SP 62-1

The Concept of Superplasticized Concrete

By P. C. HEWLETT

Synopsis: The meaning of the term superplasticised concrete and the concept to which it relates together with a brief outline of its development are described. Comparisons are made with this type of concrete and that regarded as conventional. Distinction is made between high workability/normal water content concrete as opposed to high strength/low water:cement ratio concrete.

The dependence upon mix design, admixture addition and type as well as method of mixing and placing receive attention. The fluid stage and hardened concrete properties are discussed.

Practical applications of the concept are mentioned and coupled with costs.

Keywords: admixtures; concrete construction; concretes; construction costs; high-strength concretes; mixing; mix proportioning; placing; plasticizers; water-cement ratio; water content; water-reducing agents; workability.

Dr P. C. Hewlett is Director of Cementation Research Ltd (U.K). A Chartered Chemist with a Doctorate in Physical/Organic Chemistry he has specialised in construction materials research for 15 years embracing both organic and inorganic compositions. Cement admixtures have been a particular speciality.

Dr Hewlett is Deputy Chairman of the Cement Admixtures Association (U.K) and was Chairman of the working party that produced the Cement Admixtures Association and Cement and Concrete Association document "Superplasticising Admixtures In Concrete".

INTRODUCTION

To prevent ambiguity when dealing with the concept of superplasticisers and superplasticised concrete it is important to clearly define the terms used.

Superplasticised concrete is conventional concrete containing a chemical admixture of the superplasticising type. Two main categories of superplasticiser form the basis of most proprietory admixture types. For instance,

Category A type - based upon sulphonated melamine/formaldehyde condensates.

Category B type - based upon sulphonated naphthalene/formaldehyde condensates.

Conventional concrete is mentioned as the starting point since we are, by and large, concerned with concrete made from usual cements, coarse and fine aggregates. Whilst superplasticised concrete mix design requires a particular fines component in the aggregate, even so, the concept is not "special" in the basic concreting materials sense. The uniqueness of superplasticised concrete stems from the properties imparted to the concrete as a result of the addition of one of these new admixtures. The concrete is novel on two counts:

1. If the superplasticiser is used as a concrete workability improver, then the normal slump concrete becomes "flowing concrete". This is concrete having a slump equal to 200mm (8") or more, a compacting factor of

approximately 0.98 and a Flow Table (1) value within the range 510-620mm (20.4-24.8"). In addition to having high workability, flowing concrete should not exhibit excessive bleeding or segregation. Abnormal retardation and air entrainment should also be absent. Flowing concrete is also referred to as self-compacting concrete, Flocrete, collapsed slump concrete and Soup-crete. All the terms relate to the same workability state of the concrete.

2. As with conventional workability or plasticising admixtures, one can take advantage of the enhanced workability state to make reductions in the water content of superplasticised concrete, whilst maintaining conventional workability levels, namely 50-70mm (2-2.8") slump. Concrete in this state is sometimes referred to as "water reduced" or "high strength" concrete.

Whilst the use of superplasticised concrete is relatively new in some countries such as the U.K. it is not a new concept in Germany and Japan. It is really from these countries that its use has grown into a substantial practice, both for normal construction and in the precasting industries.

The usage of placed superplasticised concrete has now reached several million cubic metres and "in service" case histories extend over a period of some 12-13 years. In this respect the concept of, and admixture materials used in superplasticised concrete are established and not a sudden departure from accepted concreting practice. Dispersing admixtures similar to the present superplasticisers were known as long ago as 1935. However, in 1954 L. S. Wertz (2) noted the improved viscosity properties of cement slurries when containing this type of chemical but did not extend the concept to concrete.

Concept Is Novel But Not Radical

The Concept Of Flowing Concrete

It has long been a desirable engineering objective to be able to make concrete that would to all intents be self-levelling and flow like a Newtonian fluid whilst maintaining w:c ratio levels that did not cause bleed, segregation or strength reductions either during or after placing of the concrete. Selecting aggregate and using high sand and cement contents high workability can be achieved but there is a limit to which mix design can be taken whilst maintaining strength and this limit appears to be a slump value of about 150-180mm (6-7.2"). Even then strengths in relation to cement contents are low.

Concrete designed to have an initial slump of 75mm (3") and suitable as a pump mix will, by the addition of a superplasticiser at the manufacturers recommended dosage (usually 1-6 litres per cubic metre), have its slump increased to something in excess of 200mm (8").

The degree to which concrete can be rendered fluid by means of a superplasticiser depends upon aggregate type, shape and overall grading. There is usually an upper limit on dosage above which the concrete or specifically the cement grout component, becomes so fluid that segregation may result.

The workability state of flowing concrete is quite distinct from conventional concrete in that whilst it remains cohesive, it will flow readily with gentle vibration and is almost self-levelling.

Let us consider some other aspects associated with the concept of superplasticised concrete and its practical use.

Due to problems of transporting high-slump concrete, it is very likely that the admixture will be added to the concrete just before it is used. In addition to the problem of transportation we have to accommodate the time dependence of the high workability effect. Figure 1 shows how flowing concrete gradually reverts to its original workability some 30-90 minutes after dosing with the superplasticiser. The data shown relate to typical truck mixing conditions for an approximately 5-m^3 (6.54 cubic yd) load. It is possible, by re-dosing the concrete, to reinstate the high workability. However, repeated admixture additions are not recommended (3) and it is best to use the concrete as soon as possible after dosing. However delays can be accommodated by stopping the mixer and re-starting just before the concrete is to be placed. Continued mix agitation causes a more rapid reversion in workability.

The concept of superplasticised concrete in the fluid state is visually obvious but the conventional methods of workability measurement are inadequate and do not measure the combination of cohesion and ease of flow. There have been attempts to categorise the workability of superplasticised concretes by tests other than the conventional tests of slump, compacting factor VB and Flow table.

Figures 2 and 3 show the variation in "yield value" and "plastic viscosity" for normal, plasticised and superplasticised (flowing) concrete. The latter is characterized by very low yield and viscosity values. The yield value is related to the extent to which the concrete will flow, whereas the viscosity values are related to the rate at which this flow will occur. The "two-point" workability test is particularly appropriate for high flow concretes (4). The relationship of Flow table and slump for a particular mix is shown in Figure 4. The inadequacy of the slump test is apparent since it is already at its practical limit although with care it is possible to extend its application to 200-220mm (8-8.8").

Flowing concrete gives rise to rapid collapse slump, but the concrete remains cohesive and non-segregating.

Considerable quantities of air are released from flowing concrete. This effect is due to both the normal air release capability associated with plasticising or water reducing admixtures and the lower "viscosity" of flowing concrete which eases the release of entrapped air. Typical residual air content figures are 1.2-2.7%. The cement content limit below which the concept of fluid concrete becomes less obvious is about 200 kg/m^3 (335 lb/yd^3) of cement.

The properties of hardened flowing concrete are dealt with in The Working Party Report, Section 6.8 (5). The concept does not appear to adversely affect strength development, load deformation/creep aspects, durability or shrinkage. However, two recent publications (6,8) infer that the long term freeze-thaw durability of high-flow superplsticised concrete is significantly lower than an appropriate control concrete. Tynes (6) attributes this reduction to an increase in the bubble spacing factor. Results by Edmeades and Hewlett (7) for "corresponding" concrete are shown in Figure 5. The presence of a superplasticiser in the paste phase shows the opposite trend and durability was improved.

Figure 6 shows the normality of the strength/w:c ratio relationship between flowing and controlled concrete.

The Concept Appears Sound

The concept has been used for practical benefit for instance,

1. Placing of concrete with reduced vibration in areas of close bunched reinforcement, and in areas of poor access. By using flowing concrete, the need to cut or adapt formwork to obtain vibrator access may be obviated.

2. The capability of placing - very rapidly, easily and without vibration - concrete for bay areas, floor slabs, roof decks and similar.

3. The very rapid pumping of concrete. Placing rates of 40 cubic metres per hour (52 cubic yards per hour) have been readily achieved using a Schwing Pump. Indications are that there are fewer operations or problems in handling superplasticised concrete by pump, than with traditional pumped concrete. Pumping pressures are less and generally the equipment can be better utilized. It has been reported (9) that superplasticised concretes have been pumped to heights of 35 m (115') in Germany. The combination of cohesion and yet easy placing properties are well suited to pumping.

4. Placing of concrete by means of tremie pipe, particularly in underwater locations, where the ability to spread some 5-6 m (16.4-19.6') from the discharge point without assistance, gives a marked advantage over traditional tremie designed concretes.

The Concept Has Wide Application In Conventional Construction

To take full advantage of the concept of flowing concrete and to justify the materials costs (£1.50 per m^3 * for the admixture) the job should be planned for. Superficially this cost can be reduced by using less labour since flowing concrete is readily placed. However, this type of comparison is an oversimplification since concrete operatives perform other functions such as cleaning up and handling formwork, etc., and hence fewer people may not represent real savings. An alternative stems from the time saving made available with flowing concrete.

Table 1 (5) shows the time needed when placing concrete in selected situations. The example allows for placing by mobile crane direct from a Ready Mix truck.

Where reinforcement is congested or if formwork has to be modified by having vibrator access holes cut into it to aid the placing of normal slump concrete, then the hours per m^3 cost can be increased above those given in Table 1.

It is in this type of time consuming operation that flowing concrete is seen to have a real advantage. It may also be necessary to place large quantities of concrete outside normal working hours, involving overtime rates for labour. Alternatively, situations where a time restriction for placing large pours has been imposed can benefit.

---

* In January 1979 the exchange rate was about 2.02 Dollars per £ Sterling.

Other factors, such as renting of vibrating equipment, finishing of surface are not significant items compared to placing labour costs.

In Table 2 (10) pumping costs are compared for a situation requiring good concrete flow around obstacles and close-bunched reinforcement. The direct cost saving is marginal but time saving is very significant. Speeding the overall job results in savings on "on costs". However, other related activities such as steel fixing and formwork have to be programmed to suit the higher output rates, hence the need for planning.

The Concept Can Show Savings But Must Be Planned For

Water-Reduced High-Strength Concrete

Superplasticisers are also used to allow a very significant water reduction resulting in high-strength concrete. Much of the development for this use of superplasticised concrete has occurred in Japan (11) where superplasticisers have been used to reduce water content by as much as 20-33%, compared with 15-16% when using normal plasticising admixtures. Their use has been to produce water-reduced high-slump concrete.

Trends relating to European concreting practice have been confirmed in the U.K. For instance, typical water reduction for a 1:2:4 mix containing 300 kg/m^3 (502 lb/yd^3) cement are given in Table 3 (12). This trend is maintained for high cement content mixes (11). Such water reductions can yield noticeable increases in early strengths for similar workability concretes, as shown in Tables 4 and 5. However it has to be noted that workability loss can be rapid with high cement content concretes negating to some degree the improved workability imparted by the use of the superplasticiser.

In general, the strength increases obtained, even at low levels of admixture addition, are well in excess of those obtained by increasing the cement content and without adverse side effects. It may be expected that by reducing the water content 25-35% increases of 50-70% in the 24-hour strength may be obtained under normal conditions and a normal 7-day strength is achieved at 3 days and 28-day strength at 7 days.

The advantageous strength/time trend shown in Figure 7 is usually maintained as the concrete matures.

This early high-strength property is particularly useful in the production of pre-stressed beams and units where overnight heat curing is normally carried out to obtain 28-day strengths but at 24 hours.

This trend allows reduction in curing time and/or curing temperature giving overall savings on energy requirements.

Concrete having improved early strength allows rapid de-stressing of wire reinforcement and quick mould stripping for pre-cast items.

Figure 8 shows that the detensioning strength in the region of 30 N/mm^2 (4350 psi) is obtained after 6-7 hours as opposed to 22 hours for the control. These data relate to the production of pre-stressed pre-cast concrete lintels (13).

In the U.K. this use accounts so far for something above 40% of total superplasticiser production.

It is not practicable - for usual concretes - to use superplasticisers to make significant cement cost savings as is the case for normal water-reducing agents and they are not recommended for this purpose.

Water Content Reduction Can Save Time, Energy And Money

Some consideration has been given to using the strength accelerating capability of superplasticisers as alternatives to conventional chemical accelerators such as calcium chloride, calcium formate, sodium aluminate and others. In the U.K. proprietory chloride-free accelerators cost approximately £1-£2.10p* per m^3 of accelerated concrete and on this basis the cost comparison does not appear that unfavourable. However, both alternatives are considerably more expensive than calcium chloride and both appear uncompetitive in this respect. None-the-less there is a considerable lobby against the continuing use of calcium chloride (14,15) particularly in situations where the concrete contains steel reinforcement and looking ahead a little both superplasticisers and other chemical accelerators could become viable alternatives.

The strength/w:c ratio property for water-reduced superplasticised concrete follows the normal trend and there is no adverse deviation from the expected strength that can be attributed to the presence of the superplasticiser (5). Nevertheless long term test data are scant (16-20) but that which has been published show good high-strength retention except at very high-dosage levels (x3 normal), when there is less increase long term than might be expected. Even so all the ultimate strengths were still above the controls (Figure 9).

It is intended in Germany at least to continue these long-term tests over a 20-year period with results available at 4, 6, 8, 10 and 15-year intervals (17).

Indirect durability tests have also shown that superplasticised concrete made to a fixed workability has enhanced resistance to freeze/thaw cycling, although, that for high-flow concrete appears in some doubt (6,7,8).

There are few results confirming the absence of any long-term corrosion hazard associated with concrete containing a superplasticising admixture. However, published data (5) imply the risk is an unlikely one.

In The Working Party Report (5) the creep, shrinkage and durability properties of water-reduced concrete are mentioned and indications are that these properties are not adversely affected. The data, however limited, may be considered as implying that there is no long term detrimental effect from the inclusion of a superplasticising admixture, as far as gain in strength is concerned.

The Concept Appears Reliable In The Long Term

In summary, the relatively high admixture cost could be more than offset by,

1. In the case of flowing concrete:

   (a) Increased ease in the rate of placing concrete particularly in difficult situations.

   (b) Reduced need to vibrate.

   (c) Perhaps a reduction in manpower.

   (d) Shortening of programme time.

2. In the case of high-strength, water-reduced concrete:

   (a) Increased rate of unit construction.

   (b) Reduced time for high-temperature steam curing.

   (c) Improved strength properties of pre-cast items, reducing breakage and wastage.

This paper outlines two new concepts offering to the construction industry certain real, practical and materials advantages that may be gained by the controlled and proper use of superplasticised concrete.

REFERENCES

1. DIN 1048 Section 1, Clause 312 Deutscher Normenausschuss Berlin 1972.

2. Wertz L S Brit. Pat. 715,032 1954.

3. Walz K and Bonzal J "Guidelines for the Manufacture and Laying of Flow Concrete (May 1947 Wording)" Beton Herstellung und Verwendung (Düsseldorf) V.24 No.9 September 1974 pp. 342-344.

4. Tattersall G H "The principles of measurement of the workability of fresh concrete and proposed two point test"; B.S.9; Dept. of Building Science, University of Sheffield (U.K) June 1973.

5. "Superplasticising admixtures in concrete" Joint Working Party Report No. 45.030, Cement Admixtures Association/Cement and Concrete Association, London January 1976 32 pp.

6. Tynes W O "Investigation of proprietory admixtures"; U.S. Army Engineer Waterways Experiment Station; Technical Report C-77-1; April 1977.

7. Edmeades R M and Hewlett P C "The durability of plasticised concrete: Freeze thaw testing of concrete containing Flocrete N and Supaflo" R12/76 Cementation Research Ltd (England) 1976.

8. Marsh P C "The effects of a superplasticiser on some of the properties of fresh and hard concrete"; MSc Thesis; The Royal Military College of Science, Shrivenham, U.K.; May 1976.

9. Blakey H "Superplasticisers"; TDH 5418; Cement and Concrete Association; 1973, 3.

10. Hart D TDH 5425; Cement and Concrete Association (England); 1975.

11. Hattori K and Yamakawa C "Cement dispersing agent (water reducing agent) 'Mighty' for high strength concrete"; Kao Soap Company Report; October 1973.

12. Private communication, Cementation Chemicals Ltd, Doncaster (U.K).