Report on Chemical Admixtures for Concrete

Reported by ACI Committee 212

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This report reviews several categories and types of chemical admixtures and their use in unique concrete technologies. They are classified into 12 groups: air-entraining; normal, mid- and high-range water-reducing; accelerating; set-retarding; extended set-control; workability-retaining; viscosity- and rheology-modifying, shrinkage-reducing and shrinkage-compensating, and corrosion-inhibiting; lithium admixtures to reduce deleterious alkali-silica reaction; permeability-reducing; and miscellaneous.

Chemical admixtures are used on a daily basis in the cast-in-place and precast concrete industries. Mixture designs using multiple chemical admixtures are more common today. Their successful use requires compatibility, setting times, and early strengths that are appropriate to the placing environment.

Each category of admixture addresses common use and the potential benefits of a properly proportioned concrete mixture to various professionals, including the concrete contractor, concrete producer, and design professional. The sustainability of chemical admixtures and their role in sustainable construction is addressed. Finely divided mineral admixtures, such as fly ash or raw and processed natural pozzolans, are addressed in ACI 232.2R and ACI 232.1R, respectively.

Keywords: accelerating; admixture(s); admixture system; air-entraining; alkali-aggregate reaction; batching order; cold weather concrete; corrosion-inhibiting; extended set control; flowing concrete; high-range water-reducing admixture; mid-range water-reducing admixture; permeability-reducing admixtures; pervious concrete; self-consolidating concrete; set-retarding; rheology-modifying; shrinkage-reducing; water-reducing; viscosity-modifying; workability-retaining.

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CHAPTER 1—INTRODUCTION

1.1—Introduction

Chemical admixtures are primarily water-soluble substances used to modify the properties of concrete, mortar, or grout in the plastic state, hardened state, or both. The effects include increased compressive and flexural strength at all ages, decreased permeability and improved durability, corrosion reduction, shrinkage reduction, initial set adjustments, extended set control, increased slump and workability, improved pumpability, finish and finishability, rheology modification, improved cement efficiency, alkali-silica reaction (ASR) reduction, and concrete mixture economy.

An admixture or combination of admixtures may be required to achieve the specific desired results. Proper mixture proportions, however, are required for optimum benefits. In some cases, a desired objective is best achieved by mixture changes in addition to proper admixture usage. Chemical admixtures are not a substitute for suitable concrete mixture proportions and acceptable construction practices.

1.2—Scope

This report deals with state-of-the-art and commonly used admixtures. Materials such as supplementary cementitious materials that are used to produce concrete are only referred to in regards to their interaction with chemical admixtures.

Chapters 1 through 4 address topics that typically apply to all admixtures, Chapters 5 through 16 categorize chemical admixtures generically or with respect to their performance characteristics, and Chapters 17 through 21 provide information on the use of multiple combinations of admixtures in the production of some unique concretes. Information characterizing each category is presented with brief statements of the general purposes and expected effects for each group of materials. The wide scope of admixture technology, the continued entrance of new or modified materials, and the variations of effects with different concreting materials and conditions preclude a complete listing of all admixtures and their effects on concrete. Table 1.2 lists the admixture types addressed in this document and summarizes their effects and benefits in concrete, and typical materials used in their manufacture.

Table 1.2—Admixtures, their characteristics, and usage

Admixture type (Chapter number)	Effects and benefits	Materials
(5) Air-entraining (ASTM C260/C260M; AASHTO M 154M/M 154)	Improve durability in freezing and thawing, deicer, sulfate, and alkali-reactive environments. Improve workability.	Salts of wood resins, some synthetic detergents, salts of sulfonated lignin, salts of petroleum acids, salts of proteinaceous material, fatty and resinous acids and their salts, tall oils and gum rosin salts, alkylbenzene sulfonates, and salts of sulfonated hydrocarbons.
(6) Water-reducing (ASTM C494/C494M; AASHTO M 194M/M 194, Type A)	Reduce water content at least 5 percent.	Lignosulfonic acids and their salts. Hydroxylated carboxylic acids and their salts. Polysaccharides, melamine polycondensation products, naphthalene polycondensation products, and polycarboxylates.
(6) Mid-range water-reducing (ASTM C494/C494M, Type A)	Reduce water content by between 5 and 10 percent without retardation of initial set.	Lignosulfonic acids and their salts. Polycarboxylates.
(6) High-range water-reducing (ASTM C494/C494M; AASHTO M 194M/M 194, Type F or G)	Reduce water content by at least 12 to 40 percent, increase slump, decrease placing time, increase flowability of concrete; used in self-consolidating concrete (SCC).	Melamine sulfonate polycondensation products, naphthalene sulfonate polycondensation products, and polycarboxylates.
(7) Accelerating (ASTM C494/C494M; AASHTO M 194M/M 194, Type C or E)	Accelerate setting and early strength development.	Calcium chloride (ASTM D98; AASHTO M 144), triethanolamine, sodium thiocyanate, sodium/calcium formate, sodium/calcium nitrite, calcium nitrate, aluminates, and silicates.
(8) Set-retarding (ASTM C494/ C494M and AASHTO M 194M/M 194, Type D)	Reduce water content at least 5 percent. Delay set time.	Refer to water-reducing materials.
(9) Extended set-controllling (hydration control) (ASTM C494/C494M, Type B or D)	Used to stop or severely retard the cement hydration process. Often used in wash water and in returned concrete for reuse, and can provide medium- to long-term set retardation for long hauls. Retain slump life in a more consistent manner than normal retarding admixtures.	Carboxylic acids. Phosphorus-containing organic acid salts.
(10) Workability retaining	Provide workability (slump) retention when used in combination with normal-, mid-, or high-range water reducer with no effect on initial slump, set time, or strength gain	Dispersants such as polycarboxylates.
(11) Viscosity- and rheology-modifying	Modify the rheological properties of plastic concrete.	Polyethylene oxides, cellulose ethers (HEC and HPMC), alginates (from seaweed), natural and synthetic gums, and polyacrylamides or polyvinyl alcohol.
(12) Shrinkage-reducing and shrinkage-compensating	Reduce drying shrinkage. Reductions of 30 to 50 percent can be achieved.	Polyoxyalkylene alkyl ether, propylene glycol, calcium sulfoaluminate, calcium-aluminate, calcium hydroxide- or magnesium oxide-based systems
(13) Corrosion-inhibiting (ASTM C1582/C1582M)	Significantly reduce the rate of steel corrosion and extend the time for onset of corrosion.	Amine carboxylates aminoester organic emulsion, calcium nitrite, and organic alkyidicarboxylic. Chromates, phosphates, hypophosphites, alkalis, and fluorides.
(14) Lithium admixtures to reduce deleterious expansions from alkali-silica reaction	Minimize deleterious expansions from alkali-silica reaction.	Lithium nitrate, lithium carbonate, lithium hydroxide, and lithium nitrite.
(15a) Permeability-reducing admixture: non-hydrostatic conditions (PRAN)	Water-repellent surface, reduced water absorption.	Long-chain fatty acid derivatives (stearic, oleic, caprylic capric), soaps and oils (tallows, soya-based), petroleum derivatives (mineral oil, paraffin, bitumen emulsions), and fine particle fillers (silicates, bentonite, talc).
(15b) Permeability-reducing admixture: hydrostatic conditions (PRAH)	Reduced permeability, increased resistance to water penetration under pressure.	Crystalline hydrophilic polymers (latex, water-soluble, or liquid polymer).
(16) Miscellaneous admixtures:		
(16a) Bonding	Increase bond strength.	Polyvinyl chloride, polyvinyl acetate, acrylics, and butadiene-styrene copolymers.
(16b) Coloring	Colored concrete.	Carbon black, iron oxide, phthalocyanine, raw burnt umber, chromium oxide, and titanium dioxide.
(16c) Flocculating	Increase interparticle attraction to allow paste to behave as one large flock.	Vinyl acetate-maleic anhydride copolymer.
(16d) Fungicidal, cermicidal, insecticidal	Inhibit or control bacterial, fungal, and insecticidal growth.	Polyhalogenated phenols, emulsion, and copper compounds.
(16e) Air-detraining	Reduce air in concrete mixtures, cement slurries, and other cementing applications.	Tributyl phosphate, dibutyl phosphate, dibutylphthalate, polydimethylsiloxane, dodecyl (lauryl) alcohol, octyl alcohol, polypropylene glycols, water-soluble esters of carbonic and boric acids, and lower sulfonate oils.
(16f) Expansive/gas forming	Control settlement and bleeding and improve the intrusion of grout and mortars.	Metallic aluminum, zinc or magnesium, hydrogen peroxide, nitrogen and ammonium compounds, and certain forms of activated carbon or fluidized coke.
(16g) Cellular	Air-generating admixtures for the production of flowable fill, lightweight concrete, insulation.	Protein and other synthetic surfactants.
(16h) Shotcrete	Shotcrete accelerators for wet and dry mixture applications.	Alkali-based and alkali-free materials.
(16i) MCP	Production efficiency, surface texture and strength.	Plasticizers such as soaps, surfactants, lubricants, and cement dispersants, accelerators both calcium chloride and non-chloride based, and water-repellent/efflorescence control admixtures such as calcium/ aluminum stearates, fatty acids, silicone emulsions, and wax emulsions.

CHAPTER 2—DEFINITIONS

2.1—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," https://www.concrete.org/store/productdetail.aspx?ItemID=CT13. Definitions provided herein complement that source.

alkali-silica reaction—generally deleterious dissolution and swelling of siliceous aggregates in the presence of pore solutions comprised of alkali hydroxides; the reaction products may cause abnormal expansion and cracking of concrete.

corrosion inhibitor—chemical compound, either liquid or powder, usually intermixed in concrete that either extends the time to corrosion initiation or significantly reduces the corrosion rate of embedded metal, or both, in concrete containing chlorides in excess of the accepted corrosion threshold value for the metal in untreated concrete

durability—ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.

rheology—science dealing with deformation and flow of materials.

slump flow—measure of the unconfined flow potential of a freshly mixed self-consolidating concrete or grout; value is equal to the average of two perpendicular diameters of the material measured to the nearest 1/2 in. (12.5 mm) after it is released from the slump cone and stops flowing.

water repellent—admixture that produces concrete that is resistant, but not impervious, to penetration by water.

yield stress—critical shear stress value below which a viscoplastic material will not flow and, once exceeded, flows like a viscous liquid.

CHAPTER 3—GENERAL

3.1—Admixture benefits

Chemical admixtures are used singularly or in combination to modify particular properties of concrete or mortar in the plastic state, hardened state, or both. Types and dosages are selected in accordance with climatic conditions for maintaining workability and pumpability, water-cementitious materials ratio (*w/cm*), air content, setting time, and early and final strengths. Proposed mixtures and admixture choices are often confirmed with successful test placements on site.

3.1.1 *Modification of fresh concrete, mortar, and grout*—Admixtures are used to modify and improve properties of fresh concrete, mortar, and grout. Examples are:

a) Increase the workability without increasing the water content, or decrease the water content without changing the workability
b) Increase the slump or slump flow without increasing the water content
c) Retard or accelerate the time of initial setting
d) Reduce or prevent settlement
e) Modify bleeding characteristics
f) Reduce segregation
g) Improve finishability
h) Improve pumpability
i) Modify rheological properties
j) Reduce the rate of slump loss
k) Increase placement rate

3.1.2 *Modification of hardened concrete, mortar, and grout*—Admixtures are used to modify properties of hardened concrete, mortar, and grout. Examples are:

a) Reduce the rate of heat evolution during early cement hydration
b) Accelerate the rate of strength development at early ages
c) Increase strength (compressive, tensile, or flexural)
d) Increase resistance to freezing and thawing
e) Reduce scaling caused by deicing salts
f) Decrease permeability and improve durability
g) Reduce expansion caused by alkali-aggregate reaction
h) Increase bond to steel reinforcement and between existing and new concrete
i) Improve impact resistance and abrasion resistance
j) Inhibit corrosion of embedded metal
k) Produce colored concrete or mortar
l) Reduce drying shrinkage and curling

3.2—Specifications for admixtures

The following standard specifications cover the admixture types that make up the bulk of products covered in this report:

a) Air-entraining admixtures: ASTM C260/C260M and AASHTO M 154M/M 154
b) Water-reducing and set-controlling admixtures: ASTM C494/C494M and AASHTO M 194M/M 194
c) Calcium chloride: ASTM D98 and AASHTO M 144
d) Corrosion-inhibiting admixtures: ASTM C1582/C1582M
e) Admixtures for use in producing flowing concrete: ASTM C1017/C1017M
f) Pigments for integrally colored concrete: ASTM C979/C979M

ASTM C494/C494M includes a Type S specialty admixture designation that includes admixtures not covered by other ASTM standards. Results obtained from tests done in accordance with ASTM C494/C494M ensures these products give values that match within limits those of the untreated reference concrete and meet standard requirements.

3.3—Sampling and testing

Admixture samples for testing and evaluation should be obtained by the procedures prescribed for each admixture's specifications using random sampling from plant production, previously unopened packages or containers, or fresh bulk shipments.

Admixtures are tested to determine compliance with specifications; evaluate effects on the properties of concrete made with materials under the anticipated ambient conditions and construction procedures; determine uniformity of the product within or between batches, lots, or containers; or reveal any undesirable effects. The quality-control procedures used by producers of admixtures should ensure product compliance with provisions from ASTM or other applicable specifications, including uniformity. Because a producer's quality-control test methods could be developed around a particular proprietary product, they may not be applicable for general use.

ASTM provides procedures for testing concrete containing admixtures. Producing concrete should be preceded by testing that allows observation and measurement of the performance of the admixture under concrete plant operating conditions in combination with the constituent materials that will be used. Uniformity of results is as important as the average result, with respect to each significant property of the admixture or the concrete.

3.4—Cost effectiveness

Economic evaluation of an admixture should be based on the test results obtained when used with the specified concrete under conditions simulating those expected on the jobsite. Characteristics of the cementitious materials and aggregate; their relative proportions; and the temperature, humidity, and curing conditions influence test results. When evaluating an admixture, its effect on the volume of a given batch should be considered. The concrete mixture should yield 27 cubic feet per yard (1 cubic meter), including the volume increase as a result of admixture behavior. All changes in the composition of a unit volume of concrete should be considered when testing the direct effect of the admixture and when estimating its benefits.

The cost effectiveness of an admixture should be based on the cost of the concrete in place, rather than the cost of the concrete alone. The cost in place, which includes transporting, placing, and finishing costs, is of greatest interest to the owner. The admixture benefits can allow the use of less-expensive construction methods or allow structural designs that offset the added cost due to its use. For example, novel and economical structural designs have resulted from the use of high-range water-reducing admixtures (HRWRAs). They are essential ingredients of cost-effective, high-performance concrete.

Water-reducing and set-retarding admixtures permit placement of large volumes of concrete over extended periods, minimizing the need for forming, placing, and joining separate units. Accelerating admixtures reduce finishing and forming costs. Air-entraining and water-reducing admixtures are typically used to meet the required physical properties of lightweight concrete (ACI 213R).

3.5—Selection and evaluation

Pay careful attention to the instructions and recommendations provided by the manufacturer of the admixture. An admixture's effects should be evaluated whenever possible using the specified materials under site conditions.

This is particularly important when:

a) The admixture has not been used previously with the particular combination of materials

b) Special types of cementitious materials are specified

c) More than one admixture is to be used

d) Mixing and placing is completed at temperatures outside recommended temperature ranges for concrete

The use of admixtures also requires a review of the concrete mixture design constituents. Prime concerns are:

a) Type and amount of cement

b) Type and amount of supplementary cementitious materials

c) Combined aggregate gradation, water, and air content

d) Climatic conditions

On-site testing of the proposed concrete mixture to verify proper workability, finishability, pumpability, and setting time is recommended.

Several admixtures affect more than one property of concrete. Rapid stiffening and significant retardation are not desirable. The cause of abnormal setting behavior should be determined through studies on compatibility of the admixtures and cementitious material to be used (ASTM C1679; Nkinamubanzi and Aïtcin 2004; Roberts and Taylor 2007; Taylor et al. 2006a,b, 2008). Early stiffening is often caused by changes in the reaction rate between the tricalcium aluminate and sulfate ions in solution in the pore fluid. Excessive retardation can be caused by an overdose of admixture or by a lowering of ambient temperature, both of which delay the hydration of the calcium silicates (Hansen 1960).

Another important consideration when using admixtures arises when there is a limit on the measurable amounts of chloride ions permitted in the concrete (ACI 318; ACI 222R). The chloride ion content of these admixtures will be limited by the chloride ions present in the water used for manufacturing. These limits are usually expressed as maximum percent of chloride ion by mass of cement, although the amount of water-soluble chloride ion per mass of cement or concrete is sometimes specified. The procedures of ASTM C1152/C1152M and ASTM C1218/C1218M can be used to measure acid-soluble and water-soluble chloride, respectively, in mortar or concrete. Be sure to know the chloride ion content of an admixture to ensure that its use will not cause the concrete to have a chloride ion content greater than specified. In spite of the misuse of such terms as chloride-free, all admixtures solutions will contain small but measurable amounts of chloride ions coming from municipal drinking water. The trace levels of chloride ions do not influence the risk of corrosion of embedded reinforcement in concrete.

Although specifications deal primarily with the influence of admixtures on specific properties of fresh and hardened concrete, the concrete supplier, contractor, and owner of the construction project may be interested in other features of concrete construction. Of primary concern are workability, pumpability, placing and finishing qualities, early strength development, reuse of forms or molds, or the appearance of formed surfaces. These additional features are important when an admixture is selected and its dosage rate is determined.

Guidance for using different categories of admixtures is given in this report. Those responsible for construction of concrete structures should bear in mind that increasing material costs and continuing development of new and improved admixtures warrant the continuous reevaluation of the benefits of using admixtures.

3.6—Proportioning and batching

The concrete mixture should be proportioned in accordance with ACI 211.1, ACI 211.2, or another method, and provide the specified qualities and characteristics as outlined by the purchaser, project specification, or both. The admix-