CHAPTER 18
Special Types of Concrete

Special types of concrete are those with out-of-the-ordinary properties or those produced by unusual techniques. Concrete is by definition a composite material consisting essentially of a binding medium and aggregate particles, and it can take many forms. Table 18-1 lists many special types of concrete made with portland cement and some made with binders other than portland cement. In many cases the terminology of the listing describes the use, property, or condition of the concrete. Brand names are not given. Some of the more common concretes are discussed in this chapter.

<table>
<thead>
<tr>
<th>Special types of concrete made with portland cement</th>
<th>Special types of concrete made with portland cement</th>
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<tbody>
<tr>
<td>Architectural concrete</td>
<td>Heavyweight concrete</td>
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<tr>
<td>Autoclaved cellular concrete</td>
<td>High-early-strength concrete</td>
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<tr>
<td>Centrifugally cast concrete</td>
<td>High-performance concrete</td>
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<tr>
<td>Colloidal concrete</td>
<td>High-strength concrete</td>
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<td>Colored concrete</td>
<td>Insulating concrete</td>
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<td>Controlled-density fill</td>
<td>Latex-modified concrete</td>
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<tr>
<td>Cyclopean (rubble) concrete</td>
<td>Low-density concrete</td>
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<td>Dry-packed concrete</td>
<td>Mass concrete</td>
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<tr>
<td>Epoxy-modified concrete</td>
<td>Moderate-strength lightweight concrete</td>
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<tr>
<td>Exposed-aggregate concrete</td>
<td>Nailable concrete</td>
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<td>Ferrocement</td>
<td>No-slump concrete</td>
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<tr>
<td>Fiber concrete</td>
<td>Polymer-modified concrete</td>
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<tr>
<td>Fill concrete</td>
<td>Pervious (porous) concrete</td>
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<tr>
<td>Flowable fill</td>
<td>Pozzolan concrete</td>
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<td>Flowing concrete</td>
<td>Precast concrete</td>
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<td>Fly-ash concrete</td>
<td>Prepacked concrete</td>
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<td>Gap-graded concrete</td>
<td>Preplaced aggregate concrete</td>
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<tr>
<td>Geopolymer concrete</td>
<td>Reactive-powder concrete</td>
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<table>
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<tr>
<th>Special types of concrete not using portland cement</th>
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<tbody>
<tr>
<td>Acrylic concrete</td>
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<tr>
<td>Aluminum phosphate concrete</td>
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<tr>
<td>Asphalt concrete</td>
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<tr>
<td>Calcium aluminate concrete</td>
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<tr>
<td>Epoxy concrete</td>
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</table>

Most of the definitions of these types of concrete appear in Cement and Concrete Terminology, ACI 116.
28-day compressive strength in excess of 17 MPa (2500 psi). Some job specifications allow air-dry densities up to 1920 kg/m³ (120 pcf). For comparison, normal-weight concrete containing regular sand, gravel, or crushed stone has a dry density in the range of 2080 to 2480 kg/m³ (130 to 155 pcf). ASTM C 567 provides a test for density of structural lightweight concrete. Structural lightweight concrete is used primarily to reduce the dead-load weight in concrete members, such as floors in high-rise buildings.

**Structural Lightweight Aggregates**

Structural lightweight aggregates are usually classified according to their production process because various processes produce aggregates with somewhat different properties. Processed structural lightweight aggregates should meet the requirements of ASTM C 330, which includes:

- Rotary kiln expanded clays (Fig. 18-1), shales, and slates
- Sintering grate expanded shales and slates
- Pelletized or extruded fly ash
- Expanded slags

Structural lightweight aggregates can also be produced by processing other types of material, such as naturally occurring pumice and scoria.

Structural lightweight aggregates have densities significantly lower than normal-weight aggregates, ranging from 560 to 1120 kg/m³ (35 to 70 pcf), compared to 1200 to 1760 kg/m³ (75 to 110 pcf) for normal-weight aggregates. These aggregates may absorb 5% to 20% water by weight of dry material. To control the uniformity of structural lightweight concrete mixtures, the aggregates are prewetted (but not saturated) prior to batching.

**Compressive Strength**

The compressive strength of structural lightweight concrete is usually related to the cement content at a given slump and air content, rather than to a water-to-cement ratio. This is due to the difficulty in determining how much of the total mix water is absorbed into the aggregate and thus not available for reaction with the cement. ACI 211.2 provides guidance on the relationship between compressive strength and cement content. Typical compressive strengths range from 20 to 35 MPa (3000 to 5000 psi). High-strength concrete can also be made with structural lightweight aggregates.

In well-proportioned mixtures, the cement content and strength relationship is fairly constant for a particular source of lightweight aggregate. However, the relationship will vary from one aggregate source or type to another. When information on this relationship is not available from the aggregate manufacturer, trial mixtures with varying cement contents are required to develop a range of compressive strengths, including the strength specified. Fig. 18-2 shows the relationship between cement content and compressive strength. An example of a 28-MPa (4000-psi) structural lightweight concrete mixture with an air-dry density of about 1800 kg/m³ (112 pcf), a combination of natural sand and gravel, and a lightweight rotary kiln expanded clay coarse aggregate follows:
• 356 kg (600 lb) Type I portland cement
• 534 kg (900 lb) sand, oven-dry
• 320 kg (540 lb) gravel (12.5 to 2.36 mm [½ in. to #8]), oven-dry
• 356 kg (600 lb) lightweight aggregate (9.5 mm to 600 µm [⅜ in. to #30]), oven-dry
• 172 kg (290 lb) mix water added
• 0.7 L (20 oz) water-reducing admixture
• 0.09 L (2.5 oz) air-entraining admixture
• 1 m³ (1 yd³) yield
• Slump—75 mm (3 in.)
• Air content—6%

Material proportions vary significantly for different materials and strength requirements.

**Entrained Air**

As with normal-weight concrete, entrained air in structural lightweight concrete ensures resistance to freezing and thawing and to deicer applications. It also improves workability, reduces bleeding and segregation, and may compensate for minor grading deficiencies in the aggregate.

The amount of entrained air should be sufficient to provide good workability to the plastic concrete and adequate freeze-thaw resistance to the hardened concrete. Air contents are generally between 5% and 8%, depending on the maximum size of coarse aggregate (paste content) used and the exposure conditions. Testing for air content should be performed by the volumetric method (ASTM C 173 or AASHTO T 196). The freeze-thaw durability is also significantly improved if structural lightweight concrete is allowed to dry before exposure to a freeze-thaw environment.

**Specifications**

Many suppliers of lightweight aggregates for use in structural lightweight concrete have information on suggested specifications and mixture proportions pertaining to their product. The usual specifications for structural concrete state a minimum compressive strength, a maximum density, a maximum slump, and an acceptable range in air content.

The contractor should also be concerned with the bleeding, workability, and finishing properties of structural lightweight concrete.

**Mixing**

In general, mixing procedures for structural lightweight concrete are similar to those for normal-density concrete; however, some of the more absorptive aggregates may require prewetting before use. Water added at the batching plant should be sufficient to produce the specified slump at the jobsite. Measured slump at the batch plant will generally be appreciably higher than the slump at the site. Pumping can especially aggravate slump loss.

**Workability and Finishability**

Structural lightweight concrete mixtures can be proportioned to have the same workability, finishability, and general appearance as a properly proportioned normal-density concrete mixture. Sufficient cement paste must be present to coat each particle, and coarse-aggregate particles should not separate from the mortar. Enough fine aggregate is needed to keep the freshly mixed concrete cohesive. If aggregate is deficient in minus 600 µm (No. 30) sieve material, finishability may be improved by using a portion of natural sand, by increasing cement content, or by using satisfactory mineral fines. Since entrained air improves workability, it should be used regardless of exposure.

**Slump**

Due to lower aggregate density, structural lightweight concrete does not slump as much as normal-weight concrete with the same workability. A lightweight air-entrained mixture with a slump of 50 to 75 mm (2 to 3 in.) can be placed under conditions that would require a slump of 75 to 125 mm (3 to 5 in.) for normal-weight concrete. It is seldom necessary to exceed slumps of 125 mm (5 in.) for normal placement of structural lightweight concrete. With higher slumps, the large aggregate particles tend to float to the surface, making finishing difficult.

**Vibration**

As with normal-weight concrete, vibration can be used effectively to consolidate lightweight concrete; the same frequencies commonly used for normal-density concrete are recommended. The length of time for proper consolidation varies, depending on mix characteristics. Excessive vibration causes segregation by forcing large aggregate particles to the surface.

**Placing, Finishing, and Curing**

Structural lightweight concrete is generally easier to handle and place than normal-weight concrete. A slump of 50 to 100 mm (2 to 4 in.) produces the best results for finishing. Greater slumps may cause segregation, delay finishing operations, and result in rough, uneven surfaces.

If pumped concrete is being considered, the specifier, suppliers, and contractor should all be consulted about performing a field trial using the pump and mixture planned for the project. Adjustments to the mixture may be necessary; pumping pressure causes the aggregate to absorb more water, thus reducing the slump and increasing the density of the concrete.

Finishing operations should be started earlier than for comparable normal-weight concrete, but finishing too early may be harmful. A minimum amount of floating
Insulating concrete is a lightweight concrete with an ovendry density of 800 kg/m³ (50 pcf) or less. It is made with cementing materials, water, air, and with or without aggregate and chemical admixtures. The ovendry density ranges from 240 to 800 kg/m³ (15 to 50 pcf) and the 28-day compressive strength is generally between 0.7 and 7 MPa (100 and 1000 psi). Cast-in-place insulating concrete is used primarily for thermal and sound insulation, roof decks, fill for slab-on-grade subbases, leveling courses for floors or roofs, firewalls, and underground thermal conduits. Moderate-strength lightweight concrete has a density of 800 to 1900 kg/m³ (50 to 120 pcf) ovendry and has a compressive strength of approximately 7 to 15 MPa (1000 to 2500 psi). It is made with cementing materials, water, air, and with or without aggregate and chemical admixtures. Insulating concrete used in roof fills. Excessive water can range between 720 to 1440 kg/m³ (45 and 90 pcf). Aggregates used in Groups I and II should meet the requirements of ASTM C 332, Standard Specification for Lightweight Aggregates for Insulating Concrete. These aggregates are made by incorporating into a cement paste or cement-sand mortar a uniform cellular structure of air voids that is obtained with preformed foam (ASTM C 869), formed-in-place foam, or special foaming agents. Ovendry densities ranging between 240 to 1900 kg/m³ (15 to 120 pcf) are obtained by substitution of air voids for some or all of the aggregate particles; air voids can consist of up to 80% of the volume. Cellular concrete can be made to meet the requirements of both insulating and moderate strength lightweight concrete.

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Mixture Proportions

Examples of mixture proportions for Group I and III concretes appear in Table 18-2. In Group I, air contents may be as high as 25% to 35%. The air-entraining agent can be prepackaged with the aggregate or added at the mixer. Because of the absorptive nature of the aggregate, the volumetric method (ASTM C 173 or AASHTO T 196) should be used to measure air content.

Water requirements for insulating and fill concretes vary considerably, depending on aggregate characteristics, entrained air, and mixture proportions. An effort should be made to avoid excessive amounts of water in insulating concrete used in roof fills. Excessive water causes high drying shrinkage and cracks that may damage the waterproofing membrane. Accelerators containing calcium chloride should not be used where galvanized steel will remain in permanent contact with the concrete because of possible corrosion problems.

Mixture proportions for Group II concretes usually are based on volumes of dry, loose materials, even when aggregates are moist as batched. Satisfactory proportions can vary considerably for different aggregates or combinations of aggregates. Mixture proportions ranging from 0.24 to 0.90 cubic meters of aggregate per 100 kg (4 to 14 cu ft per 100 lb) of cement can be used in lightweight concretes that are made with pumice, expanded shale, and expanded slag. Some mixtures, such as those for no-fines concretes, are made without fine aggregate but with total void contents of 20% to 35%. Cement contents for Group II concretes range between 120 to 360 kg per cubic meter (200 and 600 lb per cubic yard) depending on air content, aggregate gradation, and mixture proportions.

No-fines concretes containing pumice, expanded slag, or expanded shale can be made with 150 to 170 kg of water per cubic meter (250 to 290 lb of water per cubic yard), total

and troweling should be done; magnesium finishing tools are preferred.

The same curing practices should be used for lightweight concrete as for normal-weight concrete. The two methods commonly used in the field are water curing (ponding, sprinkling, or using wet coverings) and preventing loss of moisture from the exposed surfaces (covering with waterproof paper, plastic sheets, or sealing with liquid membrane-forming compounds). Generally, 7 days of curing are adequate for ambient air temperatures above 10°C (50°F).
air voids of 20% to 35%, and a cement content of about 280 kg per cubic meter (470 lb per cubic yard).

**Workability**

Because of their high air content, lightweight concretes weighing less than 800 kg/m³ (50 pcf) generally have excellent workability. Slumps of up to 250 mm (10 in.) usually are satisfactory for Group I and Group III concretes; appearance of the mix, however, may be a more reliable indication of consistency. Cellular concretes are handled as liquids; they are poured or pumped into place without further consolidation.

**Mixing and Placing**

All concrete should be mechanically mixed to produce a uniform distribution of materials of proper consistency and required density. In batch-mixing operations, various sequences can be used for introducing the ingredients; the preferred sequence is to first introduce the required amount of water into the mixer, then add the cement, air-entraining or foaming agent, aggregate, preformed foam, and any other ingredients.

Excessive mixing and handling should be avoided because they tend to break up aggregate particles, thereby changing density and consistency. Segregation is not usually a problem (though it could be for Group II) because of the relatively large amounts of entrained air in these mixtures.

Pumping is the most common method of placement, but other methods can be used. Finishing operations should be kept to a minimum; smoothing with a darby or bullfloat is usually sufficient. Placement of insulating concretes should be done by workers experienced with these special concretes.

Periodic wet-density tests (ASTM C 138 or AASHTO T 121) at the jobsite can be performed to check the uniformity of the concrete. Variations in density generally should not exceed plus or minus 32 kg/m³ (2 pcf). A close approximation of the oven-dry density can be determined from the freshly mixed density.

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**Table 18-2. Examples of Lightweight Insulating Concrete Mixtures**

<table>
<thead>
<tr>
<th>Type of concrete</th>
<th>Ratio: portland cement to aggregate by volume</th>
<th>Ovendry density, kg/m³ (pcf)</th>
<th>Type I portland cement, kg/m³ (lb/yard³)</th>
<th>Water-cement ratio, by mass</th>
<th>28-day compressive strength, MPa (psi), 150 x 300-mm (6 x 12-in.) cylinders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perlite*</td>
<td>1:4</td>
<td>480 to 608 (30 to 38)</td>
<td>362 (610)</td>
<td>0.94</td>
<td>2.75 (400)</td>
</tr>
<tr>
<td></td>
<td>1:5</td>
<td>416 to 576 (26 to 36)</td>
<td>306 (516)</td>
<td>1.12</td>
<td>2.24 (325)</td>
</tr>
<tr>
<td></td>
<td>1:6</td>
<td>352 to 545 (22 to 34)</td>
<td>245 (414)</td>
<td>1.24</td>
<td>1.52 (220)</td>
</tr>
<tr>
<td></td>
<td>1:8</td>
<td>320 to 512 (20 to 32)</td>
<td>234 (395)</td>
<td>1.72</td>
<td>1.38 (200)</td>
</tr>
<tr>
<td>Vermiculite*</td>
<td>1:4</td>
<td>496 to 593 (31 to 37)</td>
<td>380 (640)</td>
<td>0.98</td>
<td>2.07 (300)</td>
</tr>
<tr>
<td></td>
<td>1:5</td>
<td>448 to 496 (28 to 31)</td>
<td>295 (498)</td>
<td>1.30</td>
<td>1.17 (170)</td>
</tr>
<tr>
<td></td>
<td>1:6</td>
<td>368 to 464 (23 to 29)</td>
<td>245 (414)</td>
<td>1.60</td>
<td>0.90 (130)</td>
</tr>
<tr>
<td></td>
<td>1:8</td>
<td>320 to 336 (20 to 21)</td>
<td>178 (300)</td>
<td>2.08</td>
<td>0.55 (80)</td>
</tr>
<tr>
<td>Polystyrene:**</td>
<td>sand:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 kg/m³ (0 lb/yd³)</td>
<td>545 (34)‡</td>
<td>445 (750)</td>
<td>0.40</td>
<td>2.24 (325)</td>
</tr>
<tr>
<td></td>
<td>73 kg/m³ (124 lb/yd³)</td>
<td>625 (39)‡</td>
<td>445 (750)</td>
<td>0.40</td>
<td>2.76 (400)</td>
</tr>
<tr>
<td></td>
<td>154 kg/m³ (261 lb/yd³)</td>
<td>725 (44)‡</td>
<td>445 (750)</td>
<td>0.40</td>
<td>3.28 (475)</td>
</tr>
<tr>
<td></td>
<td>200 kg/m³ (338 lb/yd³)</td>
<td>769 (48)‡</td>
<td>474 (800)</td>
<td>0.40</td>
<td>3.79 (550)</td>
</tr>
<tr>
<td>Cellular*</td>
<td>(neat cement)</td>
<td>625 (39)</td>
<td>524 (884)</td>
<td>0.57</td>
<td>2.41 (350)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>545 (34)</td>
<td>468 (790)</td>
<td>0.56</td>
<td>1.45 (210)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>448 (28)</td>
<td>396 (668)</td>
<td>0.57</td>
<td>0.90 (130)</td>
</tr>
<tr>
<td></td>
<td>—</td>
<td>368 (23)</td>
<td>317 (535)</td>
<td>0.65</td>
<td>0.34 (50)</td>
</tr>
<tr>
<td>Cellular†</td>
<td>(sanded)††</td>
<td>929 (58)</td>
<td>429 (724)</td>
<td>0.40</td>
<td>3.17 (460)</td>
</tr>
<tr>
<td></td>
<td>1:1</td>
<td>929 (58)</td>
<td>429 (724)</td>
<td>0.40</td>
<td>3.17 (460)</td>
</tr>
<tr>
<td></td>
<td>1:2</td>
<td>1250 (78)</td>
<td>373 (630)</td>
<td>0.41</td>
<td>5.66 (820)</td>
</tr>
<tr>
<td></td>
<td>1:3</td>
<td>1602 (100)</td>
<td>360 (602)</td>
<td>0.51</td>
<td>15.10 (2190)</td>
</tr>
</tbody>
</table>

* Reichard (1971).
** Source: Hanna (1978). The mix also included air entrainment and a water-reducing agent.
† Source: Gustafro (1970).
‡ Dry-rodded sand with a bulk density of 1600 kg/m³ (100 pcf).
‡ Air-dry density at 28 days, 50% relative humidity.
Thermal Resistance

ASTM C 177, Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus, is used to determine values of thermal conductivity. Fig. 18-3 shows an approximate relationship between thermal resistance and density. The thermal conductivity of concrete increases with an increase in moisture content and density. See Brewer (1967) for additional density and conductivity relationships.

![Fig. 18-3. Thermal resistance of concrete versus density (PCA 1980).](image)

Strength

Strength requirements depend on the intended use of the concrete. For example, a compressive strength of 0.7 MPa (100 psi), or even less, may be satisfactory for insulation of underground steam lines. Roof-fill insulation requires sufficient early strength to withstand foot traffic. Compressive strengths of 0.7 to 1.5 MPa (100 to 200 psi) are usually adequate for roof fills, but strengths up to 3.5 MPa (500 psi) are sometimes specified. In general, the strength of insulating concrete is of minor importance. Compressive strength of lightweight insulating concrete should be determined by the methods specified in ASTM C 495 or C 513.

Table 18-2 and Fig. 18-4 give examples of the relationship between density and strength for lightweight insulating concretes. Fig. 18-5 shows examples for cellular concrete containing sand. Mixtures with strengths outside the ranges shown can be made by varying the mixture proportions. Strengths comparable to those at 28 days

![Fig. 18-4. Approximate relationship between oven-dry bulk density and compressive strength of 150 x 300-mm (6 x 12-in.) cylinders tested in an air-dry condition for some insulating and fill concretes. For the perlite and vermiculite concretes, mix proportions range from 1:3 to 1:10 by volume.](image)

![Fig. 18-5. Plastic density versus compressive strength for sanded cellular concretes. Compressive strength was determined with 150 x 300-mm (6 x 12-in.) cylinders that were cured for 21 days in a 100% relative humidity moist room followed by 7 days in air at 50% RH (McCormick 1967 and ACI 523.3R).](image)
would be obtained at 7 days with high-early-strength cement. The relationships shown do not apply to autoclaved products.

**Resistance to Freezing and Thawing**

Insulating and moderate-strength lightweight concretes normally are not required to withstand freeze-thaw exposure in a saturated condition. In service they are normally protected from the weather; thus little research has been done on their resistance to freezing and thawing.

**Drying Shrinkage**

The drying shrinkage of insulating or moderate-strength lightweight concrete is not usually critical when it is used for insulation or fill; however, excessive shrinkage can cause curling. In structural use, shrinkage should be considered. Moist-cured cellular concretes made without aggregates have high drying shrinkage. Moist-cured cellular concretes made with sand may shrink from 0.1% to 0.6%, depending on the amount of sand used. Autoclaved cellular concretes shrink very little on drying. Insulating concretes made with perlite or pumice aggregates may shrink 0.1% to 0.3% in six months of drying in air at 50% relative humidity; vermiculite concretes may shrink 0.2% to 0.45% during the same period. Drying shrinkage of insulating concretes made with expanded slag or expanded shale ranges from about 0.06% to 0.1% in six months.

**Expansion Joints**

Where insulating concrete is used on roof decks, a 25-mm (1-in.) expansion joint at the parapets and all roof projections is often specified. Its purpose is to accommodate expansion caused by the heat of the sun so that the insulating concrete can expand independently of the roof deck. Transverse expansion joints should be placed at a maximum of 30 m (100 ft) in any direction for a thermal expansion of 1 mm per meter (1 in. per 100 lin ft). A fiberglass material that will compress to one-half its thickness under a stress of 0.17 MPa (25 psi) is generally used to form these joints.

**AUTOCLAVED CELLULAR CONCRETE**

Autoclaved cellular concrete (also called autoclaved aerated concrete) is a special type of lightweight building material. It is manufactured from a mortar consisting of pulverized siliceous material (sand, slag, or fly ash), cement and/or lime, and water; to this a gas forming admixture, for example aluminum powder, is added. The chemical reaction of aluminum with the alkaline water forms hydrogen, which expands the mortar as macro pores with a diameter of 0.5 mm to 1.5 mm (0.02 in. to 0.06 in.) form. The material is then pressure steam cured (autoclaved) over a period of 6 to 12 hours using a temperature of 190°C (374°F) and a pressure of 1.2 MPa (174 psi). This forms a hardened mortar matrix, which essentially consists of calcium silicate hydrates.

This porous mineral building material has densities between 300 and 1000 kg/m$^3$ (19 and 63 lb/ft$^3$) and compressive strengths between 2.5 and 10 MPa (300 and 1500 lb/in$^2$). Due to the high macropore content—up to 80 percent by volume—autoclaved cellular concrete has a thermal conductivity of only 0.15 to 0.20 W/(m•K) (1 to 1.4 Btu•in./[h•ft•ºF]).

Autoclaved cellular concrete is produced in block or panel form for construction of residential or commercial buildings (Fig. 18-6).

Additional information can be found in ACI 523.2R, Guide for Precast Cellular Concrete.

**HIGH-DENSITY CONCRETE**

High-density (heavyweight) concrete and has a density of up to about 6400 kg/m$^3$ (400 pcf). Heavyweight concrete is used principally for radiation shielding but is also used for counterweights and other applications where high-density is important. As a shielding material, heavyweight concrete protects against the harmful effects of X-rays, gamma rays, and neutron radiation. Selection of concrete for radiation shielding is based on space requirements and on the type and intensity of radiation. Where space requirements are not important, normal-weight concrete will generally produce the most economical shield; where space is limited, heavyweight concrete will allow for reductions in shield thickness without sacrificing shielding effectiveness.
Additions

Boron additions such as colemanite, boron frits, and boro-calcite are sometimes used to improve the neutron shielding properties of concrete. However, they may adversely affect setting and early strength of concrete; therefore, trial mixes should be made with the addition under field conditions to determine suitability. Admixtures such as pressure-hydrated lime can be used with coarse-sand sizes to minimize any retarding effect.

Properties of High-Density Concrete

The properties of high-density concrete in both the freshly mixed and hardened states can be tailored to meet job conditions and shielding requirements by proper selection of materials and mixture proportions.

High-Density Aggregates

High-density aggregates such as barite, ferrophosphorus, goethite, hematite, ilmenite, limonite, magnetite, and degreased steel punchings and shot are used to produce high-density concrete. Where high fixed-water content is desirable, serpentine (which is slightly heavier than normal-weight aggregate) or bauxite can be used (see ASTM C 637 and C 638).

Table 18-3 gives typical bulk density, relative density (specific gravity), and percentage of fixed water for some of these materials. The values are a compilation of data from a wide variety of tests or projects reported in the literature. Steel punchings and shot are used where concrete with a density of more than 4800 kg/m³ (300 pcf) is required.

In general, selection of an aggregate is determined by physical properties, availability, and cost. Heavyweight aggregates should be reasonably free of fine material, oil, and foreign substances that may affect either the bond of paste to aggregate particle or the hydration of cement. For good workability, maximum density, and economy, aggregates should be roughly cubical in shape and free of excessive flat or elongated particles.

Proportioning, Mixing, and Placing

The procedures for selecting mix proportions for heavyweight concrete are the same as those for normal-weight concrete. However, additional mixture information and sample calculations are given in ACI 211.1. Following are the most common methods of mixing and placing high-density concrete:

Conventional methods of mixing and placing often are used, but care must be taken to avoid overloading the mixer, especially with very heavy aggregates such as steel.

<table>
<thead>
<tr>
<th>Type of aggregate</th>
<th>Fixed-water,* percent by weight</th>
<th>Aggregate relative density</th>
<th>Aggregate bulk density, kg/m³ (pcf)</th>
<th>Concrete density, kg/m³ (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goethite</td>
<td>10–11</td>
<td>3.4–3.7</td>
<td>2080–2240 (130–140)</td>
<td>2880–3200 (180–200)</td>
</tr>
<tr>
<td>Limonite**</td>
<td>8–9</td>
<td>3.4–4.0</td>
<td>2080–2400 (130–150)</td>
<td>2880–3360 (180–210)</td>
</tr>
<tr>
<td>Barite</td>
<td>0</td>
<td>4.0–4.6</td>
<td>2320–2560 (145–160)</td>
<td>3360–3680 (210–230)</td>
</tr>
<tr>
<td>Ilmenite</td>
<td>†</td>
<td>4.3–4.8</td>
<td>2560–2700 (160–170)</td>
<td>3520–3850 (220–240)</td>
</tr>
<tr>
<td>Hematite</td>
<td>†</td>
<td>4.9–5.3</td>
<td>2880–3200 (180–200)</td>
<td>3850–4170 (240–260)</td>
</tr>
<tr>
<td>Magnetite</td>
<td>†</td>
<td>4.2–5.2</td>
<td>2400–3040 (150–190)</td>
<td>3360–4170 (210–260)</td>
</tr>
<tr>
<td>Ferrophosphorus</td>
<td>0</td>
<td>5.8–6.8</td>
<td>3200–4160 (200–260)</td>
<td>4080–5290 (255–330)</td>
</tr>
<tr>
<td>Steel punchings or shot</td>
<td>0</td>
<td>6.2–7.8</td>
<td>3860–4650 (230–290)</td>
<td>4650–6090 (290–380)</td>
</tr>
</tbody>
</table>

* Water retained or chemically bound in aggregates.
** Test data not available.
† Aggregates may be combined with limonite to produce fixed-water contents varying from about ½% to 5%.
punchings. Batch sizes should be reduced to about 50% of the rated mixer capacity. Because some heavy aggregates are quite friable, excessive mixing should be avoided to prevent aggregate breakup with resultant detrimental effects on workability and bleeding.

Preplaced aggregate methods can be used for placing normal and high-density concrete in confined areas and around embedded items; this will minimize segregation of coarse aggregate, especially steel punchings or shot. The method also reduces drying shrinkage and produces concrete of uniform density and composition. With this method, the coarse aggregates are preplaced in the forms and grout made of cement, sand, and water is then pumped through pipes to fill the voids in the aggregate.

Pumping of heavyweight concrete through pipelines may be advantageous in locations where space is limited. Heavyweight concretes cannot be pumped as far as normal-weight concretes because of their higher densities. Puddling is a method whereby a 50-mm (2-in.) layer or more of mortar is placed in the forms and then covered with a layer of coarse aggregate that is rodded or internally vibrated into the mortar. Care must be taken to ensure uniform distribution of aggregate throughout the concrete.

MASS CONCRETE

Mass concrete is defined by ACI Committee 116 as “Any large volume of cast-in-place concrete with dimensions large enough to require that measures be taken to cope with the generation of heat and attendant volume change to minimize cracking.” Mass concrete includes not only low-cement-content concrete used in dams and other massive structures but also moderate- to high-cement-content concrete in structural members of bridges and buildings (Fig. 18-7). Mass concrete placements require special considerations to reduce heat of hydration and the resulting temperature rise to avoid damaging the concrete through excessive temperatures and temperature differences that can result in thermal cracking (Gajda and VanGeem, 2002).

In mass concrete, temperature rise (Fig. 18-8) results from the heat of hydration of cementitious materials. As the interior concrete increases in temperature and expands, the surface concrete may be cooling and contracting. This causes tensile stresses that may result in thermal cracks at the surface if the temperature different-

![Fig. 18-7. Large foundation placements as shown require mass-concrete precautions. (50918)](image)

![Fig. 18-8. (left) A drilled shaft (caisson), 3 m (10 ft) in diameter and 12.2 m (40 ft) in depth in which “low-heat” high-strength concrete is placed and (right) temperatures of this concrete measured at the center and edge and at three different levels in the caisson (Burg and Fiorato 1999). (57361)](image)
tial between the surface and center is too great. The width and depth of cracks depends upon the temperature differential, physical properties of the concrete, and the reinforcing steel.

A definite member size beyond which a concrete structure should be classified as mass concrete is not readily available. Many large structural elements may be massive enough that heat generation should be considered; this is particularly critical when the minimum cross-sectional dimensions of a solid concrete member approach or exceed 1 meter (3 feet) or when cement contents exceed 355 kg/m³ (600 lb per cubic yard). Temperature rise in mass concrete is related to the initial concrete temperature (Fig. 18-9), ambient temperature, size of the concrete element (volume to surface ratio and minimum dimension), and type and quantity of cementitious materials. Smaller concrete members less than 0.3 meters (1 ft) thick with moderate amounts of cementitious materials are typically of little concern as the generated heat is rapidly dissipated.

To avoid cracking, the internal concrete temperature for dams and other nonreinforced mass concrete structures of relatively low compressive strength should not be allowed to rise more than 11°C to 14°C (20°F to 25°F) above the mean annual ambient temperature (ACI 308). Internal concrete temperature gain can be controlled a number of ways: (1) a low cement content—120 to 270 kg/m³ (200 to 450 lb per cubic yard); (2) large aggregate size—75 to 150 mm (3 to 6 in.); (3) high coarse aggregate content—up to 80% of total aggregate; (4) low-heat-of-hydration cement; (5) pozzolans—where heat of hydration of a pozzolan can be 25% to 75% that of cement; (6) reductions in the initial concrete temperature to by cooling the concrete ingredients; (7) cooling the concrete through the use of embedded cooling pipes; (8) steel forms for rapid heat dissipation; (9) water curing; and (10) low lifts—1.5 m (5 ft) or less during placement. In massive structures of high volume-to-surface ratio, an estimate of the adiabatic temperature rise can be made using equations in a PCA publication (PCA 1987).

Massive structural reinforced concrete members with high cement contents (300 to 600 kg per cubic meter or 500 to 1000 lb per cu yard) cannot use many of the placing techniques and controlling factors mentioned above to maintain low temperatures to control cracking. For these concretes (often used in bridges, foundations, and power plants), a good technique is to (1) avoid external restraint from adjacent concrete elements, (2) reduce the size of the member by placing the concrete in multiple smaller pours, or (3) control internal differential thermal strains by preventing the concrete from experiencing an excessive temperature differential between the surface and the center. The latter is done by properly designing the concrete and either keeping the concrete surface warm through use of insulation or reducing the internal concrete temperature by precoring of the concrete or postcooling with internal cooling pipes.

Studies and experience have shown that by limiting the maximum temperature differential between the interior and exterior surface of the concrete to less than about 20°C (36°F), surface cracking can be minimized or avoided (FitzGibbon 1977 and Fintel and Ghosh 1978). Some sources indicate that the maximum temperature differential (MTD) for concrete containing granite or limestone (low-thermal-coefficient aggregates) should be 25°C and 31°C (45°F and 56°F), respectively (Bamforth 1981). The actual MTD for a particular mass concrete placement and concrete mix design can be determined using equations in ACI 207 (1995).

In general, an MTD of 20°C (36°F) should be assumed unless a demonstration or calculations based on physical properties of the actual concrete mix the geometry of the concrete member show that higher MTD values are allowable. By limiting the temperature differential to 20°C (36°F) or less, the concrete will cool slowly to ambient temperature with little or no surface cracking; however, this is true only if the member is not restrained by continuous reinforcement crossing the interface of adjacent or opposite sections of hardened concrete. Restrained concrete will tend to crack due to eventual thermal contraction after the cool down. Unrestrained concrete should not crack if proper procedures are followed and the temperature differential is monitored and controlled. If there is any concern over excess temperature differentials in a concrete member, the element should be considered as mass concrete and appropriate precautions taken.

Fig. 18-10 illustrates the relationship between temperature rise, cooling, and temperature differentials for a section of mass concrete. As can be observed, if the forms (which are providing adequate insulation in this case) are removed too early, cracking will occur once the difference between interior and surface concrete temperatures exceeds the critical temperature differential of 20°C (36°F). If higher temperature differentials are permissible, the forms can be removed sooner. For large concrete placements, surface insulation may be need for an extended period of time of up to several weeks or longer.
Fig. 18-10. Potential for surface cracking after form removal, assuming a critical temperature differential, $\Delta t$, of 20°C (36°F). No cracking should occur if concrete is cooled slowly and $\Delta t$ is less than 20°C (36°F) (Fintel and Ghosh 1978 and PCA 1987).

The maximum temperature rise can be estimated by approximation, if the concrete contains 300 to 600 kg of cement per cubic meter (500 to 1000 lb of Type I/II cement per cubic yard) and the least dimension of the member is 1.8 m (6 ft). This approximation (under normal, not adiabatic conditions) would be 12°C for every 100 kg of cement per cubic meter (12.8°F for every 100 lb of cement per cubic yard). For example, the maximum temperature of such an element made with concrete having 535 kg of Type I/II cement per cubic meter (900 lb of cement per cubic yard) and cast at 16°C (60°F) would be about

$$16^\circ C + (12^\circ C \times 535/100) \text{ or } 80^\circ C$$

$$\text{or } (60^\circ F + [12.8^\circ F \times 900/100] \text{ or } 175^\circ F)$$

Temperatures and temperature differences in mass concrete can also be calculated by a method in ACI 207 (1996).

The slow rate of heat exchange between concrete and its surroundings is due to the concrete’s heat capacity. Heat escapes from concrete at a rate that is inversely proportional to the square of its least dimension. A 150-mm (6-in.) thick wall cooling from both sides will take approximately 1 1/2 hours to dissipate 95% of its developed heat. A 1.5-m (5-ft) thick wall would take an entire week to dissipate the same amount of heat (ACI 207). Inexpensive thermocouples can be used to monitor concrete temperature.

**PREPLACED AGGREGATE CONCRETE**

Preplaced aggregate concrete is produced by first placing coarse aggregate in a form and later injecting a cement-sand grout, usually with admixtures, to fill the voids. Properties of the resulting concrete are similar to those of comparable concrete placed by conventional methods; however, considerably less thermal and drying shrinkage can be expected because of the point-to-point contact of aggregate particles.

Coarse aggregates should meet requirements of ASTM C 33 (AASHTO M 80). In addition, most specifications limit both the maximum and minimum sizes; for example, 75-mm (3-in.) maximum and 12.5-mm (1/2-in.) minimum. Aggregates are generally graded to produce a void content of 35% to 40%. Fine aggregate used in the grout is generally graded to a fineness modulus of between 1.2 and 2.0, with nearly all of the material passing a 1.25 mm (No. 16) sieve.

Although the preplaced aggregate method has been used principally for restoration work and in the construction of reactor shields, bridge piers, and underwater structures, it has also been used in buildings to produce unusual architectural effects. Since the forms are completely filled with coarse aggregate prior to grouting, a dense and uniform exposed-aggregate facing is obtained when the surface is sandblasted, tooled, or retarded and wire-brushed at an early age.

Tests for preplaced aggregate concrete are given in ASTM C 937 through C 943. Preplaced aggregate concrete is discussed in more detail in ACI 304-00, Guide for Measuring, Transporting, and Placing Concrete.

**NO-SLUMP CONCRETE**

No-slump concrete is defined as concrete with a consistency corresponding to a slump of 6 mm (1/4 in.) or less. Such concrete, while very dry, must be sufficiently workable to be placed and consolidated with the equipment to be used on the job. The methods referred to here do not necessarily apply to mixtures for concrete masonry units or for compaction by spinning techniques.

Many of the basic laws governing the properties of higher-slump concretes are applicable to no-slump concrete. For example, the properties of hardened concrete depend primarily on the ratio of water to cement, provided the mix is properly consolidated.

Measurement of the consistency of no-slump concrete differs from that for higher-slump concrete because the slump cone is impractical for use with the drier consistencies. ACI 211.3, Standard Practice for Selecting Proportions for No-Slump Concrete, describes three methods for measuring the consistency of no-slump concrete: (1) the Vebe apparatus; (2) the compacting-factor test; and (3) the Thaulow drop table. In the absence of the above test equipment, workability can be adequately judged by a trial mixture that is placed and compacted with the equipment and methods to be used on the job.

Intentionally entrained air is recommended for no-sluamp concrete where durability is required. The amount of air-entraining admixture usually recommended for higher-slump concretes will not produce air contents in no-sluamp concretes that are as high as those in the higher-slump concretes. The lower volume of entrained air, however, generally provides adequate durability for no-sluamp concretes; while the volume of entrained air is not there, sufficient small air voids are present. This departure from the usual methods of designing and controlling entrained air is necessary for no-sluamp concretes.

For a discussion of water requirements and computation of trial mixtures, see ACI 211.3.
Other water control RCC applications include use as an emergency spillway or overtopping protection for embankment dams, low permeable liner for settling ponds, bank protection, and grade control structure for channels and riverbeds.

**Pavements**

The uses for RCC paving range from pavements as thick as one meter (one yard) for the mining industry to city streets, paved surfaces for composting operations, logging, truck staging areas, and warehouse floors. The procedures for construction of an RCC pavement require tighter control than for dam construction (Arnold and Zamensky 2000). Cement content is in the same range as conventional concrete, 300 to 360 kg/m³ (500 to 600 lb/yd³), and compressive strength is of the same order, 30 to 40 MPa (4000 to 6000 psi). The nominal maximum aggregate size is limited to 19 mm (¾ in.) to provide a smooth, dense surface. For even better surface textures, a 16 mm (5⁄8 in.) maximum size aggregate is recommended.

The zero slump mix is usually produced in a continuous flow pugmill mixer at production rates as high as 400 tons per hour. It is possible to mix RCC in a central batch plant, but the plant must be dedicated to RCC production exclusively, because the material tends to stick to the inside drums. Specifications usually require that the mix be transported, placed, and compacted within 60 minutes of the start of mixing; although ambient weather conditions may increase or decrease that time window.

RCC is typically placed in layers 125 to 250 mm (5 to 10 in.) in thickness using an asphalt-type paving machine. High-density paving equipment is preferred for layers thicker than 150 mm (6 in.) since the need for subsequent compaction by rollers is reduced. Where a design calls for pavement thickness greater than 250 mm (10 in.), the RCC should be placed in multiple layers. In this type of construction, it is important that there be a minimum time delay in placing subsequent layers so that good bond is assured. Following placement by a paver, RCC can be compacted with a combination of vibratory steel-wheeled rollers and rubber-tired equipment.

Curing is vitally important in RCC pavement construction. The very low water content at the initial mixing stage means that an RCC mix will dry out very quickly once it is in place. Continuous water curing is the recommended method, although sprayed on asphaltic emulsion, plastic sheeting, and concrete curing compounds have been used in some cases. Pavement projects have had design compressive strengths of about 35 MPa (5000 psi) with field strengths in the range of 35 to 70 MPa (5000 to 10,000 psi) (Hansen 1987).

High-performance roller compacted concrete for areas subjected to high impact and abrasive loading were developed in the mid-1990’s. These mixes are based on obtaining the optimum packing of the various sizes of aggregate particles, and the addition of silica fume to the mix (Marchand and others 1997 and Reid and Marchand 1998).

**SOIL-CEMENT**

Soil-cement is a mixture of pulverized soil or granular material, cement, and water. Some other terms applied to soil-cement are “cement-treated base or subbase,” “cement stabilization,” “cement-modified soil,” and “cement-treated aggregate.” The mixture is compacted to a high density, and as the cement hydrates the material becomes hard and durable.

Soil-cement is primarily used as pavement base course for roads, streets, airports, and parking areas. A bituminous or portland cement concrete wearing course is usually placed over the base. Soil-cement is also used as slope protection for earth dams and embankments, reservoir and ditch linings, deep-soil mixing, and foundation stabilization (Fig. 18-12).

The soil material in soil-cement can be almost any combination of sand, silt, clay, and gravel or crushed stone. Local granular materials (such as slag, caliche, limestone, and scoria) plus a wide variety of waste materials (such as cinders, ash, and screenings from quarries and gravel pits) can be used to make soil-cement. Also, old granular-base roads, with or without their bituminous surfaces, can be recycled to make soil-cement.

Soil-cement should contain sufficient portland cement to resist deterioration from freeze-thaw and wet-dry cycling and sufficient moisture for maximum compaction. Cement contents range from 80 to 255 kg per cubic meter (130 to 430 lb per cubic yard).

There are four steps in soil-cement construction: spreading cement, mixing, compaction, and curing. The proper quantity of cement must be spread on the in-place soil; the cement and soil material, and the necessary amount of water are mixed thoroughly using any of several types of mixing machines; and finally, the mixture is compacted with conventional road-building equipment to 96% to 100% of maximum density. See ASTM D 558 (AASHTO T 134) and PCA 1992.

A light coat of bituminous material is commonly used to prevent moisture loss; it also helps bond and forms part of the bituminous surface. A common type of wearing surface for light traffic is a surface treatment of bituminous material and chips 13 to 19 mm (½ to ¾ in.) thick. For heavy-duty use and in severe climates a 38-mm (1½-in.) asphalt mat is used.

Depending on the soil used, the 7-day compressive strengths of saturated specimens at the minimum cement content meeting soil-cement criteria are generally between 2 to 5 MPa (300 and 800 psi). Like concrete, soil-cement continues to gain strength with age; compressive strengths in excess of 17 MPa (2500 psi) have been obtained after many years of service.

See ACI Committee 230 (1997) and PCA (1995) for detailed information on soil-cement construction.

**SHOTCRETE**

Shotcrete is mortar or small-aggregate concrete that is pneumatically projected onto a surface at high velocity (Fig. 18-13). Also known as “gunite” and “sprayed concrete,” shotcrete was developed in 1911 and its concept is essentially unchanged even in today’s use. The relatively
Shrinkage-compensating concrete is used in concrete slabs, pavements, structures, and repair work to minimize drying shrinkage cracks. Expansion of concrete made with shrinkage-compensating cement should be determined by the method specified in ASTM C 878.

Reinforcing steel in the structure restrains the concrete and goes into tension as the shrinkage compensating concrete expands. Upon shrinking due to drying contraction caused by moisture loss in hardened concrete, the tension in the steel is relieved; as long as the resulting tension in the concrete does not exceed the tensile strength of the concrete, no cracking should result. Shrinkage-compensating concrete can be proportioned, batched, placed, and cured similarly to normal concrete with some precautions; for example, it is necessary to assure the expected expansion by using additional curing. More information can be found in Chapter 2 and in ACI 223-98, Standard Practice for the Use of Shrinkage-Compensating Concrete.

PERVIOUS CONCRETE

Pervious (porous or no-fines) concrete contains a narrowly graded coarse aggregate, little to no fine aggregate, and insufficient cement paste to fill voids in the coarse aggregate. This low water-cement ratio, low-slump concrete resembling popcorn is primarily held together by cement paste at the contact points of the coarse aggregate particles; this produces a concrete with a high volume of voids (20% to 35%) and a high permeability that allows water to flow through it easily.

Pervious concrete is used in hydraulic structures as drainage media, and in parking lots, pavements, and airport runways to reduce storm water run off. It also recharges the local groundwater supply by allowing water to penetrate the concrete to the ground below. Pervious concretes have also been used in tennis courts and greenhouses.

As a paving material, porous concrete is raked or slip-formed into place with conventional paving equipment and then roller compacted. Vibratory screeds or hand rollers can be used for smaller jobs. In order to maintain its porous properties, the surfaces of pervious concrete should not be closed up or sealed; therefore, troweling and finishing are not desired. The compressive strength of different mixes can range from 3.5 to 27.5 MPa (500 to 4000 psi). Drainage rates commonly range from 100 to 900 liters per minute per square meter (2 to 18 gallons per minute per square foot).

No-fines concrete is used in building construction (particularly walls) for its thermal insulating properties. For example, a 250-mm (10-in.) thick porous-concrete wall can have an R value of 0.9 (5 using inch-pound units) compared to 0.125 (0.75) for normal concrete. No-fines concrete is also lightweight, 1600 to 1900 kg/m³ (100 to 120 pcf), and has low drying shrinkage properties (Malhotra 1976 and Concrete Construction 1983).
White and Colored Concrete

White Concrete

White portland cement is used to produce white concrete, a widely used architectural material (Fig. 18-14). It is also used in mortar, plaster, stucco, terrazzo, and portland cement paint. White portland cement is manufactured from raw materials of low iron content; it conforms to ASTM C150 (AASHTO M 85) even though these specifications do not specifically mention white portland cement.

White concrete is made with aggregates and water that contain no materials that will discolor the concrete. White or light-colored aggregates can be used. Oil that could stain concrete should not be used on the forms. Care must be taken to avoid rust stains from tools and equipment. Curing materials that could cause stains must be avoided. Refer to Farny (2001) and http://www.portcement.org/white for more information.

Colored Concrete

Colored concrete can be produced by using colored aggregates or by adding color pigments (ASTM C 979) or both. When colored aggregates are used, they should be exposed at the surface of the concrete. This can be done several ways; for example, casting against a form that has been treated with a retarder. Unhydrated paste at the surface is later brushed or washed away. Other methods involve removing the surface mortar by sandblasting, waterblasting, bushhammering, grinding, or acid washing. If surfaces are to be washed with acid, a delay of approximately two weeks after casting is necessary. Colored aggregates may be natural rock such as quartz, marble, and granite, or they may be ceramic materials.

Pigments for coloring concrete should be pure mineral oxides ground finer than cement; they should be insoluble in water, free of soluble salts and acids, colorfast in sunlight, resistant to alkalies and weak acids, and virtually free of calcium sulfate. Mineral oxides occur in nature and are also produced synthetically; synthetic pigments generally give more uniform results.

The amount of color pigments added to a concrete mixture should not be more than 10% of the mass of the cement. The amount required depends on the type of pigment and the color desired. For example, a dose of pigment equal to 1.5% by mass of cement may produce a pleasing pastel color, but 7% may be needed to produce a deep color. Use of white portland cement with a pigment will produce cleaner, brighter colors and is recommended in preference to gray cement, except for black or dark gray colors (Fig. 18-15).

To maintain uniform color, do not use calcium chloride, and batch all materials carefully by mass. To prevent streaking, the dry cement and color pigment must be thoroughly blended before they are added to the mixer. Mixing time should be longer than normal to ensure uniformity.

In air-entrained concrete, the addition of pigment may require an adjustment in the amount of air-entraining admixture to maintain the desired air content.

Dry-Shake Method. Slabs or precast panels that are cast horizontally can be colored by the dry-shake method. Prepackaged, dry coloring materials consisting of mineral oxide pigment, white portland cement, and specially graded silica sand or other fine aggregate are marketed ready for use by various manufacturers.

After the slab has been bullfloated once, two-thirds of the dry coloring material should be broadcast evenly by
hand over the surface. The required amount of coloring material can usually be determined from previously cast sections. After the material has absorbed water from the fresh concrete, it should be floated into the surface. Then the rest of the material should be applied immediately at right angles to the initial application, so that a uniform color is obtained. The slab should again be floated to work the remaining material into the surface.

Other finishing operations may follow depending on the type of finish desired. Curing should begin immediately after finishing; take precautions to prevent discoloring the surface. See Kosmatka (1991) for more information.

**POLYMER-PORTLAND CEMENT CONCRETE**

Polymer-portland cement concrete (PPCC), also called polymer-modified concrete, is basically normal portland cement concrete to which a polymer or monomer has been added during mixing to improve durability and adhesion. Thermoplastic and elastomeric latexes are the most commonly used polymers in PPCC, but epoxies and other polymers are also used. In general, latex improves ductility, durability, adhesive properties, resistance to chloride-ion ingress, shear bond, and tensile and flexural strength of concrete and mortar. Latex-modified concretes (LMC) also have excellent freeze-thaw, abrasion, and impact resistance. Some LMC materials can also resist certain acids, alkalis, and organic solvents. Polymer-portland cement concrete is primarily used in concrete patching and overlays, especially bridge decks. See ACI 548.3R for more information on polymer-modified concrete and ACI 548.4 for LMC overlays.

**FERROCEMENT**

Ferrocement is a special type of reinforced concrete composed of closely spaced layers of continuous relatively thin metallic or nonmetallic mesh or wire embedded in mortar. It is constructed by hand plastering, shotcreting, laminating (forcing the mesh into fresh mortar), or a combination of these methods.

The mortar mixture generally has a sand-cement ratio of 1.5 to 2.5 and a water-cement ratio of 0.35 to 0.50. Reinforcement makes up about 5% to 6% of the ferrocement volume. Fibers and admixtures may also be used to modify the mortar properties. Polymers or cement-based coatings are often applied to the finished surface to reduce porosity.

Ferrocement is considered easy to produce in a variety of shapes and sizes; however, it is labor intensive. Ferrocement is used to construct thin shell roofs, swimming pools, tunnel linings, silos, tanks, prefabricated houses, barges, boats, sculptures, and thin panels or sections usually less than 25 mm (1 in.) thick (ACI 549R and ACI 549.1R).

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