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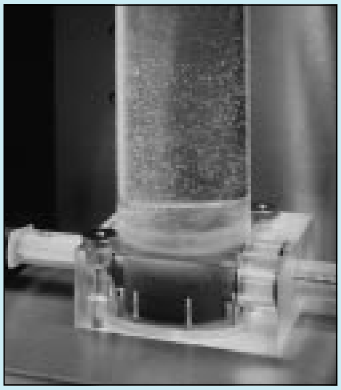



# Control of Air Content in Concrete

*New manual provides concrete producers and users with tips on achieving and controlling air in concrete.*

Air entrainment is a necessary component of concrete mixtures exposed to freezing and thawing environments. Due to changing materials, conditions of mixing, and methods of placing concrete, achieving target air contents requires attention at the design, specification, and construction stages. A new reference by NRMCA and PCA titled *Manual on Control of Air Content in Concrete* (PCA EB116)–excerpted in this article—brings together practical state-of-the-art information to control the air content of fresh and hardened concrete in the field.

Concrete pavements and structures in many regions of North America are exposed to very severe winter conditions, including snowfall, the application of large quantities of deicing agents, and many cycles of freezing and thawing.

Water expands upon freezing, exerting forces that exceed the tensile strength of concrete. Repeated cycles of freezing and thawing can result in cumulative damage in the form of cracking and scaling (Fig. 1).

## Role of Air Content

For over 50 years, entrained air has been deliberately incorporated in concrete mixtures to reduce damage due to cycles of freezing and thawing. Air-entraining admixtures or agents are used to produce a stable system of

*Figure 1. Freeze-thaw deterioration of non-air-entrained concrete railing. (S44517)*

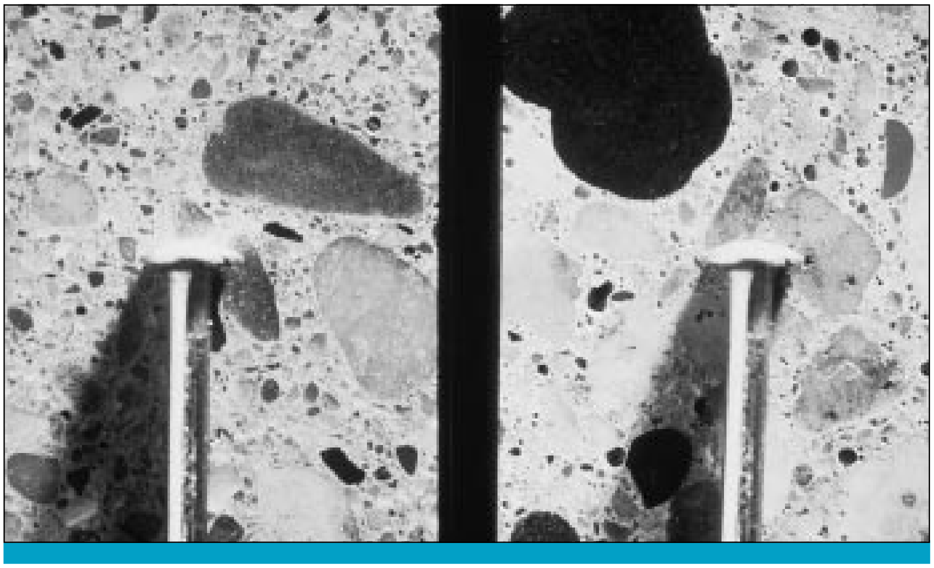

*Figure 2. Cross-section comparison of non-air entrained (left side) and air-entrained (right side) concrete. (P1104).*

discrete air voids in concrete, termed "entrained air." Non-air-entrained (left side) and properly air-entrained concretes (right side) are shown in Fig. 2. Most of the entrained air bubbles are smaller than the head of a pin (shown). The air voids provide empty spaces within the concrete that act as reservoirs for the freezing water, relieving pressure and preventing damage to the concrete.

## Forming Air in Concrete

Entrained air is produced during mechanical mixing of concrete that contains an air-entraining admixture. The shearing action of mixer blades continuously breaks up the air into a fine system of bubbles. Air-entraining admixtures stabilize these air bubbles.

## Air-Void System

Once the concrete has set, the casts of the original air bubbles are left behind in the hardened concrete as voids. This is commonly referred to as the "air-void system" in hardened concrete. The major parameters of the air-void system are the total air content, average spacing factor between air voids, and specific surface. Entrained air consists of microscopically small bubbles, almost all of which have diameters greater than 10 micrometers (0.0004 in.) and less than 1 mm (0.04 in.). These bubbles are uniformly distributed throughout the concrete. The relative distance between the voids is termed the spacing factor. The spacing factor is roughly the distance water would have to travel before entering an air void, thereby reducing the pressure. A smaller spacing is better. The specific surface indicates the relative number and size of air bubbles for a given volume of air. A larger specfic surface is better because it indicates a larger number of small bubbles. A spacing factor of less than 0.2 mm (0.008 in.) and specific surface greater than 24 $mm^2/mm^3$ (600 $in.^2/in.^3$) are believed necessary to maintain freeze-thaw durability.

The total volume of air in concrete is usually measured on the plastic concrete. Required air content of the concrete decreases with increasing aggregate size such that approximately 9 percent air is maintained in the mortar fraction. General recommendations on total air content for concrete are shown in Table 1.

## Sampling and Testing for Air

The sample size for air content testing of fresh concrete should be a minimum of 0.028 $m^3$ (1 $ft^3$). The sample should not be taken from the very first or last portion of the batch. A sample should be obtained for every 75 $m^3$ (100 $yd^3$) of concrete, at least once per day.

The common method of measuring air content in fresh concrete is the pressure method (Fig. 3). This method is based on the principle that the only significantly compressible ingredient of fresh concrete is the air. Pressure meters should not be used for concrete made with lightweight aggregates or aggregates of high porosity. In these instances the volumetric air meter should be used.

The volumetric method for determination of air content relies on simple displacement of air with water in a vessel of pre-calibrated volume.

The gravimetric method is the oldest method of determining air content of fresh concrete. The specific gravities (densities) of all materials must be known so that the theoretical unit weight (with no air) can be determined and then compared with the actual unit weight to determine air content. The actual unit weight is determined by weighing a known volume of fresh concrete.

**Table 1. Recommended Total Target Air Content for Concrete**

| Nominal maximum aggregate size, mm (in.) | Air content, percent* | | |
|---|---|---|---|
| | Severe exposure** | Moderate exposure† | Mild exposure†† |
| 9.5 (3/8) | 7-1/2 | 6 | 4-1/2 |
| 12.5 (1/2) | 7 | 5-1/2 | 4 |
| 19.0 (3/4) | 6 | 5 | 3-1/2 |
| 25.0 (1) | 6 | 4-1/2 | 3 |

* Project specifications often allow the air content of the concrete to be within –1 to +2 percentage points of the table target values.
** Concrete exposed to wet-freeze-thaw conditions, deicers, or other aggressive agents.
† Concrete exposed to freezing but not continually moist, and not in contact with deicers or aggressive chemicals.
†† Concrete not exposed to freezing conditions, deicers, or aggressive agents.



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*Figure 3. A Type B pressure meter used to measure total air content of fresh concrete. (P66113)*

**Table 2. Effects of Concrete Ingredients on Air Content**

| Material | Effects | Guidance |
|---|---|---|
| Cement | | |
| Alkali content | Air content increases with increase in cement alkali level. | Changes in alkali content require that air-entraining agent dosage be adjusted. |
| Fineness | Decrease in air content with increased fineness of cement. | Adjust agent if cement source or fineness changes. |
| Cement content | Decrease in air content with increase in cement content. | Increase air-entraining admixture dosage rate. |
| Fly ash | Air content decreases with increase in L.O.I. (carbon content). | Changes in L.O.I. or fly ash source require that air-entraining agent dosage be adjusted. |
| Water reducers | Air content increases with increase in dosage of lignin-based materials. | Reduce dosage of air-entraining agent. |
| Aggregate | Air content increases with increased sand content. | Decrease air-entraining agent dosage. |

When air content in fresh concrete is compared to air content in hardened concrete, differences can exist. Air content in hardened concrete is normally measured microscopically on a polished section of concrete taken from a laboratory beam, field cylinder, or core. Differences between fresh and hardened air content from the same lot of concrete are generally less than plus-or-minus 1 to 2 percentage points.

**Table 3. Effects of Production and Construction Variables on Air Content**

| Variable | Effects | Guidance |
|---|---|---|
| Mixer capacity | Air increases as capacity is approached. | Run mixer close to full capacity. Avoid overloading. |
| Temperature | Air content decreases with increase in temperature. | Increase air-entraining agent dosage as temperature increases. |
| Haul time and agitation | Long hauls, even without agitation, reduce air, especially in hot weather. | Optimize delivery schedules. Maintain concrete temperatures in recommended ranges. |
| Pumping | Reduction in air content ranges from 2 to 3%. | Use loop in descending pump line. Keep the pumping pressure as low as possible. |
| Internal vibration | Air content decreases under prolonged vibration or at high frequencies. | Do not overvibrate. Avoid high-frequency vibrators (>10,000 vpm). |

## Effects of Concrete Ingredients

The materials used to produce concrete–portland cement, supplementary cementitious materials, chemical admixtures, aggregates, and mixing water–can have a significant effect on air content. A discussion of the qualitative effects of these materials on the trends in air content is covered in the manual along with guidance to correct unintended changes in air content resulting from changes in materials. Table 2 summarizes just some of the effects concrete ingredients have on air.

## Production Procedures, Construction Practices, and Field Conditions

The way concrete is produced and handled can also have a significant effect on its air content and entrained air-void system. Variables associated with concrete production include the methods of batching, mixing procedures, and time and speed of mixing. Construction-related variables and field conditions such as transport and delivery, retempering, placement, consolidation, finishing, and temperature also can affect the air content of concrete. Table 3 summarizes the effect of some of these variables on air content.

## Excerpt

The information presented in this article is a brief excerpt taken from the *Manual on Control of Air Content in Concrete* (EB116), published in 1998 by NRMCA and PCA. The document presents practical information on achieving and controlling target air contents. It is available through NRMCA and PCA (see New Literature).

PCA R&D Serial No. 2093a



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# Air-Void Analyzer

By Tine Aarre, Ph. D.
Dansk Beton Teknik A/S

*A new test determines the air-void system of fresh concrete.*

It is generally accepted that entraining air in concrete improves its frost resistance. It is also recognized that it is the number of very small closely spaced air voids and not the volume of air that determines the efficiency of the (entrained) air-void system.

Most conventional methods for analyzing air in fresh concrete, such as the pressure-meter method, measure the total air content only, and consequently provide no information about the parameters that determine the quality of the air-void system.

These parameters–the size and number of voids and spacing between them–can be measured on polished samples of hardened concrete (ASTM C 457) but the result of such analysis will only be available several days after the concrete has hardened.

## A New Test Method

This problem has now been overcome by new test equipment called the air-void analyzer (AVA) or commonly referred to in North America as the Danish air test (see Fig. 1 and Ref. 2).

The AVA was developed to determine the standard ASTM C 457 air-void parameters in fresh samples of air-entrained concrete. The test apparatus determines the volume and size distributions of entrained air voids and thus allows an estimation of the spacing factor, the specific surface, and the total amount of entrained air.

Fresh concrete samples can be taken at the ready mix plant and on site. Testing concrete before and after placement into forms can verify how the applied methods of transporting, placing, and consolidation affect the air-void system. Since the samples are taken on fresh concrete, the air content and air-void system can be adjusted during production.

## Principle of the Method

In this test method, air bubbles from a sample of fresh concrete rise through a viscous liquid, enter a column of water above it, then rise through the water and collect under a submerged buoyancy recorder. The viscous liquid retains the original bubble sizes. Large bubbles rise faster than small ones through the liquids. The change in buoyancy is recorded as a function of time and can be related to the number of bubbles of different size.

*Figure 1. Equipment for the air-void analyzer. (67961)*

## Test Procedure

- A 20 cm$^3$ mortar sample is extracted from the concrete.
- The sample is injected into the bottom of a column filled with the viscous liquid and water (see Fig. 2). The mortar is stirred for 30 seconds to release the air bubbles into the viscous liquid.
- The bubbles rise through the liquid and enter the column of water above it. Bubbles collect under a submerged buoyancy recorder that is attached to a balance.
- The computer calculates voids less than 3.0 mm, spacing factor, and specific surface.

These parameters correspond to those that would be obtained from linear traverse measurements (ASTM C 457) on a hardened concrete sample. Comparison with that method yields an accuracy of ±10% for a data collection period of 25 minutes. A curve, similar to particle size distribution, shows voids versus void diameter, and a bar chart shows actual void volume in different ranges of void diameter.

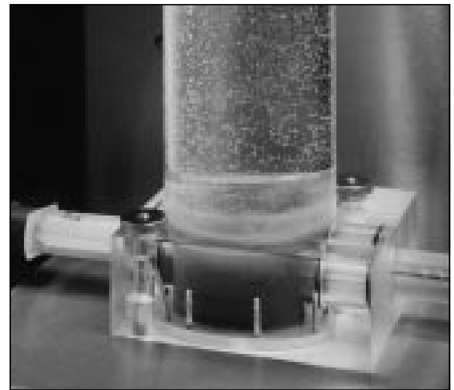

*Figure 2. Air bubbles rising through liquids in column. (67962)*

## Documentation and Use

Extensive testing and documentation of the accuracy of the AVA have been carried out. Currently no standard exists for the method. The AVA was not developed for measuring the total air content of concrete, and because of the small sample size, may not give accurate results for this quantity. However, this does not impact the use of the method for assessing the quality of the air-void system.

The AVA is used in Europe, North America, and Japan, and it was used on the Great Belt Project in Denmark. The method is used in conjunction with traditional methods for measuring air content.

## References

1. *Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete*, ASTM C 457, ASTM, West Conshohocken, Pennsylvania, 1990.
2. *Quality Assurance of Concrete Based on Testing of the Fresh, Still Plastic Material*, EC-Contract No. BRE-CT90-0.58, 1991-1995.
3. Henrichsen, A., and Vyncke. J., "Quality Assurance of Air-Void Structures in Concrete," *International Symposium on Non-Destructive Testing in Civil Engineering (NDT-CE)*, German Society for Non-Destructive Testing (DGZfP), Berlin, September 1995.

## Editor's Note

Further information can be obtained by contacting Dansk Beton Teknik A/S, Helleruplund Alle 21, DK-2900 Hellerup, Denmark, Telephone: 011-45-39-61-23-66, Fax: 011-45-39-62-28-33, e-mail: taa@dbt.dk.

# Rebar Supports for Concrete in Aggressive Environments

*By Ole T.K. Vik, P. Eng.*
*President, Con Sys Inc.*

*New reinforcement supports combat corrosion in reinforced concrete and enhance durability of reinforced concrete structures.*

*Figure 1. Bar supports and side-wall spacers made from high performance concrete featuring high strength (minimum 75 MPa (10,900 psi)); low permeability to air, water, and chloride ions; high resistance to chemicals; and geometrically and materially designed to become an integral part of the host concrete structure. (67925)*

The function of reinforcing steel supports, also referred to as bar supports and side-wall spacers, is to hold reinforcing bars securely in proper position during concreting and to ensure correct concrete cover over the reinforcement in the finished structure. Proper positioning of reinforcement is necessary for its structural function and durability. Correct concrete cover over the reinforcement helps protect it from corrosive chemicals that may be present in the service environment.

Corrosion of the reinforcement will occur if corrosive chemicals such as water-dissolved chlorides gain passage through the cover to the reinforcing steel, or if carbonation of the concrete, which starts at the exposed surface, reaches the reinforcing steel.[1] Although the conditions inducing corrosion in reinforced concrete may vary, proper position and correct cover are essential requirements for all concrete structures, especially in aggressive environments.

Aggressive environments include coastal climates with seawater and salt air, or climates where road salts/deicing agents are used, and other locations where corrosive chemicals are present. In coastal areas, practically all outdoor structures, and in particular marine structures, are subjected to an aggressive environment. Elsewhere, concrete structures most often subjected to aggressive environments include bridges, parking garages, industrial plants, and agricultural facilities.

Many of today's new bridges in Europe and North America are targeting 100 years of service life. This requires a sound, good-quality concrete cover to protect reinforcement from chemical attack by preventing water, chloride, and carbon dioxide ingress.[1] How then can bar supports, which by virtue of their function must penetrate the protective cover, minimize effects that otherwise could compromise the integrity of the protective cover? One answer is Norway's *New Code for Ensuring Concrete Cover*, which addresses this question in specifications for bar supports and their installation.[2] Requirements of these specifications include:

- **Material** – non-metallic and non-corrosive.
- **Geometric shape** – complete embedment without significant voids, minimal visual effect on finished surfaces, and stability against overturning under construction loads.
- **Dimensional tolerance** – ± 2 mm for heights ≤ 70 mm (± 0.08 in. for ≤ 2.75 in.).
- **Strength and stiffness** – minimum load-carrying capacity 6 kN (1350 lbs) for individual supports, maximum 1 mm (0.04 in.) compressive deformation of support under construction loading or 2 mm (0.08 in.) including heat loading (e.g., steam cleaning, hot weather conditions).
- **Provisions for fastening** – conditional requirements for fastening support to the form and reinforcement to the support, nails shall be stainless steel with distance between the nail and reinforcement a minimum 50% of support height, tie wire shall be annealed steel (plastic coated only if all reinforcement is coated) with concrete cover a minimum 50% of the support height.
- **Plastic supports** – only permitted in structures not exposed to chlorides.
- **Concrete supports** – silica fume content of 5-10% of portland cement by mass; shall not have an oily/smooth surface, for example, from form release agent used in production, nor be sealed by surface impregnating or by the use of hydrophobic-enhancing additives; at least 7 days of moist curing at a minimum of 15°C (59°F); maximum water absorption 5.0% after 30 minutes and 8.5% after 24 hrs.

Bar supports and side-wall spacers made from high performance concrete have been developed in order to meet the new specification requirements (see Fig. 1). This was necessary because none of the existing products on the market in the early 1990s met the new requirements. The new reinforcement supports have been used in bridge projects and other major concrete structures in Norway since 1994 and in North America since 1997.

The City of Winnipeg, Manitoba, is using concrete bar supports meeting these new specifications for their current Norwood Bridge and York Avenue Underpass projects. Fig. 2 shows the spacers attached to the reinforcement before side forms are placed. The concrete supports provided the solution to the city's re-



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quirements of ensuring adequate and uniform cover over the steel reinforcement without leaving an unsightly concrete surface with exposed non-concrete materials that might be potential weak spots in the protective cover. The combination of European technology and high performance concrete present an innovative solution to a common durability issue.

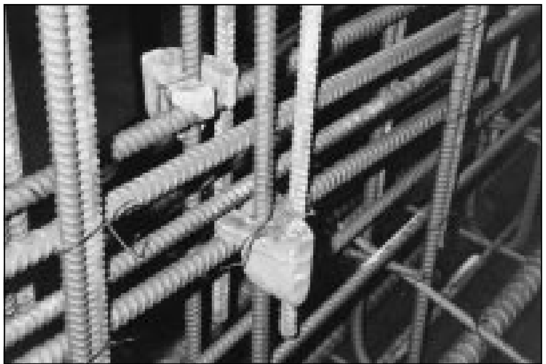

*Figure 2. Side-wall spacers in the web of a precast bridge girder ensure correct cover over reinforcement when the steel form is closed. Norwood Bridge, Winnipeg, Manitoba. (67926)*

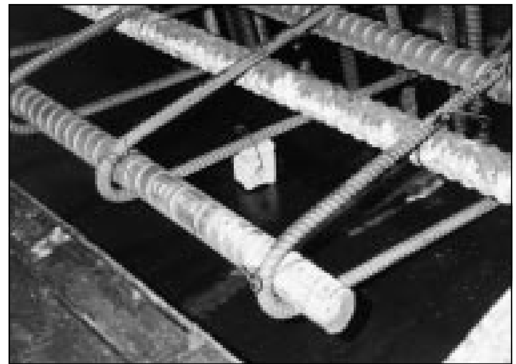

*Figure 3. Reinforcing support in the bottom flange of a precast girder will, because of its shape, be completely embedded and barely visible on the girder's surface when the form is removed. Norwood Bridge, Winnipeg, Manitoba. (67927)*

*Figure 4. Precast sections made with concrete bar supports being placed at Norwood Bridge. Photo courtesy of Lafarge Canada Inc.-Winnipeg Precast and Thomas Young Productions (photographer).*

## References

1. Montani, R., and Sohanghpurwala, A.A., *Corrosion in Reinforced Concrete*, Seminar, World of Concrete '98, Orlando, Florida, January 18, 1998.
2. *Nye regler for sikring av overdekning, Spesifikasjoner for sikring av armeringens overdekning* (New Code for Ensuring Concrete Cover, Specifications for Ensuring Cover over Reinforcement) Publication No. 78, Norwegian Road Research Laboratory, Oslo, Norway, May 1995.

## Editor's Note

Additional information can be obtained from Con Sys Inc., Box 341, Pinawa, MB, Canada R0E 1L0, Telephone 204-753-2404, Fax 204-753-8329/800-442-8850, or e-mail vik@granite.mb.ca.

# Who Uses Deicers?

Throughout North America, concrete is regularly subjected to some form of chloride by direct or indirect application, or by environmental exposure. Required air contents and chloride limits depend on whether or not deicers will be used. A limited survey of deicer usage was performed by PCA's Market Research Department. Only states with severe freeze-thaw conditions were polled. Of those 35 State Departments of Transportation contacted, 29 responded.

### Which deicers are regularly used?

There are four:
- Sodium chloride (NaCl)
- Calcium chloride ($CaCl_2$)
- Magnesium chloride ($MgCl_2$)
- Calcium magnesium acetate (CMA).

### Results:

- NaCl is still used most frequently by over 93% of respondents, although some states use it as a 1:1 salt-sand mix.
- Some amount of $CaCl_2$ (less than 1% of total deicer salts) is also used regularly by 41% of the states, often in liquid form. It is primarily used to improve the effectiveness of sodium chloride.
- 14% of states use a small amount of $MgCl_2$ (less than 1% of total).
- 10% of states use a small amount of CMA (less than 1%), most respondents citing cost (compared with other deicers) as prohibitive to more widespread use.
- Colorado uses salt-sand mix of 1:9 (10% salt).
- Massachusetts reports that $CaCl_2$ accounts for 14% of its total deicer usage.

# Prescriptive versus Performance Specifications for Cements

*A description of the differences between performance specifications and prescriptive specifications outlines some of the potential benefits and drawbacks of each.*

Specifications, or standards, are the basis to verify quality and maintain product uniformity. Conformance to standards can be determined using either prescriptive or performance specifications. A prescriptive specification gives chemical or physical requirements that are indirectly related to performance. A performance specification sets limits for physical test results only.

In the U.S., specifications for cement have had both prescriptive and performance features. Performance features have included requirements for setting time, strength, and durability. Prescriptive features have included limits on chemical composition, some physical properties, and restrictions on ingredients. Both ASTM C 150 (for portland cement) and ASTM C 595 (for blended hydraulic cement) have prescriptive and performance elements. In 1992, the first performance-only specification for cements, ASTM C 1157, was issued.

As an example of the difference between prescriptive and performance requirements, ASTM C 150 limits the tricalcium aluminate ($C_3A$) level in portland cement to provide sulfate resistance for concrete (or mortar). The $C_3A$ level is obtained from results of chemical analyses of the cement. In ASTM C 1157, sulfate resistance of concrete (or mortar) is controlled by evaluating laboratory tests of mortar prisms made with the cement. The laboratory test is intended as a predictor of field performance of concrete.

Prescriptive specifications provide a well-defined means for the manufacturer to demonstrate compliance with chemical composition, but may limit the options of cement manufacturers (by restricting the use of constituent materials) and thus pose somewhat of a barrier to innovation. Compliance with performance specifications, on the other hand, allows the use of different constituent materials but is more sensitive to the test methods used to predict performance.

Blended cements offer attractive methods of manufacturing a material to minimize environmental impact and result in very efficient use of raw, recycled, and by-product materials. Currently, the ASTM C 595 specification would not allow the most innovative and potentially efficient combination of materials. That is where C 1157 can fill in the current gaps. Users potentially can choose these cements to address particular durability or construction needs. A comparison of some features of the three cement specifications is given below.

## Comparison of ASTM Cement Specifications

| Feature | ASTM C 150 | ASTM C 595 | ASTM C 1157 |
|---|---|---|---|
| Specification limits on: | | | |
| Minimum compressive strength? | Yes | Yes | Yes |
| Autoclave expansion? | Yes | Yes | Yes |
| Time of setting? | Yes | Yes | Yes |
| Alkalies? | Optional | No | No |
| Chemical composition? | Yes | Yes | No |
| Fineness? | Yes | No | No |
| Mortar air content? | Yes | Yes | No |
| Number of basic types | 5 | 6 | 6 |
| Total number of types | 8 | 16 | 6 |
| Type designation for: | | | |
| General concrete construction | I | IS, IP, I(PM), I(SM), P | GU |
| High early strength | III | — | HE |
| Moderate sulfate resistance | II | IP(MS), IS(MS) | MS |
| High sulfate resistance | V | — | HS |
| Low heat of hydration | IV | P(LH) | LH |
| Moderate heat of hydration | II | IS(MH), IP(MH), I (PM)(MH),I(SM)(MH) | MH |
| Accepted by: | | | |
| ASTM C 55 (Concrete brick)? | Yes | Yes | Yes |
| ASTM C 90 (Concrete block)? | Yes | Yes | Yes |
| ASTM C 94 (Ready mix specification)? | Yes | Yes | No |
| ACI 301 (Structural concrete specification)? | Yes | Yes | No |
| ACI 318 (Building Code)? | Yes | Yes | No |
| Uniform Building Code? | Yes | Yes | Yes |

ASTM C 150: Standard Specification for Portland Cement
ASTM C 595: Standard Specification for Blended Hydraulic Cements
ASTM C 1157: Standard Performance Specification for Blended Hydraulic Cement



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## Manual on Control of Air Content in Concrete, EB116

While use of air-entrained concrete is a well-established practice, quality control issues may arise during production and placement of air-entrained concrete. The way concrete is produced can have a significant effect on its air content and entrained air-void system. By focusing on the variables that can affect the air content of concrete, the manual gives the reader sufficient knowledge to obtain the desired air content in concrete as well as troubleshoot any difficulties arising from mixing or placing. A compact disk version of the document is included. See an excerpt in this issue of *Concrete Technology Today.*

## Ettringite and Oxyanion-Substituted Ettringites—Their Characterization and Applications in the Fixation of Heavy Metals: A Synthesis of the Literature, RD116

The term ettringite, a mineral produced when tricalcium aluminate combines with sulfate during normal hydration of portland cement, describes a number of chemically similar substances. This report discusses the sulfate form, and also focuses on the forms of ettringite produced when other substances are incorporated into ettringite. Ettringite formation has significant potential for stabilizing wastes containing heavy metals by using portland cement. This is a valuable reference for anyone interested in the chemistry of ettringite as found in concrete as well as anyone involved with stabilizing waste with cement.

## Rectangular Concrete Tanks, IS003

This newly revised publication presents the latest technical guidelines and procedures for structural design of rectangular above- or below-ground concrete tanks. The text considers various combinations of end conditions and aspect ratios, adapts design coefficients for multicell tanks, and presents design coefficients for twisting moments to cover most design situations in practice. Numerous examples are provided.



**PUBLISHER'S NOTE:**

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