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BY

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Paper presented to the Annual Meeting of the Ontario Ready Mixed Concrete Association, held in Ottawa, March 1964

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E.G. Swenson*

The extent to which admixtures are used in concrete has greatly increased during the last 10 or 15 years. A good estimate would be that well over 75 per cent of the concrete placed in Canada in the last year contains an admixture, and in some cases more than one. Although most of these instances involve air-entraining agents, there has been an increasing use of water-reducers, retarders, accelerators, dispersing agents, and others.

There is no question as to the effectiveness of properly entrained air in improving the resistance of concrete to frost action and to de-icing salts. The general use of the many other admixture types has, however, been the subject of considerable controversy. There are those who believe that admixtures should be handled like drugs or preventive medicines, to be used only in rare and special situations, and then only when each case has been expertly diagnosed and prescribed for. On the other hand, there are those who maintain that the introduction of admixtures represents a technical advance in the basic composition of good concrete, much the same as special ingredients are incorporated in metals to produce alloys whose properties constitute an improvement over those of the original material.

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Published research literature on the subject is extensive but, unfortunately, there are so many complicating factors that the average producer or user of concrete can become highly confused. What appears to be urgently needed is practical guidance in deciding whether an admixture is required, what the risks are, and what can be done about them.

In this paper an attempt is made to clarify some of these questions, as analytically as possible, so that a user or producer of concrete can make decisions with minimum risk and cost. The following remarks apply only to ordinary concrete and do not apply to the use of admixtures in concrete block and brick manufacture and in lightweight concrete.

CONCRETE WITHOUT ADMIXTURES

Before considering the role of admixtures, one might well review briefly the steps in making concrete, its properties, how these are achieved, and whether they are adequate.

Simple 4-ingredient concrete is made from cement, water, sand, and coarse aggregate. The main steps leading to the final product are:

1. Selection of good primary ingredients.
2. Processing and sizing of aggregates.
3. Storing and handling of ingredients.
4. Determining proper mix proportions.
5. Mixing.
6. Transporting and discharging.
7. Placing and compacting.
8. Curing.

Quality control of each of these operations can be achieved by use of specifications, methods of test, and recommended practices, as provided by Canadian Standards Association, American Society for Testing and Materials, and the American Concrete Institute.

The important properties required in the plastic state are: good workability, low bleeding characteristics, low rate of stiffening, a reasonable delay before hardening begins, low tendency to segregation, and good finishing characteristics. Factors that influence these properties to a greater or lesser extent are: particle shape, grading, and absorption characteristics of the aggregates; chemical composition and fineness of the cement; air content; and the proportions and temperature of the mixture.

The important properties pertaining to the hardened state are: compressive, flexural and bond strength; dimensional stability, absorption and permeability, and durability to frost action, de-icing salts, and other chemicals. These are achieved in the required degree by control of the same factors that influence the plastic properties, plus inherent soundness of materials, proper placing and compaction, and adequate curing and protection at early ages.

To achieve these properties, and to obtain a high quality product at a reasonable cost require a high degree of technical "know-how" and organization.

Two inherent problems should be noted at this point:

(1) unlike pre-fabricated products, the manufacture of concrete "in situ" is more often than not split between the producer, e.g., ready-mix supplies, and the contractor who is responsible for placing and curing; and (2) a defective product is often difficult to detect until after placement, and then its weakness may not show up for months or even years.

Problems with the plastic and the hardened states of concrete can usually be traced to failure to maintain normal good practice, control, and organization at some point in the processing. An example is plastic shrinkage cracking which is generally agreed to be the result of rapid loss of water before the curing water can be added. Failure to compact concrete adequately can accentuate this problem.

As with any other material, even good concrete for construction purposes may have some limitations in respect of fire resistance, thermal conductivity, tensile and flexural strengths, acoustical properties, shrinkage, creep, abrasion, extensibility, weight, or durability. Except for durability, and possibly strength, these properties are not improved significantly by the use of admixtures.

TYPES OF ADMIXTURES AND THEIR EFFECTS

Concrete admixtures can be divided into types or classes, depending on the specific effects they are expected to contribute in the handling characteristics of plastic concrete or the quality of the hardened product. The main types are:

1. air-entraining agents.
2. accelerators
3. retarders.
4. water reducers.
5. dispersing or wetting agents.
6. mineral admixtures .
7. inhibitors of alkali-aggregate reaction.
8. damp-proofing and waterproofing agents.

Others include hardeners, grouting aids, and gas-forming agents.

Air-entraining Agents

After some 20 years of laboratory research and field performance, it has been established without any doubt that properly entrained air will greatly improve the resistance of concrete to frost action. Even the high-strength concretes are improved. Air-entrained concrete is especially effective for such severe cases as sidewalks exposed to freezing and thawing and de-icing salts. Air-entrainment is usually accompanied by some improvement in workability and reduction in water requirement, and in bleeding. Its great weakness lies in the reduction in strength which is normally not compensated for by the reduced water requirement. This is especially true of high-strength mixes. Over-dosages can be very detrimental.

Accelerators

The only accelerator which is generally available is calcium chloride. It accelerates the hydration of cement, thereby increasing the rate of hardening. It is used in situations where early use of a structure is required, early stripping of forms is necessary, and in cool weather when hydration is normally slow. Some undesirable side effects have been observed: increase in initial setting or stiffening, lower durability, and lower ultimate strengths. There may also be a considerable difference in response with different cements, and even small over-dosages can be very detrimental to the concrete. Calcium chloride in concrete can produce serious corrosion of prestressing steel. The effect on reinforcing steel is still a matter of some uncertainty. Calcium chloride should not be used with embedded aluminum conduits.

Retarders, Water-Reducers and Dispersing Agents

These are considered together because an agent designated to belong to one of these types usually has, or is claimed to have, properties of one or more of the others.

Retarders extend the plastic period, that is, they delay the beginning of hardening. This permits a longer period during which the concrete can be vibrated. They are used mainly in hot weather when there is risk of early hardening. They are therefore used when long hauls or long waits for discharge may be encountered. The rate of loss of slump is a separate phenomenon which is not favourably affected to any significant extent by a retarder. Adverse side effects sometimes encountered are: variability in effect with different cements and mix composition, sensitivity to temperature, increase in drying shrinkage with some agents, spongy consistency which makes finishing difficult, and introduction of air by some agents. Over-dosages can be very detrimental.

Water reducers are used primarily to obtain higher strengths through reduction in water-cement ratio and consequently are often used to save cement. These agents are frequently retarders as well and are sometimes compounded with accelerators to eliminate retarding effects, and in some cases to produce water-reducing accelerators. Their side effects are therefore similar to retarders.

Dispersing agents and wetting agents are used to improve workability. Their limitations are similar to those of retarders and water-reducers.

Most of these agents are claimed to minimize segregation and improve workability. Unless they entrain air, or are used with an air-entraining agent, these admixtures can actually be conducive to harshness and segregation, and definitely promote bleeding.

Mineral Admixtures

These include fly ashes and various pozzolanic powders which are used in partial replacement of cement, or sand and cement. They generally have some cementitious value, with strength advantages at later ages. They are used to reduce heat rise in mass concrete, to reduce expansion due to alkali aggregate reaction, and to save on cement. Their main limitation lies in extra bulk storage and handling. These admixtures are inorganic in nature and are therefore less risky to use than the organic types. Their use may increase water requirements. In such cases water-reducers are sometimes used.

Damp-proofers and Waterproofers

These are usually soaps or soap derivatives, asphalt emulsions, or oils. They are claimed to decrease permeability and absorption. Calcium chloride solutions sold under proprietary names are also used for this purpose.

Considering the risks involved and the questionable benefits derived, there is very little doubt that these admixtures should not be used in normal concreting operations, except possibly where full guarantee is made.

From this brief outline of the properties associated with the more common types of admixtures, it is evident that their use in concrete introduces extra problems of control. One must be concerned not only with the property for which a given admixture is used, but also with the various side effects.

GENERAL PROBLEMS ASSOCIATED WITH ADMIXTURES

There have been periodic outbreaks of violent controversy over the increasing use of admixtures in concrete. The most recent was caused by a paper* in which the author criticized adversely the high-pressure sales methods of many admixture manufacturers, their exaggerated claims, their misrepresentations, and their exploitation of architects and engineers. As was to be expected, there was equally

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* Mercer, L. Boyd. Watch Those Admixtures. Australian Civil Engineering and Construction. Vol. 4, 5 March 1963, p. 20-29.

sharp reaction from some admixture manufacturers and this was published in the same journal and elsewhere.

It is not intended here to discuss all the claims and counter-claims made on this subject. It is necessary, however, to outline the many general factors, in addition to the specific side effects already mentioned, that are responsible for the confusion and misunderstanding that exists, so that some sort of practical philosophy can be developed in dealing with the use of admixtures.

Briefly these general problems and issues are as follows:

1. It has been noted that there are some dozen different classes of admixtures. Within each class there are literally dozens of proprietary materials. One would guess that in Canada there are some 300 proprietary admixtures on the market. Selecting a suitable admixture is therefore not an easy matter.

2. Many of these proprietary admixtures claim more than one function, e.g. water-reducing and retarding properties. In some cases modified admixtures are compounded from more than one functional ingredient. Thus one has in effect an admixture within an admixture.

3. The great majority of commercial admixtures derive from industrial waste products or by-products which have been subjected to varying degrees of refinement, treatment or modification. They are therefore usually very complex in nature and subject to considerable variation in composition. The precise formulation or composition is usually a company secret. Analysis by a chemist is almost impossible in most cases because of this complexity, and often is useless in any case because of frequent change in formula.

4. Impartial research and testing agencies have not been able to undertake evaluation of all admixtures on the market for reasons of number, complexity, formula changes, costs, and the frequent appearance of new products. Their test information is limited to one or two specific cement and aggregate combinations or types, and usually designate the admixtures by code number.

The manufacturer's technical data are naturally, if not always accurately, suspected of bias. Even some of the research papers in the literature are suspect because the authors happen to work for admixture manufacturers.

5. Published case histories of large-scale use and good performance of admixtures can be somewhat misleading or questionable. Many of these are written up by persons associated with admixture manufacturers. There is also an understandable unwillingness to publicize unsuccessful cases, both on the part of the admixture supplier and the concrete producer or user. Frequently such "bad cases" are not due to a faulty admixture but are due to improper use.

6. Most admixture dosages are relatively small and are therefore difficult to detect in the hardened concrete. In most cases, it would be practically impossible to distinguish between a normal dose and a double dose.

7. The evaluation of an admixture for any given job or plant is necessarily a matter of economy as well as improvement in quality of concrete. Comprehensive testing to adapt a given admixture to a given situation involves initial costs which may be prohibitive for the smaller producer or user of concrete.

8. The considerable extra control required when an admixture is used is frequently not achieved. The properties which admixtures confer on concrete can vary markedly with wetness of mix, cement

content, aggregate grading, type of cement, and length of mixing.

9. The essentially chemical nature of the effects and variations associated with admixtures in concrete has not been fully recognized in practice. Background in concrete technology, with respect to materials rather than design, and a knowledge of the physical-chemical relationships, are essential to both diagnosis and prescription.

10. Reliable admixture manufacturers do, however, have concrete experts on staff who can and will advise competently on request.

SPECIFICATIONS AND TESTS FOR ADMIXTURES

Before the development of comprehensive specifications and methods of test for admixtures, the selection of an admixture was based mainly on limited field experience on some job or in some plant. If it proved satisfactory, it was thereafter designated in the specification by its proprietary name. This is still true of many specifications in use today.

Unfortunately, this practice has led to discrimination and certain abuses. Some manufacturers whose products won early acceptance and were named in specifications for major projects have been accused of exploiting this advantage unfairly by maintaining high prices for their products and by using their reputation to expand aggresively in the marketing of other admixtures they have developed. It has been claimed that this practice has made it difficult for newer and improved products to win acceptance.

Over the years a rash of single or limited tests have appeared which often were developed in the first instance by a manufacturer to show his product in a favourable light. It should be also stated that the evolution of specifications and methods of test to the present more satisfactory state has been to a considerable extent the result of research and support by responsible admixture manufacturers.

ASTM Committee C-9 on Concrete and Concrete Aggregates developed its first specification for air-entraining agents about 25 years ago. Although it was designed as a general specification, for several years it included a footnote naming three or four proprietary products as the only ones which had at that time been fully subjected to tests and found to conform.

Since then ASTM C-260, a tentative specification for Air-entraining Admixtures for Concrete, has refrained from mentioning names. It now stipulates that concrete made with an air-entraining agent must meet certain requirements for bleeding, compressive strength, flexural strength, resistance to freezing and thawing, bond strength, and volume change of concrete. The methods of test for each of these properties are covered by ASTM C-233, a tentative method of testing air-entraining admixtures for concrete.

This is essentially a performance specification and is not concerned with the source, nature, or chemical composition of the admixture. It is intended to ensure that an air-entraining agent will do specifically what is claimed for it and, of equal importance, that other properties of concrete will not be adversely affected.

Two other specifications in use today are ASTM C-350, a tentative specification for Fly Ash for Use as an Admixture in Portland Cement Concrete, and ASTM C-402, a tentative specification for Raw or Calcined Natural Pozzolans for Use as Admixtures in Portland Cement Concrete. These are similar in intent to C-260 but contain certain chemical as well as physical requirements.

The most recent document is ASTM C-494, a tentative specification for Chemical Admixtures for Concrete. It covers water-reducers, retarders, accelerators, and combinations of water-reducing and retarding agents, and water-reducing and accelerating agents. The specifications and methods of test are patterned after those of C-260. A limit is placed on the specific effect claimed for a given type of admixture and, at the same time, it requires that it does not adversely affect other properties of the concrete such as water requirement, time of set, compressive and flexural strengths, bond strength, volume change, durability to freezing and thawing, and bleeding. A footnote cautions that the tests should, if possible, be made using the cement, aggregates, admixture, and mix to be employed on the job.

These specifications, covering the most common types of admixtures, represent a great stride forward in providing a fair evaluation of commercial products. They ensure that an admixture will perform according to claim without other harmful effects, thus providing full protection to the user; they effectively show up useless, inferior or harmful products; and they provide equal opportunity for all products regardless of nature, source, and chemical composition, and thus greatly simplify the problem for the user. Perhaps their lone disadvantage is the cost of carrying out the complete series of tests.

The Canadian Standards Association has not yet developed similar specifications for admixtures.

ASTM has so far not developed corresponding specifications for certain other admixture types, such as waterproofing and damp-proofing agents, hardeners, pigments, expanding agents and wetting agents. Some of these types are of questionable value and a major difficulty is the development of tests that will yield significant information.

APPLICATION TO INDIVIDUAL PLANTS OR MATERIALS

The foregoing general specifications provide a satisfactory means of eliminating useless or harmful admixtures and for developing performance records for individual users or producers. There are still problems involved with the achievement of acceptable test records, costs of testing, and the provision of adequate plant and job facilities and control.

It would seem logical that an admixture manufacturer should provide adequate test information on his product, based on a general specification such as now provided by ASTM for the more common admixture types, and covering in part some of the more important variables, for example, high and low water cement ratios, high and low cement contents, and over-dosage. Although some admixture manufacturers have their own excellent testing facilities and competent concrete technologists, it is obvious that such information should be provided by a reliable independent testing laboratory at the expense of the admixture manufacturer. The availability of such certified information would reflect the confidence of the admixture supplier in his product.

The concrete user or producer would still be faced with applying the same tests on his own particular materials and with his own particular operations. He must know what dosages to use for best results and what facilities and controls he must provide. Although some large operators have their own competent test facilities and can tolerate the cost involved, some admixture manufacturers are willing to provide technical aids and dispensing facilities. It is not surprising that in some co-operative evaluation programs of this nature, the cost to the concrete producer has been more than compensated by the discovery and correction of weaknesses in his original operations. At least this much can be said for the admixture manufacturer who is willing to provide help in individual cases. It must also be remembered that this additional information can be used to advantage by the admixture manufacturer in dealing with smaller plants or jobs where costs of comprehensive testing would be prohibitive.

Adapting an admixture to specific materials in a plant should not be limited to laboratory tests but should include field trials followed by suitable tests carefully carried out. One of the most important requirements is uniformity of properties of both the plastic and hardened concrete. An admixture which is difficult to control in this respect can be a source of continuing trouble to the concrete producer or user. Other specific effects not normally covered by specifications should be noted, such as, for example, finishing properties.

Some admixtures are supplied in solid form, others as liquids. Powders, flakes, and pastes are obviously difficult to distribute homogeneously in a mix. It is preferable to pre-mix the water-soluble type, solid or liquid, with the gauging water. Some, even in the liquid state, form colloidal suspensions with water which appear to be stable but which may result in coagulation or settling in a tank. In such cases the suspension should be continuously stirred.

Dispensers of admixtures in a plant must be frequently calibrated and must be foolproof. Over-dosages can lead to serious field problems. This is particularly critical with retarders where delay in hardening in cool weather, for example, has been known to extend to more than a week.

Another problem, not so well known but sometimes of critical importance, is the effect of one admixture upon another under certain conditions, e.g., air-entraining agent plus retarder. If these are introduced into the mix at the same time, or are pre-mixed together in the mixing water, they sometimes react or co-precipitate, thereby producing unusual and variable effects. This can be avoided by introducing the two admixtures at different times in the sequence of batching and mixing. If possible, however, such combinations should be avoided.

In the case of air-entrainment it should be remembered that a satisfactory amount of air as determined by an air meter does not necessarily mean that good durability will naturally follow. Certain natural sands and some lignosulphonate admixtures will entrain considerable amounts of air. The concrete producer may be delighted to find that the dosage of air-entraining agent required to give the specified amount of air is small. He may be misled; the entrained air he is getting may not be conducive to good durability. The real test should be made on the hardened concrete by the so-called linear-traverse method in which the size and spacing of air bubbles is determined microscopically.

Some admixtures are claimed to possess built-in safety factors that permit considerable over-dosage with no ill effects. This should not be taken for granted.

The user of an admixture should set up a rigid specification for the product itself, just as he normally does for any other ingredient of concrete which he purchases for his operations. Each shipment should be tested for uniformity. The admixture supplier should be required to give notice of modifications or formula changes and should, in such instances, assume responsibility for retesting.

The concrete producer should inform his customer whether an admixture is present in the concrete. It is traditional that the manufacturer of a finished product can, if he wishes, keep his formula secret. Plastic concrete is not a finished product, however, and subsequent operations may involve difficulties if this information is not available.

The most important consideration in the adaptation of an admixture to plant or job operations is to obtain the advice and supervision of a competent and impartial expert on concrete technology. Normally it pays to have a good doctor to diagnose your ills and prescribe a remedy if one is needed. A thorough check-up, medical or technical, may reveal a situation where adjustment of one's present habits will be all that is necessary. It should not be forgotten that an admixture introduces a fifth ingredient into concrete, and, no matter how effective it is, the problems of control are increased.

THE QUESTION OF ECONOMY

D.L. Bloem of the National Ready Mixed Concrete Association, who has written several excellent papers on admixtures, divides these materials into two categories: the "curative types" which are used to improve the quality of concrete in the plastic state, the hardened state, or both; and the "economy types" which are usually used to save cement. He refers to the latter as "cement stretchers."

Water-reducing admixtures are frequently used to permit a reduction in mixing water and, consequently, in cement content, to achieve a given strength. Fly ash or pozzolans are sometimes used in mass concretes, in some cases in conjunction with water-reducing agents. Large jobs with precision controlled batching on the job can effect substantial savings in this way where responsibility for quality control is not divided. The general use of such admixtures in ready-mix operations is obviously subject to extra problems and risks.

Retarders of the lignosulphonate and hydroxylated carboxylic acid types usually reduce water requirements and increase strengths for a given cement content. The risk of using these as "cement stretchers" is associated mainly with the variability in their effects with variations in mix properties. In the leaner mixes it is particularly important to have enough cement to produce a dense, impermeable mass.

Air-entraining agents generally require a mix proportion using less sand. Some economy is effected in such cases. Admixtures that improve workability may facilitate placement of concrete thus reducing an important cost item.

A factor often overlooked is the effect of an admixture on yield. The difference may be quite large and here the cost would be directly affected. A simple test can be used to check this effect.

Using an admixture primarily to save cement is not recommended practice as there are many risks involved. At best such savings in cost will constitute only a small part of the total cost of the admixture itself plus the extra costs of handling, testing, and batching.

The producer of concrete can probably achieve much greater economy by simply improving the quality of his materials and the efficiency of his operations. Refinements in quarrying, crushing, sizing, stockpiling and handling of aggregates, in mix proportioning, in quality control and uniformity, go hand in hand with more economical production. Greater efficiency in the dispatching office of a ready-mix plant can be an important factor.

Ready-mix producers might well consider classification of concrete, for price purposes, into three main categories:
(a) common concretes - for ordinary unexposed structures;
(b) prescription concretes - for special purposes but having standard plant mixes, e.g. air-entrained concrete, retarded concrete, (such concretes should justify a small premium); and (c) special formula concretes - where the customer requires his own mix design to be used (such concretes should also justify a premium). This system, or some modification depending on the competitive situation, should enable a producer to make reasonable profits without resorting to means which may impair the quality of his product.

With the methods now available for rating most admixture types, it is possible to determine the least expensive product which will meet requirements.

In general, where admixtures are used, they should be employed for so-called "curative" purposes only, except possibly on large jobs where optimum and single control can be exercised through all operations from the selection of materials to the final job curing. Only in such cases can the use of "cement-stretchers" be justified. The degree of precision control required is normally not obtainable in ready-mix operations.

SITUATIONS ASSOCIATED WITH THE USE OF ADMIXTURES AND THE ALTERNATIVES

Assuming that some situations exist or occur where admixtures can have some benefit, and assuming that such benefits have been proved by tests for materials and operations for a given plant or job, there is still the question of recognizing such situations and being fully aware of alternatives which may be equally effective, less costly, and less likely to introduce control problems.

In the following an attempt is made to classify the conditions and situations which call for special measures and where admixtures or alternative measures are required.

1. Climatic Conditions

In most parts of Canada concrete is subjected to cycles of freezing and thawing. Air-entrained concrete has proved to be much more resistant to such exposure than non-air-entrained concrete, and should therefore justify the general use of air-entrainment for exposed elements. Possible exceptions are high-strength, dense concretes above ground which are not exposed to wetting.

Sidewalks and pavements subjected to de-icing salts derive particular benefit from the use of entrained air. In such severe cases there is mounting evidence that about 7 per cent air is necessary rather than the normally specified 5 per cent. There is evidence also that, following curing, a drying period before exposure to frost and de-icing salts further increases resistance to scaling. Adequate aging before exposure is also beneficial.

To the author's knowledge, there is no alternative to air-entrainment under such climatic exposures. The use of air-entraining agents solely for workability purposes in unexposed cements, such as floor slabs, is not normally justifiable or desirable.

2. Seasonal Conditions

During cold weather concreting the rate of hydration of cement and, consequently, the rate of strength gain may be unduly slow. Accelerators such as calcium chloride are often used in such situations. Alternatives which can be equally effective, and usually safer, are adequate protection by cover and/or heating, and the use of high-early-strength cement.

In hot summer weather setting and hardening are accelerated. Problems may occur with long hauls and delays in discharge, with the almost inevitable result that extra water is added to the mix. Retarders are now being used extensively, and in many instances in all concretes, to delay setting and early hardening. Alternatives are protection of aggregates against excessive temperatures, avoiding use of "hot cement", pre-cooling, and improved dispatch timing.

3. Special Job Requirements

Excessive heat rise is a special problem with mass concretes. Fly ash or pozzolan admixtures are often used to reduce the cement content. Reduced temperatures can be achieved using a low-heat cement, or possibly by pre-cooling the concrete. Modified cements are usually available for certain other special job situations, such as sulphate-resistant cement in locations where the soils contain excessive sulphate salts.

Where water problems exist the permeability of the concrete is an important factor. The use of waterproofers, such as butyl stearate, is sometimes followed. Well designed and properly placed concrete is itself quite impermeable and, as most leakage problems occur as the result of cracks or honey-combing, it can be suggested that admixtures can have no significant value in such cases.

The use of aids to improve workability and reduce the amount of water required can sometimes be justified in very special operations such as pumpcreting. Such instances, however, require special control and therefore involve less risk of variability than ordinary operations.

In most special cases of this sort, it is often possible to achieve good concrete without resort to the extra ingredient. Location of certain structures may, for economic reasons, require the use of inferior or borderline aggregates in the concrete. This problem should not concern the ready-mix operator who can be presumed to have assured himself of a continuous source of good materials before he began his operations.

4. Inherent Material Problems

Concrete made with artificial sand sometimes poses problems of workability, finishing, or early stiffening. Water reducers, retarders, or workability aids are often used in such cases. Adequate improvements can usually be effected by refinements in aggregate grading and modification in methods of finishing.

The problems produced by a false setting cement cannot be corrected by the addition of an admixture to the concrete.

Where the use of alkali-reactive aggregates is unavoidable, pozzolans or chemical inhibitors such as lithium chloride have been found to be effective in reducing expansion. A simple alternative is, of course, a low alkali cement.

Concrete made with aggregates of inferior or borderline physical quality cannot be improved by the use of admixtures, with the possible exception of air-entrainment. Bad concreting practice can never be compensated for by such extra ingredients. Inherent problems in operation, or problems with quality of materials, call for expert diagnosis and prescription, and this can be done only by a competent technologist.

RESEARCH NEEDED

It is evident from this general survey of the problems associated with the properties and use of admixtures in concrete that there are many areas in which further studies are required. The many variables involved and the complex nature of most of the commercial products make it almost impossible to discover the particular mechanism by which each one operates in concrete under different conditions. Published research is useful but is limited in value in that it applies in each case to a particular admixture, a particular combination of materials, or a particular condition of test.

The critical need is for an understanding of the fundamental processes that occur and the specific effects produced. This suggests basic studies in colloid and surface chemistry in relation to the physical structure of cement paste. The Division of Building Research, National Research Council, has begun investigations along this line. Studies to date have been mainly concerned with air-entrainment.

SUMMARY

Good concrete can be made without the use of admixtures. Entrained air is necessary, however, in exposed concretes in climates where freezing and thawing cycles occur. Certain other admixture types may provide some quality benefits in special situations but many such cases can be equally aided by better practice and control. Except in very special situations the use of an admixture specifically to reduce cement requirements has questionable merit.

Methods of test and performance specifications now make it possible to distinguish clearly between useful and useless or harmful admixtures. The practical application of these in individual cases poses certain problems, not the least of which is cost.

Determination of the adaptability of an admixture to a particular plant operation or combination of materials, and determination of the conditions under which it should be used, can be done correctly only by a concrete technologist who is fully competent to diagnose and prescribe.

Admixtures have become a part of general concrete technology and are here to stay. Used as "cure-alls" to compensate for bad practice or poor materials, they can be a serious liability. Used with intelligent discrimination, they may perform useful functions.