Chapter 9

Characteristics of Concrete

Concrete is a stone-like material that forms when a carefully proportioned mixture of cement, FA, CA, and water harden into the specific shape or dimension of a structure. Most of the material in concrete is FA and CA, and cement and water interact to bind the aggregates into a solid mass. By adjusting the proportions of the different materials, a wide range of strength properties can be achieved.

PLASTIC CONCRETE

9-1. The quality of hardened concrete depends mainly on the quality of plastic concrete, but the curing process also helps attain the specified design criteria. Carefully follow the design criteria, because mix consistency may vary. When testing ingredients for suitability, the only variable factor in the plastic mix is the proportioning and it must be accurate. Ensure that the plastic concrete is workable, free from CA segregation, and uniform in quality.

9-2. Workability is the relative ease or difficulty of placing and consolidating plastic concrete in a form. Maintain the mixture's consistency, as necessary, to obtain the workability needed for the placement method and the specific conditions. Conduct a slump test to measure the consistency and workability of a mix. To perform a slump test, place mixed concrete in a standard cone, in three layers of equal volume, and rod each layer 25 times. Place, rod, and strike off the last layer. Lift the cone away from the concrete that has slumped (settled). Record how much concrete settles below the top of the cone as a measure of workability. The allowable slump is determined by the specifications for the job. If using constant quantities of materials, the slump should remain constant. Any marked variation in slump or consistency indicates a deviation from the mix design. Investigate the deviation immediately and determine the cause.

9-3. Handle and place plastic concrete so that it is completely homogeneous (CA is not segregated). To prevent segregation, do not drop plastic concrete or allow it to fall free for a distance greater than 3 to 5 feet. To obtain uniformity, ensure that each batch is accurately proportioned according to the design criteria. Uniformity increases the economy of the mix and improves the quality of hardened concrete.

HARDENED CONCRETE

9-4. Concrete pavement must have sufficient flexural strength to carry the required load. The water-to-cement ratio is the most important factor for attaining the desired strength. For each sack of cement, use 4 to 7 gallons of water. Although a high water-to-cement ratio increases the yield of each sack
of cement, a thin paste is inherently weak. The evaporation of excess water during the curing process leaves voids that reduce the strength of the hardened concrete. When the water-to-cement ratio is increased above the minimum 4 gallons per sack, the durability decreases respectively.

9-5. The durability of finished concrete is determined by its ability to resist the effects of weather such as wind, frost, snow, ice, salt, abrasion, wetting-drying and freezing-thawing cycles, and chemical reactions of the soil. The climate, the pavement thickness, and the amount of exposure to the elements also affect the durability of concrete.

AIR-ENTRAINED CONCRETE

9-6. Air-entrained concrete is more resistant to weathering than other types of concrete. It reduces scaling, is resistant to severe frost, and is impervious to the effects of chemicals used for melting snow and ice. Compared to normal portland-cement concrete, air-entrained concrete is more durable but has slightly less strength. Air-entrained mixes have increased workability and decreased segregation.

9-7. Like other types of concrete, air-entrained concrete consists of cement, sand, gravel, and water. Millions of tiny air bubbles, which range from a few microns to 75 microns in diameter, are entrained (diffused) into the cement paste. (Calculations have indicated that as many as 400 to 600 billion air bubbles can be entrained in a cubic yard of concrete.) The percent of entrained air in concrete by volume is usually 4 1/2, with an acceptable range of 3 to 7 percent. Portland-cement concrete is normally 1/2 to 1 1/2 percent air; however, the air is usually entrapped as voids and is not dispersed uniformly throughout the mix.

PRODUCTION

9-8. Air-entrained concrete can be produced by—

- Adding air-entraining agents at the site. Use a commercially prepared agent in the quantities specified by the manufacturer. Do not dilute the agent with water unless specified. Types I, II, and III portland cement are commonly used for air-entrained concrete. Rigidly control the air content of the mix to obtain the desired uniformity. This is the preferred method for producing air-entrained concrete.
- Adding air-entraining agents during the cement manufacturing process. This method is less desirable because the air content cannot be changed at the work site, and the agents may lose their effectiveness after long storage. Sacks of air-entrained cement have an “A” suffix in their type designation, such as Type I-A.

9-9. The amount of air-entraining agents required to produce a given air content increases when the concrete’s temperature increases. Therefore, test the air content frequently, especially when the concrete’s temperature changes. During the production process, mix concrete for 1 to 2 minutes to ensure proper air content. Remember that air content—

- Increases about 1 percent when the mixing time is 1 to 5 minutes or more than 60 minutes.
• Remains unchanged when the mixing time is 5 to 10 minutes.
• Decreases gradually when the mixing time is more than 10 minutes.

9-10. Vibrating air-entrained concrete for 1 minute or more reduces the air content 15 to 20 percent. Internal vibration reduces the air content more than external vibration. (See Chapter 13 for more information on concrete vibration.)

MEASUREMENT OF AIR CONTENT

9-11. The air content of freshly mixed concrete can be measured by pressure, gravimetric, and volumetric methods. In the pressure method, which is the most widely used, the volume of gas at a given temperature is inversely proportional to the subjected pressure. To obtain the desired percentage of entrained air in a concrete mix, use a calibrated air meter to measure a known volume of concrete that is subjected to a known pressure (see FM 5-472 for more information).

SLUMP

9-12. Adding entrained air to a mix decreases the slump. A 3-inch slump is necessary to provide good workability to non-air-entrained pavement mixes. The same workability is present in an air-entrained mix that has a 1- to 2-inch slump because of the fatty character. The whipped-cream effect of air-entrained concrete allows slump reduction that maintains the original degree of workability. Slump reduction allows a decrease in the water-to-cement ratio, thus increasing the concrete’s strength.

STRENGTH

9-13. The strength of air-entrained concrete is inversely proportional to the percent of entrained air. With all other factors constant, strength is reduced about 5 percent for each 1 percent of entrained air. Decreasing the sand and the water in a mix increases the concrete’s strength and allows design specifications to be met without making major changes for air-entrainment. (Chapter 10 addresses the proper method of adjusting the mix for entrained air.)

9-14. Entrained air causes voids in concrete, thus reducing its strength. On the other hand, the changes in workability and slump allow a water-to-cement ratio reduction, thus increasing the concrete’s strength. Air-entrained concrete, which has the slump decreased and the strength properly adjusted, yields a mix that is almost equal in strength to the original non-air-entrained mix. The capillary air voids caused by the extra water is replaced by minute, evenly distributed air voids of entrained air that provide greater uniformity.
Chapter 10

Mix Design

The purpose of a mix design is to group the aggregates in different proportions to achieve the desired strength. The components of a mix are proportioned so that the resulting concrete has adequate strength, proper workability for placing, and low cost. Low cost is achieved by using the minimum amount of cement required to obtain adequate properties. Admixtures are often used for special purposes. **NOTE:** This manual addresses mix designs for concrete paving mixes. See FM 5-428 for information on mix designs for structural concrete.

**CRITERIA**

10-1. The flexural (beam) and compressive strengths of a hardened mix are used for the concrete's design criteria. Flexural strength measures the bridging capacity and is used to design nonreinforced concrete pavement. Compressive strength measures the resistance to a direct load. Strength tests are usually made after 28 days for road pavement and after 90 days for airfield pavement.

**WATER-TO-CEMENT RATIO**

10-2. Select the proper water-to-cement ratio to ensure that a mix meets the requirements for flexural strength and durability. A durable mix has a long life, requires low upkeep, and is highly resistant to exposure and freezing. Figure 10-1, page 10-2, shows the relationship between age and flexural strength for Types I and III portland cement. Table 10-1, page 10-3, lists the recommended water-to-cement ratios for durability in various exposures. Select the lowest water-to-cement ratio that satisfies the requirements for flexural strength and durability.

10-3. Use the water-to-cement ratio shown in Figure 10-1 for flexural strength and adjust the ratio for durability. For example, to find the water-to-cement ratio for Type I portland cement with a flexural strength of 600 psi at 28 days, read from the bottom of the curve. The amount is 5 1/4 gallons of water per sack of cement. Table 10-1 shows that the durability requirement is 5 1/2 gallons of water per sack of concrete. Therefore, using 5 1/4 gallons as the lowest ratio will satisfy the requirements for flexural strength and durability. Once the water-to-cement ratio has been selected, do not change it except for air-entrainment adjustments.