technique.

7.5 *Rate of Loading*—Apply the load continuously and without shock.

7.5.1 For testing machines of the screw type, the moving head shall travel at a rate of approximately 0.05 in. (1.3 mm)/min when the machine is running idle. For hydraulically operated machines, the load shall be applied at a rate of movement (platen to crosshead measurement) corresponding to a loading rate on the specimen within the range of 20 to 50 psi/s (0.14 to 0.34 MPa/s). The designated rate of movement shall be maintained at least during the latter half of the anticipated loading phase of the testing cycle.

7.5.2 During the application of the first half of the anticipated loading phase a higher rate of loading shall be permitted.

7.5.3 Make no adjustment in the rate of movement of the platen at any time while a specimen is yielding rapidly immediately before failure.

7.6 Apply the load until the specimen fails, and record the maximum load carried by the specimen during the test. Note the type of failure and the appearance of the concrete.

8. Calculation

8.1 Calculate the compressive strength of the specimen by dividing the maximum load carried by the specimen during the test by the average cross-sectional area determined as described in Section 6 and express the result to the nearest 10 psi (69 kPa).

8.2 If the specimen length to diameter ratio is less than 1.8, correct the result obtained in 8.1 by multiplying by the appropriate correction factor shown in the following table:

L/D:	1.75	1.50	1.25	1.00
Factor:	0.98	0.96	0.93	0.87 (Note 11)

NOTE 11—These correction factors apply to lightweight concrete weighing between 100 and 120 lb/ft^3 (1600 and 1920 kg/m^3) and to normal weight concrete. They are applicable to concrete dry or soaked at the time of loading. Values not given in the table shall be determined by interpolation. The correction factors are applicable for nominal concrete strengths from 2000 to 6000 psi (13.8 to 41.4 MPa).

9. Report

9.1 Report the following information:

9.1.1 Identification number,

9.1.2 Diameter (and length, if outside the range of 1.8*D* to 2.2*D*), in inches or millimetres,

9.1.3 Cross-sectional area, in square inches or square centimetres,

9.1.4 Maximum load, in pounds-force or newtons,

9.1.5 Compressive strength calculated to the nearest 10 psi or 69 kPa,

9.1.6 Type of fracture, if other than the usual cone (see Fig. 2),

9.1.7 Defects in either specimen or caps, and

9.1.8 Age of specimen.

10. Precision and Bias

10.1 *Precision*—The single operator precision of tests of individual 6 by 12 in. (150 by 300 mm) cylinders made from a well-mixed sample of concrete is given for cylinders made in a laboratory environment and under normal field conditions (see 10.1.1).

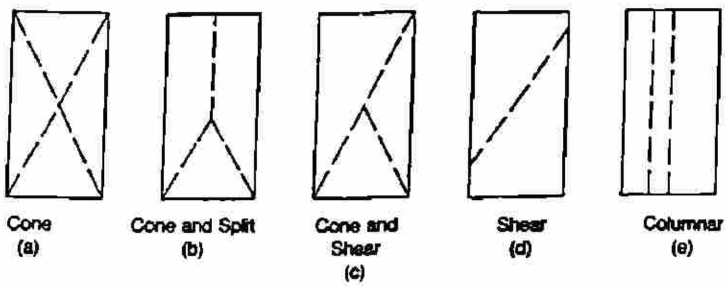


FIG. 2 Sketches of Types of Fracture

	Coefficient of Variation[A]	Acceptable Range of[A] 2 results	3 results
Single operator			
Laboratory conditions	2.37 %	6.6 %	7.8 %
Field conditions	2.87 %	8.0 %	9.5 %

[A] These numbers represent respectively the (1s) and (d2s) limits as described in Practice C 670.

10.1.1 The values given are applicable to 6 by 12 in. (150 by 300 mm) cylinders with compressive strength between 2000 and 8000 psi (12 to 55 MPa). They are derived from CCRL concrete reference sample data for laboratory conditions and a collection of 1265 test reports from 225 commercial testing laboratories in 1978.[5]

NOTE 12—Subcommittee C09.03.01 will re-examine recent CCRL Concrete Reference Sample Program data and field test data to see if these values are representative of current practice and if they can be extended to cover a wider range of strengths and specimen sizes.

10.2 *Bias*—Since there is no accepted reference material, no statement on bias is being made.

[5] Research report RR:C09-1006 is on file at ASTM Headquarters.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Designation: C 192/C 192M – 95

Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory[1]

This standard is issued under the fixed designation C 192/C 192M; 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 practice has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This practice covers procedures for making and curing test specimens of concrete in the laboratory under accurate control of materials and test conditions using concrete that can be consolidated by rodding or vibration as described herein.

1.2 The values stated in either inch-pound units or SI units shall be regarded separately as standard. The SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of each other. Combining values from the two systems may result in nonconformance.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 31 Practice for Making and Curing Concrete Test Specimens in the Field[2]

C 70 Test Method for Surface Moisture in Fine Aggregate[2]

C 125 Terminology Relating to Concrete and Concrete Aggregates[2]

C 127 Test Method for Specific Gravity and Absorption of Coarse Aggregate[2]

C 128 Test Method for Specific Gravity and Absorption of Fine Aggregate[2]

C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]

C 143 Test Method for Slump of Hydraulic Cement Concrete[2]

C 172 Practice for Sampling Freshly Mixed Concrete[2]

C 173 Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method[2]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 470 Specification for Molds for Forming Concrete Test Cylinders Vertically[2]

C 511 Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[3]

C 566 Test Method for Total Moisture Content of Aggregate by Drying[2]

C 567 Test Method for Unit Weight of Structural Lightweight Concrete[2]

C 617 Practice for Capping Cylindrical Concrete Specimens[2]

C 1064 Test Method for Temperature of Freshly Mixed Portland-Cement Concrete[2]

C 1077 Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation[2]

E 171 Specification for Standard Atmospheres for Conditioning and Testing Materials[5]

2.2 *NIST Document:*[6]

Handbook 44 Specifications, Tolerances, and other Technical Requirements for Commercial Weighing and Measuring Devices

2.3 *American Concrete Institute Publications:*[7]

211.3 Practice for Selecting Proportions for No-Slump Concrete

3. Significance and Use

3.1 This practice provides standardized requirements for preparation of materials, mixing concrete, and making and curing concrete test specimens under laboratory conditions.

3.2 If specimen preparation is controlled as stipulated herein, the specimens may be used to develop information for the following purposes:

3.2.1 Mixture proportioning for project concrete,

3.2.2 Evaluation of different mixtures and materials,

3.2.3 Correlation with nondestructive tests, and

3.2.4 Providing specimens for research purposes.

NOTE 1—The concrete test results for concrete specimens made and cured using this practice are widely used. They may be the basis for acceptance testing for project concrete, research evaluations, and other studies. Careful and knowledgeable handling of materials, mixing concrete, molding test specimens, and curing test specimens is necessary. Many laboratories performing this important work are independently inspected or accredited. Practice C 1077 identifies and defines

[1] This practice is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.61 on Testing Concrete for Strength.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 04.03.

[5] *Annual Book of ASTM Standards*, Vol 15.09.

[6] Available from the National Institute of Standards and Technology, Gaithersburg, MD 20899.

[7] Available from the American Concrete Institute, P.O. Box 19150, Detroit, MI 48219-0150.

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duties responsibilities, including minimum responsibilities of the laboratory personnel and minimum technical requirements for laboratory equipment used. Many laboratories ensure qualified technicians by participating in national certification programs such as the American Concrete Institute Laboratory Technician Program or an equivalent program.

4. Apparatus

4.1 *Molds, General*—Molds for specimens or fastenings thereto in contact with the concrete shall be made of steel, cast iron, or other nonabsorbent material, nonreactive with concrete containing portland or other hydraulic cements. Molds shall conform to the dimensions and tolerances specified in the method for which the specimens are required. Molds shall hold their dimensions and shape under all conditions of use. Watertightness of molds during use shall be judged by their ability to hold water poured into them. Test procedures for watertightness are given in the section on Test Methods for Elongation, Absorption, and Watertightness of Specification C 470. A suitable sealant, such as heavy grease, modeling clay, or microcrystalline wax, shall be used where necessary to prevent leakage through the joints. Positive means shall be provided to hold base plates firmly to the molds. Reusable molds shall be lightly coated with mineral oil or a suitable nonreactive release material before use.

4.2 *Cylinder Molds:*

4.2.1 *Molds for Casting Specimens Vertically* shall conform to the requirements of 4.1 and Specification C 470.

4.2.2 *Horizontal Molds for Creep Test Cylinders* shall conform to the requirements of 4.1 and to the requirements for symmetry and dimensional tolerance in the section on General Requirements except for verticality requirements of Specification C 470. The use of horizontal molds is intended only for creep specimens that contain axially embedded strain gages. Molds for creep cylinders to be filled while supported in a horizontal position shall have a filling slot parallel to the axis of the mold which extends the full length to receive the concrete. The width of the slot shall be one half the diameter of the specimen. If necessary the edges of the slot shall be reinforced to maintain dimensional stability. Unless specimens are to be capped or ground to produce plane ends, the molds shall be provided with two machined metal end plates at least 1 in. [25 mm] thick and the working surfaces shall comply with the requirements for planeness and surface roughness given in the section on Capping Plates of Practice C 617. Provision shall be made for fixing both end plates firmly to the mold. The inside surface of each end plate shall be provided with at least three lugs or studs approximately 1 in. [25 mm] long, firmly fastened to the plate for embedment in the concrete. One base plate shall be drilled from the inside at an angle to permit the lead wire from the strain gage to exit the specimen through the edge of the plate. Provision shall be made for accurately positioning the strain gage. All necessary holes shall be as small as possible to minimize disturbance to subsequent strain measurements and shall be sealed to prevent leakage.

4.3 *Beam and Prism Molds* shall be rectangular in shape (unless otherwise specified) and of the dimensions required to produce the desired specimen size. The inside surfaces of the molds shall be smooth and free from indentations. The sides, bottom, and ends shall be at right angles to each other and shall be straight and true and free of warpage. Maximum variation from the nominal cross section shall not exceed 1/8 in. [3 mm] for molds with depth or breadth of 6 in. [150 mm] or more, or 1/16 in. [2 mm] for molds of smaller depth or breadth. Except for flexure specimens, molds shall not vary from the nominal length by more than 1/16 in. [2 mm]. Flexure molds shall not be shorter than 1/16 in. [2 mm] of the required length, but may exceed it by more than that amount.

4.4 *Tamping Rods*—Two sizes are specified in ASTM methods. Each shall be a round, straight steel rod with at least the tamping end rounded to a hemispherical tip of the same diameter as the rod. Both ends may be rounded, if preferred.

4.4.1 *Larger Rod,* 5/8 in. [16 mm] in diameter and approximately 24 in. [600 mm] long.

4.4.2 *Smaller Rod,* 3/8 in. [10 mm] in diameter and approximately 12 in. [300 mm] long.

4.5 *Mallets*—A mallet with a rubber or rawhide head weighing 1.25 ± 0.50 lb [0.6 ± 0.20 kg] shall be used.

4.6 *Vibrators*—Internal vibrators may have rigid or flexible shafts, preferably powered by electric motors. The frequency shall be 7000 vibrations or cycles per minute [120 Hz] or greater while in use. The outside diameter or side dimension of the vibrating elements shall be at least 0.75 in. [20 mm] and not greater than 1.5 in. [40 mm]. The combined length of the shaft and vibrating element shall exceed the maximum depth of the section being vibrated by at least 3 in. [75 mm]. External vibrators may be of two types: table or plank. The frequency for external vibrators shall be not less than 3600 vibrations per minute [60 Hz], and preferably higher. For both table and plank vibrators, provision shall be made for clamping the mold securely to the apparatus. A vibrating-reed tachometer should be used to check the frequency of vibration.

NOTE 2—Vibratory impulses are frequently imparted to a table or plank vibrator through electromagnetic means, or by use of an eccentric weight on the shaft of an electric motor or on a separate shaft driven by a motor.

4.7 *Small Tools*—Tools and items such as shovels, pails, trowels, wood float, blunted trowels, straightedge, feeler gage, scoops, rulers, rubber gloves, and metal mixing bowls shall be provided.

4.8 *Slump Apparatus*—The apparatus for measurement of slump shall conform to the requirements of Test Method C 143.

4.9 *Sampling and Mixing Pan*—The pan shall be flat-bottom and of heavy-gage metal, watertight, of convenient depth, and of sufficient capacity to allow easy mixing by shovel or trowel of the entire batch; or, if mixing is by machine, to receive the entire batch on discharge of the mixer and allow remixing in the pan by trowel or shovel.

4.10 *Wet-Sieving Equipment*—If wet-sieving is required, the equipment shall conform to the requirements of Practice C 172.

4.11 *Air Content Apparatus*—The apparatus for measuring air content shall conform to the requirements of either Test Methods C 231 or C 173.

4.12 *Scales*—Scales for determining the mass of batches of materials and concrete shall be accurate within 0.3 % of the test load at any point within the range of use. They shall meet the requirements for sensitivity and tolerances prescribed by the National Institute of Standards and Technology Handbook 44.[6] Where the scales are graduated in decimal fractions of a pound instead of ounces, or where the SI system is used, the equivalent percentage sensitivity requirement and tolerances shall apply.

NOTE 3—In general the mass of small quantities should not be determined on large capacity scales. In many applications the smallest mass determined on a scale should be greater than about 10 % of the maximum capacity of the scale; however, this will vary with the performance characteristics of the scale and the required accuracy of the determination. Acceptable scales used for determining the mass for concrete materials preferably should determine mass accurately to about 0.1 % of total capacity and the foregoing precaution is applicable. However, certain analytical and precision balances are exceptions to this rule and should weigh accurately to 0.001 %. Particular care must be exercised in measuring small quantities of material by determining the difference between two much larger masses.

4.13 *Concrete Mixer*—A power-driven concrete mixer shall be a revolving drum, tilting mixer, or suitable revolving pan or revolving-paddle mixer capable of thoroughly mixing batches of the prescribed sizes at the required slump.

NOTE 4—A pan mixer is usually more suitable for mixing concrete with less than 1-in. [25 mm] slump than a revolving drum mixer. The rate of rotation, degree of tilt, and rated capacity of tilting mixers are not always suitable for laboratory mixed concrete. It may be found desirable to reduce the rate of rotation, decrease the angle of tilt from the horizontal, and use the mixer at somewhat less than the manufacturer's rated capacity.

5. Specimens

5.1 *Cylindrical Specimens*—Cylinders for such tests as compressive strength, Young's modulus of elasticity, creep, and splitting tensile strength may be of various sizes with a minimum of 2-in. [50-mm] diameter by 4-in. [100-mm] length. Where correlation or comparison with field-made cylinders (Practice C 31) is desired, the cylinders shall be 6 by 12 in. [or 150 by 300 mm]. Otherwise, dimensions should be governed in accordance with 5.4 and the specific test method concerned.

NOTE 5—The hard conversion to SI units is shown. However, during the conversion period to SI units in the United States, cylinder molds with hard conversion may not be available and soft conversion of 6 by 12 in. to 152 by 305 mm should be permitted. Also, soft conversion should be permitted for other sizes and types where molds in hard conversion size are not available.

5.1.1 Cylindrical specimens for tests other than creep shall be molded and allowed to harden with the axis of the cylinder vertical.

5.1.2 Cylindrical creep specimens may be cast with the cylindrical axis either vertical or horizontal and allowed to harden in the position in which cast.

5.2 *Prismatic Specimens*—Beams for flexural strength, prisms for freezing and thawing, bond, length change, volume change, etc., shall be formed with their long axes horizontal, unless otherwise required by the method of test in question, and shall conform in dimension to the requirements of the specific test method.

5.3 *Other Specimens*—Other shapes and sizes of specimens for particular tests may be molded as desired following the general procedures set forth in this practice.

5.4 *Specimen Size versus Aggregate Size*—The diameter of a cylindrical specimen or minimum cross-sectional dimension of a rectangular section shall be at least three times the nominal maximum size of the coarse aggregate in the concrete as defined in Terminology C 125. Occasional oversize aggregate particles (of a size not normally found in the average aggregate grading) shall be removed by hand picking during the molding of the specimens. When the concrete contains aggregate larger than that appropriate for the size of the molds or equipment to be used, wet-sieve the sample as described in Practice C 172.

5.5 *Number of Specimens*—The number of specimens and the number of test batches are dependent on established practice and the nature of the test program. Guidance is usually given in the test method or specification for which the specimens are made. Usually three or more specimens are molded for each test age and test condition unless otherwise specified (Note 6). Specimens involving a given variable should be made from three separate batches mixed on different days. An equal number of specimens for each variable should be made on any given day. When it is impossible to make at least one specimen for each variable on a given day, the mixing of the entire series of specimens should be completed in as few days as possible, and one of the mixtures should be repeated each day as a standard of comparison.

NOTE 6—Test ages often used are 7 and 28 days for compressive strength tests, or 14 and 28 days for flexural strength tests. Specimens containing Type III cement are often tested at 1, 3, 7, and 28 days. For later test ages, 3 months, 6 months, and 1 year are often used for both compressive and flexural strength tests. Other test ages may be required for other types of specimens.

6. Preparation of Materials

6.1 *Temperature*—Before mixing the concrete, bring the concrete materials to room temperature in the range of 68 to 86°F [20 to 30°C] in accordance with Specification E 171, unless otherwise specified.

6.2 *Cement*—Store the cement in a dry place, in moisture-proof containers, preferably made of metal. The cement shall be thoroughly mixed to provide a uniform supply throughout the tests. It shall be passed through a 850-µm [No. 20] or finer sieve to remove all lumps, remixed on a plastic sheet, and returned to sample containers.

6.3 *Aggregates*—In order to preclude segregation of a coarse aggregate, separate into individual size fractions and for each batch recombine in the proper proportions to produce the desired grading.

NOTE 7—Only rarely is a coarse aggregate batched as a single size fraction. The number of size fractions will generally be between 2 and 5 for aggregate smaller than 2½ in. [60 mm]. When a size fraction to be batched is present in amounts in excess of 10 %, the ratio of the opening of the larger to the smaller sieve should not exceed 2.0. More closely sized groups are sometimes advisable.

6.3.1 Unless fine aggregate is separated into individual size fractions, maintain it in a damp condition or restore to a damp condition until use, to prevent segregation, unless material uniformly graded is subdivided into batch size lots using a sample splitter with proper size openings. If unusual gradings are being studied, the fine aggregate may need to be dried and separated into individual sizes. In this instance, if the total quantity of fine aggregate required is larger than can be efficiently blended in a single unit, then the individual size fractions should be determined in a mass required for each

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individual batch. When the total quantity of fine aggregate needed for the complete investigation is such that it can be thoroughly mixed, blended, and maintained in a damp condition, then it should be handled in that manner. Determine the specific gravity and absorption of aggregates in accordance with either Test Methods C 127 or C 128.

6.3.2 Before incorporating in concrete, prepare the aggregate to ensure a definite and uniform condition of moisture. Determine the weight of aggregate to be used in the batch by one of the following procedures:

6.3.2.1 Determine the mass of low-absorption aggregates (absorption less than 1.0 %) in the room-dry condition with allowance made for the amount of water that will be absorbed from the unset concrete (Note 8). This procedure is particularly useful for coarse aggregate which must be batched as individual sizes; because of the danger of segregation it can be used for fine aggregate only when the fine aggregate is separated into individual size fractions.

NOTE 8—When using aggregates with low absorption in room-dry condition the amount of water that will be absorbed by the aggregates before the concrete sets may be assumed to be 80 % of the difference between the 24-h absorption of the aggregates determined by Test Methods C 127 or C 128, and the amount of water in the pores of the aggregates in their room-dry state, as determined by Test Method C 566.

6.3.2.2 Individual size fractions of aggregate may be weighed separately, recombined into a tared container in the amounts required for the batch, and immersed in water for 24 h prior to use. After immersion the excess water is decanted and the combined weight of aggregate and mixing water determined. Allowance shall be made for the amount of water absorbed by the aggregate. The moisture content of the aggregates may be determined in accordance with Test Methods C 70 and C 566.

6.3.2.3 The aggregate may be brought to and maintained in a saturated condition, with surface moisture contained in sufficiently small amounts to preclude loss by draining, at least 24 h prior to use. When this method is used, the moisture content of the aggregate must be determined to permit calculation of proper quantities of the damp aggregate. The quantity of surface moisture present must be counted as a part of the required amount of mixing water. Surface moisture in fine aggregate may be determined in accordance with Test Methods C 70 and C 566, making due allowance for the amount of water absorbed. The method outlined here (moisture content slightly exceeding absorption) is particularly useful for fine aggregate. It is used less frequently for coarse aggregate because of the difficulty of accurately determining the moisture content, but if used, each size fraction must be handled separately to ensure that the proper grading is obtained.

6.3.2.4 Aggregates, fine or coarse, may be brought to and maintained in a saturated surface-dry condition until batched for use. This method is used primarily to prepare material for batches not exceeding ¼ ft^3 [0.007 m^3] in volume. Care must be taken to prevent drying during weighing and use.

6.4 *Lightweight Aggregates*—The procedures for specific gravity, absorption, and preparation of aggregates mentioned in this practice pertain to materials with normal absorption values. Lightweight aggregates, air-cooled slag, and certain highly porous or vesicular natural aggregate may be so absorptive as to be difficult to treat as described. The moisture content of lightweight aggregate at the time of mixing may have important effects on properties of freshly mixed and hardened concretes such as slump loss, compressive strength, and resistance to freezing and thawing.

6.5 *Admixtures*—Powdered admixtures that are entirely or largely insoluble, that do not contain hygroscopic salts and are to be added in small quantities, should be mixed with a portion of the cement before introduction into the batch in the mixer so as to ensure thorough distribution throughout the concrete. Essentially insoluble materials which are used in amounts exceeding 10 % by mass of cement, such as pozzolans, should be handled and added to the batch in the same manner as cement. Powdered admixtures which are largely insoluble but contain hygroscopic salts may cause balling of cement and should be mixed with the sand. Water-soluble and liquid admixtures should be added to the mixer in solution in the mixing water. The quantity of such solution used shall be included in the calculation of the water content of the concrete. Admixtures, incompatible in concentrated form, such as solutions of calcium chloride and certain air-entraining and set-retarding admixtures, should not be intermixed prior to their addition to concrete. The time, sequence, and method of adding some admixtures to a batch of concrete can have important effects on concrete properties such as time of set and air content. The method selected must remain unchanged from batch to batch and should simulate good field practice.

NOTE 9—The mixing apparatus and accessories shall be thoroughly cleaned to ensure that chemical additions or admixtures used in dissimilar batches of concrete do not affect subsequent batches.

7. Procedure

7.1 *Mixing Concrete:*

7.1.1 *General*—Mix concrete in a suitable mixer or by hand in batches of such size as to leave about 10 % excess after molding the test specimens. Hand-mixing procedures are not applicable to air-entrained concrete or concrete with no measurable slump. Hand mixing should be limited to batches of ¼ ft^3 [0.007 m^3] volume or less. Mixing procedures are given in 7.1.2 and 7.1.3. However, other procedures may be used when it is desired to simulate special conditions or practices, or when the procedures specified are impracticable. A machine-mixing procedure suitable for drum-type mixers is described. It is important not to vary the mixing sequence and procedure from batch to batch unless the effect of such variation is under study.

7.1.2 *Machine Mixing*—Prior to starting rotation of the mixer add the coarse aggregate, some of the mixing water, and the solution of admixture, when required, in accordance with 6.5. When feasible, disperse the admixture in the mixing water before addition. Start the mixer, then add the fine aggregate, cement, and water with the mixer running. If it is impractical for a particular mixer or for a particular test to add the fine aggregate, cement, and water while the mixer is running, these components may be added to the stopped mixer after permitting it to turn a few revolutions following charging with coarse aggregate and some of the water (Note 10). Mix the concrete, after all ingredients are in the mixer, for 3 min followed by a 3-min rest, followed by a 2-min final mixing. Cover the open end or top of the mixer to prevent evaporation during the rest period. Take precautions to compensate for mortar retained by the mixer so that the discharged batch, as used, will be correctly proportioned (Note 11). To eliminate segregation, deposit machine-mixed concrete in the clean, damp mixing pan and remix by shovel or trowel until it appears to be uniform.

NOTE 10—An experienced operator may add water incrementally during mixing to adjust to the desired slump.

NOTE 11—It is difficult to recover all of the mortar from mixers. To compensate for this difficulty one of the following procedures may be used to ensure the correct final proportions in the batch:

(1) "Buttering" the Mixer—Just prior to mixing the test batch, the mixer is "buttered" by mixing a batch proportioned to simulate closely the test batch. The mortar adhering to the mixer after discharging is intended to compensate for loss of mortar from the test batch.

(2) "Over-Mortaring" the Mix—The test mix is proportioned by the use of an excess mortar, the amount established in advance, to compensate for that which, on the average, adheres to the mixer. In this case the mixer is cleaned before mixing the test batch.

7.1.3 *Hand Mixing*—Mix the batch in a watertight, clean (Note 9), damp, metal pan or bowl, with a bricklayer's blunted trowel, using the following procedure when aggregates have been prepared in accordance with 6.3.2.1, 6.3.2.3, and 6.3.2.4.

7.1.3.1 Mix the cement, powdered insoluble admixture, if used, and fine aggregate without addition of water until they are thoroughly blended.

7.1.3.2 Add the coarse aggregate and mix the entire batch without addition of water until the coarse aggregate is uniformly distributed throughout the batch.

7.1.3.3 Add water, and the admixture solution if used, and mix the mass until the concrete is homogeneous in appearance and has the desired consistency. If prolonged mixing is necessary because of the addition of water in increments while adjusting the consistency, discard the batch and make a new batch in which the mixing is not interrupted to make trial consistency tests.

7.1.4 *Mixed Concrete*—Select the portions of the batch of mixed concrete to be used in tests for molding specimens so as to be representative of the actual proportions and condition of the concrete. When the concrete is not being remixed or sampled cover it to prevent evaporation.

7.2 *Slump, Air Content, Yield, and Temperature:*

7.2.1 *Slump*—Measure the slump of each batch of concrete immediately after mixing in accordance with Test Method C 143.

NOTE 12—The slump test is unsuitable for concrete so dry that it slumps less than ¼ in. [6 mm]. No-slump concrete may be tested by one of several means described in ACI 211.3.

7.2.2 *Air Content*—Determine the air content, when required, in accordance with either Test Methods C 173 or C 231. Test Method C 231 should not be used with concretes made with lightweight aggregates, air-cooled blast-furnace slag, or aggregates of high porosity. Discard the concrete used for the determination of air content.

7.2.3 *Yield*—Determine the yield of each batch of concrete, if required, in accordance with Test Method C 138. Concrete used for slump and yield tests may be returned to the mixing pan and remixed into the batch.

7.2.4 *Temperature*—Determine the temperature of each batch of concrete in accordance with Test Method C 1064.

7.3 *Making Specimens:*

7.3.1 *Place of Molding*—Mold specimens as near a practicable to the place where they are to be stored durin the first 24 h. If it is not practicable to mold the specimer where they will be stored, move them to the place of storag immediately after being struck off. Place molds on a rigi surface free from vibration and other disturbances. Avoi jarring, striking, tilting, or scarring of the surface of th specimens when moving the specimens to the storage place

7.3.2 *Placing*—Place the concrete in the molds using a scoop, blunted trowel, or shovel. Select each scoopful trowelful, or shovelful of concrete from the mixing pan to ensure that it is representative of the batch. It may be necessary to remix the concrete in the mixing pan with a shovel or trowel to prevent segregation during the molding of specimens. Move the scoop or trowel around the top edge of the mold as the concrete is discharged in order to ensure a symmetrical distribution of the concrete and to minimize segregation of coarse aggregate within the mold. Further distribute the concrete by use of a tamping rod prior to the start of consolidation. In placing the final layer the operator shall attempt to add an amount of concrete that will exactly fill the mold after compaction. Do not add nonrepresentative samples of concrete to an underfilled mold.

7.3.2.1 *Number of Layers*—Make specimens in layers as indicated in Table 1.

7.4 *Consolidation:*

7.4.1 *Methods of Consolidation*—Preparation of satisfactory specimens requires different methods of consolidation. The methods of consolidation are rodding, and internal or external vibration. Base the selection of the method of consolidation on the slump, unless the method is stated in the specifications under which the work is being performed. Rod concretes with a slump greater than 3 in. [75 mm]. Rod or vibrate concretes with slump of 1 to 3 in. [25 to 75 mm]. Consolidate by vibration concretes with slump of less than 1 in. [25 mm] (Note 13). Do not use internal vibration for cylinders of 4-in. [100-mm] diameter or less, and beams or prisms of 4-in. [100-mm] breadth or depth, or less.

NOTE 13—Concrete of such low water content that it cannot be properly consolidated by the methods described herein is not covered by this practice. Provisions for specimens and methods of testing will be found in the standards concerned. There are concretes that can be consolidated by external vibration, but additional forces on the surface are required to embed the coarse aggregate thoroughly and consolidate the mixture. For such mixtures the following procedures may be followed: using external vibration fill 6 by 12-in. [150 by 300-mm] cylinder molds in 3 in. [75 mm] lifts using a 10-lb [4.5-kg] cylindrical surcharge, or 3 by 6-in. [75 by 150-mm] cylinder molds in 2 in. [50 mm] lifts using a 2.5-lb [1-kg] cylindrical surcharge. The surcharge should have a diameter ¼ in. [6 mm] less than the inside of the mold. Simultaneously each lift should be compacted by external vibration with the surcharge on the top surface of the concrete, until the mortar begins to ooze around the bottom of the surcharge.

7.4.2 *Rodding*—Place the concrete in the mold, in the required number of layers of approximately equal volume. Rod each layer with the rounded end of the rod using the number of strokes and size of rod specified in Table 2. Rod the bottom layer throughout its depth. Distribute the strokes uniformly over the cross section of the mold and for each upper layer allow the rod to penetrate about ½ in. [12 mm] into the underlying layer when the depth of the layer is less than 4 in. [100 mm] and about 1 in. [25 mm] when the

TABLE 1 Number of Layers Required for Specimens

Specimen Type and Size, as Depth, in. (mm)	Mode of Compaction	Number of Layers	Approximate Depth of Layer, in. (mm)
Cylinders:			
up to 12 (300) incl	rodding	3 equal	4 (100) as near as practicable
over 12 (300) incl	rodding	as required	
up to 18 (460) incl	vibration	2 equal	8 (200) as near as practicable
over 18 (460) incl	vibration	3 or more	
Prisms and horizontal creep cylinders:			
up to 8 (200) incl	rodding	2 equal	
over 8 (200) incl	rodding	3 or more	4 (100) as near as practicable
up to 8 (200) incl	vibration	1	
over 8 (200) incl	vibration	2 or more	8 (200) as near as practicable

TABLE 2 Diameter of Rod and Number of Roddings to be Used in Molding Test Specimens

Cylinders		
Diameter of Cylinder, in. (mm)	Diameter of Rod in. (mm)	Number of Strokes/Layer
2 (50) to <6 (150)	3/8 (10)	25
6 (150)	5/8 (16)	25
8 (200)	5/8 (16)	50
10 (250)	5/8 (16)	75
Beams and Prisms		
Top Surface Area of Specimen, in.² (cm²)	Diameter of Rod in. (mm)	Number of Roddings/Layer
25 (160) or less	3/8 (10)	25
26 to 49 (165 to 310)	3/8 (10)	one for each 1 in.² (7 cm²) of surface
50 (320) or more	5/8 (16)	one for each 2 in.² (14 cm²) of surface
Horizontal Creep Cylinders		
Diameter of Cylinder in. (mm)	Diameter of Rod in. (mm)	Number of Roddings/Layer
6 (150)	5/8 (16)	50 total, 25 along both sides of axis

depth is 4 in. [100 mm] or more. After each layer is rodded, tap the outsides of the mold lightly 10 to 15 times with the mallet to close any holes left by rodding and to release any large air bubbles that may have been trapped. Use an open hand to tap light-gage single-use molds which are susceptible to damage if tapped with a mallet. After tapping, spade the concrete along the sides and ends of beam and prism molds with a trowel or other suitable tool.

7.4.3 *Vibration*—Maintain a standard duration of vibration for the particular kind of concrete, vibrator, and specimen mold involved. The duration of vibration required will depend upon the workability of the concrete and the effectiveness of the vibrator. Usually sufficient vibration has been applied as soon as the surface of the concrete has become relatively smooth. Continue vibration only long enough to achieve proper consolidation of the concrete. Overvibration may cause segregation. Fill the molds and vibrate in the required number of approximately equal layers. Place all the concrete for each layer in the mold before starting vibration of that layer. Add the final layer, so as to avoid overfilling by more than 1/4 in. [6 mm]. When the finish is applied after vibration, add only enough concrete with a trowel to overfill the mold about 1/8 in. [3 mm], work it into the surface and then strike it off.

7.4.3.1 *Internal Vibration*—The diameter of the shaft or side dimensions of the internal vibrator shall not be greater than one third of the width of the mold in the case of beams or prisms. For cylinders the ratio of the diameter of the cylinder to the diameter of the vibrating element shall be 4.0 or higher. In compacting the specimen the vibrator shall not be allowed to rest on or touch the bottom or sides of the mold or strike embedded items such as strain meters. Carefully withdraw the vibrator in such a manner that no air pockets are left in the specimen.

7.4.3.2 *Cylinders*—Use three insertions of the vibrator at different points for each layer. Allow the vibrator to penetrate through the layer being vibrated, and into the layer below, approximately 1 in. [25 mm]. After each layer is vibrated, tap the outsides of the mold lightly 10 to 15 times with the mallet. Use an open hand to tap light-gage single-use molds which are susceptible to damage if tapped with a mallet.

7.4.3.3 *Beams, Prisms, and Horizontal Creep Cylinders*—Insert the vibrator at intervals not exceeding 6 in. [150 mm] along the center line of the long dimension of the specimen, or along both sides but not in contact with the strain gage in the case of creep cylinders. For specimens wider than 6 in. [150 mm], use alternating insertions along two lines. Allow the shaft of the vibrator to penetrate into the bottom layer approximately 1 in. [25 mm]. After each layer is vibrated, tap the outsides of the mold lightly 10 to 15 times with the mallet to close any holes left by vibrating and release any large air bubbles that may have been trapped.

7.4.4 *External Vibration*—When external vibration is used, take care to ensure that the mold is rigidly attached to or securely held against the vibrating element or vibrating surface (Note 13).

7.5 *Finishing*—After consolidation by any of the methods, strike off the surface of the concrete and float or trowel it in accordance with the method concerned. If no finish is specified, finish the surface with a wood or magnesium float. Perform all finishing with the minimum manipulation necessary to produce a flat even surface that is level with the rim or edge of the mold and which has no depressions or projections larger than 1/8 in. [3 mm].

7.5.1 *Cylinders*—After consolidation finish the top surfaces by striking them off with the tamping rod where the consistency of the concrete permits, or with a wood float or trowel. If desired, cap the top surface of freshly made cylinders with a thin layer of stiff portland cement paste which is permitted to harden and cure with the specimen. See the section on Capping Materials of Practice C 617.

7.5.2 *Horizontally Cast Creep Cylinders*—After consolidation strike off the specimen with a trowel or float, then trowel the minimum amount required to form the concrete in the opening concentrically with the rest of the specimen. Use a screed curved to the radius of the specimen to more precisely shape and finish the concrete in the opening.

8. Curing

8.1 *Protection*—To prevent evaporation of water from the unhardened concrete, cover the specimens immediately after finishing, preferably with a nonabsorptive, nonreactive plate or a sheet of tough, durable, impervious plastic. Wet burlap may be used for covering, but care must be exercised to keep the burlap wet until the specimens are removed from the molds. Placing a sheet of plastic over the burlap will facilitate keeping it wet. Protect the outside surfaces of cardboard molds from all contact with wet burlap or other sources of water for the first 24 h after cylinders have been molded in them. Water may cause the molds to expand and damage specimens at this early age.

8.2 *Removal from Molds*—Remove the specimens from the molds 24 ± 8 h after casting.

8.3 *Curing Environment*—Unless otherwise specified all specimens shall be moist cured at 73 ± 3°F [23 ± 2°C] from the time of molding until the moment of test (Note 14). Storage during the first 48 h of curing shall be in a vibration-free environment. As applied to the treatment of demolded specimens, moist curing means that the test specimens shall have free water maintained on the entire surface area at all times. This condition is met by using water storage tanks or a moist room in accordance with the requirements of Specification C 511. When water storage tanks are used, specimens shall be immersed in a water saturated with calcium hydroxide to prevent leaching from the specimens. Specimens shall not be exposed to dripping or running water. Cure structural lightweight concrete cylinders in accordance with this practice or as prescribed in Test Method C 567.

NOTE 14—The temperature within damp sand and under wet burlap or similar materials will always be lower than the temperature in the surrounding atmosphere if evaporation takes place.

8.4 *Flexural Strength Test Specimens*—Cure the flexural strength test specimens in accordance with 8.1 and 8.2 except that while in storage for a minimum period of 20 h immediately prior to testing they shall be immersed in water saturated with calcium hydroxide at 73 ± 3°F [23 ± 2°C]. At the end of the curing period, between the time the specimen is removed from curing until testing is completed, drying of the surfaces shall be prevented.

NOTE 15—Relatively small amounts of drying of the surface of flexural strength specimens will induce tensile stresses in the extreme fibers that will markedly reduce the indicated flexural strength.

9. Precision and Bias

9.1 Data to establish precision statements for various testing required by this standard were obtained in the Concrete Proficiency Sample Program of the Cement and Concrete Reference Laboratory. Analysis of those data for single-operator and multilaboratory precision is presented in Table 3.

9.2 The single-operator standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 0.7 in., 0.9 lb/ft^3, 0.3 %, and 203 psi, respectively; therefore the results of properly conducted tests on two trial batches made in the same laboratory should not differ by more than 2.0 in., 2.5 lb/ft^3, 0.8 %, and 574 psi, respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a constant water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 in. [50 mm] or over 6 in. [150 mm], or concrete made with other than normal weight aggregate or aggregate larger than 1 in. [25 mm] nominal maximum size.

9.3 The multilaboratory standard deviations for slump, unit weight, air content, and 7-day compressive strength of trial batches have been found to be 1.0 in., 1.4 lb/ft^3 0.4 %, and 347 psi, respectively; therefore, the results of properly conducted tests on single trial batches made in two different laboratories should not differ by more than 2.8 in., 4.0 lb/ft^3, 1.1 %, and 981 psi, respectively. This precision statement is considered applicable to laboratory trial batches proportioned to contain prescribed quantities of materials and to have a prescribed water-cement ratio. The values should be used with caution for air-entrained concrete, concrete with slump less than 2 in. [50 mm] or over 6 in. [150 mm], or concrete made with other than normal weight aggregate or aggregate larger than 1 in. [25 mm] nominal maximum size.

9.4 *Bias*—The procedures for the test methods in 9.3 have no bias because the values obtained from each of those test methods are defined only in terms of the test method.

10. Keywords

10.1 concrete; cylinders; laboratory; prisms; strength testing

TABLE 3 Values for Precision Statements Relating to Making Trial Batches by Practice C 192/C 192M and Testing by Appropriate Methods

Practice C 192/C 192M and Appropriate Test Methods		Multilaboratory Precision		Single-Laboratory Precision	
		1s	d2s	1s	d2s
Slump, in.	C 143	1.0	2.8	0.7	2.0
Unit weight—lb/ft^3	C 138	1.4	4.0	0.9	2.5
Air content (Non AE Concrete), % by volume	C 173	0.4	1.1	0.3	0.8
Compressive strength 7 days, psi	C 39	347	981	203	574

Standard Specification for Chemical Admixtures for Concrete[1]

This standard is issued under the fixed designation C 494; 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 specification has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 This specification covers materials for use as chemical admixtures to be added to portland cement concrete mixtures in the field for the purpose or purposes indicated for the seven types as follows:

1.1.1 *Type A*—Water-reducing admixtures,

1.1.2 *Type B*—Retarding admixtures,

1.1.3 *Type C*—Accelerating admixtures,

1.1.4 *Type D*—Water-reducing and retarding admixtures,

1.1.5 *Type E*—Water-reducing and accelerating admixtures,

1.1.6 *Type F*—Water-reducing, high range admixtures, and

1.1.7 *Type G*—Water-reducing, high range, and retarding admixtures.

1.2 This specification stipulates tests of an admixture with suitable concreting materials as described in 11.1 through 11.3 or with cement, pozzolan, aggregates, and an air-entraining admixture proposed for specific work (11.4). Unless specified otherwise by the purchaser, the tests shall be made using concreting materials as described in 11.1 through 11.3.

NOTE 1—It is recommended that, whenever practicable, tests be made using the cement, pozzolan, aggregates, air-entraining admixture, and the mixture proportions, batching sequence, and other physical conditions proposed for the specific work (11.4) because the specific effects produced by chemical admixtures may vary with the properties and proportions of the other ingredients of the concrete. For instance, Types F and G admixtures may exhibit much higher water reduction in concrete mixtures having higher cement factors than that listed in 12.1.1.

Mixtures having a high range water reduction generally display a higher rate of slump loss. When high-range admixtures are used to impart increased workability (6 to 8-in. slump), the effect may be of limited duration, reverting to the original slump in 30 to 60 min depending on factors normally affecting rate of slump loss. The use of chemical admixtures to produce high-slump (flowing) concrete is covered by Specification C 1017.

NOTE 2—The purchaser should ensure that the admixture supplied for use in the work is equivalent in composition to the admixture subjected to test under this specification (see Section 6, Uniformity and Equivalence).

NOTE 3—Admixtures that contain relatively large amounts of chloride may accelerate corrosion of prestressing steel. Compliance with the requirements of this specification does not constitute assurance of acceptibility of the admixture for use in prestressed concrete.

1.3 This specification provides for three levels of testing.

1.3.1 *Level 1*—During the initial approval stage, proof of compliance with the performance requirements defined in Table 1 demonstrates that the admixture meets the requirements of this specification. Uniformity and equivalence tests of Section 6 shall be carried out to provide results against which later comparisons can be made.

1.3.2 *Level 2*—Limited retesting described in 5.2, 5.2.1 and 5.2.2 may be requested at intervals by the purchaser. Proof of compliance with the requirements of Table 1 demonstrates continued conformity of the admixture with the requirements of the specification.

1.3.3 *Level 3*—For acceptance of a lot or for measuring uniformity within or between lots, when specified by the purchaser, the uniformity and equivalence tests of Section 6 shall be used.

1.4 The following precautionary caveat pertains only to the test method portion, Sections 11 through 18 of this Specification: *This standard does not purport to address all of the safety problems, 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.*

1.5 The values stated in inch-pound units are to be regarded as the standard.

2. Referenced Documents

2.1 *ASTM Standards:*

C 33 Specification for Concrete Aggregates[2]

C 39 Test Method for Compressive Strength of Cylindrical Concrete Specimens[2]

C 78 Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)[2]

C 136 Test Method for Sieve Analysis of Fine and Coarse Aggregate[2]

C 138 Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete[2]

C 143 Test Method for Slump of Hydraulic Cement Concrete[2]

C 150 Specification for Portland Cement[3]

C 157 Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete[2]

C 183 Practice for Sampling and the Amount of Testing of Hydraulic Cement[3]

[1] This specification is under the jurisdiction of ASTM Committee C-9 on Concrete Aggregates and is the direct responsibility of Subcommittee C09.21 on Lightweight Aggregates and Concrete.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

TABLE 1 Physical Requirements[A]

	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
Water content, max, % of control	95	...	...	95	95	88	88
Time of setting, allowable deviation from control, h:min:							
Initial: at least	...	1:00 later	1:00 earlier	1:00 later	1:00 earlier	...	1:00 later
not more than	1:00 earlier nor 1:30 later	3:30 later	3:30 earlier	3:30 later	3:30 earlier	1:00 earlier nor 1:30 later	3:30 later
Final: at least	...	...	1:00 earlier	...	1:00 earlier	...	...
not more than	1:00 earlier nor 1:30 later	3:30 later	...	3:30 later	...	1:00 earlier nor 1:30 later	3:30 later
Compressive strength, min, % of control:[B]							
1 day	...	...	...	...	...	140	125
3 days	110	90	125	110	125	125	125
7 days	110	90	100	110	110	115	115
28 days	110	90	100	110	110	110	110
6 months	100	90	90	100	100	100	100
1 year	100	90	90	100	100	100	100
Flexural strength, min, % control:[B]							
3 days	100	90	110	100	110	110	110
7 days	100	90	100	100	100	100	100
28 days	100	90	90	100	100	100	100
Length change, max shrinkage (alternative requirements):[C]							
Percent of control	135	135	135	135	135	135	135
Increase over control	0.010	0.010	0.010	0.010	0.010	0 010	0.010
Relative durability factor, min[D]	80	80	80	80	80	80	80

[A] The values in the table include allowance for normal variation in test results. The object of the 90 % compressive strength requirement for a Type-B admixture is to require a level of performance comparable to that of the reference concrete.

[B] The compressive and flexural strength of the concrete containing the admixture under test at any test age shall be not less than 90 % of that attained at any previous test age. The objective of this limit is to require that the compressive or flexural strength of the concrete containing the admixture under test shall not decrease with age.

[C] Alternative requirements, see 17 1 4, % of control limit applies when length change of control is 0.030 % or greater; increase over control limit applies when length change of control is less than 0 030 %.

[D] This requirement is applicable only when the admixture is to be used in air-entrained concrete which may be exposed to freezing and thawing while wet

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 231 Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method[2]

C 260 Specification for Air-Entraining Admixtures for Concrete[2]

C 403 Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance[2]

C 666 Test Method for Resistance of Concrete to Rapid Freezing and Thawing[2]

C 1017 Specification for Chemical Admixtures for Use in Producing Flowing Concrete[2]

D 75 Practice for Sampling Aggregates[2]

D 1193 Specification for Reagent Water[4]

E 100 Specification for ASTM Hydrometers[5]

Manual of Aggregate and Concrete Testing[2]

2.2 *American Concrete Institute Standard:*

ACI 211.1-77 Practice for Selecting Proportions for Concrete[6]

3. Terminology

3.1 *Definitions:*

3.1.1 *accelerating admixture*—an admixture that accelerates the setting and early strength development of concrete.

3.1.2 *retarding admixture*—an admixture that retards the setting of concrete.

3.1.3 *water-reducing admixture*—an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency.

3.1.4 *water-reducing admixture, high range*—an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency by 12 % or greater.

3.1.5 *water-reducing and accelerating admixture*—an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and accelerates the setting and early strength development of concrete.

[4] *Annual Book of ASTM Standards*, Vol 11.01

[5] *Annual Book of ASTM Standards*, Vol 14 03.

[6] Available from the American Concrete Institute, P.O. Box 19150, Redford Station, Detroit, MI 48219.

3.1.6 *water-reducing and retarding admixture*—an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and retards the setting of concrete.

3.1.7 *water-reducing, high range, and retarding admixture*—an admixture that reduces the quantity of mixing water required to produce concrete of a given consistency by 12 % or greater and retards the setting of concrete.

4. Ordering Information

4.1 The purchaser shall specify the type of chemical admixture desired.

5. General Requirements

5.1 For initial compliance with this specification, test concrete in which each type of admixture shown in 1.1 is used shall conform to the respective requirements prescribed in Table 1.

5.2 The purchaser may require a limited retesting to confirm current compliance of the admixture to specification requirements. The limited retesting will cover physical properties and performance of the admixture.

5.2.1 The physical properties retesting shall consist of uniformity and equivalence tests for infrared analysis, residue by oven drying and specific gravity.

5.2.2 The performance property retesting shall consist of water content of fresh concrete, setting time and compressive strength at 3, 7 and 28 days.

NOTE 4—Additional performance tests currently in this standard may be required by users having special requirements.

5.3 At the request of the purchaser, the manufacturer shall state in writing that the admixture supplied for use in the work is identical in all essential respects, including concentration, to the admixture tested under this specification.

5.4 At the request of the purchaser, when the admixture is to be used in prestressed concrete, the manufacturer shall state in writing the chloride content of the admixture and whether or not chloride has been added during its manufacture.

5.5 Tests for uniformity and equivalence, as indicated in Section 6, shall be made on the initial sample and the results retained for reference and comparison with the results of tests of samples taken from elsewhere within the lot or subsequent lots of admixture supplied for use in the work.

6. Uniformity and Equivalence

6.1 When specified by the purchaser, the uniformity of a lot, or the equivalence of different lots from the same source shall be established by the use of the following requirements:

6.1.1 *Infrared Analysis*—The absorption spectra of the initial sample and the test sample, obtained as specified in 18.1, shall be essentially similar.

NOTE 5—Other procedures of infrared analysis may be employed pursuant to agreement between the purchaser and the supplier.

6.1.2 *Residue by Oven Drying* (Liquid Admixtures)—When dried as specified in 18.2, the oven-dried residues of the initial sample and of subsequent samples shall be within a range of variation of not greater than 5 percentage points.

6.1.3 *Residue by Oven Drying* (Nonliquid Admixtures)—When dried as specified in 18.3, the oven-dried residues of the initial sample and of the subsequent samples shall be within a range of variation not greater than 4 percentage points.

6.1.4 *Specific Gravity* (Liquid Admixtures)—When tested as specified in 18.4, the specific gravity of subsequent test samples shall not differ from the specific gravity of the initial sample by more than 10 % of the difference between the specific gravity of the initial sample and that of reagent water at the same temperature. Reagent water conforming to Specification D 1193, Types III or IV, and prepared by distillation ion exchange, reverse osmosis, electrodialysis, or a combination of these procedures is adequate.

6.2 In some instances, the nature of the admixture or analytical capability of the purchaser may make some or all of these procedures unsuitable. In such cases, other requirements for uniformity and equivalence from lot to lot or within a lot may be established by agreement between the purchaser and the manufacturer.

7. Packaging and Marking

7.1 When the admixture is delivered in packages or containers, the proprietary name of the admixture, the type under this specification, and the net weight or volume shall be plainly marked thereon. Similar information shall be provided in the shipping advices accompanying packaged or bulk shipments of admixtures.

8. Storage

8.1 The admixture shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment, and in a suitable weathertight building that will protect the admixture from dampness and freezing.

9. Sampling and Inspection

9.1 Every facility shall be provided the purchaser for careful sampling and inspection, either at the point of manufacture or at the site of the work, as may be specified by the purchaser.

9.2 Samples shall be either "grab" or "composite" samples, as specified or required by this specification. A grab sample is one obtained in a single operation. A composite sample is one obtained by combining three or more grab samples.

9.3. For the purposes of this specification, it is recognized that samples will be taken for two reasons:

9.3.1 *Quality Tests*—A sample taken for the purpose of evaluating the quality of a source or lot of admixture will be required to meet all the applicable requirements of this specification. Samples used to determine conformance with the requirements of this specification shall be composites of grab samples taken from sufficient locations to ensure that the composite sample will be representative of the lot.

9.3.2 *Uniformity and Equivalence Tests*—When specified by the purchaser, a sample taken for the purpose of evaluating the uniformity of a single lot, or equivalence of different lots from one source shall be tested as provided in Section 6. Such samples shall be composite samples from individual lots when different lots from the same source are being compared. When the uniformity of a single lot is being determined, grab samples shall be used.

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9.4 *Liquid Admixtures*—Liquid admixtures shall be agitated thoroughly immediately prior to sampling. Grab samples taken for quality or uniformity tests shall represent a unit shipment or a single production lot. Each grab sample shall have a volume of at least 1 pt (0.5 L). A minimum of three grab samples shall be taken. Composite samples shall be prepared by thoroughly mixing the grab samples selected and the resultant mixture sampled to provide at least 1 gal (4 L) for quality tests. Grab samples shall be taken from different locations well distributed throughout the quantity to be represented.

9.4.1 Admixtures in bulk storage tanks shall be sampled equally from the upper, intermediate, and lower levels by means of drain cocks in the sides of the tanks or a weighted sampling bottle fitted with a stopper that can be removed after the bottle is lowered to the desired depth.

9.4.2 Samples shall be packaged in impermeable, airtight containers which are resistant to attack by the admixture.

9.5 *Nonliquid Admixtures*—Grab samples taken for quality or uniformity tests shall represent not more than 2 tons (2 metric tons) of admixture and shall weigh at least 2 lb (1 kg). A minimum of four grab samples shall be taken. Composite samples shall be prepared by thoroughly mixing the grab samples selected and the resultant mixture sampled to provide at least 5 lb (2.3 kg) for the composite sample. Grab samples shall be taken from different locations well distributed throughout the quantity to be represented.

9.5.1 Samples of packaged admixtures shall be obtained by means of a tube sampler as described in Practice C 183.

9.5.2 Samples shall be packaged in moisture-proof, airtight containers.

9.6 Samples shall be thoroughly mixed before testing to ensure uniformity. When recommended by the manufacturer, the entire sample of a nonliquid admixture shall be dissolved in water prior to testing.

10. Rejection

10.1 For initial compliance testing, the admixture may be rejected if it fails to meet any of the applicable requirements for this specification.

10.2 For limited retesting, the admixture may be rejected if it fails to meet any of the requirements of the Uniformity and Equivalence Section and of the applicable parts of Table 1.

10.3 An admixture stored at the point of manufacture, for more than 6 months prior to shipment, or an admixture in local storage in the hands of a vendor for more than 6 months, after completion of tests, may be retested before use and may be rejected if it fails to conform to any of the applicable requirements of this specification.

10.4 Packages or containers varying more than 5 % from the specified weight or volume may be rejected. If the average weight or volume of 50 packages taken at random is less than that specified, the entire shipment may be rejected.

10.5 When the admixture is to be used in non-air-entrained concrete, it may be rejected if the test concrete containing it has an air content greater than 3.0 %; when the admixture is to be used in air-entrained concrete, it may be rejected if the test concrete containing it has an air content greater than 7.0 %.

TEST METHODS

NOTE 6—These tests are based on arbitrary stipulations which make possible highly standardized testing in the laboratory and are not intended to simulate actual job conditions.

11. Materials

11.1 *Cement*—The cement used in any series of tests shall be either the cement proposed for specific work in accordance with 11.4, a Type I or Type II cement conforming to Specification C 150, or a blend of two or more cements, in equal parts. Each cement of the blend shall conform to the requirements of either Type I or Type II, Specification C 150. If when using a cement other than that proposed for specific work, the air content of the concrete made without admixture, tested as prescribed in 14.3, is more than 3.0 %, select a different cement, or blend, so that the air content of the concrete will be 3.0 % or less.

11.2 *Aggregates*—Except when tests are made in accordance with 11.4 using the aggregates proposed for specific work, the fine and coarse aggregates used in any series of tests shall come from single lots of well-graded, sound materials that conform to the requirements of Specification C 33, except that the grading of the aggregates shall conform to the following requirements:

11.2.1 *Fine Aggregate Grading:*

Sieve	Weight Percent Passing
No. 4 (4.75-mm)	100
No. 16 (1.18-mm)	65 to 75
No. 50 (300 µm)	12 to 20
No. 100 (150 µm)	2 to 5

11.2.2 *Coarse Aggregate Grading*— The coarse aggregate shall meet the requirements for size number 57 of Specification C 33.

NOTE 7—Take care in loading and delivery to avoid segregation.

11.2.3 The coarse aggregate used for each set of reference concrete and comparable test admixture-treated concrete shall be essentially the same. Therefore, a set of test concrete consists of one reference concrete and as many test admixture-containing concretes as are intended to be compared to that one reference. Thus, coarse aggregate for one set shall consist of enough material for one reference concrete, the test admixture-containing concrete to be compared with that reference and the sample for grading analysis testing.

11.2.3.1 Prepare coarse aggregate for a set, comprising a sample large enough for concrete trials, as follows: Fill tared containers, one each for a sample, a batch of reference concrete and one or more test concretes to the required mass from the aggregate stockpile. Accomplish this by starting with a scoopful into the first container and repeat this procedure until all containers have their required mass. Repeat the process for each of the three or more sets needed. One or more spare sets may be needed. See the Appendix of Practice D 75, Sampling from Stockpiles, and the Manual of Aggregate and Concrete Testing for guidance for conditions and procedures.

11.2.4 Test coarse aggregate samples representing each set by Method C 136 requirements for the sieves shown below. Discard any set for which the sample does not comply with size 57. Average test results for samples which comply with size 57 for each sieve size. Discard any set for which the sample deviates from this average by more than the amount shown in column 3. Continue the process of preparation, testing and averaging until sufficient sets of aggregate within tolerance are obtained.

Sieve	Specification C 33, No. 57 Percent Passing	Maximum variation from average/passing
1.5 in.	100	00
1.0 in.	95 to 100	1.0
0.5 in.	25 to 60	4.0
No. 4	0 to 10	4.0
No. 8	0 to 5	1.0

NOTE 8—All of the results required for demonstrating compliance under this specification are dependent on the uniformity of the aggregate samples prepared and used. Careful, skilled and well-supervised work is essential.

11.3 *Air-Entraining Admixture*—Except when tests are made in accordance with 11.4 using the air-entraining admixture proposed for specific work, the air-entraining admixture used in the concrete mixtures specified in Section 12 shall be a material such that when used to entrain the specified amount of air in the concrete mixture will give concrete of satisfactory resistance to freezing and thawing. The material to be so used will be designated by the person or agency for whom the testing is to be performed. If no material is designated, "neutralized Vinsol resin"[7] shall be used.

NOTE 9—Neutralization may be accomplished by treating 100 parts of Vinsol resin with 9 to 15 parts of NaOH by weight. In an aqueous solution, the ratio of water to the resinate shall not exceed 12 to 1 by weight.

11.4 *Materials for Tests for Specific Uses*—The effects of a chemical admixture on the time of setting and water requirement of concrete may vary with the time of its addition during the batching and mixing sequence. To test a chemical admixture for use in specific work, the cement, pozzolan, aggregates, and air-entraining admixture used shall be representative of those proposed for use in the work. Add the chemical admixture in the same manner and at the same time during the batching and mixing sequence as it will be added on the job. Proportion the concrete mixtures to have the cement content specified for use in the work. If the maximum size of coarse aggregate is greater than 1 in. (25.4 mm), screen the concrete over a 1-in. (25.0-mm) sieve prior to fabricating the test specimens.

11.4.1 *Other Use Conditions*—Other conditions may affect the overall suitability of the concrete mixture for specific intended uses. These include the temperature of the materials or the surroundings, the humidity, the length of time between mixing and placing, the amount of mixing activity and other factors. These physical conditions may be incorporated into the tests with intention for indicating the potential interactions. These tests would be only for guidance. After incorporation of such test conditions it would not be suitable to expect compliance with this specification requirement.

11.5 *Preparation and Weighing*—Prepare all material and make all weighings as prescribed in Practice C 192.

12. Proportioning of Concrete Mixtures

12.1 *Proportions*—Except when tests are being made for specific uses (see 11.4), all concrete shall be proportioned using ACI 211.1-77 to conform to the requirements described in 12.1.1 through 12.1.4. Unless otherwise specified, the admixture shall be added with the first increment of mixing water that is added to the mixer.

12.1.1 The cement content shall be 517 ± 5 lb/yd^3 (307 ± 3 kg/m^3).

12.1.2 The first trial mixture shall contain the amount of coarse aggregate shown in Table 5.3.6 of ACI 211.1-77 for the maximum size of aggregate and for the fineness modulus of the sand being used.

NOTE 10—Values in Table 5.3.6 of ACI 211.1-77 are intended to ensure workable mixtures with the least favorable combinations of aggregate likely to be used. It is suggested, therefore, that for a closer approximation of the proportions required for this test, the values selected from Table 5.3.6 be increased by about 7 for the first trial mixture.

12.1.3 For the non-air-entrained mixtures, the air content used in calculating the proportions shall be 1.5, as shown in Table 5.3.3 of ACI 211.1-77. For the air-entrained mixtures, the air content used for this purpose shall be 5.5.

12.1.4 Adjust the water content to obtain a slump of 3½ ± ½ in. (88 ± 12 mm). The workability of the concrete mixture shall be suitable for consolidation by hand rodding and the concrete mixture shall have the minimum water content possible. Achieve these conditions by final adjustments in the proportion of fine aggregate to total aggregate or in the amount of total aggregate, or both, while maintaining the yield and slump in the required ranges.

12.2 *Conditions*—Prepare concrete mixtures both with and without the admixture under test. Refer herein to the concrete mixture without the chemical admixture as the reference or control concrete mixture. Add the admixture in the manner recommended by the manufacturer and in the amount necessary to comply with the applicable requirements of the specifications for water reduction or time of setting, or both. When desired by the person or agency for whom the tests are being performed, the admixture may be added in an amount such as to produce a specific time of setting of the concrete mixture within the limits of the applicable provisions of this specification.

12.2.1 *Non-Air-Entrained Concrete*—When the admixture is to be tested for use only in non-air-entrained concrete, the air content of both the mixture containing the admixture under test and the reference concrete mixture shall be 3.0 % or less, and the difference between the air contents of the two mixtures shall not exceed 0.5. If necessary, the air-entraining admixture specified in 11.3 shall be added to the reference concrete mixture. Tests for resistance to freezing and thawing shall not be made.

12.2.2 *Air-Entrained Concrete*—When the admixture is to be tested for use only in air-entrained concrete, the air-entraining admixture specified in 11.3 shall be added to the reference concrete mixture and, if necessary, to the concrete

[7] Vinsol resin is manufactured by Hercules Inc., Wilmington, DE.

mixture containing the admixture under test in sufficient amounts to produce air contents in the range 3.5 to 7.0, except that for tests for resistance to freezing and thawing, the range shall be 5.0 to 7.0. In both cases the difference between the air content of the reference concrete and that of the concrete containing the admixture under test shall not exceed 0.5.

13. Mixing

13.1 Machine mix the concrete as prescribed in Practice C 192.

14. Tests and Properties of Freshly Mixed Concrete

14.1 Samples of freshly mixed concrete from at least three separate batches for each condition of concrete shall be tested in accordance with the methods described in 14.2 through 14.5.

14.2 *Slump*—Test Method C 143.

14.3 *Air Content*—Test Method C 231.

14.4 *Time of Setting*—Test Method C 403, except that the temperature of each of the ingredients of the concrete mixtures, just prior to mixing, and the temperature at which the time of setting specimens are stored during the test period shall be 73 ± 3°F (23.0 ± 1.7°C).

14.5 *Water Content:*

14.5.1 Report the water-cement ratio of the concrete, computed to the nearest 0.001, as follows: Determine the net water content of the batch as the weight of water in the batch in excess of that present as absorbed water in the aggregates. Calculate the actual volume of concrete in the batch by determining the weight per unit volume of concrete in the batch as prescribed in Test Method C 138. Determine the water-cement ratio by dividing the net weight of water by the weight of cement in the batch.

14.5.2 Calculate the relative water content of the concrete containing the admixture under test as a percentage of the water content of the reference concrete as follows: Divide the average water content of all batches of concrete containing the admixture under test by the average water content of all batches of the reference concrete and multiply the quotient by 100.

TABLE 2 Types and Minimum Number of Specimens and Tests

	Number of Types of Specimens[A]	Number of Test Ages	Number of Conditions of Concrete[B]	Number of Specimens, min
Water content	. .	1	2	[C]
Slump	1	1	2	C
Air content	1	1	2	C
Time of setting	1	[D]	2	6
Compressive strength	1	5	2	30
Flexural strength	1	3	2	18
Freezing and thawing	1	1	2	12
Length change	1	1	2	6
Water reducing, high range	. . .	6		36
Water reducing, high—range and retarding		6	.	36

[A] See Section 14 and 16.2.
[B] See 12.2
[C] Determined on each batch of concrete mixed
[D] See 14.4

15. Preparation of Test Specimens

15.1 Make specimens for tests of hardened conc representing each test and age of test and each conditio concrete being compared, from at least three sepa batches, and the minimum number of specimens shall b prescribed in Table 2. On a given day make at least specimen for each test and age of test from each conditio concrete, except make at least two specimens for the free and thawing test from each condition of concrete. Comp the preparation of all specimens in three days of mixing.

15.2 *Manifestly Faulty Specimens*—Visually exam each group of specimens representing a given test or a gi age of test, including tests of freshly mixed concrete, bef or during the test, or both, whichever is appropriate. Disc any specimen found to be manifestly faulty by such exa nation without testing. Visually examine all specim representing a given test at a given age after testing, a should any specimen be found to be manifestly faulty the t results thereof shall be disregarded. Should more than c specimen representing a given test at a given age be fou manifestly faulty either before or after testing, the entire t shall be disregarded and repeated. The test result report shall be the average of the individual test results of t specimens tested or, in the event that one specimen or o result has been discarded, it shall be the average of the t results of the remaining specimens.

16. Test Specimens of Hardened Concrete

16.1 *Number of Specimens*—Six or more test specime for the freezing and thawing test and three or more te specimens for each other type of test and age of test specifie in Table 2 shall be made for each condition of concrete to b compared.

16.2 *Types of Specimens*—Specimens made from co crete with and without the chemical admixture under te shall be prepared in accordance with the following:

16.2.1 *Compressive Strength*—Make and cure test spec mens in accordance with Practice C 192.

16.2.2 *Flexural Strength*—Make and cure test specimen in accordance with Practice C 192.

16.2.3 *Resistance to Freezing and Thawing*—Test speci mens shall consist of prisms made and cured in accordanc with the applicable requirements of Practice C 192. Tes specimen dimensions shall be as required by Test Metho C 666. Make one set of specimens from the concrete mixtur containing the chemical admixture under test and from th reference concrete mixture, the air content of each mixtur being as specified in 12.2.2.

16.2.4 *Length Change*—Make and cure test specimens ir accordance with Test Method C 157. The moist-curing period, including the period in the molds, shall be 14 days.

17. Tests on Hardened Concrete

17.1 Test specimens of hardened concrete in accordance with the following methods (see Table 1):

17.1.1 *Compressive Strength*—Test Method C 39. Test specimens at ages of 1, 3, 7, and 28 days, 6 months, and 1 year. Calculate the compressive strength of the concrete containing the admixture under test as a percentage of the compressive strength of the reference concrete as follows:

17.1.1.1 Divide the average compressive strength of the specimens made from the concrete containing the admixture under test at a given age of test by the average compressive strength of the specimens made from the reference concrete at the same age of test and multiply the quotient by 100.

17.1.1.2 When tests are conducted with materials representative of those proposed for use in specific work in accordance with 11.4, and if the results of the tests are required in a period of time that will not permit curing of specimens to ages of 6 months and 1 year, the tests at those ages as required in accordance with 17.1.1 may be waived.

17.1.2 *Flexural Strength*—Test Method C 78. Test specimens at ages 3, 7, and 28 days. Calculate the flexural strength of the concrete containing the admixture under test as a percentage of the flexural strength of the reference concrete as follows:

17.1.2.1 Divide the average flexural strength of the specimens made from the concrete containing the admixture under test at a given age of test by the average flexural strength of the specimens made from the reference concrete at the same age of test, and multiply the quotient by 100.

17.1.3 *Resistance to Freezing and Thawing*—Comparison tests of the concrete containing the admixture under test with the reference concrete mixture shall be made concurrently using Procedure A of Test Method C 666. Place specimens under test at the age of 14 days. Calculate the relative durability factors as shown in Specification C 260.

17.1.4 *Length Change*—Test specimens shall consist of molded prisms made and tested in accordance with Test Method C 157 except that the moist curing period, including the period in the molds, shall be 14 days. Then store the specimens in air under conditions specified in Section 7.1.2 of Test Method C 157 for a period of 14 days, at which time determine the length change of the specimen. Consider the drying shrinkage to be the length change during the drying period, based on an initial measurement at the time of removal of the specimen from the mold, and express it as percent to the nearest 0.001 % based on the specimen gage length. If the length change of the reference concrete after 14 days of drying is 0.030 % or greater, the length change on drying of concrete containing the admixture under test, expressed as percent of the length change of the reference concrete, shall not exceed the maximum specified in Table 1. If the length change of the reference concrete after 14 days of drying is less than 0.030 %, the length change on drying of concrete containing the admixture under test shall be not more than 0.010, expressed as a percentage change in length, greater than that of the reference concrete.

NOTE 11—Since the specific effects produced by chemical admixtures may vary with the properties of the other ingredients of the concrete, results of length change tests using aggregates of such a nature that the length change on drying is low may not accurately indicate relative performance to be expected with other aggregates having properties such as to produce concrete of high length change on drying.

18. Uniformity and Equivalence Tests

18.1 *Infrared Analysis*—This test procedure is intended to compare qualitatively the composition of different samples and results should not be interpreted quantitatively. Sections 18.1.1, 18.1.2, and 18.1.3 give a general procedure for the infrared analysis of admixtures (see Notes 5 and 12).

18.1.1 *Liquid Admixtures*—Determine the dissolved solids concentration by 18.2 and dilute an aliquot of the liquid admixture sample with distilled water to yield a dissolved solids concentration of about 0.015 g/mL, for example, a 5-mL aliquot diluted to 200 mL. Pipet 5 mL of above solution and add it to a petri dish with 2.5 g of potassium bromide of a grade suitable for use in infrared analysis and 5 mL of distilled water. Stir and mix to dissolve. Place in a drying oven (18.2.1.1) and dry for 17 ± ¼ h at 105 ± 3°C. Cool and transfer the dried residue to a mortar and grind to a fine powder. Work quickly to avoid moisture pick-up. Weigh 0.1 g of the powder and 0.4 g of potassium bromide of a grade suitable for use in infrared analysis. Mix in an electric amalgamator for 30 s using stainless steel capsule and balls. Proceed in accordance with 18.1.3.

18.1.2 *Non-liquid Admixtures*—Grind 10 g to a fine powder with mortar and pestle. Transfer the sample to a petri dish, place in a drying oven (18.2.1.1) and dry for 17 ± ¼ h at 105 ± 3°C. Weigh approximately 0.005 g of the dry powder and 0.995 g of potassium bromide of a grade suitable for use in infrared analysis. Mix in an electric amalgamator for 30 s using stainless steel capsule and balls. Proceed in accordance with 18.1.3.

18.1.3 To prepare a disk for infrared analysis, weigh 0.300 g of the mixture prepared in 18.1.1 or 18.1.2 and transfer into a suitable die. If an evacuable die is used, apply vacuum for 2 min prior to pressing. Continue vacuum and press at a suitable force for 3 min, producing a disk about 1 mm thick. Remove the disk from the die, insert into the infrared spectrophotometer and obtain infrared absorption spectra.

NOTE 12—It is important that the same procedures be used on all samples to be compared with each other and preferably that they be conducted by the same analyst. Major changes in infrared spectra may result from (*a*) water content differences due to drying variations, (*b*) water picked up by hygroscopic materials, (*c*) reaction between the potassium bromide and some other compound present, and (*d*) differences in time between formation of the disk and its use. Also, the threshold for detection of individual components by infrared absorption varies widely, depending upon the identity and concentration of accompanying substances. For example, significant amounts of saccharides may be present in a lignosulfonate admixture without their presence being indicated by this method.

18.2 *Residue by Oven Drying* (Liquid Admixtures):

18.2.1 Place 25 to 30 g of standard Ottawa sand (20 to 30 mesh) in a wide-mouth, low-form (about 60 mm inside diameter and 30 mm in height) glass weighing bottle provided with a ground-glass stopper. Place the weighing bottle and stopper, with stopper removed, in a drying oven (18.2.1.1) and dry for 17 ± ¼ h at 105 ± 3°C (Note 11). Insert the stopper in the weighing bottle, transfer to a desiccator, cool to room temperature, and weigh to the nearest 0.001 g. Remove the stopper and, using a pipet, evenly distribute 4 ml of the liquid admixture over the sand. Immediately insert the stopper to avoid loss by evaporation and weigh to the nearest 0.001 g. Remove the stopper and place both the bottle and stopper in a drying oven (18.2.1.1). Dry for 17 ± ¼ h at 105 ± 3°C. At the end of the drying period, stopper the weighing bottle, transfer to a desiccator, cool to room temperature, and weigh to the nearest 0.001 g.

18.2.1.1 The drying oven shall be either a forced circulation type or one with provision for free access of air. There shall be precise control of temperature and time of drying so that the degree of volatilization of the material other than water from sample to sample will not vary.

18.2.2 *Calculation:*

18.2.2.1 Record the following weights:

w_1 = weight of stoppered bottle with sand and sample,
w_2 = weight of stoppered bottle with sand,
w_3 = $w_1 - w_2$ = weight of sample,
w_4 = weight of stoppered bottle with sand and dried residue, and
w_5 = $w_4 - w_2$ = weight of dried residue.

18.2.2.2 Calculate the residue by using the following equation:

$$\text{Residue by oven drying (percent by weight)} = (w_5 \times 100)/w_3$$

NOTE 13—For laboratories conducting this test as a routine operation, previously dried sand and weighing bottles can be maintained in desiccators so that they are immediately available for use when a sample is to be tested.

18.2.3 *Precision Statement*—The maximum multilaboratory coefficient of variation for residue by oven drying (liquid admixtures) has been found to be 1.25 %. Therefore, results of tests by two different laboratories on identical samples of an admixture should not differ from each other by more than 3.5 % of their average (Note 14). The maximum single-operator coefficient of variation has been found to be 0.6 %. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 1.7 %.

NOTE 14—The precision statements are based on the maximum variation of tests made in 18 laboratories on sets of three duplicate samples of two different admixtures.

18.3 *Residue by Oven Drying* (Nonliquid Admixtures):

18.3.1 Place about 3 g of the nonliquid admixture into a dried and tared glass-stoppered weighing bottle (similar to the one described in 18.2.1). Stopper and weigh bottle and contents to the nearest 0.001 g. Remove the stopper and immediately place both bottle and stopper in a drying oven (18.2.1.1). Dry for 17 ± ¼ h at 105 ± 3°C. At the end of the drying period, stopper the weighing bottle, transfer to the desiccator, cool to room temperature, and weigh to the nearest 0.001 g.

18.3.2 *Calculation:*

18.3.2.1 Record the following weights:

w_1 = weight of tared stoppered weighing bottle and sample before drying,
w_2 = weight of empty, stoppered weighing bottle,
w_3 = weight of sample = $(w_1 - w_2)$,
w_4 = weight of tared stoppered weighing bottle and sample after drying, and
w_5 = weight of oven-dried residue = $w_4 - w_2$.

18.3.2.2 Calculate the oven-dried residue by using the following equation:

$$\text{Residue by oven drying (weight percent)} = [w \times 100]/w_3$$

18.3.3 *Precision Statement*—The maximum multilaboratory coefficient of variation for residue by oven-drying (non-liquid admixture) has been found to be 1.40 %. Therefore, results of tests by two different laboratories on identical samples of an admixture should not differ from each other by more than 4.0 % of their average. The maximum single-operator coefficient of variation for residue by oven drying (non-liquid admixture) has been found to be 0.48 %. Ther fore, results of two properly conducted tests by the sa operator on the same material should not differ by mo than 1.4 % of their average. Note 14 also applies to 18.3.3

18.4 *Specific Gravity* (Liquid Admixtures):

18.4.1 Determine the specific gravity at 25 ± 1°C of liquid admixture using hydrometers complying with Speci cation E 100. Hydrometers No. 112H through 117H wi cover the range for most determinations. A 250-mL grad ated cylinder, and a water bath capable of maintaining 25 1°C will also be required.

18.4.2 Place a sample in the 250-mL graduated cylinde and put in the hydrometer in such a manner that it floats fre and does not touch the side of the cylinder. Place th cylinder with sample and hydrometer in the constan temperature bath until the temperature of the cylinder hydrometer, and sample is uniform at 25 ± 1°C. If all are a proper temperature prior to insertion of the hydrometer approximately 10 min should be allowed for equilibrium. I the sample shows evidence of foaming, hydrometer reading should be continued until constant readings are obtained Read the hydrometer at the base of the meniscus to the nearest 0.005.

18.4.2.1 If foaming is encountered during transfer of the admixture to the cylinder, sufficient time shall be allowed for the foam to dissipate or rise to the surface, where it shall be removed before inserting the hydrometer. Crusting of the admixture on the hydrometer stem due to evaporation during temperature adjustment shall be avoided.

18.4.3 *Precision Statement*—The maximum multilaboratory coefficient of variation for specific gravity (liquid admixtures) has been found to be 0.316 %. Therefore, results of two different laboratories on identical samples of an admixture should not differ from each other by more than 0.9 % of their average (Note 14). The maximum single-operator coefficient of variation has been found to be 0.09 %. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.275 %.

19. Report

19.1 Report the following:

19.1.1 Results of the tests specified in Sections 6, 14, and 17, and the relevant specification requirements with which they are compared,

19.1.2 Brand name, manufacturer's name, and lot number, character of the material, and quantity represented by the sample of the admixture under test,

19.1.3 Brand name, manufacturer's name, and other pertinent data on the material used as the air-entraining admixture,

19.1.4 Brand name, manufacturer's name, type, and test data on the portland cement or cements used,

19.1.5 Description of, and test data on the fine and coarse aggregates used,

19.1.6 Detailed data on the concrete mixtures used, including amounts and proportions of admixtures used, actual cement factors, water-cement ratios, unit water contents, ratios of fine to total aggregate, slump, and air content, and

19.1.7 In the event that, in accordance with the provisions of 17.1.1.2, some of the tests have been waived, the circumstances under which such action was taken shall be stated.

Standard Specification for Moist Cabinets, Moist Rooms, and Water Storage Tanks Used in the Testing of Hydraulic Cements and Concretes[1]

This standard is issued under the fixed designation C 511; 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.

1. Scope

1.1 This specification covers requirements for moist cabinets, moist rooms, and water storage tanks used for storage of paste, mortar, and concrete test specimens.

1.2 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 911 Specification for Quicklime, Hydrated Lime, and Limestone for Chemical Uses[2]

E 77 Test Methods for the Inspection and Verification of Thermometers[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *moist cabinet, n*—a compartmented storage facility of moderate dimensions with controlled temperature and relative humidity.

3.1.2 *moist room, n*—a "walk-in" storage facility with controlled temperature and relative humidity, commonly called a fog room when the prescribed relative humidity is achieved by the atomization of water.

4. Requirements

4.1 *General*—The atmosphere in a moist cabinet or room shall have a temperature of 23.0 ± 2.0°C and a relative humidity of not less than 95 %. The moisture in the atmosphere shall be saturated to the degree needed to ensure that the exposed surfaces of all specimens in storage will both look moist and feel moist at all times. All storage units shall be equipped with recording thermometers. The recording thermometer shall be calibrated at least every six months or whenever there is a question of accuracy. The reference measuring device must be a thermometer, graduated to 0.5°C which has been verified or calibrated, or both, in accordance with Test Methods E 77 (Note 1). The calibration of the recording thermometer shall be performed at 23.0 ± 2.0°C according to the reference thermometer. Position the reference thermometer in a readable position in air as near as is practical to the recording temperature probe. Keep the cabinet or room closed for at least 5 min prior to taking readings. For the temperature, the reference thermometer shall remain in the cabinet or room and be read immediately upon opening the moist cabinet or room door. Record both temperatures. If the difference between the two temperatures is greater than 1°C, the recording thermometer shall be adjusted to within 0.5°C of the reference thermometer. The use of humidity recording devices is optional. Shelves on which fresh specimens are placed shall be level.

NOTE 1—Liquid-in-glass thermometers, as well as other types of thermometers, are commerically available. These thermometers should be verified according to Test Methods E 77 to ensure that no damage has occurred during shipping. The ice-point method is the simplest procedure to use.

4.1.1 The air in a moist storage unit must be nearly saturated with moisture in order to provide specified storage conditions. In many cases, saturation is below optimum during periods when specimens are being placed in or removed from storage. Measurements of relative humidity should not be made at such obviously inopportune times.

4.1.2 The recordings from the recording thermometers shall be audited in order to ascertain the adequacy of the mechanisms used to control the moist room air temperature.

4.1.3 The air temperature inside the storage facility (moist cabinet or moist room) shall be controlled with provisions made for heating or cooling, or both, as may be necessary. This shall be accomplished in one of two ways:

4.1.3.1 Thermostatically control the air temperature within the storage facility when surrounding space is not conditioned. In this case the sensing element for the controls shall be located inside the storage facility.

4.1.3.2 Thermostatically control the space surrounding the storage facility and manually control the temperature within the storage facility.

4.1.4 In either of the preceding cases, the laboratory shall demonstrate the ability of the controls to maintain the required temperature in the storage facility over an extended period of time. Charts from the recording thermometer that indicate that the temperatures are within the temperature limits specified in 4.1 shall be required as evidence of this ability.

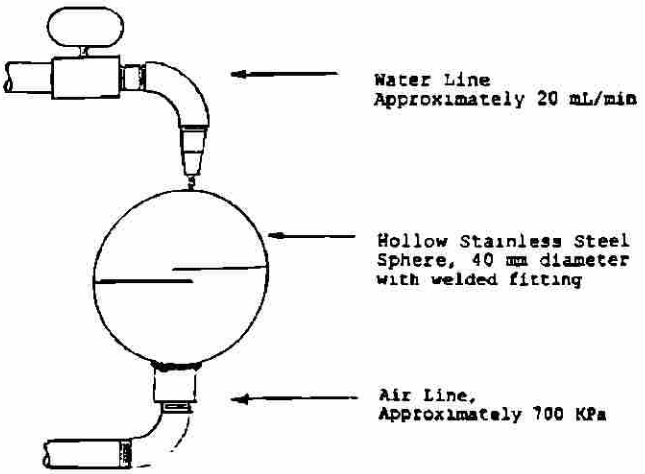
4.2 *Moist Cabinets*—A moist cabinet shall be constructed of durable materials and the doors shall be tight-fitting. The specified relative humidity shall be maintained by the use of one or more fog sprays, water sprays, or curtains of water on the inner walls that are so directed that the discharge will collect in a pool at or near the bottom of the moist storage section.

[1] This specification is under the jurisdiction of ASTM Committee C-1 on Cement and is the direct responsibility of Subcommittee C01.95 on Coordination of Standards.

Current edition approved July 10, 1996. Published September 1996. Originally published as C 511 – 68. Last previous edition C 511 – 95a.

[2] *Annual Book of ASTM Standards*, Vol 04.01.

[3] *Annual Book of ASTM Standards*, Vol 14.03.



NOTE—Cut three horizontal air slots around circumference of hollow sphere using a 0.20 mm thick diamond lapidary saw covering 120° to 150° each and spaced approximately 5 mm apart.[4]

FIG. 1 Example of a Fog Spray for Maintaining Relative Humidity in Moist Rooms (Full Scale)

4.3 *Moist Rooms:*

4.3.1 *General*—The walls of a moist room shall be constructed of durable materials, and all openings shall be provided with tight-fitting doors or windows (Note 2). The specified relative humidity may be maintained in any convenient and suitable manner (Note 3).

NOTE 2—Well insulated walls will substantially help maintain necessary conditions.

NOTE 3—A fog spray found suitable for this purpose is shown in Fig. 1.

4.3.2 *Moist Rooms Used in Cement Testing*—Durable shelving that is properly shielded to prevent droplets of water from falling on the surfaces of freshly molded specimens shall be available within each room.

4.3.3 *Moist Rooms Used in Concrete Testing*—Atmospheric conditions within each room shall be such that test specimens in storage shall have free water maintained on their entire surface area at all times. Specimens shall not be exposed to dripping or running water.

4.4 *Water Storage Tanks:*

4.4.1 *General*—Tanks shall be constructed of noncorroding materials. Provision for automatic control of water temperature at 23.0 ± 2.0°C shall be made where a tank is located in a room not having temperature controlled within that range and in any other instance where difficulty in maintaining temperatures within the specified range is encountered. Each tank located in a space not controlled at 23.0 ± 2.0°C shall be equipped with a recording thermometer with its sensing element in the storage water. Water storage recording thermometers shall be checked for accuracy at least every six months by comparing their output with that of a mercury in glass thermometer, graduated in 0.5°C divisions, placed in the water adjacent to the probe of the recording thermometer. Adjustments shall be made if differences in the observed readings exceed 1°C. The water in a storage tank shall be saturated with calcium hydroxide to prevent leaching of calcium hydroxide from the specimens (Note 4). Water not saturated with calcium hydroxide (high-calcium hydrated lime) may affect test results due to leaching of lime from the test specimens and shall not be used in storage tanks. To maintain saturation with calcium hydroxide, excess calcium hydroxide shall be present. For the purposes of lime saturation to prevent leaching, lime means calcium hydroxide only (hydrated lime, such as Type CH, meeting the requirements of Specification C 911), not calcium carbonate. The water in the storage tank shall be thoroughly stirred at intervals not to exceed one month to help replace calcium ions that have depleted. Tanks shall be cleaned and refilled with water containing 3 g/L of calcium hydroxide at intervals not to exceed 24 months (Note 5).

NOTE 4—pH is not a reliable indicator of lime saturation in storage tank water since severe reductions in dissolved calcium ions can occur before pH values are significantly reduced.

NOTE 5—The 3 g/L level is intended to provide a quantity of calcium hydroxide approximately two times that required for initial saturation.

4.4.2 Do not use continuously running fresh water or demineralized water in storage tanks because it may effect test results due to excessive leaching. A closed system circulating the saturated lime water between or among storage tanks, may be used.

5. Keywords

5.1 cement paste; concrete; moist cabinets; moist rooms mortar; water storage tanks

[4] One spray will supply sufficient water to supply moisture to a space of 25 m^3. Hollow spheres available through McMaster Carr Supply Co., PO Box 4355, Chicago, IL 60680-4355.

Standard Test Method for Abrasion Resistance of Concrete or Mortar Surfaces by the Rotating-Cutter Method[1]

This standard is issued under the fixed designation C 944; 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.

1. Scope

1.1 This test method covers a procedure for determining the resistance of either concrete or mortar to abrasion. It is not intended to be used as an alternative to Test Method C 418, or Test Method C 779.

1.2 The values stated in SI units are to be regarded as standard.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 42 Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete[2]

C 418 Test Method for Abrasion Resistance of Concrete by Sandblasting[2]

C 779 Test Method for Abrasion Resistance of Horizontal Concrete Surfaces[2]

3. Significance and Use

3.1 This test method gives an indication of the relative wear resistance of mortar and concrete based on testing of cored or fabricated specimens. This test method has been successfully used in the quality control of highway and bridge concrete subject to traffic. Primarily intended for use on the top ends of 152-mm (6-in.) diameter concrete cores, mortar specimens, or other samples of concrete of insufficient test area to permit the conduct of tests by Test Methods C 418 or C 779, this test method is also applicable on concrete surfaces in place by measuring the abrasion loss as described in Section 9, Procedure B, of Test Method C 779.

4. Apparatus

4.1 *Abrasion Device*—A drill press[3] or similar device with a chuck capable of holding and rotating the abrading cutter at a speed of 200 r/min and exerting a force of 98 ± 1 N (22 ± 0.2 lbf) on the test specimen surface. Fig. 1 shows a commercial drill press and Fig. 2 illustrates details of the rotating cutter. The difficulty in maintaining a constant load on the abrading cutter when using the lever, gear, and spring system of a drill press has been eliminated by placing the desired load directly upon the spindle that turns the cutter. The machine consists essentially of a frame that supports the drive motor, stepped pulley, and spindle. A clamping device to hold the specimen is built into the base.

4.2 *Rotating Cutter*—A rotating cutter similar to that shown in Figs. 2 and 3 shall be used in which 24 No. 1 Desmond-Huntington grinding dressing wheels[4] are mounted. The washers shall be of a smaller diameter than the dressing wheels before and after the test. The washer diameter shall be maintained at a diameter less than the dressing wheels throughout the test (see also 4.2.2). (See Note 1.) The overall diameter of the cutter or the diameter of the circular area abraded is 82.5 mm (3¼ in.). Care shall be taken to achieve constant contact between the rotating cutter and the entire test surface of the sample. This can be better accomplished if the cutters have a swivel connection allowing some vertical movement. If the dressing wheels have one rounded edge, they shall be mounted with the rounded edge toward the vertical shaft. The individual grinding wheel dressers on the horizontal shaft of the cutter shall be repositioned whenever a change in the diameter of the outer cutters becomes apparent. This is accomplished by reversing each set of dressing wheels to bring the smaller diameter cutters toward the vertical shaft.

NOTE 1—The washers between the dressing wheels are usually supplied by the manufacturer.

4.2.1 In making a test, the rotating cutter is held in a raised position by means of the rod provided, the specimen clamped securely in position, and motor started. The rotating cutter is then lowered into contact with the specimen for a specified time, after which the cutter is raised.

4.2.2 A set of dressing wheels shall be replaced periodically, preferably after each 90 min of use. The washers may be ground or replaced to maintain the proper diameter.

4.3 *Balance*—A balance having a capacity of at least 4 kg, and accurate to at least 0.1 g.

4.4 *Leveling Plate*—The base plate upon which the specimen rests shall be capable of rotating in the horizontal plane so that the specimens when placed thereon can be positioned to secure maximum contact with the rotating cutter throughout the full test area.

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[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.62 on Abrasion Testing of Concrete.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] Available from Soiltest Inc., 2205 Lee St., Evanston, IL 60202.

[4] Available from Desmond-Stephan Manufacturing Co., 713 South Walnut, Urbana, OH.

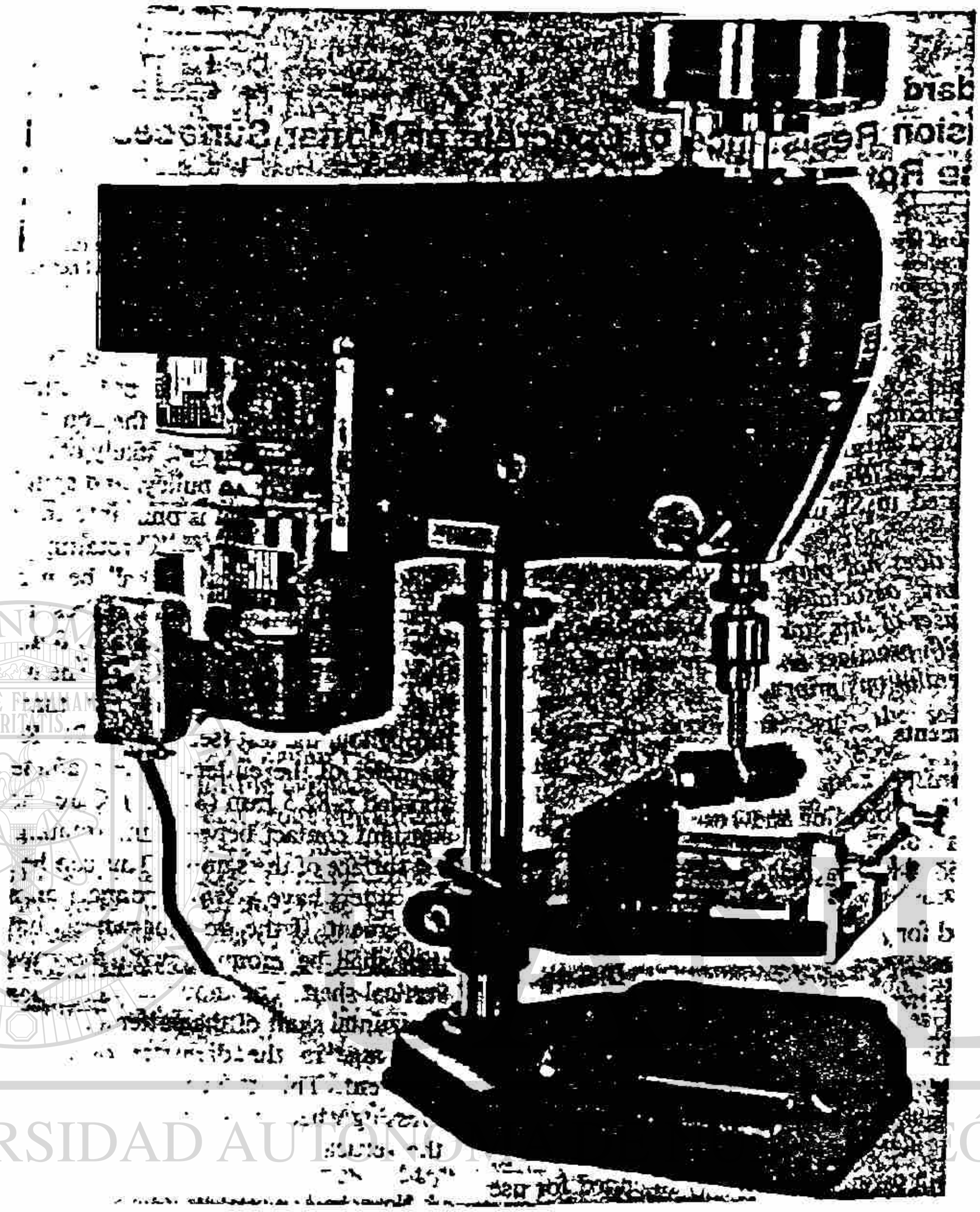

FIG. 1 Rotating-Cutter Drill Press

5. Sampling

5.1 Cores shall be taken in accordance with Test Method C 42.

6. Specimens

6.1 The specimens used in this test shall be of any size and shape that can be accommodated by the abrasion device and the balance provided. The surface to be tested shall be either formed or finished and shall be positioned in the plane of contact of the cutter.

7. Procedure

7.1 Determine the mass of the specimen to the nearest 0.1 g.

7.2 Fasten the specimens securely in the abrasion device so that the surface to be tested is normal to the shaft.

7.3 Mount the rotating cutter device in the abrasion device.

7.4 Start the motor and lower the cutter slowly until just in contact with the surface of the specimen.

7.5 Continue abrasion with a load of 98 ± 1 N (22 ± 0.2 lbf) on the specimen for 2 min after contact between the cutter and the surface. At the end of each 2-min abrasion period, remove the test specimen from the device and clean surfaces to remove debris using a soft brush or blow the surface with air. Determine the specimen mass to the nearest 0.1 g. The minimum test schedule shall involve three 2-min periods conducted on three separate areas of representative surfaces of the concrete or mortar.

7.6 For concrete that is highly resistant to abrasion additional testing may be required. Doubling the applied load, or the time, or both, as shown in the following chart, should provide more comprehensive information on such concrete

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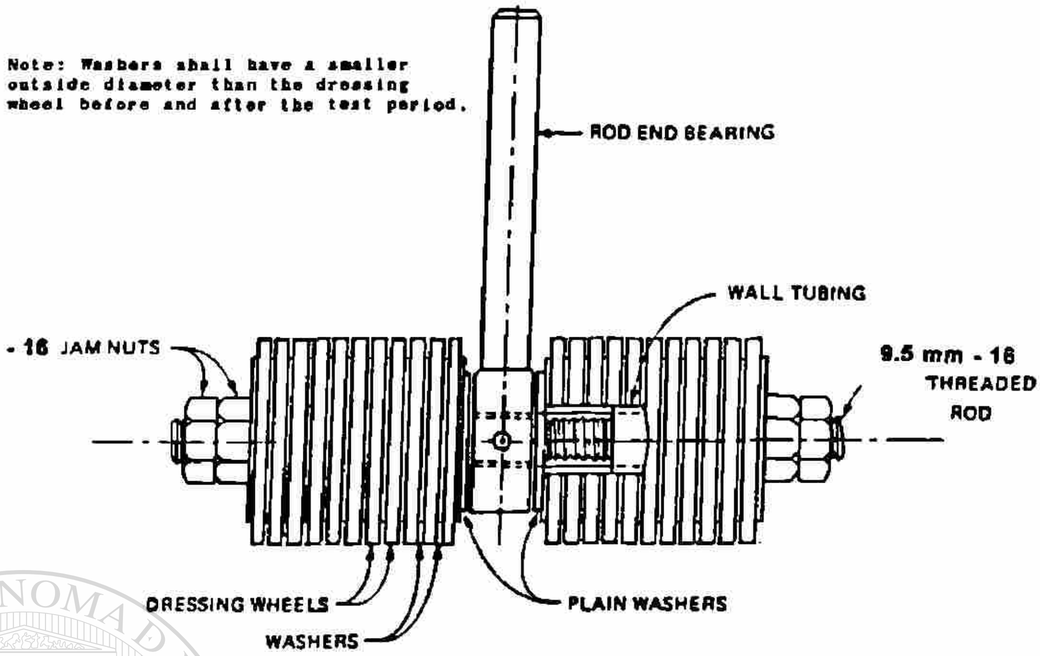

FIG. 2 Typical Rotating Cutters

	Abrasion Cycle	Load, N (lbf)	Test Frequency/Period
A	Normal	98 (22)	3 × 2 min
B	Double load	197 (44)	3 × 2 min

7.7 When testing surfaces in place, or when the depth of wear is to be determined due to significant differences in surface density, refer to Test Method C 779 Procedure B, (Sections Apparatus, Test Specimen, and Procedure) to determine abraded depth using the apparatus in this test method.

8. Report

8.1 Report the following information on:

8.1.1 Description of surface,

8.1.2 Size of specimen,

8.1.3 Type of finish,

8.1.4 Concrete compaction, age, and strength,

8.1.5 Applied surface treatment,

8.1.6 Load and time of abrasion used in the normal or severe test,

8.1.7 Average loss in grams or depth of wear in millimetres and,

8.1.8 Loss in mass and time abraded.

9. Precision and Bias

9.1 The precision and bias statements are only valid for inch-pound units. An exact conversion of units is required to ensure no effect on the original precision and bias data.

9.2 *Normal Test Condition*—The single-operator coefficient of variation has been found to be 21 %. Therefore, the results of two properly conducted tests by the same operator on similar samples should not differ from each other by more than 59 % of the average.

9.3 *Severe Test Condition*—The single-operator coefficient of variation has been found to be 12.6 %. Therefore, the results of two properly conducted tests by the same operator on similar samples should not differ from each other by more than 36 % of their average.

9.4 *Bias*—The procedure in this test method has no bias because the value of Abrasion Resistance of Concrete Surfaces can be only defined in terms of a test method.

10. Keywords

10.1 abrasion; concrete; impact; mortar; wear

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