ACI 212.4R-04

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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ACI 212.4R-04 supersedes ACI 212.4R-93 and became effective September 9, 2004.

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 116R defines high-performance concrete as concrete meeting 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

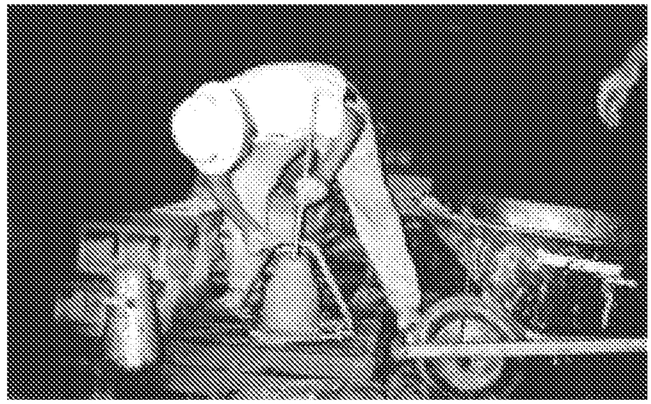

Fig. 2.1—Initial concrete slump before the addition of HRWRA.

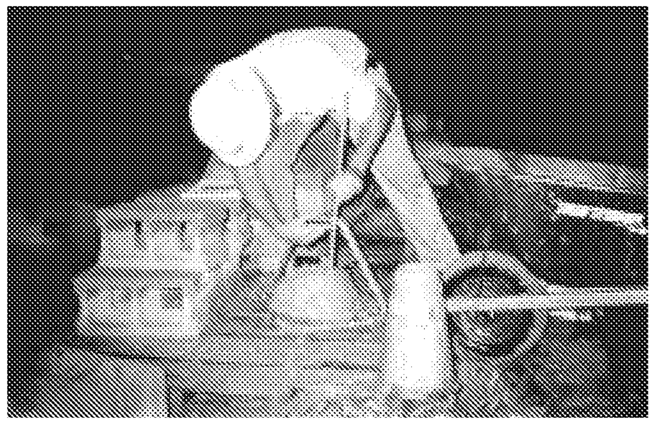

Fig. 2.2—Slump after the addition of HRWRA.

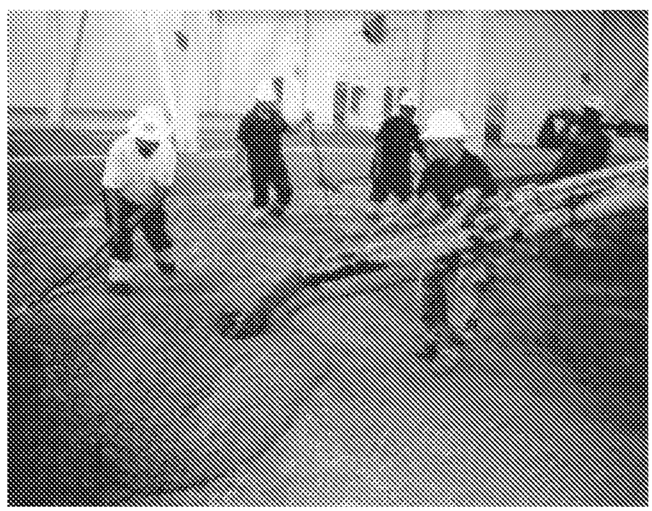

Fig. 2.3—Flowing concrete produced with HRWRA.

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