

Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete

Reported by ACI Committee 212

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High-range water-reducing admixtures can increase the strength of concrete and provide greatly increased workability without adding more water. Consequently, the use of high-range water-reducing admixtures is increasing substantially in the concrete industry. This guide contains information on the effects of these admixtures on the properties of fresh and hardened concrete, the uses of concrete, and the quality control of the concrete. This guide is designed for concrete suppliers, contractors, designers, specifiers, and all others engaged in concrete construction.

Keywords: admixture; batch; consolidation; high-range water-reducing admixture; mixture; mixture proportion; plasticizer; portland cement; quality control; water-reducing admixture; workability.

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CHAPTER 1—GENERAL INFORMATION

1.1—Introduction

Since the late 1970s, use of a new class of chemical admixture has increased substantially in various segments of the concrete industry. These admixtures are used to significantly increase slump without adding more water or to substantially reduce water content without a loss in slump. Often referred to as a superplasticizer, this material is properly categorized as a high-range water-reducing admixture (HRWRA) meeting the requirements of ASTM C 494 Type F or G or ASTM C 1017 Type I or II. To be categorized as a HRWRA under the requirements of ASTM C 494, the admixture must be capable of reducing the water requirement by at least 12%. As originally marketed in Germany and Japan in the late 1960s, HRWRA consisted primarily of sulfonated condensation products of naphthalene or melamine. In the early 1980s, work began on the development of polyacrylate-based HRWRAs (Bradley and Howarth 1986). These materials and other polycarboxylates have now begun to find practical applications in the field (Okazawa, Umezawa, and Tanaka 1993; Tanaka and Okazawa 1993; Nmai, Schlagbaum, and Violetta 1998; Jeknavorian et al. 1997; Jeknavorian 1998).

Much information on the properties and uses of HRWRAs was published during the period of their introduction and use in the U.S. market. The literature included six ACI special publications based on proceedings of international symposia (SP-62; SP-68; SP-119; SP-148; SP-173; SP-195), a Transportation Research Record (Transportation Research Board 1979), and publications by the Portland Cement Association

(Whiting 1979), CANMET (Malhotra 1977, 1979), and the Cement and Concrete Association (1976). Textbooks on concrete admixtures (Ramachandran and Malhotra 1995; Rixom and Mailvaganam 1999) also contain considerable information on HRWRAs.

In the early years, problems in using the admixture in concrete, such as a higher-than-normal rate of slump loss, leading to the need for job-site addition of the material, limited the use of HRWRAs. Under laboratory conditions, Mather (1978) reported a lowered resistance to freezing and thawing. Eventually under laboratory and field conditions, concrete containing HRWRAs proved to be at least as durable as conventional concrete (refer to Section 4.6); however, rapid slump loss was a problem in some concrete mixtures. This concern led to the development of new products aimed at maintaining workability for longer periods of time.

Extended-life HRWRAs were developed in the 1980s, which imparted up to 2 h longer working life to concrete, depending on mixture ingredients and environmental conditions. This allowed adding HRWRAs at the batch plant rather than at the job site, reducing wear on truck mixers, and lessening the need for ancillary equipment such as truck-mounted admixture tanks and dispensers. The result was an increase in the use of HRWRAs in almost all areas of the concrete industry.

1.2—Specifications

Two ASTM specifications include coverage of HRWRAs. ASTM C 494 is normally cited when HRWRAs are used to produce conventional-slump concrete at reduced water content. ASTM C 494 describes two types: Type F, used when high-range water reduction is desired within normal setting times; and Type G, used when high-range water reduction is required with a retarded setting time.

When flowing concrete is desired, HRWRAs are generally specified to conform to the second document, ASTM C 1017. Flowing concrete is defined by ASTM C 1017 as “concrete that is characterized by a slump greater than 7-1/2 in. (190 mm) while maintaining a cohesive nature.” ASTM C 1017 describes two types: Type I is used when flowing concrete is desired with normal setting times, and Type II is used when flowing concrete is required with a retarded setting time. Many HRWRAs conform to both ASTM C 494 and ASTM C 1017, and ACI 318 and ACI 301 require HRWRAs to conform to these ASTM standards, as applicable.

CHAPTER 2—EFFECTS OF HIGH-RANGE WATER-REDUCING ADMIXTURES

2.1—General effects

HRWRAs can be used in concrete to increase slump, increase strength by decreasing water content and the resultant water-cementitious material ratio (w/cm), or to decrease water and cement content, thus reducing temperature rise and volume change (refer to Section 4.5). All these results are attainable in a wide variety of concrete mixtures. HRWRAs are one of the essential materials in the production and use of high-performance concrete (ACI 1993). High-performance concrete as defined by ACI 308R-94 is concrete that meets special

combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing, and curing practices). HRWRAs improve the fresh and hardened physical properties of concrete, increase the efficiency of construction, and help to achieve specific design objectives (refer to Section 2.6). HRWRAs in dry form are also used in some high-performance grouts, mortars, and packaged concrete for similar reasons.

2.2—Mechanisms

The mode of action for naphthalene- or melamine-based HRWRA depends on surface chemistry. The mechanism involves adsorption of the anionic part of the admixture at the solid-water interface. The nonpolar backbone of the polymer is the end that adsorbs onto the cement surface, causing the highly charged hydrophilic end group to be thrust toward the solution. The net effect is an increased negative charge on the cement grain. Consequently, these fine cement grains repel one another (electrostatic repulsion), thus requiring less water for a given degree of concrete workability. Without HRWRAs, these fine grains tend to flocculate due to the attraction of opposite charges adjacent to different particle surfaces. Polycarboxylate HRWRAs provide significantly improved cement dispersion over naphthalene- or melamine-based HRWRAs due to their dual mechanism of electrostatic and steric repulsion. In addition to electrostatic repulsion, side chains of varying lengths, which are formulated to be a part of the backbone of the molecule, physically help keep the cement particles apart allowing water to surround more surface area of the cement particles (steric hindrance) (Ohta, Sugiyama, and Tanaka 1997; Flatt et al. 2000; Burge 2000).

2.3—Fresh concrete properties

Chapter 3 covers the effects of HRWRAs on fresh concrete in detail. In general, however, concrete slump is increased when HRWRAs are added to concrete mixtures and no other changes are made in the mixture proportions (Fig. 2.1 and 2.2). The degree of slump increase can be varied, depending on the performance requirements of the concrete required for various applications. For example, flowing concrete can be proportioned with a slump capable of attaining a level surface with little consolidation effort from the placer (Fig. 2.3). Flowing concrete should be adequately consolidated, with or without vibration, in accordance with ACI 309R.

High-slump or flowing concrete can offer an advantage in the ready-mixed, precast, and prestressed concrete industries. The concrete's ability to flow easily is especially beneficial in applications involving areas of congested reinforcing steel, special form linings, or treatments where the embedments obstruct concrete placement (Fig. 2.4). The flowing characteristic is also advantageous for filling deep forms because the flowability facilitates consolidation around the reinforcing or prestressing steel. Flowing concrete, when placed rapidly, can increase the pressure on formwork. Therefore, the formwork may require additional strengthening (ACI 347). Flowing concrete is used in



Fig. 2.1—Initial concrete slump before the addition of HRWRA.



Fig. 2.2—Slump after the addition of HRWRA.

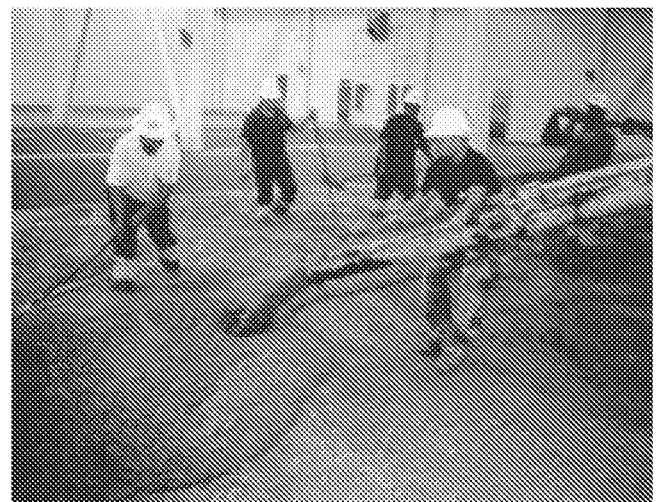


Fig. 2.3—Flowing concrete produced with HRWRA.

flatwork and foundations where it can improve the rate of placement. In general, flowing concrete can reduce costs of placing, consolidation, and finishing of concrete in flatwork and foundations (Zurbrugg and Henry 1982).

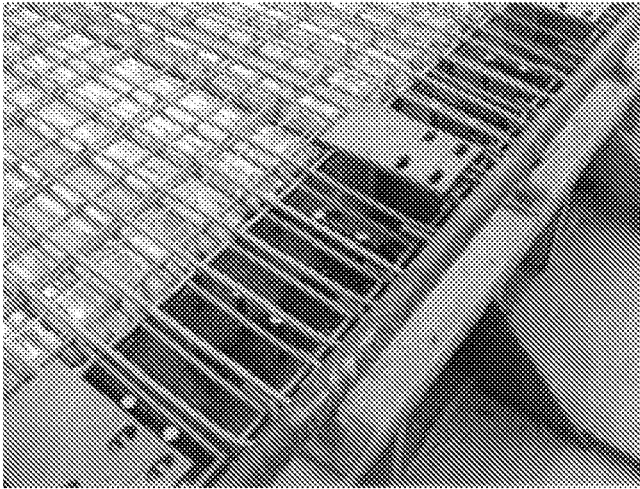


Fig. 2.4—Reinforcing steel and embedments.

2.4—Hardened concrete properties

Chapter 4 covers the effects of HRWRAs on hardened concrete in detail. In general, however, HRWRAs can be used to reduce the water content of concrete, thus decreasing the w/cm , which decreases paste porosity and increases strength. High-strength concrete is used in many applications, among them high-rise commercial buildings, high-strength prestressed beams and slabs, impact-resistant structures, and offshore structures. A low w/cm is also beneficial in specialty concretes, including the following:

- Low-permeability concrete mixtures used for bridge deck overlays;
- Silica-fume concrete used to obtain very low-permeability and very high-strength concrete in structures, such as parking garages, where they protect reinforcing steel from corrosive deicing agents; and
- Various grouts and prepackaged concretes used for repair and rehabilitation.

Due to the dispersing effect of HRWRAs, more cement surface area is available for hydration, therefore increasing cement efficiency (Bury and Christensen 2002). Increased cement efficiency results in higher strength at all ages at the same cement and water content.

The rate of strength development in flowing concrete containing a HRWRA is equal to or greater than that of low-slump concrete, assuming the same w/cm in each mixture. Flowing concrete mixtures are proportioned to fulfill both conventional strength and high-strength (6000 psi [41 MPa] and greater) requirements (Nmai and Violetta 1996). Applications requiring workable high-strength concrete with low water content include structural elements that are either thin or congested with steel, conduit, pipe sleeves, other embedded items, and boxouts (ACI 309R).

In addition to reaching high ultimate strength, concrete with a HRWRA and reduced w/cm exhibits strength greater than normal-strength concrete at all ages. This characteristic is desirable in precasting operations where early form stripping is needed.

HRWRAs can reduce both water and cement contents, permitting the use of less cement without reducing strength. Cost savings from the reduced cement content depends on the relative prices of cement and HRWRA. In most cases, the direct economic benefits from cement reductions are minor, although the indirect benefits to the contractor or owner, through paste reduction, may be significant. For example, an application may need lower heat rise or drying shrinkage (refer to Sections 4.4 and 4.5) without changing the slump or w/cm and, therefore, strength. Such concrete is desirable for use in massive sections because of its reduced tendency to crack when it cools and dries.

2.5—Increase in the efficiency of construction

When HRWRAs are used to increase slump, reduce w/cm , or both, four general benefits to the concrete construction process may occur:

- *Increased productivity*—faster placing, finishing, and stripping of forms;
- *Reduced equipment costs*—increased use of forms, reduced pump pressures, faster turnaround time of concrete trucks, and reduced vibration;
- *Reduced materials costs*—reduction in cement content or use of regular cement instead of high-early cement, and use of more commonly available and less-expensive cementitious material; and
- *Improved quality*—increased certainty that concrete will meet the design specifications for strength, durability, dimensional tolerance by reducing volume change, and appearance.

2.6—Enhanced design and engineering of concrete structures

Engineers and architects use high-performance concrete, often made possible by the application of HRWRAs, to achieve specific design objectives: longer spans, smaller columns, more usable space, flatter slabs, thinner sections, reduced maintenance, longer service life, improved appearance, and architectural flexibility.

CHAPTER 3—EFFECTS ON FRESHLY MIXED CONCRETE

3.1—General

The addition of HRWRA to concrete has many potentially beneficial effects on freshly mixed concrete, such as higher slump without additional water, lower w/cm at equivalent slumps, and improved workability and pumpability. Job-site problems that may occur include rapid slump loss, increased time of setting, segregation, or bleeding. Early identification of these problems is accomplished by field trial batches. These problems can then be avoided by field trial batches that will reflect job-site conditions more accurately than laboratory testing, allowing potential problems to be corrected before concrete is used on the project.

3.2—Water reduction

HRWRAs are often used to reduce the water content of concrete while maintaining the same slump. HRWRAs should be capable of reducing the water requirement by at