COMPATIBILITY OF BINDER AND SUPERPLASTICIZER IN HIGH-STRENGTH CONCRETE.

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With the results from the electrophoresis tests and the penetration tests done by the Vicat-apparatus best compatible binder and superplasticizer combinations were selected. The results were applied to high-strength concrete produced by silica fume, class F fly ash, blast-furnace slag and ordinary cements together with compatible superplasticizers. By nearly triplicating the compression strength of the concrete the material costs rise merely 20-25 percent.

Keywords: High-strength concrete, superplasticizers, test methods.

INTRODUCTION

The most essential feature in the production of high-strength concrete is the selection of the water reducing agent. It has been noticed that different superplasticizers have quite varying efficiencies when used with different binder types. A good water reducing effect with certain cement type does not ensure similar action with other binders and the order of superiority of different superplasticizers can change rather much.

In this paper the compatibility of binder and superplasticizer is considered to be the joint effects of the superplasticizers causing both the reduction of the mutual friction between the binder particles and the dispersing action which scatters the binder particles homogeneously into the concrete mixture.

MECHANISM OF ACTION OF SUPERPLASTICIZERS

The most common commercial superplaticizers are sulfonated melamineformaldehyde condensates, sulfonated naphthaleneformaldehyde condensates or modified lignosulfonates. They consist of long-chained organic polymers where the sulfonate SO_3-groups project out from the polymer chain. Superplasticizers are mainly attached onto the binder particles with these sulfonate groups and the surface potential of the particles is increased causing electrostatic repulsion forces which overcome the van der Waal´s attraction forces that keep the cement particles in large irregular heaps of 40-50 μm in diameter in water suspension. By the addition of a superplasticizer the binder material is dispersed into small individual particles and a stable dispersion state is achieved. However, not merely electrical forces induced into the particles cause the dispersion state but also the polymer chains of the superplasticizer cause a steric hindrance which also stabilizes the dispersion state. It is also possible that some of the polymers adsorbing onto the particles produce solid-liquid affinity forces which overcome some of the van der Waal's attraction forces and can contribute to the formation of a stable suspension.

Despite of the dispersion mechanism or united mechanisms the internal friction between the binder particles is considerably diminished increasing the fluidity of the concrete paste. This enables the production of high-strength concrete with normal workability having a water cement ratio of even below 0,25. The main problem is how to select the most advantageous or economical superplasticizer-binder combination without a tedious and simple straight forward trial and error procedure using concrete mixes.

As a conclusion of the mechanisms of action governing the interaction between the superplasticizer and the binder particles, it seems highly improbable that it could be mastered by a single mechanism e.g. the electrostatic repulsive forces. Due to the high concentration of polymers in the vicinity of the binder particles steric hindrance ought to be also taken into consideration /2/.

TEST METHODS

The dispersion action of inalert mineral particles due to electrostatic repulsion can be measured by a variety of methods such as electro-osmosis, streaming potential and electrophoresis methods /3, 4/. Every method tends to measure the electrokinetic potential or zeta potential between the outer fixed layer of the adsorbed ions tightly bound onto the charged particle and the bulk of the dispersing medium. The higher the absolute value of the zeta potential is the higher stability there is in the dispersion state of the solution.

Cement reacts with water in an aqueous suspension and therefore has a surface area and a surface composition that is varying with time. E. Nägele /5/ has shown that a well defined zeta potential exists when cement is in the induction period of the hydration reaction and the before mentioned methods can be used to evaluate the dispersion stability of cementitous materials. The microelectrophoresis method has been proven to be the most suitable in this context.

The writer of this article is unaware of any practical methods with which one could estimate the role of steric hindrance in the dispersion stability of cementitous materials. Therefore the results from the electrophoresis test should be dealt with caution and its limitations should be recognized.

In comparing the plasticizing effects of superplasticizers in concrete Tattersall´s two point test is superior to conventional slump and V-B consistometer tests. However, presently there are commercially available 13 different superplasticizers in Finland and over 10 possible binder variations for high-strength concrete including separately ground blast-furnace slag, silica fume and fuel ash. Taking into consideration merely two different superplasticizer dosages and one silica or fuel ash combination with every cement type there are easily over 500 rational concrete combinations. It is inappropriate to produce so many concrete tests. The compatibility of the superplasticizer and the binder ought to be able to solve in a simpler and in a less material consuming way.

This could be done by a viscometer examining the differences in the consistency of cement and water paste as a function of the water cement ratio and the superplasticizer dosage. The aim of the investigation was to develop a quality control method suitable for an ordinary concrete laboratory where the use of a viscometer is inadequate.

To compare the efficiencies of superplasticizers the penetration test of the Vicat-apparatus was applied. The test is performed using a metal rod of 10 mm in diameter as a plunger in a similar way as the standard consistency of the paste in the setting time test is found. The water cement ratio of the solution of binder, water and superplasticizer is changed until the value is found where the rod plunges through the paste specimen to a distance of 3...5 mm from the bottom plate of the paste mould in the time of 30 seconds. One of the advantages of the test is that it is standardized (ASTM C 191-79, ASTM C 187-79 and ASTM C 305-80, DIN 1164 Teil 5, SFS 3169) and the Vicat-apparatus is frequently available in concrete laboratories. The test device is comparatively unexpensive and easy to work with. In fact the discussed penetration test is performed every time the standard consistency of the paste in the setting time test is found.

The only deviation from the procedure mentioned in the standard is that water is replaced with a solution of water and the dose of the superplasticizer in question. The only test devices needed are a Hobart N-50 mixer, Vicat-apparatus, weighing apparatus, seconds counter and a thermometer. The penetration test is sensitive enough to be suitable for a quality control method where the differences in quality of the binder or the superplasticizer can be noticed before the concrete production.

APPLICATION TO HIGH-STRENGTH CONCRETE

The electrophoresis and penetration tests were applied to select the most suitable superplasticizer and binder combinations in the production of high-strength concrete. Because of the high binder content the grading of the aggregates does not effect the consistency and strength results as much as with normal-strength concretes.

The most important factor effecting compression strength and other mechanical properties of concrete is the porosity and pore distribution of cement paste, the fewer pores the better strength properties. In principle there are four ways to diminish the porosity of cement paste

- lowering the water cement ratio
- increasing hydration degree of cement paste
- filling the pores with more finely divided materials or
- using high pressure or a very effective compaction method.

The last mentioned way is unsuitable in normal concreting and is not discussed here. High-strength concrete was produced using three different methods

- silica fume 10 % of the binder content both with rapid hardening and low-heat Portland cements
- pulverized class F fuel ash 25 % of the binder content both with rapid hardening and low-heat Portland cements and
- using merely superplasticizers with low-heat Portland cements, blast-furnace slag cements and a combination where half was rapid hardening Portland cement and half separately ground blast-furnace slag.

The fuel ash versions were taken into consideration mostly because of their more economical price compared to the silica combinations. Customary concrete mixing equipment was used and the aim was to produce concrete in strength classes from 60 to 120 MPa with a workability of 2-3 sVB in the V-B test. With the penetration test by the Vicat-apparatus the plasticizing effects of different superplasticizers were compared and using the zeta potential values obtained in the electrophoresis tests the dispersing action of the superplasticizers was examined. Using the test results the binders and superplastisizers for the actual concrete tests were selected.

Because of the limited space available the test results of only one binder combination is presented in figures 1 and 2. Blast-furnace slag cement M 40/91 LH SR (Oy Lohja Ab) where slag content is over 70 % is chosen because together with the binder combination where half was rapid hardening Portland cement and half separately ground blast-furnace slag they were the two economically most advantageous binder combinations in producing high-strength concrete.

Most of the studied plasticizers belonged to the group of sulfonated naphthaleneformaldehyde condensates such as Sikament Nn, Fliessmittel SF, Conflow 200, Aqualow, Scancem SP62 and Gratong Mp. Sikament FF and Peramin F can be characterized as sulfonated melamineformaldehyde condensates. Peramin V and Consave N155 can be defined as modified lignosulfonates while Parmix N is a mixture of lignosulfonate and melamineformaldehyde condensate. Superplasticizer Fliessmittel 2000 is a polyacrylatecopolymer.

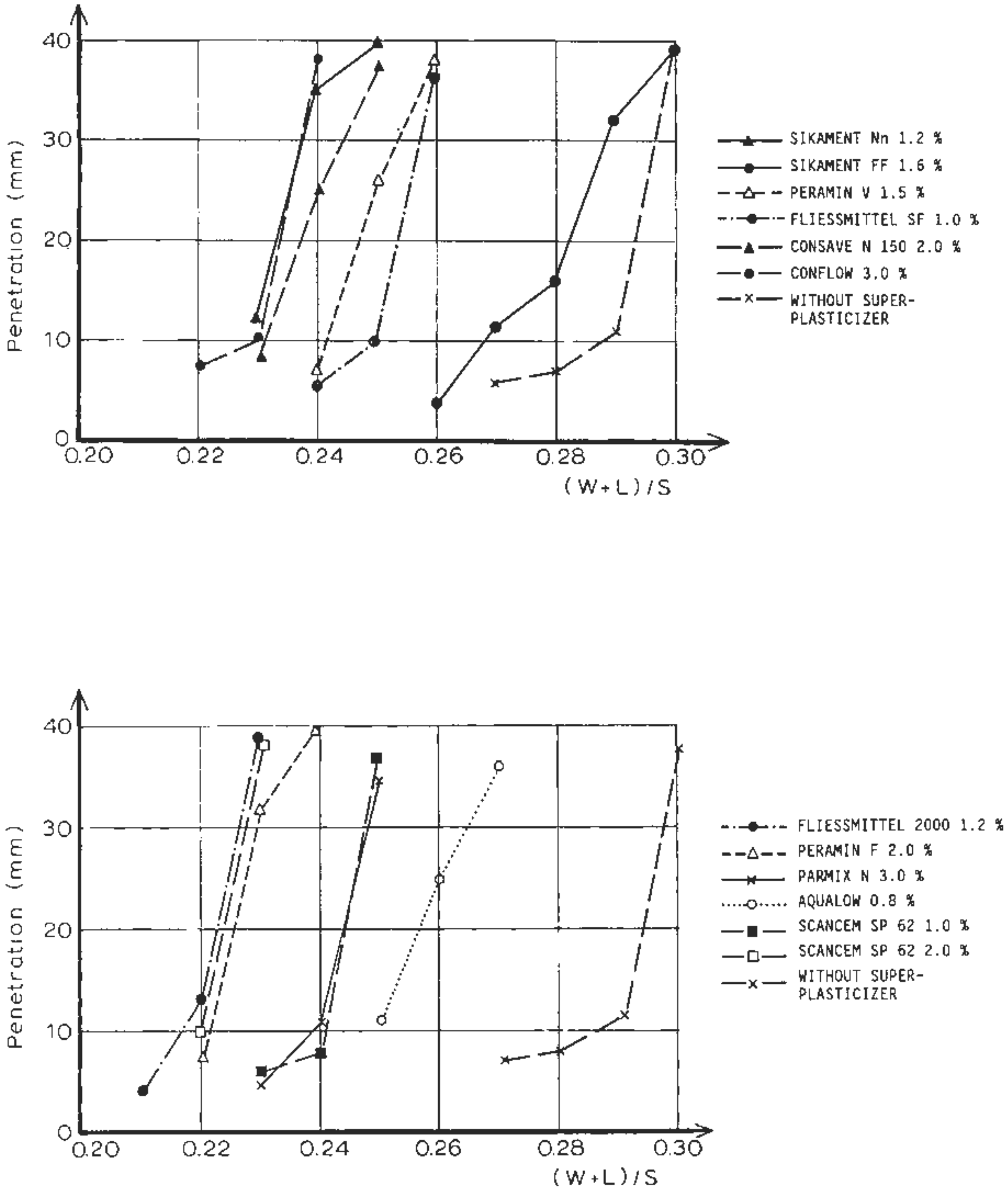

Fig. 1. The penetration test results when binder was blast-furnace slag cement M 40/91 LH SR (Oy Lohja Ab). W denotes the amount of water, L the amount of superplasticizer and S the binder amount.

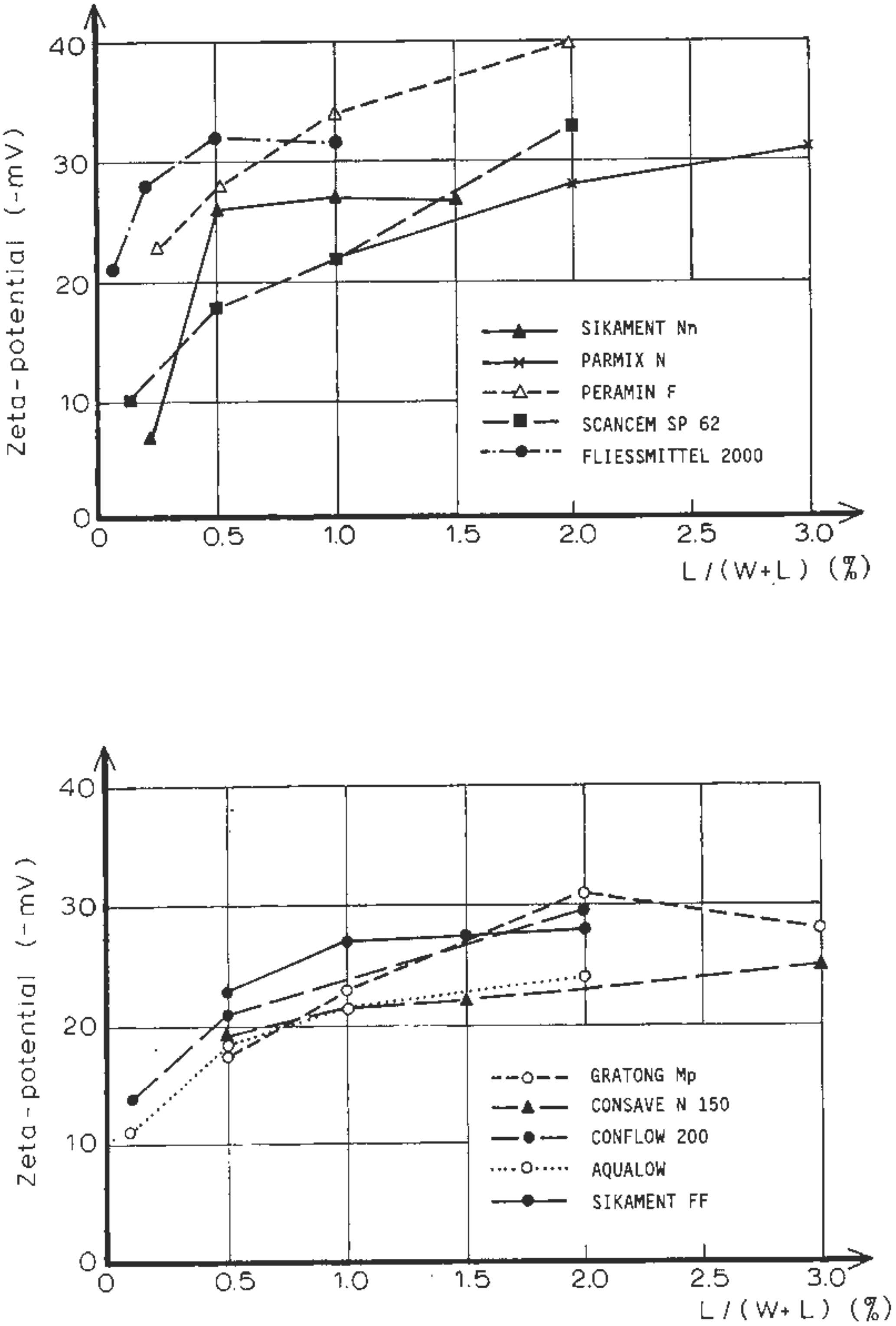

Fig. 2. The zeta potential values of the electrophoresis tests when the binder was blast-furnace slag cement M 40/91 LH SR (Oy Lohja Ab). L denotes the amount of superplasticizer and W the amount of water.

In selecting the superplasticizers to the actual concrete tests not merely technical compatibility was considered but also the price of the superplasticizer was taken into account. Therefore as an example Fliessmittel 2000 was not chosen because of its remarkably higher price compared to the other agents. With this cement type the superplasticizers used in the actual concrete tests were Conflow 200 (3 %), Parmix N (4 %), Peramin F. (3 %) and Scancem SP 62 (2,5 %) where the last mentioned additive is better known as Mighty 150. The dosages in the actual concrete tests are shown in parenthesis and they have been chosen little higher than the dosages used in the tests of figure 1.

The mix proportions of the 20 different test concretes are given in table 1 where P 40/7 denotes rapid hardening Portland cement, P 40/91 denotes low-heat Portland cement and M 40/91 denotes blast- furnace slag cement. The results from the compression strength tests are shown in figures 3-7.

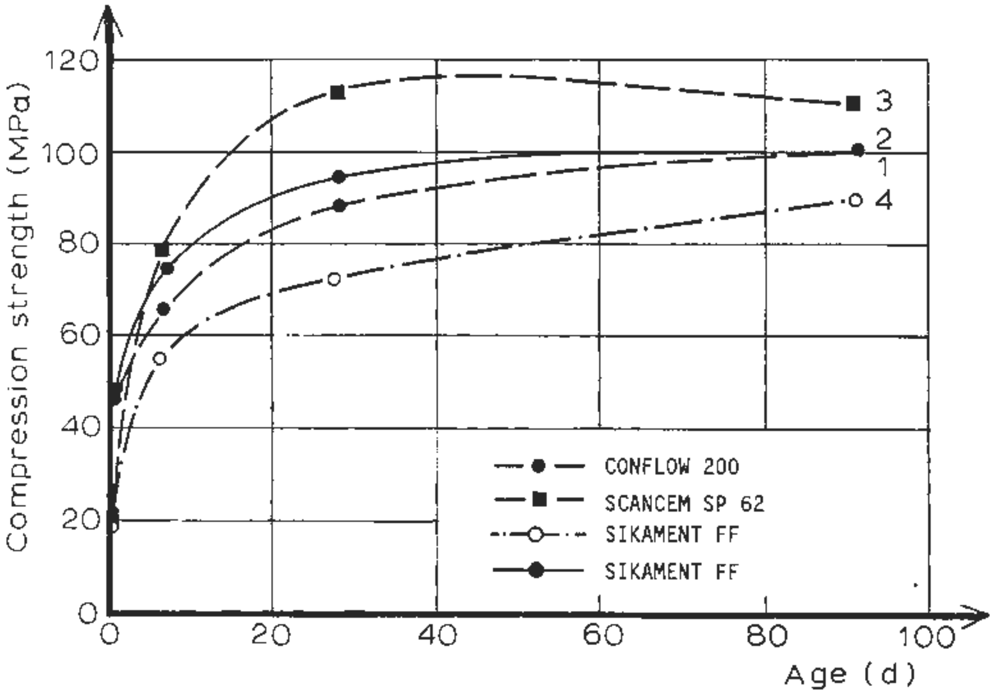

Fig. 3. The compression strength results of the silica concretes. The numbers denote the test concretes reported in table 1.

Table 1. The mix proportions of the test concretes.

Batch number	1	2	3	4	5	6	7	8	9	10
Cement type - content [kg/m^3]	P 40/7 500,0	P 40/7 500,0	P40/91 500,0	P40/91 500,0	P 40/7 450,0	P 40/7 450,0	P40/91 450,0	P40/91 450,0	P40/91 500,0	P40/91 500,0
Additional binder - content [kg/m^3]	silica 50,0	silica 50,0	silica 50,0	silica 50,0	fly ash 150,0	fly ash 150,0	fly ash 150,0	fly ash 150,0		
Water content [kg/m^3]	165,0	170,5	129,2	170,5	147,0	168,0	154,8	165,0	137,5	130,0
Superplasticizer - dosage [kg/m^3]	Conflow 200 16,5	Sikament FF 11,0	Scancem SP 62 13,8	Sikament FF 11,0	Scancem SP 62 15,0	Sikament FF 12,0	Sikament 7,2	Consave N 155 9,0	Conflow 200 15,0	Scancem SP 62 15,0
Aggregate amount [kg/m^3]	1666,8	1666,8	1770,0	1666,8	1649,0	1601,0	1649,0	1616,8	2020,0	2020,0
Water cement ratio	0,33	0,33	0,26	0,33	0,27	0,30	0,27	0,29	0,305	0,29

Batch number	11	12	13	14	15	16	17	18	19	20
Cement type - content [kg/m^3]	P40/91 500,0	P40/91 500,0	M40/91 500,0	M40/91 500,0	M40/91 500,0	M40/91 500,0	P 40/7 250,0	P 40/7 250,0	P 40/7 250,0	P 40/7 250,0
Additional binder - content [kg/m^3]							b-f slag 250,0	b-f slag 250,0	b-f slag 250,0	b-f slag 250,0
Water content [kg/m^3]	146,5	137,5	145,0	145,0	145,0	145,0	137,7	130,0	140,0	142,5
Superplasticizer - dosage [kg/m^3]	Fliessmittel 2000 6,0	Parmix N 15,0	Conflow 200 15,0	Scancem SP 62 12,5	Peramin F 15,0	Parmix N 20,0	Conflow 200 15,0	Scancem SP 62 15,0	Peramin F 15,0	Parmix N 15,0
Aggregate amount [kg/m^3]	2020,0	2020,0	2000,0	2000,0	2020,0	2000,0	2000,0	2020,0	2020,0	1980,0
Water cement ratio	0,305	0,305	0,32	0,315	0,32	0,33	0,305	0,29	0,31	0,315

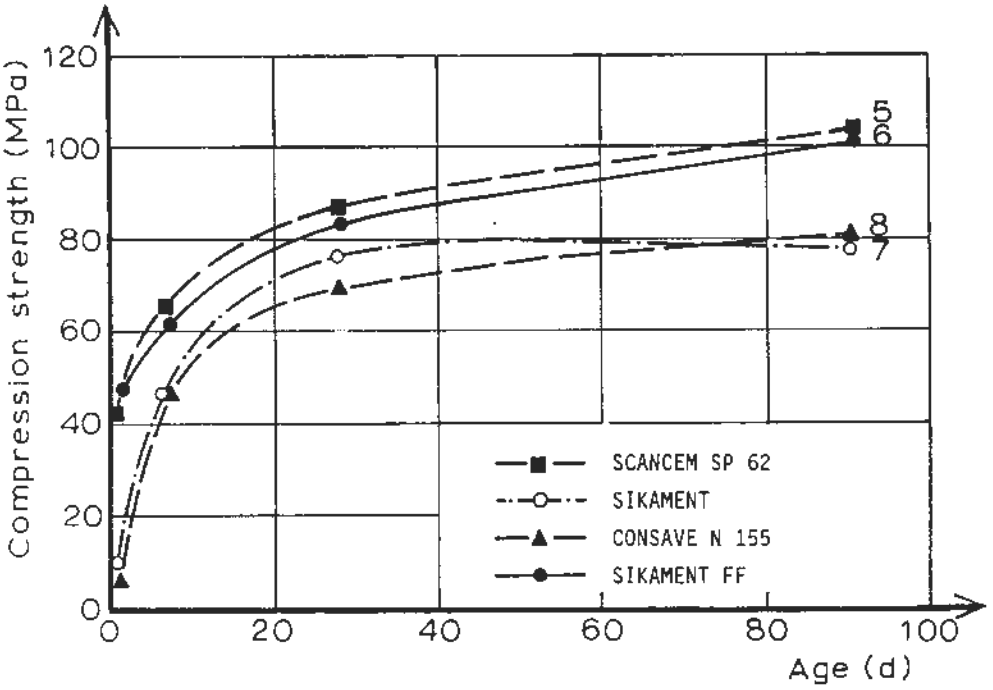

Fig. 4. The compression strength results of the fuel ash concretes.

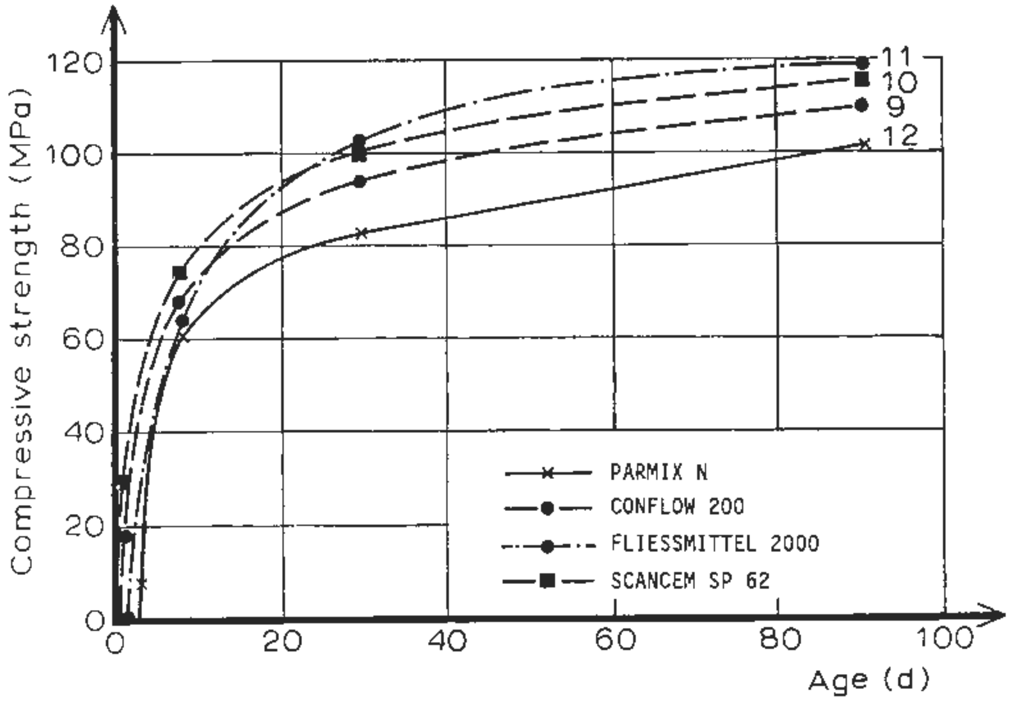

Fig. 5. The compression strength results of the concretes where the binder was low-heat Portland cement P 40/91 LH SR.

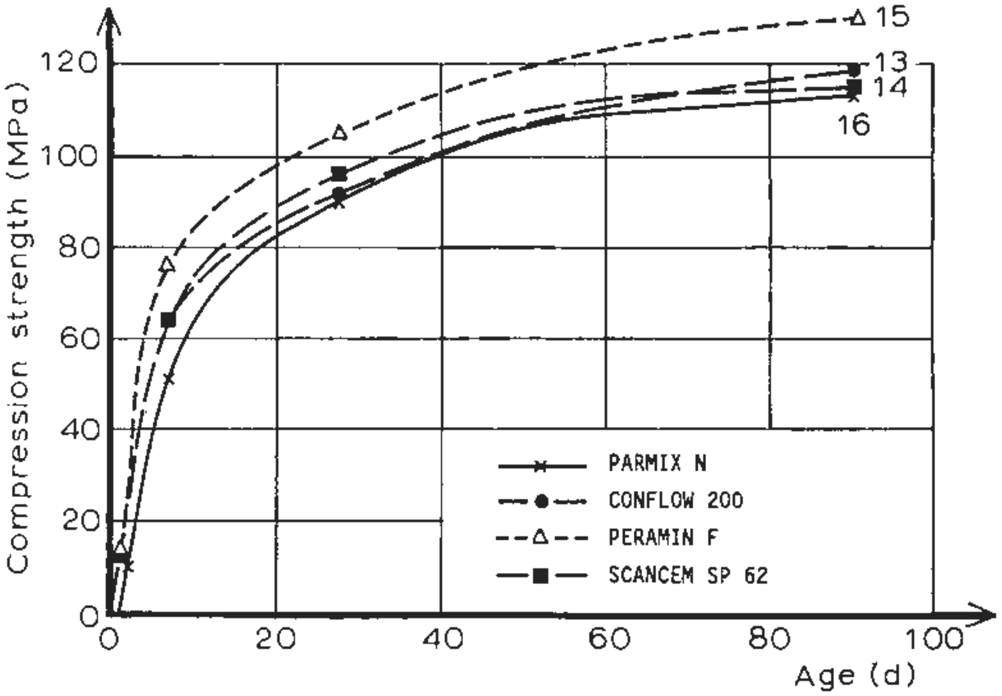

Fig. 6. The compression strength results of the concretes where the binder was blast-furnace slag cement M 40/91 LH SR.

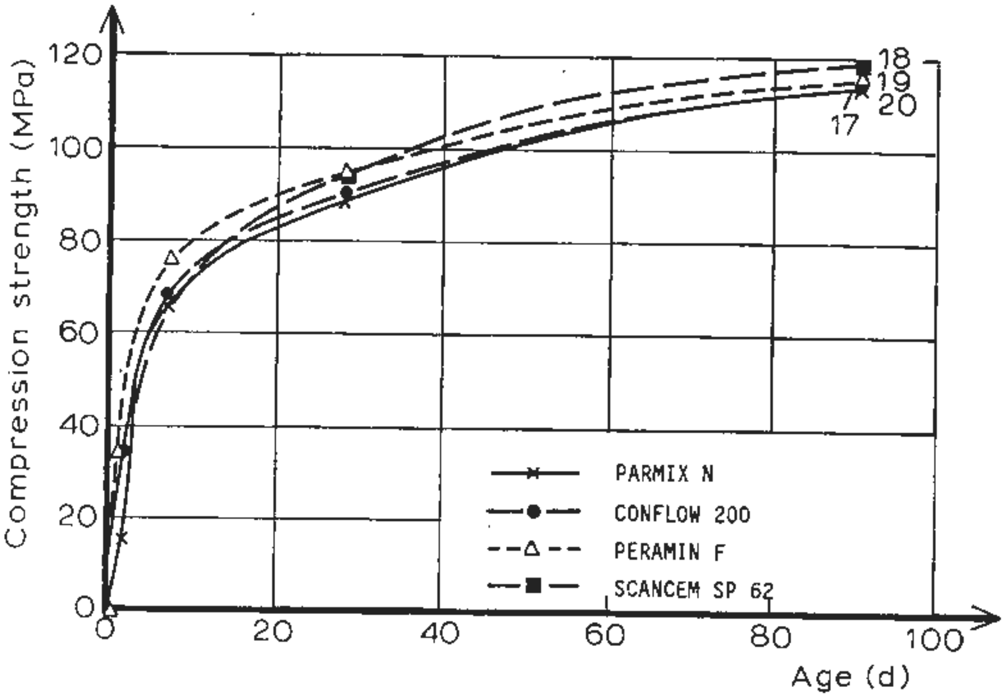

Fig. 7. The compression strength results of the concretes where half of the binder consisted of rapid hardening Portland cement P 40/7 and the other half was separately ground blast-furnace slag.

As the compression strength results show every alternative production method gives somewhat similar results except the fly ash version where low-heat Portland cement was used. This gives a possibility to choose alternative binders to comply with certain other technical requirements as fire endurance, creep and shrinkage values, dynamic properties or setting times. In addition the five different binder combinations cause quite different material costs.

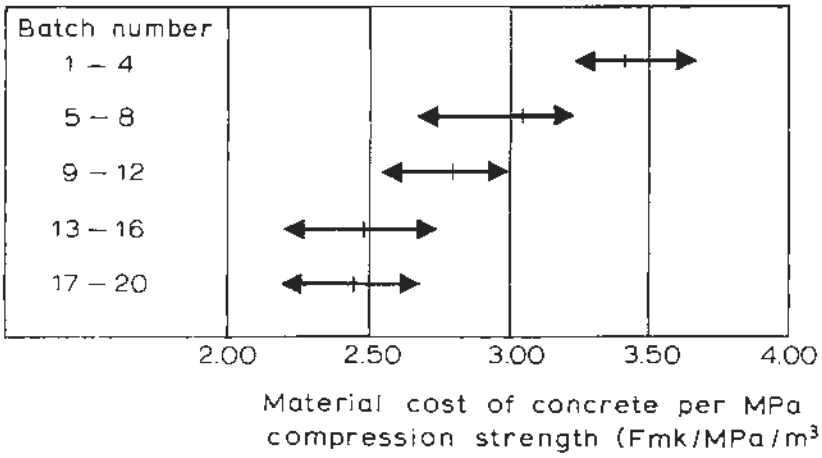

Fig. 8. Material costs of the test concretes in Finnish marks per MPa compression strength for 1 m^3 of concrete.

In the production of high-strength concrete the cheapest binders were blast-furnace slag cements and the combination where half of the binder comprised of rapid hardening Portland cement and the other half was separately ground blast-furnace slag. Low-heat Portland cement concretes and fly ash concretes follow next while the most expensive way to produce high-strength concretes appears to be the use of silica fume. Calculating the same material cost for ordinary concrete of strength class 40 MPa we get an unit cost of 5,2 Fmk/MPa/m^3. By nearly triplicating the compression strength of the concrete the material costs rise merely 20-25 % in the cheapest combinations.

CONCLUSIONS

The use of the penetration test by the Vicat-apparatus is a simple and rational method to select compatible superplasticizers to different binders in the production of high-strength concrete. The method is also suitable as a quality control procedure with which the deviations in the quality of the superplasticizer or the binder material can be observed before the concreting takes place.

The test results show that similar compression strength values can be achieved by very different superplasticizer and binder combinations and no chemical superplasticizer group can be named superior to the others. However in the economical comparison there exists rather large variations between the different binder groups as well as between the different superplasticizers within a binder group.

REFERENCES

/1/ Penttala, V., Högman, T., Schreck, J. & Ipatti, A., Production methods of high-strength concrete (in Finnish). Espoo 1986. Helsinki University of Technology, Department of Civil Engineering, Division of Structural Engineering, Publication 77. 128 p.

/2/ Banfill,P.F.G., A discussion of the papers "Rheological properties of cement mixes", by M. Daimon and D.M. Roy. Cement and Concrete Research 9(1979)6, p. 795-796.

/3/ Daimon, M. & Roy, D.M., Rheological properties of cement mixes: I. Methods, preliminary experiments, and adsorption studies. Cement and Concrete Research 8(1978)6, p. 753-764.

/4/ Daimon, M. & Roy, D.M., Rheological properties of cement mixes: II. Zeta potential and preliminary viscosity studies. Cement and Concrete Research 9(1979)1, p. 103-110.

/5/ Nägele, E., The zeta-potential of cement. Cement and Concrete Research 15(1985)3, p. 453-462.