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SI

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Chemical Admixtures for Concrete

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Chemical Admixtures for Concrete

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American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
Phone: +1.248.848.3700
Fax: +1.248.848.3701

www.concrete.org

CHEMICAL ADMIXTURES FOR CONCRETE

Prepared under the direction and supervision of ACI Committee E701,
Materials for Concrete Construction

Mark R Lukkarila, Chair
Corina-Maria Aldea
Richard P. Bohan
David A. Burg

Jonathan Drury
Thomas M Greene
Clifford N. MacDonald
Charles K. Nmai

Shannon Pole
David M. Suchorski
Lawrence L. Sutter
Joseph E. Thomas

William L Thrasher
Kari L. Yuers*
Robert C. Zellers

*Chair of document subcommittee.

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This document discusses commonly used chemical admixtures for concrete. It is targeted to anyone who needs a basic understanding of the role, function, and benefits of chemical admixtures. This document is not intended to be a state-of-the-art report, user's guide, or a technical discussion of past and present research findings. More detailed information is available in ACI 212.3R.

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CHAPTER 1—INTRODUCTION

1.1—History

Admixtures have long been recognized as important components of concrete used to improve its performance. The original use of admixtures in cementitious mixtures is not well documented. It is believed that the introduction of some of these materials may have been part of rituals or other ceremonies. It is known that cement mixed with organic matter was applied as a surface coat for water resistance or tinting purposes. Materials used in early concrete and masonry included milk and lard by the Romans; eggs during the Middle Ages in Europe; polished glutinous rice paste, lacquer, tung oil, blackstrap molasses, and extracts from elm soaked in water and boiled bananas by the Chinese; and, in Mesoamerica and Peru, cactus juice and latex from rubber plants. The purpose of these materials is widely unknown. It is known that the Mayans used bark extracts and other substances as set retarders to keep stucco workable for a long period of time. More recently chemical admixtures have been used to help concrete producers meet sustainability requirements that are necessary for modern construction. For concrete, these requirements can be related to extended life cycles, use of recycled materials, stormwater management, and reduced energy usage. Chemical admixtures are used to facilitate the increased use of supplementary cementitious materials, lower permeability, and improve the long-term durability of concrete.

1.2—Definitions and Glossary

Concrete is composed principally of aggregates, hydraulic cement, and water, and may contain supplementary cementitious materials (SCMs), chemical admixtures, and other additives such as fibers. It will contain some amount of entrapped air and may also contain purposely entrained air obtained by use of a chemical admixture or air-entraining cement. Chemical admixtures are usually added to concrete as a specified volume in relation to the mass of portland cement or total cementitious material.

Admixtures interact with the hydrating cementitious system by physical and chemical actions, modifying one or more of the properties of concrete in the fresh or hardened states. The term “chemical admixture” is generally accepted to exclude SCMs (as described in ACI E-3) and fiber reinforcement (as described in ACI E-2). According to ACI 212.3R, an admixture or combination of admixtures may be the only feasible way to achieve the desired performance from a concrete mixture. There are many kinds of chemical admixtures that can function in a variety of ways to modify the chemical and physical properties of concrete. This bulletin provides information on the types of chemical admixtures and how they affect the properties of concrete, mortar, and grout. Definitions of certain types of admixtures and other selected terms can be found below and are taken from ACI Concrete Terminology (ACI CT).

admixture, accelerating—an admixture that causes an increase in the rate of hydration of the hydraulic cement, and thus, shortens the time of setting, increases the rate of

strength development, or both.

admixture, air-entraining—an admixture that causes the development of a system of microscopic air bubbles in concrete, mortar, or cement paste during mixing, usually to increase its workability and resistance to freezing and thawing.

admixture, high-range water-reducing—a water-reducing admixture capable of producing great water reduction, great flowability, or both, without causing undue set retardation or air entrainment in cementitious paste.

admixture, permeability-reducing—an admixture used to reduce the ingress of water and water borne chemicals into concrete. Admixtures may be further sub-divided into permeability-reducing admixtures for non-hydrostatic conditions (PRAN) or hydrostatic conditions (PRAH).

admixture, retarding—an admixture that causes a decrease in the rate of hydration of the hydraulic cement and lengthens the time of setting.

admixture, water-reducing—an admixture that either increases slump of a fresh cementitious mixture without increasing water content or maintains slump with a reduced amount of water, the effect being due to factors other than air entrainment.

aggregate, reactive—aggregate containing substances capable of reacting chemically with the products of solution or hydration of the portland cement in concrete or mortar under ordinary conditions of exposure, resulting in some cases in harmful expansion, cracking, or staining.

air, entrained—microscopic air bubbles intentionally incorporated in a cementitious paste during mixing, usually by use of a surface-active agent; typically between 0.0004 and 0.04 in. (10 and 1000 μm) in diameter and spherical or nearly so.

air, entrapped—air voids in concrete that are not purposely entrained and that are larger, mainly irregular in shape, and less useful than those of entrained air; and 0.04 in. (1 mm) or larger in size.

air content—the volume of air voids in cement paste, mortar, or concrete, exclusive of pore space in aggregate particles, usually expressed as a percentage of total volume of the paste, mortar, or concrete.

alkali—salts of alkali metals, principally sodium and potassium; occurring in constituents of concrete and mortar, usually expressed in chemical analysis as the oxides Na_2O and K_2O .

alkali-aggregate reaction—chemical reaction in either mortar or concrete between alkalies (sodium and potassium) from portland cement or other sources and certain constituents of some aggregates; under certain conditions, deleterious expansion of concrete or mortar may result.

alkali-carbonate reaction—the reaction between the alkalies (sodium and potassium) in portland cement and certain carbonate rocks, particularly calcitic dolomite and dolomitic limestones, present in some aggregates; the products of the reaction may cause abnormal expansion and cracking of concrete in service.

alkali silica reaction—the reaction between the alkalies (sodium and potassium) in portland cement and certain sili-

ceous rocks or minerals, forming a gel which can expand on absorption of water, resulting in cracking of the concrete.

calcium chloride—a crystalline solid, CaCl_2 ; in various technical grades, used as a drying agent, as an accelerator for fresh concrete, a deicing chemical, and for other purposes.

cement, portland—a hydraulic cement produced by pulverizing clinker formed by heating a mixture, usually of limestone and clay, to 2550 to 2900°F (1400 to 1600°C). Calcium sulfate is usually ground with the clinker to control set.

cementitious—having cementing properties.

chemical admixture—liquid, or dispersible powder, used as an ingredient in a cementitious mixture to improve its economy and/or properties in the plastic and/or hardened state.

sulfate attack—either a chemical or physical reaction or both between sulfates usually in soil or groundwater and concrete or mortar; the chemical reaction is primarily with calcium aluminate hydrates in the cement-paste matrix, often causing deterioration.

sulfate resistance—ability of concrete or mortar to withstand sulfate attack.

CHAPTER 2—OVERVIEW

2.1—Function

Chemical admixtures discussed in this document are available in liquid and powder form. Liquid admixtures are dispensed through mechanical dispensers as the concrete is batched, but can be introduced to the concrete by other means, such as hand dosing or truck mounted dispensers. Powders are usually introduced in prepackaged units that contain a prescribed amount, although bulk handling and dosing is sometimes available. Most times, the units consist of bags that can be opened and the contents added while mixing, or bags that are made to disintegrate and disperse their contents while mixing. Generally, admixtures in powdered form are introduced to the concrete after batching. A discussion of dispensing equipment for liquid admixtures is given in Chapter 6. The dosages used vary widely depending on several factors including, type of admixture, performance desired, environmental conditions, and many others. The uses of admixtures are outlined by the following functions that they perform:

- Increase workability without increasing water content or decrease the required water content at the same workability
- Retard or accelerate initial time of setting
- Reduce or prevent shrinkage or create slight expansion
- Modify the rate or capacity for bleeding
- Reduce segregation
- Improve pumpability
- Reduce rate of slump loss
- Retard or reduce heat evolution during early hardening
- Accelerate the rate of strength development at early ages
- Increase strength (compressive, tensile, or flexural)

- Increase durability or resistance to severe conditions of exposure, including application of deicing salts and other chemicals
- Decrease water permeability of concrete
- Control expansion caused by the reaction of alkalis with reactive aggregate constituents
- Increase bond of concrete to steel reinforcement
- Increase bond between existing and new concrete
- Improve impact, abrasion, and erosion resistance
- Inhibit corrosion of embedded metal
- Produce colored concrete or mortar
- Aid in achieving sustainability requirements

2.2—Effectiveness and compatibility

The effectiveness of any admixture will vary depending on its concentration in the concrete and the effect of the various other constituents of the concrete mixture. Each class of admixture is defined by its primary function. It may have one or more secondary functions, however, and its use may affect, positively or negatively, concrete properties other than those desired. Therefore, adequate testing should be performed to determine the effects of an admixture on the plastic properties of concrete such as slump, rate of slump loss (that is the relationship between slump and time), air content, and setting time. In addition, testing should be performed to determine the effect of the admixture on the hardened properties of concrete that may be of interest, for example, strength development, drying shrinkage, modulus of elasticity, or permeability. The final decision as to the use of any admixture and the brand, class, or type, depends on its ability to meet or enhance specific concrete performance needs.

Many improvements can be achieved by proper selection and application of specific admixtures. The selection process should focus on the functional qualities required by structural demands, architectural requirements, and contractor needs.

Whatever the approach, be it a single water-reducing admixture or a combination approach, the use of admixtures can be beneficial. Admixtures provide additional means of controlling the quality of concrete by modifying some of its properties, however, they cannot correct for poor-quality materials, improper proportioning of the concrete, and inappropriate placement procedures.

It is quite common for a concrete mixture to contain more than one admixture. In the simplest cases, such as paving or residential applications, a concrete mixture may be dosed with only a water-reducing admixture and an air-entraining admixture. High-performance concrete mixtures may be dosed with as many as five admixtures or more, depending on the specific application. Therefore, admixtures used in a given concrete mixture must be compatible to prevent undesired effects such as rapid slump loss, air-entrainment difficulties, severe set retardation, or improper strength development.

A typical rule of thumb is for all admixtures to be added separately to a concrete mixture and thoroughly mixed into the mixture. In addition, admixture manu-

facturers typically provide information on potential incompatibility with other admixture chemistries on product data sheets. However, incompatibility issues in concrete mixtures are typically due to undesired chemical interactions, physical interactions, or both, between chemical admixtures and other mixture ingredients, in particular, the cementitious materials system. Sulfate imbalance in the system is typically a contributing factor in such cases. In addition, certain types of clay that may be present on aggregate surfaces can also result in incompatibility issues. Therefore, preproject testing should be performed using materials proposed for use on a project to identify potential incompatibility issues prior to the start of a project. This testing requires knowledge of the rate of slump loss and the setting time under relatively hot and cold conditions (in addition to laboratory conditions). Concrete producers have used a number of means to determine the potential for incompatibility including calorimetry, other types of thermal measurements, laboratory concrete trials, and concrete plant trials. Test placements on-site are recommended to verify proper workability, finishability, and setting time of the proposed mixture.

CHAPTER 3—AIR-ENTRAINING ADMIXTURES

3.1—History

One of the most significant innovations in concrete technology was made during the 1930s. It was noted that certain concrete pavements were more able to withstand the detrimental effects of freezing and thawing cycles than others. These cycles, and the damage caused, were a major inhibitor to durability of concrete pavements and other exterior applications. Investigation showed that the more durable pavements were slightly less dense, and that the cement used had been obtained from mills using beef tallow as a grinding aid in the manufacturing of cement. The beef tallow acted as an air-entraining admixture, which improved the durability of the pavements. Later, after rigorous investigation, air-entrained concrete was specified in climates where freezing-and-thawing resistance was needed.

Air-entraining admixtures (AEA) are primarily used to stabilize tiny air bubbles in concrete that protect against damage from repeated freezing-and-thawing cycles. Until the mid-1990s, the most commonly used air-entraining admixture for concrete was a neutralized wood resin. Newer formulations may instead be formulated from synthetic detergents such as the salts of organic acids and sulfonated hydrocarbons. These modern formulations offer enhanced performance such as improved stability compared to early formulations. Today, most state departments of transportation (DOT) specifications have limits that require the use of an air-entraining admixture in pavements.

3.2—Mechanism

The space occupied by the mixing water in fresh concrete rarely becomes completely filled with cementitious hydration products after the concrete has hardened. The remaining spaces are capillary pores. Under saturated conditions, these cavities are filled with water. If this water freezes,

the resulting expansion of water to ice (approximately 9%) creates internal pressure in a confined space. This stress exceeds the tensile strength of concrete. The result in non-air-entrained concrete is cracking, scaling, and spalling.

Entrained air voids make the capillaries discontinuous. As a result of the mixing action, air-entraining admixtures stabilize air bubbles in the cement paste that become a component of the hardened concrete. The resultant air-void system consists of uniformly dispersed spherical voids that are between 0.0004 and 0.04 in. (10 and 1000 μm) in diameter, but in well air-entrained concrete, the majority are between 0.0004 and 0.004 in. (10 and 100 microns). Because the air voids are generally larger than the capillaries, they form tiny reservoirs that act as safety valves during ice expansion, accommodating the increased volume and preventing the build-up of internal pressure. Air entrainment in concrete is expressed as a percent of the overall concrete volume.

Entrained air should not be confused with entrapped air. Entrapped air is due to normal mixing and results in large, nonuniform air bubbles that do not have the correct size and spacing required to prevent damage in concrete caused by freezing water. Proper air entrainment, or air void structures, require the use of an admixture, either added to the plastic concrete or blended with the cement during manufacturing.

3.3—Use of air-entraining admixtures

Air-entraining admixtures should be required to conform to ASTM C260/C260M. Dosage rates of air-entraining admixtures generally range from 1/4 to 2 fl oz per 100 lb (15 to 130 mL per 100 kg) of cementitious material. Higher dosages are sometimes required depending on the materials, mixture proportions, and conditions. For example, concrete containing fly ash or other pozzolans often requires higher doses of air-entraining admixture to achieve the same air content compared to a similar concrete using only portland cement. Higher doses of air entrainer are also needed to maintain the desired air content as the concrete's temperature increases. Trial mixtures should be performed to ensure compatibility between air-entraining admixtures and other concrete components, including other chemical admixtures. Table 3.3 summarizes some of the factors that influence the entrained air content of fresh concrete.

3.4—Properties of entrained air

Entrained air must be present in the proper amount and have the proper size and spacing factor to provide protection from freezing and thawing. The term "spacing factor" represents the maximum distance that water would have to move before reaching an air void. For adequate protection in a water-saturated, freezing-and-thawing environment, it is generally accepted that the spacing factor should not be greater than 0.008 in. (0.2 mm).

Another factor that must be considered is the size of the air voids. For a given air content, the air voids cannot be too large if the proper spacing factor is to be achieved without using an unacceptable amount of air. The term "specific surface" is used to indicate the average size of the air voids. It represents the surface area of the air voids in concrete per unit volume of