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Please note

The addition of small amounts of certain materials to concrete to promote desirable properties is as old as the use of cement itself. The Romans used blood, pig's fat and milk as additions to pozzolanic cements to improve their workability and durability. Today, many hundreds of chemicals claimed to possess one or more beneficial effects have been suggested for incorporation in concrete. These are known as admixtures and are added to water, aggregate and hydraulic cement immediately before or during mixing (**CBD 103**). Most admixtures are known by the function they perform. Typical examples include water reducers, retarders, water reducing accelerating agents, accelerators, and water-proofers.

An accelerator, as the term suggests, increases the rate of development of certain characteristic properties of cement and concrete. It does not necessarily accelerate the development of every one of them. In a chemical sense acceleration may mean an over-all increase in the rate of reaction; in the physical sense, an increase in the rate of setting; in a mechanical sense, an increase in the rate of development df strength. From the practical point of view this means reduction in the curing period and reduction in the time during which concrete must be protected in cold weather, earlier finishing operations, and earlier availability for public use.

Several chemicals are known to act as accelerators for concrete — calcium formate, aluminum chloride, potassium carbonate, sodium chloride and calcium chloride (among others) — but calcium chloride is most widely used. Its popularity is due to its ready availability, low cost, predictable performance characteristics, and successful application over several decades.

Concrete has to satisfy many performance requirements. The addition of calcium chloride promotes certain desirable properties and affects others; but the performance of a concrete containing calcium chloride admixture can reasonably be predicted only when both the short- and long-range effects have been established. Such knowledge permits judicious use of admixtures. Originally, the science of admixture was the province of a specialist, but with advanced building technology and ever increasing new demands on builder, engineer and architect it is necessary that all involved in building have as much knowledge of admixtures and their effects as of cement, aggregate or the mixing water.

Methods of Adding Calcium Chloride

The amount of calcium chloride to be used for a particular job depends on the requirements, although it is generally recommended that the dosage should not exceed 2 per cent by weight of cement. It should be noted, however, that this percentage refers to calcium chloride in the flake form, which is a hydrate containing about 2 molecules of water (2 per cent of flake calcium chloride is equal to about 1.5 per cent anhydrous $CaCl_2$).

Calcium chloride is available as pellets or other granules, flakes, or in solution form. The regular flake form contains a minimum of 77 per cent calcium chloride and the pellet and other granular forms a minimum of 94 per cent. The material is supplied in moisture-proof bags, air-tight drums, or other appropriate means and should be stored carefully against moisture pick-up. If any lumps develop during storage they should be discarded.

Calcium chloride is soluble in either cold or hot water. In making a solution it is good practice to add the salt to the water, for if water is added to the salt a hard coating forms, making dissolution slow. Freshly made, the solution is warm and should be cooled before use.

Very concentrated solutions of calcium chloride are not prepared because of the possibility that excess chloride will settle to the bottom. It is more convenient to prepare a solution containing 4 pounds of regular flake form (with 77 per cent minimum calcium chloride) or 3¼ pounds of pellet or concentrated flake or other granulated form (with 94 per cent minimum calcium chloride) in each gallon of solution. It then becomes practical, though not exact, to add 1 quart of standard solution per sack of cement when 1 per cent calcium chloride is specified or 2 quarts per sack for 2 per cent calcium chloride. The solution is considered to be a part of the mixing water for concrete. For example, for a 5-sack, 5-cubic yard mix (5 sacks per cubic yard) requiring 2 per cent calcium chloride and 150 gallons of mixing water, the chloride solution would account for 12.5 gallons and the water for 137.5 gallons.

Calcium chloride solution may be added manually, but an automatic dispenser is more reliable. The solution should not come into direct contact with cement because it may flash set. It is usually added to the mixing water or to the aggregates. When calcium chloride solution is supplied directly by the manufacturer, its strength can be assessed by determining the specific gravity with a hydrometer.

Effect on Physical Properties of Concrete

Calcium chloride significantly reduces both initial and final setting time of concrete. This is particularly useful for concreting operations carried out at low or moderate temperatures. It permits quicker finishing and earlier use of slabs. Excessive amounts (for example, 4 per cent) cause a very rapid set, however, and should be avoided. Even small amounts should not be used in hot weather because setting may occur so rapidly that placing and finishing may become very difficult; strength may also be affected. Both CSA A266.2-1973 and ASTM C494-1971 standards require that with calcium chloride the initial setting time should occur at least 1 hour earlier (but no more than 3 hours [CSA] or 3½ hours [ASTM]) with respect to the reference concrete. The ASTM standard also specifies that final setting time should be at least 1 hour earlier than that of the concrete without calcium chloride. The influence of different amounts of calcium chloride on initial and final setting times of a neat cement paste is indicated in Figure 1.

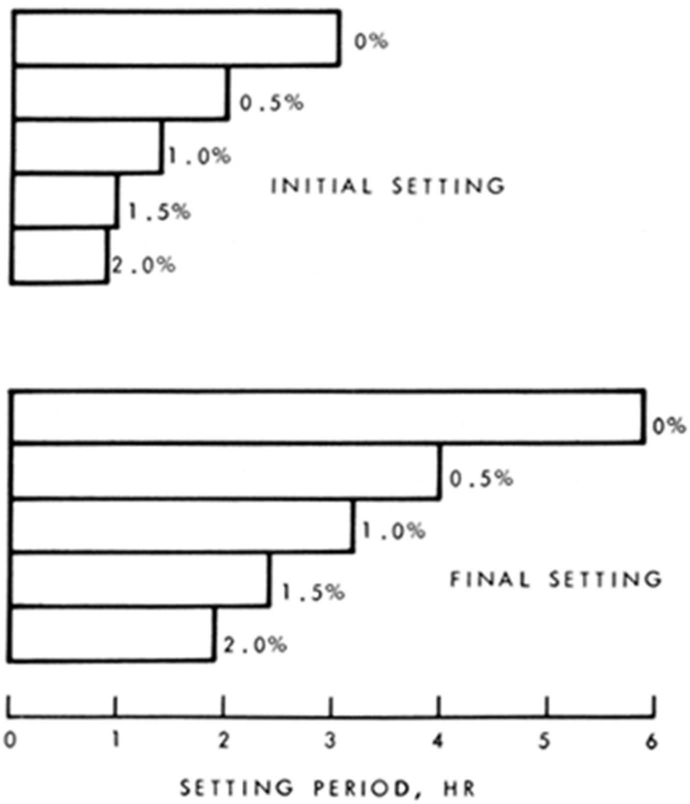

Figure 1. Initial and final setting periods of a cement paste containing different amounts of calcium chloride.

Calcium chloride does not significantly reduce the water required to produce a given slump and this factor is not expected to play any dominant role in the strengthening of concrete. As it is an accelerator, it may tend to induce early stiffening and thus reduce bleeding.

By itself, calcium chloride does not cause entrainment of air in concrete. When used with air entraining agents, however, generally less agent is required to produce a given air content. As it may not be compatible with some air entraining agents, preliminary tests should be made; and if compatibility is a problem the admixtures should be added separately.

In many instances a whitish deposit on cured concrete is attributed to the presence of calcium chloride. Under normal conditions of exposure, however, it attracts water (being deliquescent) and is not likely to cause efflorescence as other salts do. In addition, part of the added chloride becomes intimately bound with the hydrated cement phases and is not easily soluble in water. When efflorescence does occur it can be removed with dilute hydrochloric acid, followed by rinsing with water.

Concrete containing calcium chloride hardens rapidly and develops early resistance to damage by freezing and thawing. This may be important in winter concreting when the material can be subjected to early application of de-icing salts. At later ages the matured concrete containing calcium chloride may be less resistant to frost attack.

The volume changes that occur in concrete in the presence of calcium chloride under different conditions of curing and drying and under comparable degree of hydration are not well established. In most cases calcium chloride is known to increase drying shrinkage, the magnitude depending on the amount of calcium chloride added, the type of cement, the period of curing, and environmental conditions. Some work has shown that it is possible to reduce drying shrinkage by the addition of sodium sulphate. In both CSA and ASTM standards the maximum shrinkage allowed for concrete containing chemical admixtures, including calcium chloride, is 135 per cent over that of the reference specimen (when the shrinkage of the control specimen is 0.03 per cent or more). In the usual recommended dosage this requirement is fulfilled.

Effects of Calcium Chloride on Mechanical Behaviour of Concrete

Addition of calcium chloride results in accelerated hardening of concrete containing any type of portland cement. This has naturally made the use of calcium chloride very widespread. Maximum rate of increase is attained within 1 to 3 days of curing, its development depending on curing conditions, water/cement ratio, type of cement, amount of admixture, etc. In comparison with a reference concrete (without calcium chloride), strength gain may vary between 30 and 100 per cent in the first three days, the value falling with further curing. The specifications recognize this fact. For example, ASTM C-494 requires an increase of at least 125 per cent over the control concrete at 3 days, but at 6 months or one year the requirement is only 90 per cent of the control specimen. Amounts of calcium chloride in excess of accepted standards cause lower strengths. For the same amount of chloride strength increases are larger for richer mixes. The effect of calcium chloride on the percentage gain in strength is particularly significant at lower temperatures (Figure 2).

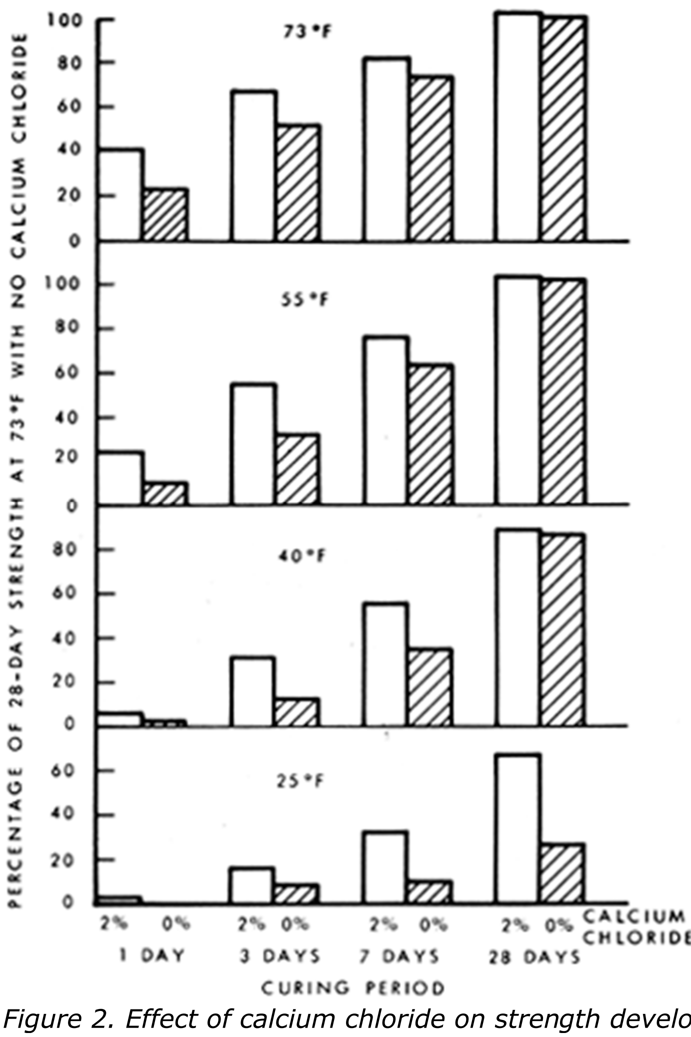

Figure 2. Effect of calcium chloride on strength development in concrete at different temperatures. (Replotted from results published in Journal, Amer. Concrete Inst., Vol. 52, June 1956, p. 1043).

Flexural strength does not increase so much as compressive strength with addition of $CaCl_2$. ASTM C-494 requires that flexural strength at 3 days should be at least 110 per cent of the control specimen, but the corresponding requirement for compressive strength is 125 per cent.

After longer periods of curing the flexural strength of concrete containing calcium chloride may even be lower than that of the control specimen.

Shrinkage and creep in cement pastes seem to be interrelated. As calcium chloride tends to increase shrinkage of concrete, it seems possible that it will also increase creep.

Chemical Effects on Concrete

In certain situations where concrete is exposed to solutions of sulphates it may deteriorate; the sulphates react with calcium and aluminum ions in the cement paste to form calcium sulphate and calcium sulphoaluminate hydrates, accounting for disruption of the concrete. If calcium chloride is present, there is evidence that resistance to sulphate attack is reduced. Thus, calcium chloride is not recommended for concrete exposed to sulphate attack. In certain instances it may be used in a concrete member exposed to a sea water environment, but its use should be determined by the function of the member and the severity of exposure (CSA A231-1973).

Certain types of aggregate used with cement containing high amounts of alkali can cause swelling and deterioration of concrete by reacting with the alkalis. Experiments have shown that calcium chloride in concrete aggravates the alkali-aggregate reaction. If calcium chloride has to be used in such situations expansion may be controlled by the use of low alkali cement, pozzolan or a non-reactive aggregate.

In addition to increasing the rate of cement hydration, calcium chloride also causes the hydration reaction to start sooner. Hydration of cement produces heat, and because hydration is more rapid in the presence of calcium chloride heat is produced at a faster rate, particularly in the first 10 to 12 hours. The total amount developed is not much changed, but its early development may be useful in winter concreting.

In well made, reinforced concrete, corrosion of steel is uncommon because in the alkaline environment a protective oxide film forms over the steel and makes it passive. The film is stable, however, only so long as a certain minimum pH is maintained. In concrete containing calcium chloride, this stable film cannot be maintained with the same efficiency and a potential for corrosion exists. For this reason precautions must be taken when calcium chloride is used in reinforced concrete: normally an adequate concrete cover and thorough consolidation.

Some countries do not recommend the use of calcium chloride in reinforced concrete. Corrosion is critical in prestressed steel because the surface area of the wires is large and stress differences are greater Calcium chloride is therefore prohibited for prestressed concretes. In post-tensioned concrete, in which the wires are encased in tubes, the use of calcium chloride is not prohibited but it should not be used in grout. Neither should it be used in concrete containing a combination of dissimilar metals or where there is a possibility that stray electric currents will be present. Calcium chloride is not advocated for steam cured concreting unless it is shown that for a specific case no corrosion occurs.

There is a general belief that the detrimental effect of calcium chloride on reinforced steel is caused by the presence of the total amount of chloride added initially to the concrete mix. Experiments have shown, however, that part of calcium chloride reacts with the constituents of cement and is not easily soluble — for this reason the corrosive effect is not so great as would otherwise be expected.

Concluding Remarks

This Digest has described the role of calcium chloride in concrete, its beneficial and deleterious effects, and has suggested in what situations it should be used with caution. It is quite possible that future modifications may remove these restrictions.

There is a continuing misconception with regard to the use of calcium chloride as an "antifreeze." In the amounts used in concrete it has only a negligible effect on freezing so that although the time required for protection may be reduced the standard methods of protection should be followed for cold weather concreting.

Calcium chloride will not "cure" all problems in concrete practice, nor should it be treated with grave suspicion. It can make a well made concrete better; it cannot correct poorly made concrete. It is no substitute for good design, proper workmanship or quality materials. Its use should be dictated by a particular situation. If it is not, alternative methods such as the use of Type III cement, additional cement, finer cement or the application of a different method of curing or protection or a combination of these should be considered.

Although there has been extensive work carried out on the mechanism of the action of calcium chloride in concrete, it is not yet clearly understood. Theories are generally based on chemical effects, micromechanics, morphology, porosity, solubility, surface area or other considerations, but it is probable that a combination of these effects may be responsible for its action.

There is a continuing search for an alternative to calcium chloride, one without its limitations. Experiments on several inorganic salts have shown, however, that calcium chloride is still the most practical accelerator for concrete.