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Admixtures in Portland Cement Concrete

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Please note

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Most of the concrete produced in Canada, whether precast or cast *in situ*, is made with an admixture. Perhaps the best known admixtures are calcium chloride and the air-entraining agent, both of which are associated with cold weather construction problems. The use of set-retarders and water-reducers has become very extensive in recent years; and in the increasingly sophisticated and specialized processes and products of concrete demanded by industry today there is a growing use of such lesser known admixtures as corrosion inhibitors, expansion producing agents, and colour pigments.

The building designer has not usually felt the need to concern himself with details of concrete composition, leaving this to the specialist and to the concrete manufacturer. He has been content to specify certain minimum requirements such as compressive strength. Today, however, more is demanded of concrete than ever before, and it is being used in an ever-increasing variety of structural forms and functional situations. It is required to perform under severe environmental conditions, and is further faced with a high degree of competitiveness, with attendant emphasis on mass production and job scheduling. These developments have made it necessary for the building designer and the builder to know the full capabilities and limitations of their material.

Owing to these very developments, the concrete admixture has found more extensive application. Its purpose is to modify one or more properties of either the plastic mix or the hardened state of concrete. It thus makes possible certain adaptations of products and processes not always readily attainable by other adjustments. It is the "fifth" ingredient in concrete, an addition to the four basic components: portland cement, water, sand and stone. Concrete specifications today recognize the uses and functions of these agents, and they have become an integral part of concrete technology and practice.

Although it may solve a particular problem, an admixture may at the same time create other problems that must be anticipated. Like drugs, admixtures produce side effects that can be beneficial, harmless, or harmful, depending on the situation. The concrete producer may be aware of these, but he may not know whether they can be tolerated in the structure. The architect and builder should therefore become knowledgeable about the nature of admixtures, their advantages, and the problems connected with their use. This is particularly important in *in situ* concreting where the concrete is actually manufactured in place.

Workability of Plastic Concrete

The earliest use of a concrete admixture was probably in connection with improvement of mixing, placing and finishing properties of the plastic mix. This is an important consideration for the architect, for it makes possible the reduction or elimination of bleeding, segregation, honey-combing and other unsightly surface defects that can result from harshness of mix. Most of the admixtures used, whether air-entraining agents, set-retarders, or water-reducing agents, will improve workability. Although considered a side effect, the improvement of workability is often the primary reason for their use.

Air-Entrainment and Durability

Canadian winters produce cycles of freezing and thawing that can damage ordinary concrete in a relatively short time, especially if it is also exposed to the de-icing salts commonly used on pavements and sidewalks. Concrete with small discrete air bubbles entrained by an air-entraining admixture will resist such severe conditions. Because no general alternative has been established and because the improvement in durability is so great, all concrete specifications now require air-entrainment if the concrete is to be exposed to continuous or frequent wetting.

Air-entraining agents that produce proper air-void systems in the cement paste are formulated from such organic materials as wood resins, sulphonated hydrocarbons, and synthetic detergents. Specified dosages of the proprietary agents to produce the normally required 5 to 7 per cent air are in the order of 1 per cent by weight of the cement. The strength loss to be expected from the air can usually be compensated for by reduction in water-cement ratio through improved workability.

It has been established that air-bubble spacing should be in the order of 0.008 inch for optimum durability. The air-pressure meter and other such apparatuses are useful for quality control purposes but measure only total air. The determination of the type of air-void system requires a microscopic procedure not normally possible.

Accelerators

Cold weather concreting in Canada is associated with extensive use of the inorganic admixture calcium chloride. Contrary to some lingering opinions, it is not effective as an anti-freeze and is therefore not a substitute for cover or enclosure with heat, which are required for below-freezing temperatures. It is effective in maintaining satisfactory strength-gain of concrete at low temperatures at or above freezing.

In normal dosages of 1 to 2 per cent by weight of the cement calcium chloride accelerates time of set of plastic concrete as well as rate of strength-gain. In practice, a decrease in time of set may be required or desirable for earlier finishing of floors, reduction of form pressures, or quick-setting in spray-type processes. As an accelerator of strength-gain it can provide for early application of load and reduced curing period.

Unfortunately, calcium chloride has a number of side effects that are generally deleterious. These effects are not large, however, and they can normally be accommodated if provision is made for them. They are associated mainly with corrosion of reinforcing steel, drying shrinkage, creep, heat evolution and resistance to sulphate attack. Triethanolamine is an organic accelerator used in formulations to compensate for set-retarding properties of other admixtures. In this connection it is used in some air-entraining and water-reducing admixtures.

There are alternatives to accelerators, for example increased fineness of cement and elevated temperature, and these are often preferable from the point of view of both quality and cost.

Set-Retarders

In recent years the problems of hot weather concreting have been recognized as requiring special codes of practice. Premature stiffening and hardening can create difficulties in discharging, placing, and compacting fresh concrete. Set-retarding admixtures are now used extensively in such situations, particularly in ready-mixed concrete where long hauls in hot weather are involved. They extend the plastic period without subsequently affecting strength gain significantly. Practical alternatives do exist such as protecting aggregates from excessive temperatures by cover and precooling concrete with ice in the mix water.

A set-retarder may be useful in other situations: preventing unsightly "construction joints" by ensuring that the concrete in one "lift" remains plastic long enough for the next lift to be intermixed with it. It may help to reduce maximum temperatures in mass concrete by extending the time over which the heat of reaction is given off. It finds use also in grouts, pumped concrete and other processes.

Set-retarders used in Canada derive mainly from two sources, salts of lignosulphonic and hydroxy carboxylic acids. Some use is made of detergents, sugars, and, more recently, of silicones. Dosages range from 0.2 to 1 per cent by weight of the cement, overdosages being an obvious hazard. Concretes have been reported to remain unhardened after two weeks because of apparent overdosage.

Set-retarding admixtures provide a bonus by acting as water-reducers and workability agents. The lignosulphonate type tends to reduce bleeding and entrain air, whereas the hydroxy carboxylic type has the opposite effect. Either may be beneficial or detrimental, depending on the job requirements; and both types tend to increase the rate at which the concrete will stiffen, i.e. will lose "slump," an undesirable characteristic. A potential problem with these admixtures is that their presence in concrete is not easy to determine, especially quantitatively.

Water-reducers

The water-reducing properties of most chemical admixtures are interesting for two reasons. By lowering the mix water requirement they make possible an increase in compressive strength for a given cement content and slump. This also makes it possible to reduce the cement content for a given strength and slump. The latter is an attractive economic feature, cement being the most expensive ingredient of concrete. "Cement-stretching" can be carried too far, however, so that the quality of the concrete may be adversely affected, for example, in the areas of absorption, permeability, durability. An alternative to using the water-reducer is vibration compaction of low-slump concrete.

Water-reducers are marketed as such, although their basic ingredient is the same as that for set-retarders (lignosulphonates or hydroxy carboxylates). They are formulated so that the set-retardation properties are reduced or eliminated. They therefore possess the same side effects as set-retarders.

Other Admixture Types

Damp-proofing and water-proofing admixtures are intended to reduce water penetration of the larger pores in concrete. They include soaps, butyl stearate, mineral oil, and asphalt emulsions. Much uncertainty remains regarding the value and the hazards involved in their use. Some advantage is claimed in concrete block and brick manufacture where no-slump mixes are used. Generally, impermeability and low absorption characteristics of ordinary concrete can be achieved by attention to good concreting practices.

Corrosion problems with reinforcing steel are normally avoided by adequate cover of concrete, but they may be increased by the presence of calcium chloride or by carbonation. Corrosion-inhibiting admixtures are in limited use in the precast industry. Examples are: sodium benzoate, stannous and ferric chlorides, and sodium nitrite.

Bonding new concrete to old is an ever-present problem. Modified mortars made with bonding admixtures such as polyvinyl chlorides and acetates, acrylics, and butadiene-styrene co-polymers can be used in these situations.

The types of admixture discussed thus far are the so-called chemical admixtures, which are distinguished from the mineral powder type such as fly ash. Chemical admixtures are added in very small quantities, in the order of 1 per cent by weight of the cement, whereas the mineral powder type is added in quantities from 10 to 50 per cent by weight of the cement.

Fly ash and pozzolanic materials such as volcanic ash and calcined shale and clay are used as replacements or substitutes for part of the cement. They have some cementitious value at later ages and thus can contribute to ultimate strength and impermeability. They are used to reduce heat development in mass concretes, to reduce bleeding and segregation, to improve workability, to reduce excessive expansion caused by alkali-aggregate reaction, and often simply to reduce the cost of cement. As they are added in relatively large proportions and because they are inorganic in nature, their effects are less complex and the possibility of side effects is smaller than is the case with organic chemical admixtures. Integrally added colour pigments of the metal oxide type belong to this type of admixture. Dosages of iron or chromium oxides, for example, may range from 2 to 10 per cent by weight of the cement.

The admixture types considered here do not constitute a complete list, but they represent the main ones. The factors discussed serve to illustrate the growing complexity of modern concretes and the need for the designer and builder as well as the manufacturer to be aware of the potentials and hazards of admixtures.

General Applications and Problems

The requirements and problems encountered in the use of concrete admixtures vary considerably with manufacturing and placing processes. In precast plants there is single control of all materials and operations from the selection of component materials to the final curing of the product. Problems can thus be reduced to a minimum. There is extensive use of accelerators to reduce curing periods, water-reducers to cut costs, and retarders to provide homogeneity of large elements. On-site concreting also involves a single authority and therefore good control.

The ready-mix concrete operation poses a problem in that the producer loses control when the job contractor takes over. This divided authority can lead to difficulties such as those having to do with the effects of admixtures. The designer or builder may be the heir to unsatisfactory consequences if proper measures are not taken to ensure the necessary quality control. With precast concrete the architect and builder may not find it necessary to be concerned with any detail of concrete composition or with ancillary properties, because the products are finished in form, as is glass and wood. But for *in situ* concreting the producer, the placing contractor, and the builder are involved in the actual manufacturing process, so that the quality and performance of the finished concrete will depend on their combined knowledge and decisions. Dependence on specifications alone is never adequate. In fact, a meaningful specification for concrete for a given job cannot be properly developed without a thorough technical knowledge of the materials and processes concerned.

Selection of a suitable admixture for a particular job may present problems, not least of which is whether one is in fact necessary. Alternatives should always be considered. For any one type of admixture, there are usually many brands on the market, each with more than one basic ingredient. As was true with set-retarders, this means different side effects. The chemicals are usually complex and sometimes variable in composition, and the formulas are changed often with no warning to the user.

At the very least, the building designer should be aware of these general considerations. He should also be aware of the plant adjustments required to accommodate the use of an admixture: handling, storage, preparations, and dispensing. For example, special storage is required where an admixture is sensitive to temperature; and many chemical admixtures, contrary to casual information, form colloidal suspensions rather than true solutions. The consequent danger of coagulation and settlement may be avoided by a system of stirring. Dispensing equipment must be essentially fool-proof and frequently calibrated.

Every mix design requires modification when an admixture is to be included. Most concrete admixtures of the organic chemical type are influenced by cement type and brand, aggregate grading, water-cement ratio, and temperature. Thus, there should be assurance that the admixture to be used has been properly tested. Test data supplied by the admixture manufacturer or test data involving other materials is not adequate. The tests must be made in the plant on the materials to be used.

Today, after years of evolution, excellent performance specifications have been developed for concrete admixtures. Early selection was based on limited field performance, and resulted in specification by brand name. Consequent abuses, therefore, led to attempts to specify such material requirements as chemical composition. The present performance specifications are those required and referenced in the Canadian Standards Association Standard for Concrete Materials and Methods of Concrete Construction, A23.1-1967. The essential features of these specifications, in addition to requirements on the specific effect claimed for the admixture, are that the admixture does not adversely affect other properties of the concrete. By a series of corresponding tests it is thus possible to evaluate an admixture on a performance basis.

Concluding Statement

Admixtures can be used to advantage in modern concretes. They are used for "curative" or "preventive" purposes, for example, air-entrainment; they are used as "aids," for example acceleration of hardening; and they are used for purely money-saving purposes, for example water-reducers. The full list of benefits is impressive for both producer and consumer of concrete. As has also been noted, however, these benefits are contingent on proper use and knowledge of side effects and other hazards. An admixture cannot compensate for inferior materials or bad practice. In most cases there are alternatives worth consideration on economic as well as quality counts.

Admixtures in every-day concreting operations will continue to have an important place in concrete technology. Their successful use depends upon proper diagnosis and correct prescription for each situation. This, in turn, requires not only a basic knowledge of concrete technology, but also recognition that an admixture requires modification of procedures. It also implies recognition of the essentially chemical nature of admixtures and the processes they are involved in. The architect or builder need not become an expert on admixtures, but it has become evident that it is to his advantage to be familiar with their type, nature, and general effect.