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Superplasticizers in Concrete

Please note

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A superplasticizer is one of a class of admixtures called water-reducers that are used to lower the mix water requirement of concrete. Normal water-reducers based on lignosulphonic acids, hydroxycarboxylic acids or processed carbohydrates are capable of reducing water requirements by about 10 to 15 per cent. Incorporating larger amounts to produce higher water reductions results in undesirable effects on setting, air content, bleeding, segregation and hardening characteristics. Superplasticizers are chemically different from normal water-reducers, and are capable of reducing water contents by about 30 per cent. They are variously known as superplasticizers, superfluidizers, superfluidifiers, super water-reducers or high range water-reducers. Since they were first introduced in Japan about 15 years ago they have been used to produce several million cubic metres of concrete; in the construction of the Olympic stadium in Montreal alone, 5000 precast concrete units were produced utilizing superplasticizers.

The basic advantages of superplasticizers include, (1) high workability of concrete, resulting in easy placement without reduction in cement content and strength; (2) high strength concrete with normal workability but lower water content; and (3) a concrete mix with less cement but normal strength and workability.

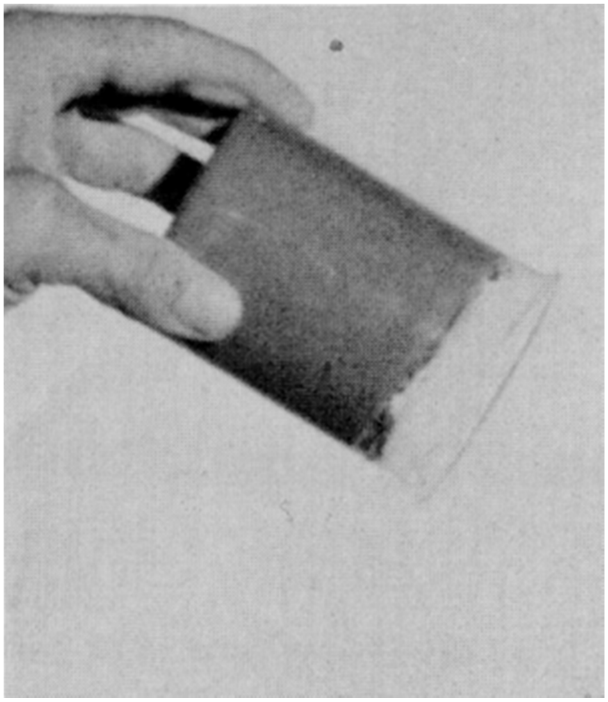
Superplasticizers are broadly classified in four groups, viz, sulphonated melamine-formaldehyde condensates (SMF), sulphonated naphthalene-formaldehyde condensates (SNF), modified lignosulphonates (MLS), and others including sulphonic acid esters, carbohydrate esters, etc. variations exist in each of these classes and some formulations may contain a second ingredient. Most available data, however, pertain to SMF- and SNF-based admixtures. They are supplied either as solids or as aqueous solutions. In this Digest the dosage refers to the solid as a percentage of the weight of cement.

Flowing Concrete

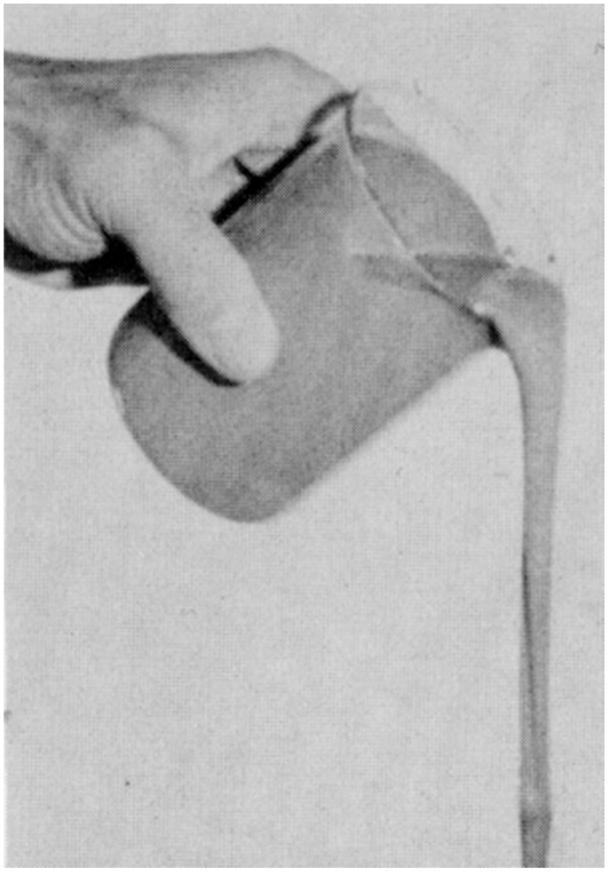
Concrete of good workability has advantages in that it permits easy and quick placement. A reasonably workable concrete can be obtained by using a high cement content while maintaining the normal water: cement ratio or by increasing the water content while maintaining the same cement content. Both methods, however, lead to segregation, excessive shrinkage, undesirable heat development, and long-term detrimental effects.

With the advent of superplasticizers it has become possible to achieve a slump in excess of 200 mm from an initial slump of about 50 mm with dosages of from 0.3 to 0.6 per cent. Within a few minutes of the addition of superplasticizer concrete begins to flow easily and becomes self-levelling. It remains cohesive and does not have undesirable bleeding, segregation or strength loss characteristics. Such a concrete is variously known as flowing concrete, self-compacting concrete, flocrete, soupcrete, liquid, fluid or collapsed concrete. For best results high fine contents should be used.

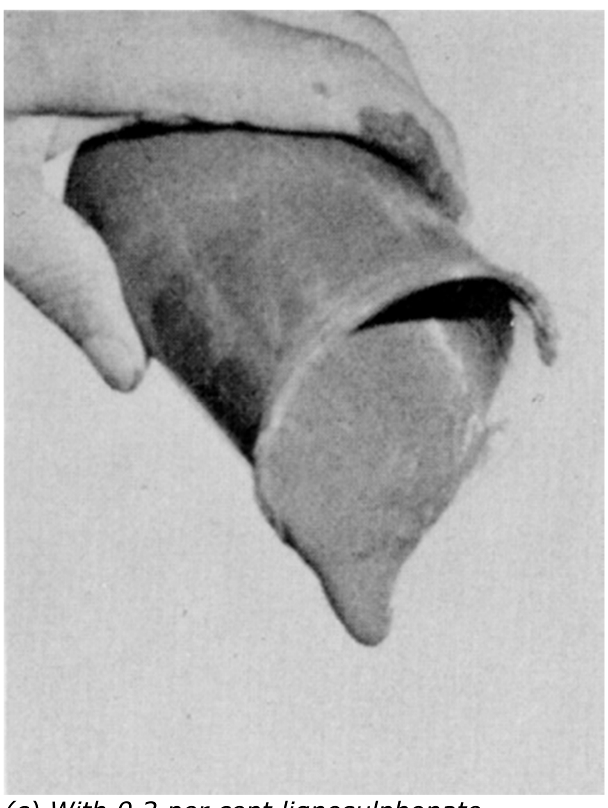
Figure 1. Effect of plasticizers on the flowability of cement paste (water:cement ratio = 0.3).



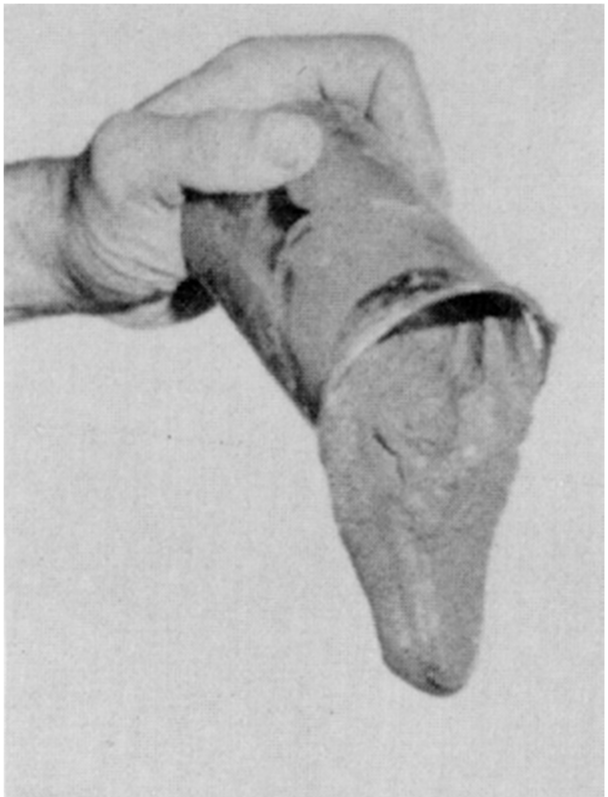
(a) No plasticizer.



(b) With 0.3 per cent superplasticizer.



(c) With 0.2 per cent lignosulphonate.



(d) With 0.4 per cent lignosulphonate.

The fluidizing effect achieved by the addition of 0.3 per cent superplasticizer to cement formed at a water: cement ratio of 0.3 is illustrated in Figure 1a, Figure 1b, Figure 1c, & Figure 1d. Without admixture (Figure 1a) the cement paste does not flow, but with the superplasticizer it flows like a liquid (Figure 1b). The addition of a normal water reducer (0.2 or 0.4 per cent lignosulphonate), on the other hand, induces the formation of only a viscous cement paste (Figure 1c and Figure 1d).

Flowing concrete permits placement in congested reinforcement and in relatively inaccessible areas. The problem of cutting and adapting formwork for vibration is thus eliminated. Easy and quick placement characteristics and the need for only nominal vibration make it suitable for placement in bay areas, floors, foundation slabs, bridges, pavements, roof decks, etc. Pumping of concrete is very much improved by incorporating superplasticizers, which have also been found successful in concrete placed by tremie, particularly under water.

The use of superplasticizers necessitates changes in the normal procedure for making and placing concrete. The proportions of cement, sand, aggregate and dosage of superplasticizer should be adjusted to avoid segregation. In addition, high flowing concrete generates more than normal pressures on the forms, so that they must be designed to withstand them. Flowing concrete is not amenable to easy placement on slopes exceeding about 3 deg to the horizontal. In many instances incorporation of more than normally suggested dosage yields further advantages, but this does not mean that excessive amounts can be tolerated. Beyond a particular amount the superplasticizer may produce undesirable side effects.

High-Strength Concrete

A concrete of high strength can be made without admixtures provided it is mixed with low amounts of water and has desirable workability characteristics. At low water. cement ratios however, it is not easy to achieve good workability. As water reductions of about 25 to 30 per cent can be achieved by using superplasticizers without loss in workability characteristics, significantly higher initial and ultimate strengths are realized. Although high cement content may also be used to obtain high initial strengths in concrete, the higher heat developed by the chemical reactions produces undesirable cracks and shrinkage.

High early strength development, a characteristic of concrete made using superplasticizers at low water:cement ratios, is particularly advantageous in the production of precast units. For prestressed beams and units, which need overnight heat-curing, use of superplasticizers allows reduction in curing time and curing temperatures. High early strengths are particularly useful for placing concrete in traffic areas such as city roads and airport runways. Pumping at reduced water content is also facilitated by the use of superplasticizers.

Fresh Concrete

Plasticizing Action. In normal cement paste large irregular agglomerates of cement particles predominate in the water suspension. The addition of a superplasticizer causes them to disperse. Available data suggest that the admixture is absorbed by the cement particles and causes them to repel each other, resulting in better workability.

Slump -- Influence of Various Factors. The slump increase in flowing concrete depends on the type, dosage and time of addition of the superplasticizer, on water:cement ratio, nature and amount of cement and aggregate, temperature etc. For example, to obtain a slump of about 260 mm from an initial value of 50 mm it may be necessary to add 0.6 per cent SMF- or MLS-based superplasticizer, whereas the same results can be achieved with only 0.4 per cent SNF-based admixture. The slump increases with the amount of superplasticizer added, but effectiveness will not improve beyond a particular dosage. Although the slump value of concrete is increased by the addition of superplasticizer along with the mix water, much higher slump values are obtained when the admixture is added a few minutes after the concrete has been mixed with water.

Most types of cement show an increase in workability with the addition of superplasticizer. The relative fluidity values depend on factors such as the chemical and mineralogical characteristics of the cement and its surface area. It is essential, therefore, that preliminary tests should be carried out, especially if a cement other than type I portland cement has to be used for the production of flowing concrete. The slump values are also influenced by the cement content of the concrete, increasing with cement content.

Slump Loss. Higher than normal workability of flowing concrete containing a superplasticizer is generally maintained for about 30 to 60 minutes, so that it is necessary to place the concrete as early as possible after the superplasticizer has been added. In ready-mix operations the superplasticizer can be added only at the point of use. Factors that affect slump loss include initial slump value, type and amount of superplasticizer added, type and amount of cement, time of addition of the superplasticizer, humidity, temperature, mixing criteria and the presence of other admixtures in the mix. The rate of slump loss can be decreased by adding a higher than normal dosage of superplasticizer, by adding the superplasticizer at different intervals of time, or by including some type of retarder in the formulation.

Setting properties. The initial and final setting times of flowing concrete may or may not be changed by the use of superplasticizers. The type and amount will determine whether setting times are retarded, accelerated, or unaffected. In high-strength concrete containing small amounts of superplasticizer, the setting times are retarded; at higher dosage they are accelerated.

Air Content. During mixing of a non-air-entrained flowing concrete containing a superplasticizer air may be released owing to the low viscosity and dispersed state of the fluid concrete. The total air content of an air-entrained concrete undergoes change in the presence of a superplasticizer. At low dosages the difference in air content is marginal, but at higher dosages air content may decrease with the addition of SMF- and SNF-based admixtures and increase with an MLS-based admixture.

Water Reduction. In high-strength concrete the amount of water reduction achievable with a particular superplasticizer depends on dosage and initial slump. There is evidence that beyond a particular dosage further water reduction may not be possible. At a constant slump and dosage, different cements show different water reductions, but the amount generally increases with increased cement content. It appears that for equal water reductions more SMF- than SNF-type admixture is required.

Hardened Concrete

Strength. In general, higher strengths result in flowing concretes containing SMF and SNF superplasticizers than in concretes of the same mix proportions that contain no admixture. In high-strength concrete increased strengths are obtained with all types of superplasticizer using all types of cement, in comparison with the reference concrete made at the same slump. If comparison is made on the basis of equal water:cement ratio, however, strengths become almost equal after several months. The enhanced strengths are thus mainly attributable to lower water:cement ratio.

Although in flowing concretes made with SMF superplasticizers the splitting tensile strength, flexural strength, and Young's modulus are not different from those of concrete without admixture, these values are higher in high-strength concretes as the water:cement ratio decreases. Data available on concretes with SMF admixture indicate no evidence of long-term strength impairment.

Shrinkage and Creep. Shrinkage and creep characteristics of flowing concrete containing types SMF and SNF admixture are basically the same as those of the base concrete produced at the same water:cement ratio. In high-strength concrete these values will generally be lower.

Durability. Studies of air-entrained flowing or high-strength concrete containing SMF-, SNF and MLS-type superplasticizers reveal that they are as durable as the control concrete. There is considerable evidence that in spite of a higher air-void spacing factor in concrete containing superplasticizers its resistance to freeze-thaw cycles is not affected.

Concluding Remarks

It has long been a concrete technologist's dream to discover a method of making concrete at the lowest possible water: cement ratio while maintaining high workability. To a considerable extent this dream may be fulfilled with the advent of superplasticizers. They have added a new dimension to the application of admixtures, and have made it possible to produce concrete with compressive strength of the order of 90 MPa.

Superplasticizers have other possible applications. Energy conservation and diminishing supplies of high quality raw materials will increasingly necessitate the use of marginal quality cements and aggregates. In such instances the use of superplasticizers may permit production of concrete at low water:cement ratios that will be strong enough to meet normal performance requirements. There are literally countless possible applications of superplasticizers, for example, in the production of fly ash concrete, blast furnace slag cement concrete, composites with various types of fibres and lightweight concrete. In addition, the dispersing effect of superplasticizers is not limited to portland cement and may find application in other cementitious systems.

The fact that superplasticizers show remarkable advantages in producing concrete should not imply that there are no problems associated with their use. A satisfactory solution to the high rate of slump loss in superplasticized concrete is yet to be found and the relative effects of materials, production methods and external conditions that influence this phenomenon are not completely understood. Further study will be necessary of the compatibility of other admixtures such as retarders, accelerators and air-entraining agents in combination with superplasticizers. Though surface area, tricalcium aluminate, and sulphate contents seem to influence slump, no definite trend has been established.

Most available data on superplasticized concrete have been obtained using SMF- and SNF-based superplasticizers. Even within a single type, variations in behaviour have occurred, possibly because of the differences in molecular weight and in the type of cation associated with the superplasticizer. Consequently it is difficult to predict exactly the properties and behaviour of superplasticized concrete. As more data become available, especially on the long-term behaviour of these concretes, it will be possible to formulate standards and codes of practice. The future use of superplasticizers will, however, be dictated by cost factors (of admixture and operating costs) and by acceptance by industry.