Chapter 8

Components of Concrete

Concrete is a mixture of sand, gravel, crushed rock, and/or other aggregates that are held together by a hardened paste of cement and water. The properties of concrete vary depending on the ingredients used and their proportions in the mix. Generally, concrete mix consists of 25 to 40 percent cement paste, 25 to 40 percent aggregate, and 7 to 15 percent concrete. When cement and water are combined, hydration (liberation of heat) occurs. The strength of concrete begins with hydration and increases as long as hydration continues. After 28 days, the relative strength increase levels off.

TYPES OF PORTLAND CEMENT

8-1. Various types of portland cement have been standardized for different uses. The type of construction, the chemical composition of the soil, the economy, and the speed of construction determine the type of cement used. The five types of portland cement are described below. Types I, II, and III are the most widely used; Types IV and V are used for specific applications.

NOTE: Chapter 9 addresses air-entrained cement, which is a special type of cement made with an air-entraining admixture.

- **Type I, normal portland cement.** Type I cement is used in general construction. It is used for pavement construction where concrete is not subject to sulfate hazards or where heat generated through hydration does not cause an objectionable rise in temperature.

- **Type II, modified portland cement.** Type II cement generates lower heat at a slower rate than Type I, and it has improved resistance to sulfate. It is used in hot weather when moderate heat generation tends to minimize the rise in temperature; Type I may be preferable in cold weather. Type II cement can be used as a precaution in areas where sulfate concentrations are higher than normal but are not severe.

- **Type III, high-early-strength portland cement.** Type III cement is used when high strengths are needed very early in an operation. Forms can be removed in a short time, and the concrete can be put into quick service. It is also used to reduce the amount of time uncured cement is exposed to low temperatures. Type III cement usually cures in two days at 70°F and three days at 50°F. High strength can be obtained at an early stage more satisfactorily and economically with Type III cement than with Type I.

- **Type IV, low-heat portland cement.** Type IV cement is used when the amount and rate of generated heat must be kept to a minimum. It develops strength at a slower rate than Type I. Type IV is normally used in large, mass projects, such as concrete dams, to combat the rise
in temperature where heat generated during hardening may be a critical factor. It is seldom used for road or airfield construction.

- **Type V, sulfate-resistant portland cement.** Type V cement is used in structures that are exposed to severe sulfate action, such as areas that have water with a high acid content. It gains strength at a slower rate than Type I.

### WATER

8-2. Water is mixed with cement to form a paste and produce hydration. Foreign materials in the water that tend to retard or change the chemical reaction are detrimental to concrete. Organic material and oil may inhibit the bond between the hydrated cement and the aggregate by coating the aggregate and preventing the paste from adhering to the aggregate. Several alkalies and acids react chemically with cement and retard normal hydration, and organic material may have the same effect. The result is a weakened paste, and the contaminating substance will likely cause deterioration or structural failure of the finished concrete.

### SEA WATER

8-3. Sea water and cement can be mixed with satisfactory results; however, concrete strength may be reduced by 10 to 20 percent. Salt water acts as an accelerant much the same as calcium chloride (CaCl₂). Avoid using sea water in reinforced concrete if possible; but as a field expedient, decrease the water-to-cement ratio to offset the strength loss. If the water-to-cement ratio cannot be changed, consider the following to offset strength reduction:

- If using ocean water with an average salt content, multiply the design thickness by 1.15 to obtain a thickness of equal strength.
- If using water from a landlocked sea, such as the Dead Sea, with an extremely high salt content, multiply the design thickness by 1.25 to obtain a thickness of equal strength.

### WELL WATER (SULFUR)

8-4. Avoid using water with a high sulfur content (normally present in wells and streams near underground mines) in concrete. If it is the best type of water available, however, use sulfur-resistant cements. Sulfur water that is not unpleasant to drink produces excellent results with Type V cement, good results with Type II cement, and fair results with other types of cement. If the water contains enough sulfates to make it unpleasant to drink, it produces good results with Type V cement, fair results with Type II cement, and marginal or unsatisfactory results with other types of cement. Some sulfur water may also contain acids or alkalies, and adding an accelerator may offset the harmful effects of these contaminants.

### AGGREGATE

8-5. Aggregates can be added to cement paste as a filler; however, they affect the proportions and the economy of a mix and the qualities of the finished
concrete. The most common fillers are crushed rock and natural deposits of sand and gravel. Artificial aggregates, such as blast-furnace slag or specially burned clay, can be used if natural aggregates are unavailable. A satisfactory expedient aggregate can sometimes be produced by crushing the rubble from demolished structures.

**TYPES**

8-6. FA and CA can be used to produce concrete. Combining both types yields a well-graded mix that produces a strong, durable, almost voidless building stone. For portland-cement concrete, aggregate is considered fine when it passes a number 4 sieve and is retained on a number 200 sieve with 3 to 5 percent passing a number 100 sieve. Use FA to fill voids between CA particles and to reduce the amount of paste needed. Aggregate is considered coarse when it passes a 3-inch sieve and is retained on a number 4 sieve. CA is primarily used as a filler. For pavement, ensure that the maximum size CA does not exceed 2 inches or one-third the thickness of the slab. The larger the particle, the less paste is needed to coat the aggregate.

**CHARACTERISTICS**

8-7. To produce high-quality concrete, ensure that the aggregate is clean, hard, strong, durable, and round or cubical in shape. (See FM 5-472 for information on testing bulk-specific gravity, absorption of aggregates, surface moisture of FA, and organic matter in sand.)

8-8. Organic matter, dirt, silt, clay, or chemicals may cause finished concrete to deteriorate by inhibiting the bond between the cement paste and the aggregate or by reacting with the constituents of the cement. Excessive fines may also inhibit bonding and produce a mix that is structurally weak and susceptible to breakdown by weathering. Wash the aggregate to remove harmful ingredients. To determine mix proportions, ensure that the aggregate is in a saturated, surface-dry condition or adjust the water-to-cement ratio to compensate for the amount of water contained in the aggregate.

8-9. Aggregate should be strong and resistant to abrasion from weathering and wear. Weak, friable, laminated, or very absorptive aggregate particles are likely to cause deterioration of the finished concrete. Inspect aggregate frequently to disclose weaknesses.

**GRADATIONS**

8-10. Aggregate gradation and size affect the relative proportions, workability, and economy of a mix and the watertightness and shrinkage of finished concrete. In general, aggregate used for concrete must be well-graded to produce a dense mass with minimum voids. Aggregate that is not well-graded may reduce the strength of finished concrete and increase the cost of the mix because of the additional paste required to fill voids. (See FM 5-472 for a more detailed explanation of aggregate gradations.) Table 8-1 lists the recommended limits for FA and CA.
FINENESS MODULUS

8-11. The fineness modulus is an index of the relative fineness or coarseness of sand in a concrete mix. It is calculated by adding the cumulative percentages of an aggregate sample that is retained on each sieve of a specified series and dividing the result by 100. The sieves ordinarily used are numbers 3, 4, 8, 16, 50, and 100. Aggregate with a very low or high fineness modulus is not as satisfactory for concrete as aggregate with a medium fineness modulus.

BLENDING

8-12. If the aggregate gradation does not meet recommended limits due to the lack or abundance of certain particle sizes, blend the material to meet the requirements. Correct deficiencies by adding missing particles or screening out abundant particles.

ADMIXTURES

8-13. Admixtures used with portland cement are air-entraining agents, accelerators, retardants, plasticizers, cement-dispersing agents, concrete densifiers, and waterproofing agents. They are used to change the characteristics of a mix or a finished concrete. Do not use admixtures if the end result can be achieved more economically by altering mix proportions. This manual addresses admixtures used in concrete pavements; cement-dispersing agents, concrete densifiers, and waterproofing agents are only used for constructing structural members.

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Table 8-1. Recommended Aggregate Gradation Limits for Portland-Cement Concrete

<table>
<thead>
<tr>
<th>Size Number</th>
<th>Nominal Size</th>
<th>Amounts Finer Than Laboratory Sieve (Square Openings), Percent by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2 1/2 Inch</td>
</tr>
<tr>
<td>3, 5, 7</td>
<td>2 inch to No. 4</td>
<td>100</td>
</tr>
<tr>
<td>4, 6, 7</td>
<td>1 1/2 inch to No. 4</td>
<td>---</td>
</tr>
<tr>
<td>5, 7</td>
<td>1 inch to No. 4</td>
<td>---</td>
</tr>
<tr>
<td>6, 7</td>
<td>3/4 inch to No. 4</td>
<td>---</td>
</tr>
<tr>
<td>7</td>
<td>1/2 inch to No. 4</td>
<td>---</td>
</tr>
<tr>
<td>3</td>
<td>2 to 1 inch</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>1 1/2 to 3/4 inch</td>
<td>---</td>
</tr>
</tbody>
</table>
AIR-ENTRAINING AGENTS

8-14. Air-entraining agents increase the resistance to frost action and chemicals and improve the workability of a mix. These agents are liquids derived from wood resin, animal fats, vegetable oils, and other wetting agents (alkali salts, sulfonated organic compounds, various water-soluble soaps). Many different air-entraining agents can be used to produce air-entrained concrete.

ACCELERATORS

8-15. Accelerators are used in a concrete mix to hasten hydration, which increases generated heat and produces a high-early strength cement. CaCl\textsubscript{2} is the most widely used accelerator, and it can be used if it is economical and the increased hydration will not cause flash set or undue shrinkage. Use 1 to 2 percent CaCl\textsubscript{2} by weight of the cement. This amount increases the flexural strength by 40 to 90 percent on the first day and 5 to 35 percent by the third day when moist-cured at 70°F. Flexural strength increases are lower at 40°F, and acceleration is usually greatest during the first three days.

8-16. With the same water-to-cement ratio, the ultimate strength at one year is about the same or slightly higher for cement mixed with CaCl\textsubscript{2}. Because CaCl\textsubscript{2} increases the workability of a mix, lower water-to-cement ratios can be used with subsequent increases in strength. Do not use CaCl\textsubscript{2} for curing, on the surface, or as an admixture. Sodium chloride (NaCl) can also be used to accelerate hydration, but it will reduce the strength of concrete.

RETARDANTS

8-17. Retardants are used when the rate of hydration must be slowed down to allow proper placement and consolidation of the concrete before it sets. They can also be used to increase the strength and durability of concrete when it is revibrated before it sets. Many commercial retardants are available; and they basically consist of fatty acids, sugars, and starches. Use retardants when the—

- Danger of flash set exists.
- Heat of hydration is expected to be excessively high.
- Cement comes in contact with high ground temperatures (as in grouting operations).
- Concrete is laid during hot weather.

PLASTICIZERS

8-18. Plasticizers are used to make the concrete more workable. Do not use them as substitutes for proper aggregate gradation. Some materials that can be used as plasticizers include—

- Admixtures, which increase the workability of a mix.
- Air-entraining agents.
- CaCl\textsubscript{2} and other pozzolans.
- Lime.
• Finely pulverized inert fillers, which increase the workability of a mix that is deficient in fines. They also increase the amount of mixing water required.

8-19. A pozzolan is a siliceous material that becomes cement-like when it is combined with lime. It is normally used as a cement replacement agent. Fly ash, volcanic ash, calcined diatomaceous earth, and calcined shale are examples of pozzolans.

8-20. Fly ash, the most widely used pozzolan, is a waste product from large, powdered-coal furnaces. Used as a cement replacement agent, fly ash can replace up to 50 percent of the cement by weight. Using fly ash changes nearly all the properties of concrete in its plastic and hardened states. In general, fly ash improves the workability of plastic concrete. If the same amount of aggregate is used in a mix, identical slumps are obtained with cement/fly-ash mixes and portland-cement mixes; however, cement/fly-ash mixes have a lower water-to-cement ratio. Fly ash acts as a plasticizer, improves the workability of a mix, and greatly reduces bleeding and segregation. When compared to modified portland cement, fly ash reduces the heat of hydration by 40 to 50 percent. Fly-ash concrete does not gain strength and durability as fast as portland-cement concrete during the first month of hydration. Although after the first year, the strength and durability of fly-ash concrete are equal to or greater than portland-cement concrete.

MATERIALS HANDLING AND STORAGE

AGGREGATE

8-21. Concrete quantities that justify batch plants also justify stockpiles of aggregates at batch, crushing, and screening plants. Stockpiling prevents shortages at the batch plant and the paver. Stockpile aggregates for concrete pavement using the procedures discussed in Chapter 4 for bituminous pavements.

CEMENT

8-22. Sacked cement that will be stored for a long time should be in a warehouse or a shed that is as airtight as possible. Ensure that the floor of the shed is above ground, and close up all cracks in the walls. Store the sacks close together to reduce air circulation; however, do not stack them against a wall. Stack cement sacks on a raised, wooden platform and cover them with tarpaulins (Figure 8-1, page 8-8). Note that tarpaulins extend over the edge of the platform to prevent rain from collecting on the platform and reaching the bottom sacks. Use tarpaulins for protection against moisture even when storing a small amount of cement for a short time. Ensure that the concrete mixer is located near the storage shed.

8-23. Cement retains its quality indefinitely when it is kept dry. If it is packed tightly and stored for a long time, it may develop warehouse pack. To correct warehouse pack, roll the sacks on the floor. Cement must be free-flowing and free of lumps when it is used. If the lumps are hard to break up, test the cement for suitability (see FM 5-472).
8-24. Bulk portland cement is blown through ducts from railroad cars to cement bins and weighing hoppers. The hoppers stand alongside trucks, beyond the aggregate batcher, and dump the cement into each batch. Open cement sacks and dump them into each batch from a roadside platform. Stack the sacks on the platform or the dunnage and cover them with tarpaulins or roofing paper. When hauling cement, cover it on the truck beds with tightly fitted canvas to prevent loss from wind and avoid damage from light showers. Depending on the length of the haul and the weather conditions, unopened sacks of cement may have to be opened at the mixer and dumped into each batch.

8-25. Loading platforms may be located at any point along the route from the batching plant to the paver. Hand trucks and roller conveyors are useful at loading points. Two people can toss cement sacks using a lifting-and-swinging rhythm. Empty sacks by cutting the underside lengthwise with a sharp, curved linoleum knife and pulling the empty sack free. When handling cement, wear goggles, respirators, and gloves. Avoid skin irritation by precoating exposed skin surfaces with petroleum jelly or neat's-foot oil. Store water near the mixer or water trailers, and ensure that water containers are clean and rust-free.

Figure 8-1. Cement Stored Under Tarpaulins

8-8 Components of Concrete