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USE OF WATER-REDUCING, RETARDING AND WATER REDUCING AND RETARDING ADMIXTURES IN HIGHWAY CONCRETE

Introduction

This report covers use in highway concrete of chemical admixtures defined as water-reducers, retarders, and water-reducing retarders in and complying with the requirements of the Specifications for Chemical Admixtures for Concrete, ASTM Designation: C 494 (1)* as follows:

Water-reducing admixture - An admixture that reduces the quantity of mixing water required to produce concrete of a given consistency. (ASTM type A)

Retarding admixture - An admixture that retards the setting of concrete. (ASTM Type B)

Water-reducing and retarding admixture - An admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and retards setting of concrete. (ASTM Type D)

Use of accelerating admixtures (admixtures of Types C and E in ASTM Specification C 494) is covered by another Highway Research Board report, Highway Research Circular No. 6, July 1965.

A report on this subject is timely and worthwhile because of the increasing use of admixtures for water reduction and retardation of setting in concrete for highway pavements and structures. It is estimated that water-reducing and set retarding admixtures have been used in some 400 million cubic yards of all types of concrete in the United States and Canada, and are being employed presently in 50-60 million cubic yards of concrete per year in these countries.

Water-reducing, retarding and water-reducing and retarding admixtures are used to modify the properties of fresh and hardened concrete, such as to increase fluidity and working qualities of a given mixture without increase

* Numbers in parentheses refer to appended List of References

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in water content, delay setting, increase strength, or decrease the cost of the concrete and concreting operations. Use of admixtures does not minimize the need for proper proportioning of the concrete, proper control and inspection practices, and good workmanship. Before its use in construction, an admixture should be tested in concrete, preferably containing cement and aggregates proposed for use in the work, under conditions simulating those anticipated on the job. Attention should be given to the instructions and recommendations of the manufacturer of any admixture product considered for use, especially with respect to its preparation for use and rate of use.

In addition to the selected references, the reader is directed to the comprehensive Annotated Bibliography published by Highway Research Board.[2] This bibliography lists 86 papers and reports that provide original data and information on the properties, effects, and use of these materials in concrete.

Classification

Materials that are readily available for use as water-reducing or water-reducing and retarding admixtures Types A and D of ASTM Specification C 494 may be classified chemically into five classes, as follows:

1. Lignosulfonic acids and their salts,

2. Modifications and derivatives of lignosulfonic acids and their salts,

3. Hydroxylated carboxylic acids and their salts,

4. Modifications and derivatives of hydroxylated carboxylic acids and their salts,

5. Carbohydrates and modifications and derivatives thereof.

The common constituents of Classes 1 and 2 are calcium, sodium, or ammonium salts of lignin sulfonates produced during the sulfite process of wood pulping. Lignosulfonates produced from lignin by the Kraft (alkaline) process of paper manufacture constitute a very small proportion of admixture products for concrete. In general, the effluent from the wood pulping operation is not suitable for use in concrete; the raw sulfite liquor solids must be refined to produce a uniform product containing a minimum of impurities. For example, raw lignonsulfonates contain varying proportions of wood sugars; the content of such sugars should be reduced to small and uniform proportions during the processing of lignonsulfonates for use in concrete.

The essential constituents of admixtures of Classes 3 and 4 are sodium, calcium, or triethanolamine salts of such compounds as hydroxylated adipic acid and gluconic acid. Compounds of these classes can ben produced by fermentation or oxidation of carbohydrates like glucose, dextrose, and starch.

In Classes 2 and 4, these compounds are combined with organic or inorganic compounds which act as accelerators, retarders, catalysts, air-entraining agents, or possibly air-detraining agents to produce special effects in the performance of the admixtures.

Class 5, carbohydrates, such as sucrose (table sugar), glucose, and maltose, cause retardation of setting of portland cement and concrete when used alone. In general, carbohydrates must be used with caution because widely varying retardation can be obtained with relatively small changes in rate of use with respect to the proportion of cement in the concrete. However, the effects on retardation, water requirement, and strength development vary widely among carbohydrates and, moreoever, these effects can be modified by combining the carbohydrates with suitable accelerators or catalysts.

Type B retarders of ASTM Specification C 494 comprise a wide range of inorganic and organic admixtures that can produce retardation of setting without adverse effects on compressive strength, flexural strength, bond strength, volume change, bleeding, and freezing and thawing resistance of concrete. The specifications for Type B retarders include no requirement on water reduction. Hence, chemicals meeting the requirements of ASTM Specification C 494 for Type B retarder include water-reducing and retarding admixtures conforming to the requirements for Type D admixtures. Therefore, a chemical classification of Type B retarding admixtures must include the five classes stipulated above as well as admixtures based upon various inorganic compounds, such as salts of zinc and water-soluble borates and phosphates.

Effect on Fresh Concrete

The effects of the admixture on the properties of fresh concrete vary with the type of admixture and the materials composing the concrete. The properties which are most affected are:

1. Slump
2. Air Content
3. Water Requirement
4. Bleeding or Sedimentation
5. Rate of Hardening

The slump, air content, and water requirement of concrete are interrelated so that the specific effect of admixtures on each of these properties is difficult to separate. Indication of the individual effects can, however, be gained by considering the behavior when two of the variables are controlled. The cumulative effects may then be related in a rational manner.

For equal water and air contents, the slump of concrete containing an admixture with water-reducing properties is increased up to 100 percent as compared with comparable reference concrete within the range of slump usually used in highway work. The change in slump with given change of water content is usually more pronounced in admixtured concrete than in conventional concrete and relatively small changes in water content in some cases may markedly affect the fluidity of the mixture. Under these conditions, the relatively rapid increase in slump is not detrimental to the properties of the hardened concrete provided the fluidity is not sufficient to cause segregation. The placeability of concrete at a given slump is generally improved for concretes containing these admixtures.

Some admixtures of these types entrain air in concrete, although, in general, a supplementary quantity of conventional air entraining admixture is required to produce air content such as those required by American Concrete Institute Standard 613 and other nationally recognized specifications. When the admixtures are used at rates recommended by the manufacturer for ordinary purposes, admixtures of Classes 1 and 2 typically produce air contents 1 to 4 percentage points higher than those of equivalent concrete not containing the admixture; however, some products of these classes entrain more air than these amounts when employed at rates sufficient to effect even mild retardation of setting of concrete. Admixtures of Class 3 do not entrain air in concrete and those of Classes 4 and 5 do not entrain air in concrete unless a separate air entraining substance is included in the product. Where a separate air entraining admixture is needed in concrete containing a water reducing, set retarding or water reducing set retarding admixture, the amount required to produce a given volume of air is usually less than that for concrete without the admixture. Certain admixtures interact if intermiexed prior to their introduction into the concrete; the fact that individual admixtures interact in this manner does not indicate that they will not be fully effective when combined in a batch of concrete if dispensed separately. This affects the method of addition as discussed later. The influence of the admixtures on the characteristics of the air voids will be treated in the subsequent discussion of hardened concrete.

For concretes of equal slump and air content, the use of Types A and D admixtures (ASTM Specification C 494) will permit a reduction of the water content of up to 12 percent. The corollary properties associated with reduction in water requirement are also important since a given water cement ratio can be maintained while producing concrete of a higher slump, or a specific strength may be obtained with a cement content proportionately lower or water content proportionately higher than in concrete not containing the admixture.

The bleeding characteristics of concrete containing these admixtures are modified in any of several ways by the use of these admixtures. Admixtures of Classes 1 and 2 reduce bleeding and settlement of the concrete as compared with concrete having the same slump and mixture proportions but not containing the admixture. This reduction in bleeding is attributed to the entrainment of air, reduction of the amount of water in the mixture, and other more complex factors. Admixtures of Classes 3 and 4 may modify bleeding characteristics by increasing the rate and capacity to bleed water at early ages. This rapid bleeding reduces the water content of the concrete in place and retards the drying of the surface of the concrete. However, excessive bleeding is not desirable and should be avoided. The user of concrete containing admixtures should be aware of the differences in bleeding characteristics and provide accordingly.

Types B and D admixtures (ASTM Specification C 494) extend the setting time as measured by the various empirical methods employed in specifications. The amount of retardation is largely a function of the chemical nature and the amount of admixture added, so that practically any degree of retardation may be achieved. The maximum, practical dosage of any given admixture is often limited by the amount of air entrained. On the other hand, for the degree of retardation that frequently may be desirable for highway concrete, air entrainment related to use of these admixtures is rarely a problem. When experienced,

excessive air entrainment may be controllable by use of non-air-entraining cement in lieu of air-entraining cement or by reduction in the proportion of air entraining admixture that otherwise would be employed. To some extent, excessive air entrainment can be controlled by supplementary use of an air detraining admixture. However, care should be exercised in the use of these air detraining admixtures. As shown in Table 1, ASTM C 494, requirements for Types B and D admixtures dictate that the initial setting time must be delayed over comparable plain concrete at least 1 and no more than 3 hours under conditions specified. The retarding admixtures delay setting but, after setting has occurred, the hydration reactions, hardening, and strength development proceed at normal or accelerated rates.

Effect on Hardened Concrete

Concrete prepared with these admixtures will normally give compressive strengths which at 24-48 hours are equal to and at later ages are higher than those of concrete of the same cement content, air content, and slump without the admixtures. The amount of strength at early ages is somewhat dependent upon the amount of retardation, and for concrete in which the setting time is abnormally long an increase may not be achieved. The increase at 28 days is usually 10-20 percent. Increases at ages earlier than 28 days are somewhat greater and at later ages somewhat less when expressed as a percentage of the strength of a corresponding reference concrete. A factor influencing the increase in compressive strength is the amount of water reduction, but the increase is usually greater than would be expected from the reduction in water-cement ratio. Factors such as more complete hydration of cement also have beneficial effects on strength gain.

Flexural strength of concrete usually is increased by the use of these admixtures relative to that of equivalent reference concrete, but the increases so obtained are not proportionally as great as the increases in compressive strength.

Because drying shrinkage of concrete is primarily a function of total water content, admixtures which reduce the water requirement usually effect a slight reduction in drying shrinkage. However, some admixtures may reduce or increase drying shrinkage dependent upon their specific chemical composition.

The resistance to freezing and thawing of concrete containing chemical admixtures is primarily related to the amount and characteristics of the air void system which is entrained. The resistance increases in a normal manner, with increasing air content and decreasing air-void spacing factors. Most admixtures commercially available and meeting the requirements of ASTM C 494 develop a satisfactory void system, but this is an area in which additional study is needed. The requirements of ASTM C 494 are written with statistical tolerances intended to insure equal performance, as will be discussed in a later section. Improvement of resistance to freezing and thawing beyond that resulting from the entrained air would be dependent upon the amount of water reduction and increase in strength achieved.

In general the modulus of elasticity and bond to reinforcing steel are increased and creep of the concrete is decreased by the use of an admixture,

but the changes appear to relate to the improvement in compressive strength. Increases in abrasion resistance and decreases in permeability have been obtained which are also related to the degree to which other properties, such as strength and density, are improved.

Need (Applications)

Water-reducing, set-retarding, and water-reducing and set-retarding admixtures should be used when it is desirable or necessary to modify the properties of concrete in any of the ways previously discussed. The economic considerations of using admixtures are discussed by Committee 212 of ACI. (3)

The major use of admixtures in the highway industry has been in structural concrete for bridges and tunnels, but some significant paving projects have also utilized them successfully. An extensive summary of specific applications has been presented by Mielenz. (4)

Water-reducing and retarding admixtures (ASTM Type D) which cause both water reduction and retardation are the most commonly used in the highway industry. Where retardation is desired or can be tolerated, simultaneous water reduction is always beneficial. For this reason Type B admixtures which affect only setting time are not extensively employed. Under certain conditions water reduction is needed when retardation would be undesirable. In such cases water-reducing admixtures (ASTM Type A) are used.

The following applications of the water reducing properties of admixtures are important:

1. Economy of proportioning of the concrete mixture, including use of lower cement content and overcoming of problems associated with aggregates which are poorly graded or result in a high water requirement.

2. Meeting requirements of job specifications such as maximum permissible water-cement ratio and early development of strength and elasticity. Numerous examples may be drawn from experiences in production of prestressed concrete.

3. Improvement of quality of fresh concrete as a result of improved workability, reduced water content for a given consistency or increased slump at constant or reduced water content. This is particularly desirable in cases of concrete which is to be placed in heavily reinforced sections, under water, or by pumping.

The following applications of retardation of setting are important:

1. Compensation for adverse ambient conditions particularly in hot weather concreting. Extensive use is made of retarding admixtures to permit proper placement and finishing and to overcome damaging and accelerating effects of high temperatures.

2. Control of setting of large structural units to keep concrete workable throughout the entire placing period. This is particularly important for elimination of cold joints and discontinuities in large structural units and to prevent cracking of concrete beams, bridge decks and composite construction from causes such as form deflection or movement associated with placing of adjacent units. Adjustment of the dosage as placement proceeds permits various portions of a unit, a large post-tensioned beam for example, to attain a given level of early strength at approximately the same time.

Factors Affecting Performance

The specific effect of water-reducing and set-retarding admixtures varies with composition of cement, water-cement ratio, temperature of the concrete, ambient temperatures, and other job conditions.

Different brands and types of cement, because of variations in chemical composition, may require different amounts of the admixture to obtain the desired results. The effectiveness of the admixture seems to be related primarily to the amount of tricalcium aluminate (C_3A) and alkali (Na_2O and K_2O) content. [5] The sulfur trioxide (SO_3) content also may have a very marked influence on the effect of the admixture on the time of setting of the concrete. [6, 7, 8]

In general, the quantity of water-reducing admixture required to produce the desired results will vary less with changes in cement composition or other mix conditions than is true for the set-retarding admixtures. These latter types are designed to delay the set of the concrete for a predetermined period of time at a given temperature. Slight changes from this temperature do not require a change in addition rate, but if either the temperature of the concrete or the ambient temperature varies more than 10 F from that contemplated, a change in addition rate is generally necessary to maintain the desired retardation. The higher the temperature, the more admixture required to hold a constant degree of retardation.

The effectiveness of the water-reducing types of materials varies with the water-cement ratio of the mixture. Concrete of excessive water content and high water-cement ratio cannot benefit by this type of admixture to the extent realized in a medium to low slump concrete.

The addition of these materials to the mixture in liquid form is highly desirable to obtain a more uniform distribution throughout the concrete mass within the time allotted to adequately and properly mix the concrete. Care should also be taken when using liquids to avoid adding them directly to the cement or dry, absorptive aggregate. A fixed procedure for the method and time of dispensing the admixture should be followed for each job.

Recent studies have indicated that the time of addition of set-retarding admixture has a marked effect on the resulting mix. [9, 10] A short delay of 1/2 to 2 minutes in adding the admixture after all other materials are batched and mixing started will often result in an increase in slump and retardation.

Testing Methods and Specifications

The testing of water-reducing, retarding or water-reducing and retarding admixtures should be conducted on concretes prepared with and without the admixture to be evaluated in strict accordance with the procedures outlined in ASTM Specification C 494. The admixture should be added in the manner recommended by the manufacturer and in the amount necessary to comply with the applicable requirements of the specifications. The requirements are given in Table 1 of ASTM C 494. The concretes with and without the admixture should have approximately the same slump and air content. The test should be made in accordance with ASTM Specification C 494 and the admixture should meet the requirements of those specifications.

The time of setting should be determined in strict accordance with ASTM Method C 403 in order to insure reproducibility of results. Attempts to correlate data obtained from a mortar mix with those obtained from mortar screened from a concrete mix have been unsatisfactory to date.

The specification limits given in Table 1 of ASTM C 494 take into account the variability of test data, which is greater when comparing concretes than when no comparison is required, as is the case of usual specifications. (11) The limits are designed to insure equal performance between the concretes under test, recognizing the inescapable statistical variation.

Addition

Water-reducing and set-retarding admixtures are generally used in relatively small quantities. It is therefore important that suitable and accurate dispensing equipment be used. These admixtures are available as both liquids and powders. Water-soluble powders should be dissolved in water prior to use so that they can be dispensed as liquids. Unless complete solution of the admixture is effected, these solutions should be agitated before taken from storage or shipping tanks or containers; and agitation should be provided before and during dispensing into concrete mixture. Manufacturers' recommendations should be followed.

Admixtures furnished as liquids by the manufacturer may not require such agitation; the manufacturer's instruction should be followed. Powdered admixtures that are not completely water-soluble may be dispensed manually by volume or weight. In this case, they should be added preferably to the fine aggregate. All admixtures can be added after the concrete has been partially mixed; however, the same sequence and timing of addition of the admixtures should be used throughout a given project because available data indicate that time of addition may affect the efficiency of these admixtures.

Accurate and durable dispensers for liquid admixtures are available. These dispensers work on either a time-flow or a positive displacement principle. The time-flow type of dispenser should be equipped with a transparent measuring tube and each addition should be dispensed through this tube since any inaccuracy in flow rate with this type of a dispensing equipment will change the volume delivered. A positive displacement type dispenser does not

depend on flow rate for accuracy, but is generally adaptable only to dispensing fixed quantities of the admixture.

It may be necessary to add an air-entraining agent to the concrete in addition to the set-retarding or water-reducing admixture. The admixtures should not be mixed prior to addition as in most instances they will react causing precipitation and loss of effectiveness, and may clog the dispenser lines. The incompatibility of air-entraining admixtures and set retarders when mixed alone or in water does not indicate that such admixtures will not be effective when added separately to the concrete.

Storage

Powdered admixtures generally have an indefinite shelf life if stored dry. Liquid admixtures may freeze or precipitate at low temperatures. Freezing may permanently damage some liquid admixtures. Other liquid admixtures may be frozen and thawed without damage. The manufacturers' storage directions should be followed.

Quality Control

To insure uniformity of shipments or to insure shipments that are identical to samples submitted for tests, quality control procedures should be employed. Complete chemical analysis of admixtures is usually very time consuming and ordinarily is not practical for Quality Control. Conventional methods of chemical analysis may take a week or more to complete. It has been suggested that infrared spectroscopic analysis be employed for this purpose. This procedure may be applicable to admixtures of the hydroxy carboxylic acid type but does not differentiate between the various admixtures of the lignosulfonic acid type that differ markedly in their effect on concrete. Further, with all admixtures infrared techniques may not indicate the percentage of sugar or other detrimental or essential compounds which either should or should not be present in the admixture under test.

The most practical means of insuring quality would be based upon index tests which although not specific or definitive as a group can be used to control uniformity of the product. Suggested tests for this purpose are as follows:

1. Observation of physical nature.

2. Moisture content of solid products.

3. Determine pH of standard solutions.

4. Specific gravity or solids content of liquid admixtures.

5. Analysis for specific ingredients such as percentage chlorides, carbohydrates and/or other compounds of a special interest.

6. Infrared analysis or ultraviolet light spectrum of active constituents.

These tests can establish uniformity or variability of the product. A water-reducing or set-controlling admixture can be specified by chemical class, but in general it is not practical to specify them by exact chemical composition because the performance of these admixtures cannot be controlled by these means and the difficulties of chemical analysis preclude rapid and reliable quantitative determinations.

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