SUMMARY

By Bruce Foster

This closing paper is a summary of the main points brought out in the symposium.

CLASSIFICATION AND QUALIFICATION OF MATERIALS

The water-reducing admixtures and set-retarding admixtures discussed were divided into four classes: (1) Lignosulfonic acids and their salts, (2) modifications and derivatives of lignosulfonic acids and their salts, (3) hydroxylated carboxylic acids and their salts, and (4) modifications and derivatives of hydroxylated carboxylic acids and their salts. In each, the primary component has both water-reducing and set-retarding properties. These may be modified by the addition of other components to give various degrees of retardation, no appreciable change in setting time, or acceleration, while at the same time preserving water-reducing properties.

Some of the admixtures are produced by refining sulfite liquors from the wood pulp industry. In these it is necessary to reduce the sugar content, and of course it is desirable to produce a uniform product in all cases.

Data are included on the performance of a number of admixtures of varying sugar contents and it was concluded that the sugar content, per se, was not an important factor. However, these data covered only satisfactorily refined products. High sugar content in unsuitably refined products has resulted in excessive retardation.

1 National Bureau of Standards, Washington, D. C.

This summary refers only to materials which have been suitably refined and controlled in their manufacture and which have been used successfully in concrete. It does not necessarily refer to all the many other materials which might be included in one of the four general chemical classes.

NATURE AND ACTION OF THE ADMIXTURES

The admixtures discussed in the symposium are surface active chemicals which are adsorbed on the cement grains, giving them a negative charge. The presence of the adsorbate, and the charge, was pictured as resulting in (a) a reduction of the interfacial tension, (b) an increase in the electrokinetic potential, and (c) a protective sheath of oriented water dipoles around each cement particle. The resulting reduction in natural flocculating tendency of the cement particles then leaves them with increased mobility, and the water freed from the restraining influence of a highly flocculated system becomes available to lubricate the mix. Less water is required, therefore, for a given consistency.

To offer a mechanism explaining set retardation Hansen first advanced a solid state reaction theory to explain the role of calcium sulfate, normally incorporated in portland cement, in modifying the setting properties of cement. He pictured the surfaces of cement crystals as consisting predominantly of Ca++ and O- ions. When exposed to water, the Ca++ ions attract OH- ions of the water and the O- ions
attract the $\text{H}_3\text{O}^+$ ions. The rate of chemisorption and migration of these ions from the water into the crystals of the cement minerals was regarded as determining the setting and hardening characteristics of the cement. The rate may be modified by controlling the concentrations of $\text{OH}^-$ and $\text{H}_3\text{O}^+$ ions available to the surfaces of the cement particles and by controlling the amount of surface available to the ions.

As the large admixture anions and molecules are adsorbed on the cement particle surfaces the hydration is blocked and the hardening process slowed. Later, as a result of reaction between the organic salts and tricalcium aluminate from the cement, the former are removed from the liquid phase of the system by precipitation. This explanation is in qualitative agreement with observations that retarding admixtures are often particularly effective with low tricalcium aluminate cements and that the initial retardation period is followed by rapid hydration and hardening of the paste.

In a prepared discussion, Steinour\(^2\) advanced arguments against the solid state reaction theory on the basis that such reactions could not proceed fast enough. He agreed, however, with Hansen's\(^3\) treatment of the mechanism by which retarding admixtures achieve their effect.

**Effects on Plastic Concrete**

**Water Reduction:**

Water-reducing admixtures permit the use of less water, with the same slump, and were indicated as being effective with a wide variety of concretes. The water reduction was reported to vary from 5 to 15 per cent, but a portion of the reduction in many cases is due to entrained air which may result from use of the admixture.

The agents have been found to be effective with all types of portland cement, with portland blast-furnace slag cement, with portland pozzolan cement, and with high alumina cement. The range in the performance of a given admixture with a number of cements of the same type is likely to be greater than the difference in performance of a number of properly formulated admixtures of the same type when used with the same cement. Evidence was presented indicating that generally the admixtures are more effective with cements low in tricalcium aluminate and alkali content than with those in which these constituents are higher. The benefits when used with some cements are very small.

It was brought out that the amount of water reduction is also influenced by admixture dosage, cement content, type of aggregate, and presence of other admixtures such as air-entraining agents and pozzolans.

**Retardation:**

Like water reduction, retardation of set and extension of the vibration limit have been produced with a wide variety of concretes and under a wide variety of conditions. And, in a similar manner, the amount of retardation obtained is dependent upon the specific admixture used, its dosage, and the brand and type of cement. Retarding admixtures were said to retard the set at all temperatures, the amount being dependent upon the dosage.

With class 1 and class 3 agents the degree of retardation can be controlled by varying the dosage, provided that the allowable air content is not exceeded. Overdosage of properly formulated retarders was said to normally cause no permanent reduction in strength of the concrete provided the concrete is protected from drying, and forms are not removed too soon. Other data, however,
showed an average loss in strength of about 25 per cent.

With class 2 and class 4 retarders there may be no retardation or there may even be acceleration, both properties being brought about by the addition of a catalyst or of an accelerator.

**Air Entrainment:**

The use of class 1 admixtures in normal doses was described as generally entraining about 2 to 3 per cent of air. Tests reported show that the bubble spacing, and hence effectiveness from a durability standpoint, of such entrained air is in the same range as that produced by regular air-entraining agents. Class 2 admixtures may contain an additional air-entraining component or may be used with an air-detraining agent, as required by job conditions. It was pointed out that class 3 admixtures do not normally entrain air, but that they may be used with air-entraining agents or the latter may be included in the formulation of a class 4 agent. Usually when a water-reducing admixture is added to an air-entrained concrete the dosage of air-entraining agent must be reduced to maintain the same air content, even with a class 3 admixture. The degree of the effect may be different in laboratory mixes than in field concrete.

**Bleeding:**

Water-reducing admixtures that entrain air reduce bleeding. This reduction is due to the entrained air and the lower water content. Water-reducing admixtures that do not entrain air were reported to increase the rate and amount of bleeding. Such bleeding was suggested as being responsible for a portion of the strength increase observed with the use of such admixtures.

**Slump Loss:**

While reduction in slump loss occurring between mixing and placing was claimed for retarding admixtures, two authors reported data showing no improvement and one case was cited where the problem was aggravated by addition of lignin. However, as will be mentioned later, water-reducing admixtures were indicated as having an application under conditions where slump loss is a problem.

**Effects on Hardened Concrete**

**Strength:**

*Strength at 28 days.*—The reduction in strength due to entrained air may normally be compensated for by the increase in strength brought about by the reduced water and sand content made possible by the presence of entrained air. The portion of the water reduction brought about by a water-reducing admixture which is in excess of that due to any air which may be introduced through its use results in a net increase in strength. Further, in general, this increase in strength was reported to be greater than would be expected simply from the amount of water reduction produced.

An analysis of one extensive block of data with one admixture in which 28-day strengths were compared with the ratio of water-plus-air to cement contents showed that, on the average, and with air-entrained concrete, a 19 per cent increase in strength resulted from the use of the admixture even with a water reduction of only 5 per cent. For concrete with no air-entraining admixture 15 to 18 per cent increase in compressive strength might be expected with a water reduction of 10 to 15 per cent. In many mixes the strength was considerably lower or higher than the averages given, and the average for other brands and types of admixtures would in general be different.

Water-reducing admixtures were found to be particularly advantageous in mass concrete where pozzolans were used. It

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4 See under Finishing Characteristics, p. 60 of this symposium.
was suggested that the admixture might increase the pozzolanic activity.

Increases in compressive strength were reported to be accompanied by increases in flexural, tensile, shearing, and bond strength. Usually the improvement in flexural strength is less pronounced than that in compressive strength. The bond strength may be benefited not only by the increase in concrete strength, but also by improvement in bleeding and volume change characteristics. The resistance to abrasion may also be improved.

Strength at Other Ages.—When retarding or accelerating admixtures are employed, the rates of strength gain are altered. In most cases a retarder should be effective only for a limited period, after which the concrete should gain strength rapidly to reach normal or higher levels at 1 day. Properly formulated retarding admixtures were said to perform in this manner unless the dosage is too large. The strength increase, expressed as a percentage, is usually greater at 3- and 7-day than at 28-day and later ages. This is particularly true for type I cements.

Strength tests on hermetically-sealed cylinders at ages up to 5 yr showed that strength advantage due to the admixture is still present at those ages.

Permeability:

Data were presented indicating that concretes made with water-reducing admixtures had a substantially lower permeability to water under pressure as compared to similar concretes without admixture and with the same or higher cement factor.

Volume Change:

Other factors being equal, the dimensional stability of concrete as a function of moisture content depends upon the original water content of the concrete.

A reduction in original water content brought about through reduction in water-cement ratio, or a reduction in cement content while maintaining the same water-cement ratio—as shown to be possible by using a water reducing agent—may lead to less volume change with varying moisture conditions. Data presented by two authors showed some reduction in drying shrinkage in some cases, none in others. The effect is not large. It was brought out in the discussion that shrinkage was reduced with higher-SO₃ cements and increased with lower ones.

Resistance to Freezing and Thawing:

Laboratory test data were presented which, in general, showed some improvement in performance when water-reducing admixtures were used, as compared to control concretes with similar air contents, but the test results were not conclusive.

Water-reducing admixtures may increase the resistance of concrete to the action of freezing and thawing because they permit use of a lower water-cement ratio and because they often entrain air. Some modified types contain an air-entraining agent which may furnish a fully-protective air void system.

Resistance to Sulfates:

Laboratory data were reported which showed, in some cases, modest improvement in resistance to sulfate attack for concretes with water-reducing admixtures as compared with those without.

Applications

The modifications of concrete properties, both in the plastic and hardened state, made possible by the addition of water-reducing admixtures and set-retarding admixtures were reported to have been taken advantage of in all types of construction. The various advantages
have been utilized to overcome a variety of problems, increase the quality of the concrete, and in many cases decrease the cost of concrete and concreting operations. Some applications will be enumerated further under headings descriptive of modifications made possible in concrete properties.

Use of Less Water While Maintaining Slump:

In general, the use of less water was mentioned as being advantageous in all types of concrete, since the strength, dimensional stability, permeability, and other properties are improved. It could aid materially in meeting a maximum water-cement ratio specification requirement. It might eliminate the need to use excess water when aggregates with high water requirements are used.

A particular advantage to the small user was brought out in a prepared discussion which considered the danger of poor quality concrete caused by overly wet mixes. Data presented indicated that considerably less water needed to be added to increase slump from 2 in. to 8 in. when a water-reducing admixture was used than when none was used, and that the decrease in strength resulting from such a change was correspondingly less. Such an admixture property might lead to increased uniformity in other types of concrete.

By contrast, it was stated that the "sticky" appearance which may result from use of an admixture often leads to the addition of unneeded excess water.

Use of Greater Slump While Maintaining Water-Cement Ratio:

The increased workability was described as promoting easier handling and placing of the concrete and better compaction, which are particularly desirable where formwork and reinforcement make placing unduly difficult. Higher initial slump may compensate for loss in slump between mixing and placing of the concrete. This applies to conventional as well as pumped concrete. It was pointed out that by changing the dosage as a function of the fresh concrete temperature, the water-cement ratio may be held relatively constant, thereby promoting uniformity in the concrete.

Use of Less Cement:

The increase in strength which was shown to result from the use of water-reducing admixtures would permit a reduction in cement content while still maintaining the design strength. This lower cement content may increase the dimensional stability of the concrete, result in lower total materials cost, and be of considerable advantage in reducing the temperature rise in mass concrete.

Achievement of Increased Strength at Early Ages:

The strength advantage shown for concrete containing water-reducing and set-retarding admixtures at ages of 24 hr and later would permit early stripping and re-use of forms. It is of particular value in slip-form, prestress, and tunnel-lining operations.

Modification in Bleeding Rates:

Various views have been expressed on the possible advantages and disadvantages of bleeding. Reduced bleeding produced by air-entraining types of water-reducing agents was described as beneficial, from a segregation standpoint, in many types of construction. Induced early bleeding produced by the non air-entraining types was said to help prevention of plastic cracks in concrete placed in hot, arid areas.

Use of Retardation:

The control of the setting time was reported to be a very substantial aid in
concreting at elevated temperatures. Advantages accruing from extension of the vibration limit were cited in reducing the incidence of cold joints in a number of types of construction including those employed in tunnel lining, mass concrete, slip-form work, and large cast-in-place bridge girders and decks made monolithic by vibration even up to 10 hr after placing the first concrete.

Longer setting time was credited with minimizing cracking due to form movement under increasing loads as filling proceeds.

Advantages accruing in steam-cured concrete units due to lengthening the period between placing and steaming were reported.

PROCEDURES IN USE

Specifications:

Ideally, water-reducing admixtures and set-retarding admixtures should be purchased under specifications that assure the production of the desired concrete properties, that demonstrate the absence of any resulting deleterious effects, and that permit evaluation of the uniformity of the admixture from one lot to another.

In practice this is difficult because of the variability of results obtained with an admixture when used with various cements, aggregates, mixtures, etc., and because no simple, rapid, reliable tests are usually available to compare one lot with the next.

One procedure recommended consists of comparing laboratory batches of concrete made with each successive lot of admixtures with one made with identical materials and design except for the use of admixture from a reference lot.

Often the uniformity may be roughly judged by observing the uniformity in the rate of hardening, water requirement, and slump in the field concrete.

All tests should preferably be made using the materials and mix design proposed for the work, and should be made on concrete rather than mortar.

Development of a qualitative method for indicating the presence or absence of the reaction products resulting from the use of lignosulfonates in cement paste was described. Such a method applied to hardened concrete should prove useful as an addition to other tests employed in conducting examinations of distressed concrete. The method utilizes optical absorption techniques in the ultraviolet region, applied to extracts from hardened paste.

Dosage:

It was suggested that either the dosage recommended by the manufacturer should be used or laboratory tests should be employed to determine the optimum dosage. Some admixture producers formulate different products for use under different conditions; others recommend use of different amounts, depending on the conditions. Admixtures which also entrain air should not be used in excess of a certain amount unless used in conjunction with an air-detraining agent. Limitation on the desired degree of retardation may limit the usable dosage of water-reducing agents unless catalysts or accelerators are incorporated in the formulation.

A correlation between time of set of cement pastes and rate of stiffening of concrete mortars was reported, which might permit the correct admixture dosage for various conditions to be determined in the laboratory.

Control of Dosage:

It was stressed that the quantity of admixture added must be accurately measured if uniform results are to be obtained. Automatic dispensers are avail-
able for liquid admixtures, but these must be kept in good working order and should preferably be of a type in which the volume added may be checked visually. Admixtures in powder form should preferably be accurately weighed out in individual packages.

The handling and dispensing of admixtures may be a considerable problem in a ready-mix plant, one of which was reported to stock 14 different agents.

Possible Reduction in Cement Content:

Recommendation was made that claims made concerning the quantity of cement reduction made possible by addition of the admixture should be checked by making strength tests.

Research on Admixtures

Water-reducing and set-retarding admixtures are undergoing improvement, both in performance and reliability. Much remains to be learned about their action in concrete and how this action is affected by the properties of the other concrete ingredients. A substantial amount of research is under way in the laboratories of a number of admixture manufacturers. Even better products and better concretes made possible through their use are anticipated.