

Design and Control of Concrete Mixtures

The guide to applications, methods, and materials

FIFTEENTH EDITION

by Steven H. Kosmatka and Michelle L. Wilson

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An organization of cement companies to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

EXH. A

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ABSTRACT: This book presents the properties of concrete as needed in concrete construction, including strength and durability. All concrete ingredients (cementing materials, water, aggregates, admixtures, and fibers) are reviewed for their optimal use in designing and proportioning concrete mixtures. Applicable ASTM, AASHTO, and ACI standards are referred to extensively. The use of concrete from design to batching, mixing, transporting, placing, consolidating, finishing, and curing is addressed. Concrete sustainability, along with special concretes, including high-performance concretes, are also reviewed.

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Cover photos show the world's tallest building, the Burj Khalifa in Dubai, U.A.E. The tower is primarily a concrete structure, with concrete construction utilized for the first 155 stories, above which exists a structural steel spire.

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WARNING: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS (THIRD-DEGREE), or SERIOUS EYE DAMAGE. Frequent exposure may be associated with irritant and/or allergic contact dermatitis. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

Because of improved workability with entrained air, water and sand content can be reduced significantly as shown in Figure 7-4. A volume of air-entrained concrete requires less water than an equal volume of non-air-entrained concrete of the same consistency and maximum size aggregate. Water reductions in the range of 15 L/m^3 to 25 L/m^3 (25 lb/yd^3 to 40 lb/yd^3) may be achieved with adequate air entrainment (Figure 7-4). Freshly mixed concrete containing entrained air is cohesive, looks and feels "fatty" or workable, and can usually be handled with ease. On the other hand, high air contents can make a mixture sticky and more difficult to finish. Furthermore, the air bubbles reduce the tendency for segregation and bleeding.

Improvements in the performance of hardened concrete obviously include improved resistance to freezing and thawing, and deicer-salt scaling. Furthermore, the incorporation of air also results in a reduced permeability and possibly improved resistance to sulfate attack and alkali-silica reactivity (see Chapter 11).

The single detrimental effect is that an increase in air content results in a decrease in the strength of the concrete. When the air content is maintained constant, strength varies

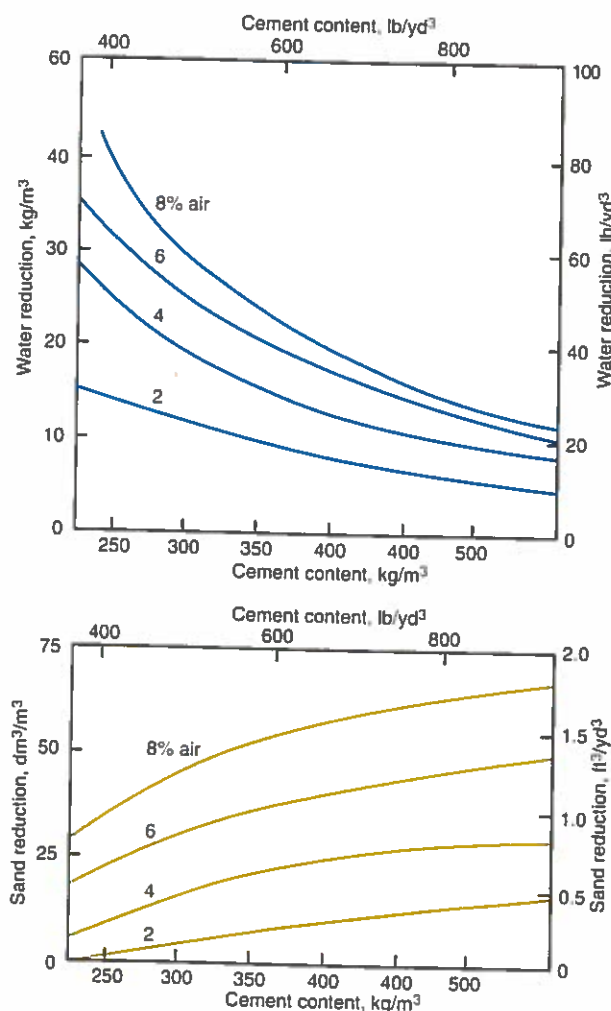


Figure 7-4. Reduction of water and sand content obtained at various levels of air and cement contents (Gilkey 1958).

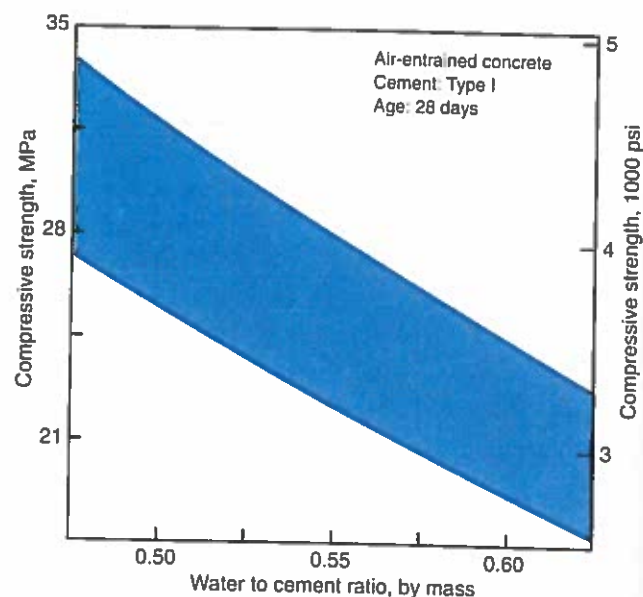


Figure 7-5. Typical relationship between 28-day compressive strength and water-cement ratio for a wide variety of air-entrained concretes using Type I cement.

inversely with the water-cement ratio (see Figure 7-5). A good rule of thumb is that each 1% increase in air content is accompanied by 5% to 6% reduction in strength. More information on the impact of air content on fresh and hardened properties of concrete can be found in Chapter 9.

Water-Reducing Admixtures

A water-reducing admixture is an admixture that increases workability without increasing the water content of concrete, or that permits a decrease in water content without decreasing the slump and conforms to ASTM C494, *Standard Specification for Chemical Admixtures for Concrete* (AASHTO M 194). Some water-reducing admixtures, typically high-range, are also plasticizers conforming to ASTM C1017, *Standard Specification for Chemical Admixtures for Use in Producing Flowing Concrete* (AASHTO M 194).

When used as a water-reducer, the water content is reduced while maintaining the slump; this reduces the water-cement ratio of the concrete and increases its strength and durability. When the same chemical is used as a plasticizer, the workability is increased while the water content is kept constant. This can improve the placing characteristics of the concrete without adversely affecting the strength and durability.

If the flow is maintained, the water content can be reduced. The conditions are ideal for the strength and durability of concrete. Here the admixture is used as a true water-reducer; allowing concrete to be produced with low water-to-cement ratios and good workability. Advantage

may be taken for both purposes of a water-reducing admixture when designing concrete; producing concrete with improved fresh and hardened properties (Figure 7-6) (see Chapter 12).

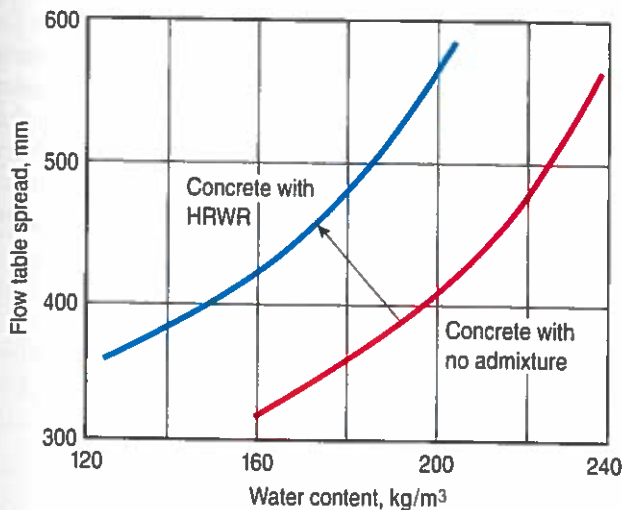


Figure 7-6. Advantage may be taken for both purposes of a water-reducing admixture (lowering w/cm, and increasing flow) when designing concrete. (Adapted from Neville 1995)

Normal (Conventional) Water Reducers

When used as a water reducer, normal range, or conventional water reducers can reduce the water content by approximately 5% to 10%. Alternatively, they may be used as plasticizers to provide a moderate increase in workability. Normal water reducers are intended for concretes with slumps up to 100 mm or 125 mm (4 in. or 5 in.), but they are also used in combination with mid-range and high-range water reducers in higher slump concrete mixtures.

Mid-Range Water Reducers

Mid-range water reducers were first introduced in 1984 to bridge the gap between normal range water reducers and high-range water reducers (superplasticizers). These admixtures provide significant water reduction (between 6% and 12%) for concretes with slumps of 125 mm to 200 mm (5 in. to 8 in.) without the retardation associated with high dosages of conventional (normal) water reducers. Mid-range water reducers can be used to reduce stickiness and improve finishability, pumpability, and placeability of concretes containing silica fume and other supplementary cementing materials. Some can also entrain air and be used in low slump concretes (Nmai, Schlagbaum, and Violetta 1998).

High-Range Water Reducers

High-range water reducers, ASTM C494 (AASHTO M 194) Types F (water reducing) and G (water reducing and retarding), can be used to impart properties induced

by regular water reducers, only much more efficiently. They can greatly reduce water demand and cement contents and make low water-cement ratio, high-strength concrete with normal or enhanced workability and to generate slumps greater than 150 mm (6 in.). A water reduction of 12% to 40% can be obtained using these admixtures. The reduced water content and water-cement ratio can produce concretes with: (1) ultimate compressive strengths in excess of 70 MPa (10,000 psi), (2) increased early strength gain, (3) reduced chloride-ion penetration, and (4) other beneficial properties associated with low water-cement ratio concrete.



Figure 7-7. High-range water reducers, also known as superplasticizers, produce flowing concrete with slumps greater than 150 mm (6 in.).

When the same chemicals used for high-range water reducers are used to make flowing concrete, they are often called plasticizers or superplasticizers meeting ASTM C1017. This specification has provisions for two types of admixtures: Type 1 – plasticizing, and Type 2 – plasticizing and retarding. These admixtures are added to concrete with a low-to-normal slump and water-cement ratio to make high-slump flowing concrete (Figures 7-6 and 7-7). Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction while still remaining essentially free of excessive bleeding or segregation. Applications where flowing concrete is used include: (1) thin-section placements (Figure 7-8), (2) areas of closely spaced and congested reinforcing steel (Figure 7-9), (3) tremie pipe (underwater) placements, (4) pumped concrete to reduce pump pressure, thereby increasing lift and distance capacity, (5) areas where conventional consolidation methods are impractical or can not be used, and (6) for reducing handling costs. The addition of a plasticizer to a 75-mm (3-in.) slump concrete can easily produce a concrete with a 230-mm (9-in.) slump. Flowing concrete is defined by ASTM C1017 as a concrete having a slump greater than 190 mm (7.5 in.), yet maintaining cohesive properties.