FLEXURAL STRENGTH OF POLYMER CEMENT CONCRETES

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ABSTRACT

Flexural and compressive strengths of nine different polymer concretes were studied and 11 different polymers were used. Flexural strength was obtained by bending test performed by two line loads. Majority of the flexural strength specimens were concrete prisms of 100*100*500 mm^3 but few tests were also done with 40*40*160 mm^3 mortar prisms.

According to the results flexural strength values of polymer cement concrete prisms ranged from 4,5 MPa to 9,3 MPa at the age of 28 days. Small mortar prisms gave usually better flexural strength values, even 16,7 MPa at the age of 28 days. Compressive strength of polymer cement concretes varied from 26,6 MPa to 72,0 MPa at the age of 28 days while comparison concretes produced with portland cement achieved 69,0 - 72,6 MPa compressive strengths and 5,2 - 5,4 MPa flexural strength values at the same age. Studied silica fume amounts were 0, 10 and 20 % of the cement amount. Addition of silica fume usually increased the flexural strengths when the addition was 10 % of the cement amount. When silica fume dosage was 20 % of the cement amount the flexural strength decreased to the same level as it was without silica fume.

Keywords: flexural strength, polymer cement concrete

1 INTRODUCTION

Increased tensional properties of concrete can enhance the use and competitiveness of many unreinforced concrete structures. These range from concrete pavements and floors to many environmental concrete products.

In this work different kinds of polymers were used in improving the flexural strength of plain concrete. The aim of the project was to produce concretes having as good flexural strength

values as possible measured by 100*100*500 mm^3 beams with a two point bending test. The maximum aggregate size of the test concretes was 16 mm and customary concrete aggregates were used. The different polymers studied in this work include styrene butadiene rubbers, polymethyl methacrylate, epoxy resin, polyacrylic ester, polyvinyl acetate, styrene acrylate and pure acrylate. These polymers are water dispersed latexes except styrene acrylate and pure acrylate which are powders. The concretes produced by them are polymer cement concretes because they are mixed with ordinary inorganic binders like portland cements and condenced silica fume. In addition to the flexural properties of these polymer cement concretes their compressive strength properties and fresh mix properties were measured. The chemical structure of the concretes was studied by phase maps produced with EDX element maps.

2 POLYMER CEMENT CONCRETES

Concrete is classified as polymer cement concrete if the polymer amount exceeds 5% of the cement amount. The aims of using polymers in concrete are usually to improve water impermeability, to increase acid resistance of the concrete, and to increase flexural, tensile, and splitting strengths of concrete. In many cases the addition of polymer decreases compressive strength.

The comatrix of cement and polymer is generally formed according to a three-step simplified model introduced by Y. Ohama (Ohama 1987, p. 511). In the model mixtures of cement gel and unhydrated cement particles are enveloped with a close-packed layer of polymer particles. The influence of polymer particles on $Ca(OH)_2$ crystal formation can be explained in the following manner. When a nucleus of calcium hydroxide is formed and it attains a face to accomodate polymer particles and its further growth is inhibited due to the blocking action of adsorbed polymer particles. Instead of further growth of this crystal new nuclei are formed where other polymer particles adsorb on and so on. Since in this process only small crystallites are formed many of them can be attached to a polymer particle. In this way few polymer particles are sufficient in producing a big aggregate. As a consequence large crystals are not formed and the microcracks usually developing due to crystal formation are reduced. (Chandra & Flodin 1989, p. 266) Even if cracks are formed their further propagation will be hindered due to the presence of polymer particles and the flexural properties of polymer cement concretes are improved.

The spatial distribution of the polymer particles in polymer cement concrete can be studied in the phase map of Figure 1 where a micrograph of polymer cement concrete produced by styrene butadiene rubber (15 % of the sulfate resistant portland cement content) is shown. The phase map has been produced from the EDX element maps with statistical principal component analysis. Because color pictures can not be presented due to printing costs the aggregate particle is colored gray 1, the nearly unhydrated cement particles are colored black, and the different hydration products are colored with another tone of gray 2 and white, subsequently. The element compositions of the different phases are presented in Table 1. Due to the polishing procedures of the sample its surface was coated with a carbon layer which had to be subtracted in the EDX analysis. This additional carbon amount has been calibrated out from the results.
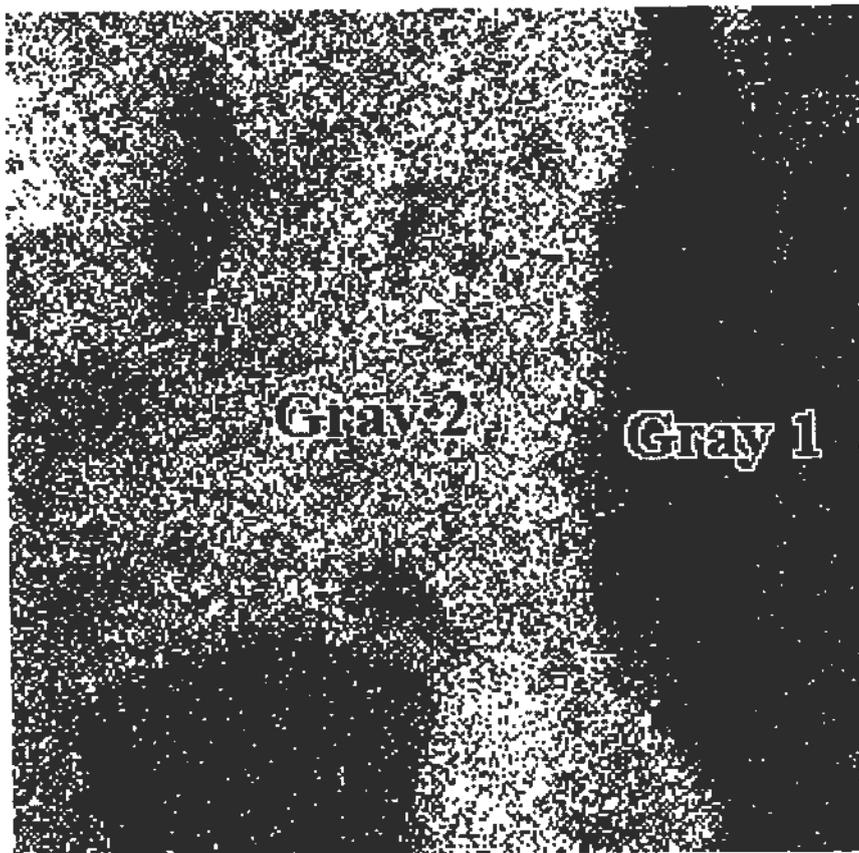
Figure 1. The ESEM image and the phase map of a polymer cement concrete produced by 400 kg/m^3 of sulfate resistant portland cement and 120 kg/m^3 styrene butadiene. Granite based aggregates were used. The edge of the pictures equals 60 μm.

Table 1. Element composition of the phase map of Figure 1 in weight percents.

Phase	Gray 1	White	Gray 2	Black
Ca/Si	0,4	2,0	3,0	3,9
Ca	12,7	37,1	45,3	50,8
Si	35,2	18,6	15,1	13,1
C	0	4,4	3,8	3,6
O	30,7	26,0	25,2	24,6
Al	11,2	5,0	3,7	2,6
Fe	1,9	3,5	2,8	2,2
S	1,0	2,0	1,7	1,2
K	0,3	0,5	0,4	0,3
Na	7,1	2,9	.2,1	1,7

From the phase map one can notice that most part of the carbon from the polymer envelopes the hydration products and no obvious transition zone is present around the aggregate particle. Special precausions have been taken in the sample preparation to polish as even sample surface as possible but the intrinsic porosity of the white and gray 2 phases of the cement paste causes inevitable errors in the phase compositions due to the more inhomogeneous matrix structure. It should be noticed that the percentual weight amounts of carbon, aluminium, iron, sulphur, and sodium increase as Ca/Si-ratio of the cement paste phases diminish.

3 FACTORS CONTROLLING THE FLEXURAL STRENGTH OF POLYMER CEMENT CONCRETES

Usually the termoplastic latexes cause better compressive strength and rigidity to polymer cement concrete, while the elastomeric latexes possess better flexural strengths. Unsuitable polymers can produce quite opposite strength changes. It is important to note that polymers of the same type but of different brands can produce greatly differing changes in the properties of the modified mortar. (Popovics 1985. P.210) The amount of polymer affects the strength of the concrete strongly. Usually the latex amount is 5 - 25 % of the cement amount, but some latex producers recommend to use 30 % latex amounts. The polymer-cement ratio varies between 0,025 and 0,15.

In some studies the use of condensed silica fume has increased the flexural strength of polymer cement concrete. The amount of binding material should be limited because too high cement amount may cause cracking in polymer cement concretes. According to research reports remarkably bigger cement amounts than 370 kg/m^3 should not be used. (Matela, E. 1989)

The optimum curing of latex polymer cement concrete is different from ordinary concrete. The optimum properties are obtained by moist curing for 1 to 3 days followed by air curing of the concrete at ambient temperature. (Ohama 1987, P.513)

4 LABORATORY TESTS

4.1 MATERIALS

Polymers

In the tests following polymer types were used. Five different styrene butadiene rubber (SBR) brands, polyacrylic ester (PAE), polyvinyl acetate (PVAC), styrene-acrylic (S-A) polymer powder, pure acrylate powder, polymethyl methacrylate (PMMA) and epoxy were tested. All of the tested polymers were water dispersed latexes, except styrene-acrylate and pure acrylate. These polymers were in pulverized form. Chosen polymers were intentionally selected so that they would represent all kinds of polymers suitable for polymer cement concretes.

Inorganic binders

The four Finnish cement types used in the project were sulfate resistant Portland cement P40/28 SR, ordinary Portland cement P40/28, extra rapid hardening Portland cement P40/3, and rapid hardening Portland cement P40/7. Condensed silica fume was also used as an additive in some of the test concretes.

Aggregates and admixtures

Normal granite based sieved aggregates were used in the test concretes. Also sieved gabro based aggregates were used to improve tensile strength properties of the aggregates. Standard sand was used in mortar prism tests.

Modified naphtalene formaldehyde polycondensate and lignosulfonate based superplasticizers were applied in the test concretes. Similarly anti-foaming agents were used in most of the test concretes.

4.2 CONCRETE TESTS

Concrete tests were done according to test plan. The test plan is presented in Table 2. RH denotes for relative humidity.

Mix designs

All test concretes were proportioned to have a consistency between 1 to 3 seconds in the VB-consistometer test. The used latex amounts were 30 % of the cement amount by weight except in the batches of test series V. Latexes contained about 50 % of water and the other half was solid polymer. The most common cement amount in the test concretes was 400 kg/m^3. When superplasticizers were used the dosage was 2,5 % of the cement amount by weight. Silica fume dosages were 10 % and 20 % of the cement amount.

Table 2. Test scheme of the research project.

Test Series I	Test Series II	Test Series III
Tested polymer types were Styrene butadiene rubber(SBR) Polyacrylic ester (PAE) Polyvinyl acetate (PVAC) Polymethyl methacrylate (PMMA) Styrene-acrylate (S-A) Pure Acrylate Epoxy	Tested inorganic binders were P40/28 SR P40/3 P40/28 Condensed silica fume	Tested cement amounts were 400 kg/m^3 350 kg/m^3 300 kg/m^3
Test Series IV	**Test Series V**	**Test Series VI**
Tested curing methods at 20°C were (all specimens kept 1d in molds) A. 6 or 27d in RH 45% B. 6 or 27d in H$_2$O C. 27d in RH 70% D. 20d in H$_2$O, 7d in RH 45% E. 6d in RH 45%, 21d in H$_2$O F. 6d in RH 45%, 14d in H$_2$O, 7d in RH 45% G. 6d in RH 45%, 7d in H$_2$O, 14d in RH 45% H. First 24h in +45°C, 6 or 27d in RH 45% J. 1d in H$_2$O, 2d in RH 95%, 3 or 24d in RH 45%	Tested latex amounts were 30% of the cement amount 20% of the cement amount 10% of the cement amount 0% of the cement amount	Tested aggregates, particle size distributions, and effect of using superplasticizers were A. Normal grading curve, with only a small amount of fine aggregate. B. Normal type of grading curve. C. Normal grading curve, more finer aggregates in the mix than in aggregate A. D. Similar grading curve as in aggregate A, but the aggregate mineral was gabro.
Test Series VII		
Tested mixing orders and times were A. Aggregates, cement and silica fume were mixed for 5 seconds until 75% of water was added. These components were mixed for 55 seconds and then the rest of the water, latex and superplasticizer were added separately. The total mixing time was 4 minutes.	B. Aggregates, cement and silica fume were mixed for 30 seconds Latex and 75% of the water were mixed together and added into the dry mix. This mixture was mixed for 1 minute and then the rest of the water and superplasticizer were added separately. The total mixing time was 2½ minutes.	C. Aggregates and latex were mixed for 1 minute and then there was added cement and the water-superplasticizer mixture. The total mixing time was 2½ minutes.

Production of the test specimens

From each batch 9 beams of 100*100*500 mm^3 were cast and vibrated internally. Test specimens covered with plastic sheats were kept in molds for one day. After the first day the beams were unmolded and shifted to climate room baving a temperature of +20°C and relative humidity of 45%. Test beams were kept in the climate room up to the testing time. Few exceptions were made during the curing tests of polymer cement concretes.

Testing of the specimens

The beams were tested at the ages of 1, 7 and 28 days. Three specimens were tested in respective age. Flexural strength was measured according to standard SFS 5444 with two line loads using a step motor controlled universal testing machine. After flexural strength test compressive strength was measured from the end parts of the beams.

4.3 MORTAR TESTS

Mortar test were made to supplement the coucrete tests. Mortar test specimens were prisms of $40*40*100$ mm^3. Cement amount was about 500 kg/m^3 and latex amount 30% of the cement amount (polymer amount 15% of the cement amount). Mortars were mixed with Hobart N-50 mixer, batch volume was about one dm^3.

4.4 TEST RESULTS AND DISCUSSIONS

Usually the latexes contained anti-foaming agents and therefore the air contents were only in few cases relatively high. The flexural and compressive strength results of the concretes and mortars are presented in Figures 2 to 10. The results are averages of three separate specimens.
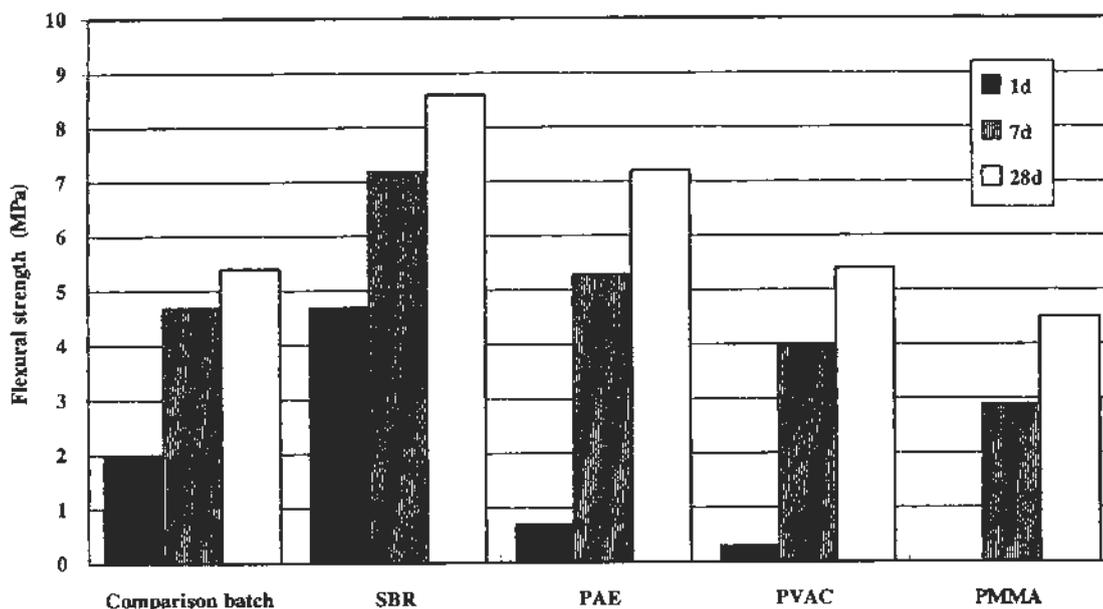

Figure 2 a. Test series I, concrete beams. Cement type was sulfate resistant portland cement P40/28 SR and cement content was 400 kg/m^3. Latex amounts were 30 % and superplasticizer dosage was 2,5 % of the cement amount.
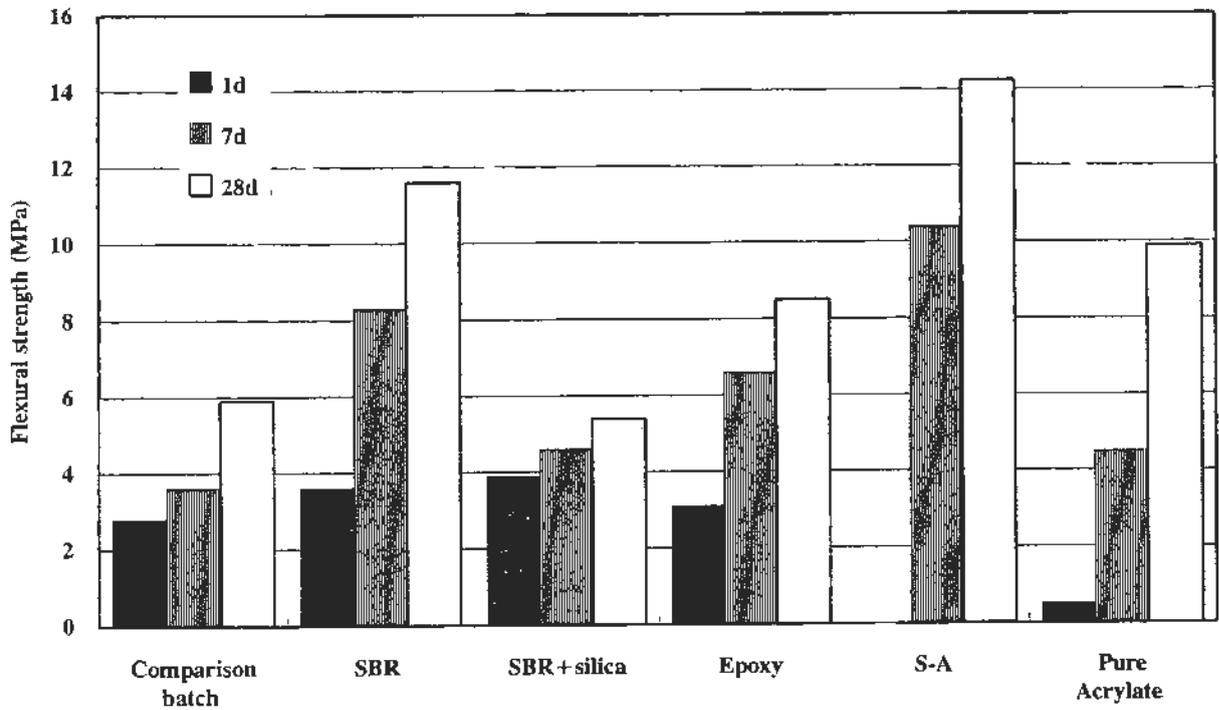
Figure 2 b. Test series I, mortar prisms. Cement type was P40/28 SR and cement content was 500 kg/m³. Latex amounts were 30 % (solid polymer amount 15 %) and superplasticizer dosage was 2,5 % of the cement amount.
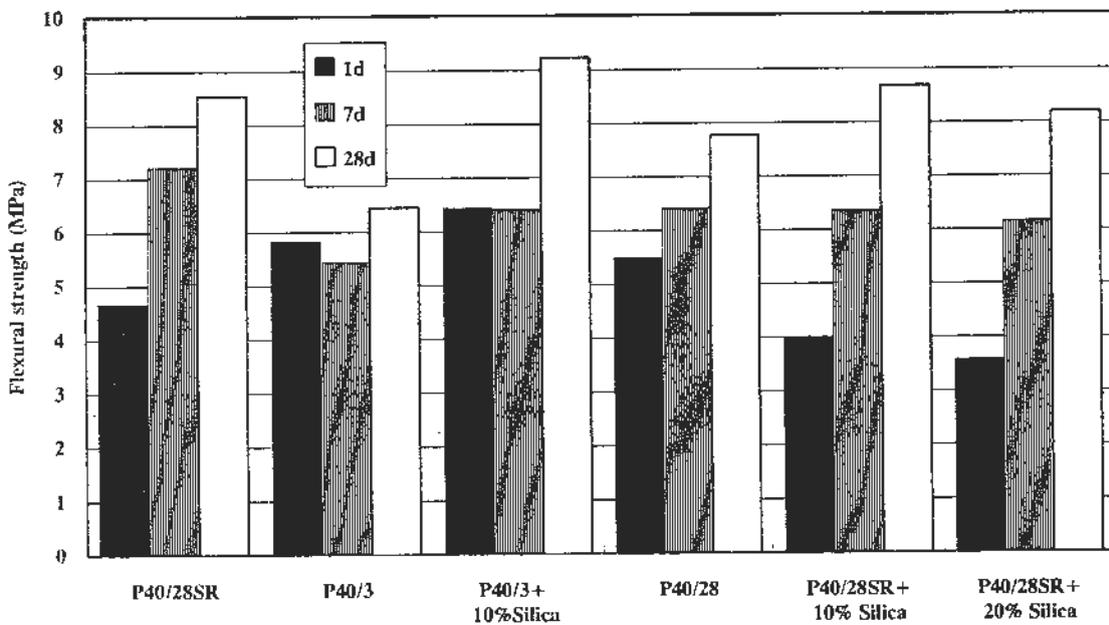

Figure 3. Test series II. SBR latex was used 30 % of the total amount of cement and silica fume. Cement amount was 400 kg/m³ when no silica fume was used. Cement amount was 350 kg/m³ when silica fume content was 10 % of the cement amount and the cement amount was 330 kg/m³ when silica fume dosage was 20 % of the cement amount.
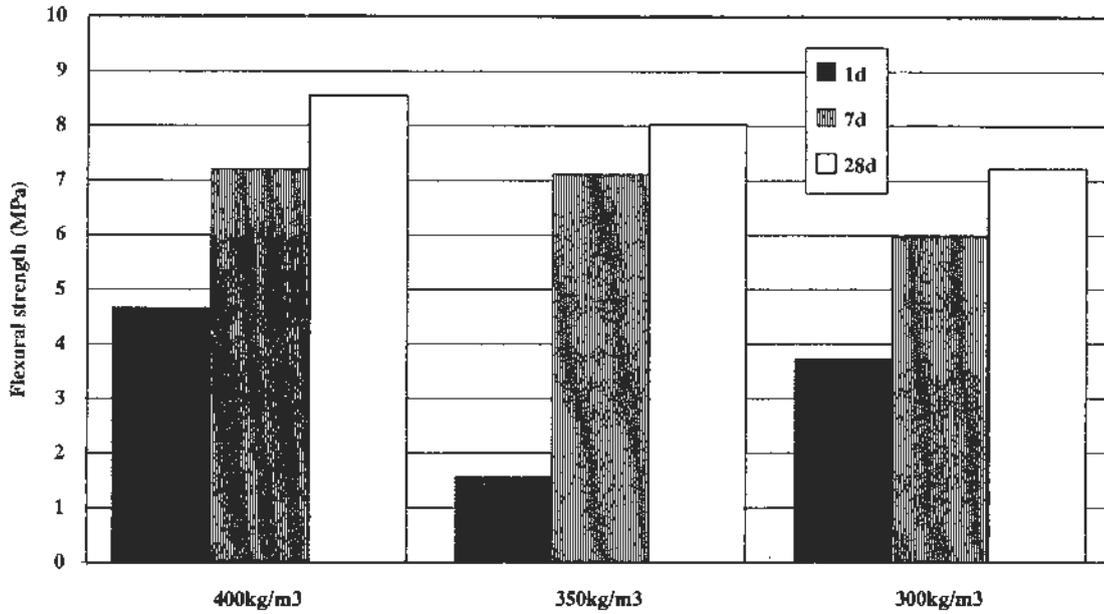
Figure 4. Test series III. Cement type was P40/28 SR, SBR latex amount was 30 % and the superplasticizer amount was 2,5 % of the cement amount.
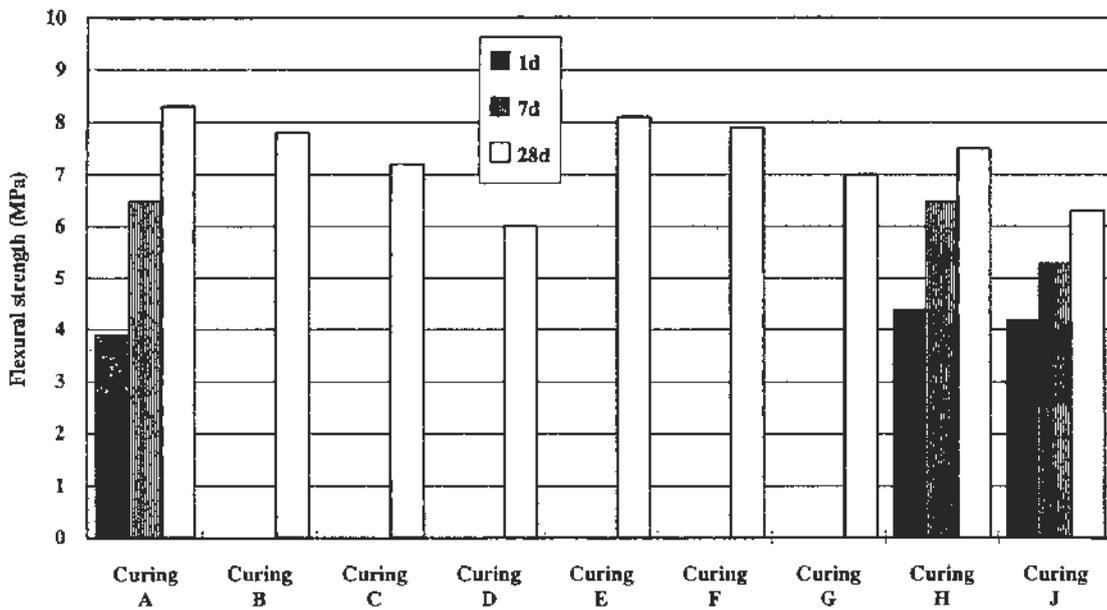

Figure 5. Test series IV. Cement type was P40/28 SR and cement content was 400 kg/m³. SBR latex amount was 30 % of the cement amount. No superplasticizers were used.
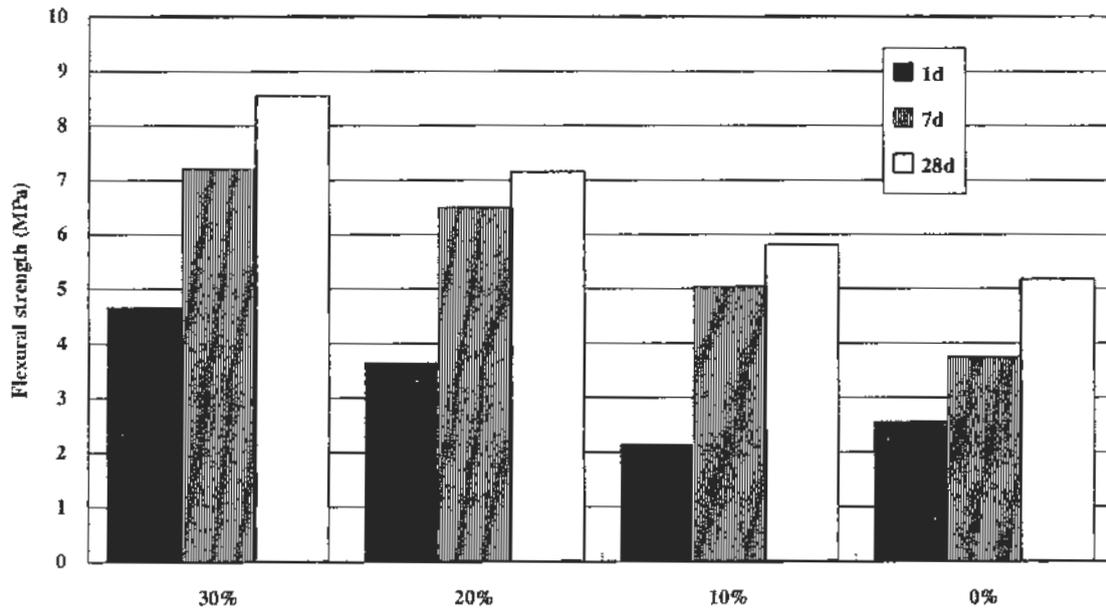
Figure 6. Test series V. Cement type was P40/28 SR and cement content was 400 kg/m³ when latex dosages were 0 and 30 %. When latex dosages were 10 and 20 % the cement content was 470 kg/m³ . (Oksa 1992)
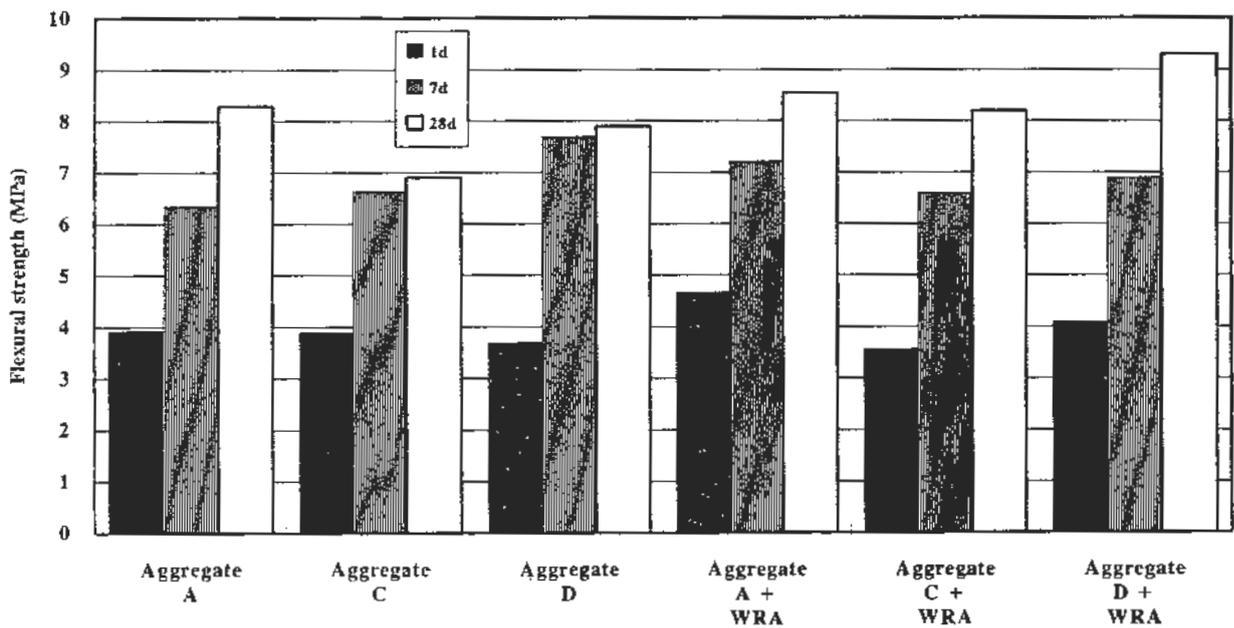

Figure 7. Test series VI. Cement type was P40/28 SR and cement content was 400 kg/m³. SBR latex amount was 30 % and superplasticizer amount was 2,5 % of the cement amount.
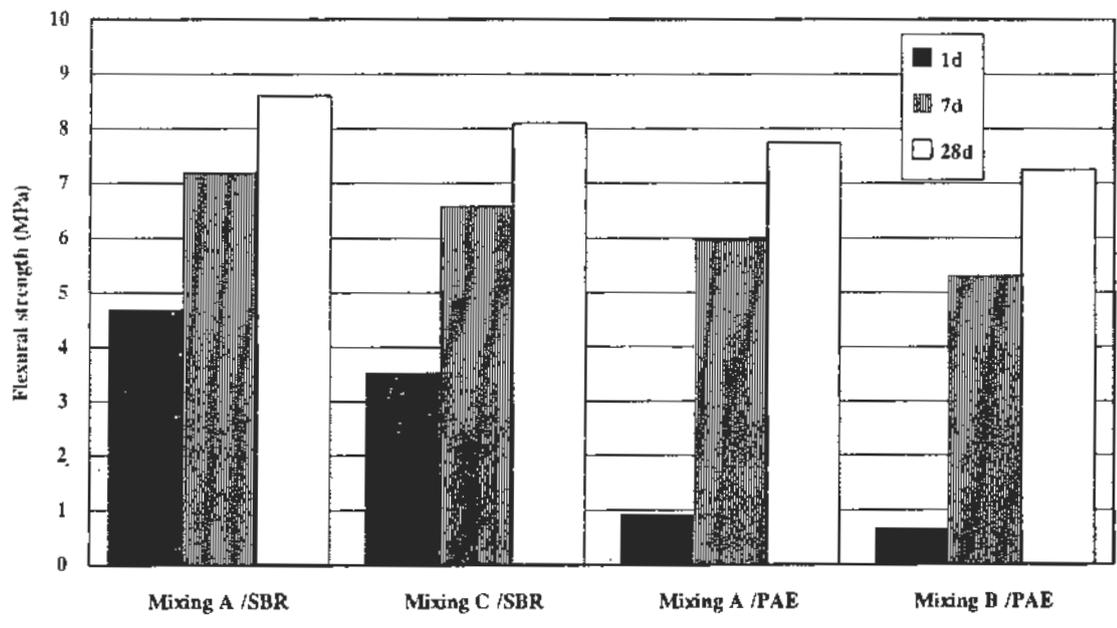
Figure 8. Test series VII. Cement type was P40/28 SR and cement content was 400 kg/m³. Latex amounts were 30 % and superplasticizer dosage was 2,5 % of the cement amount.
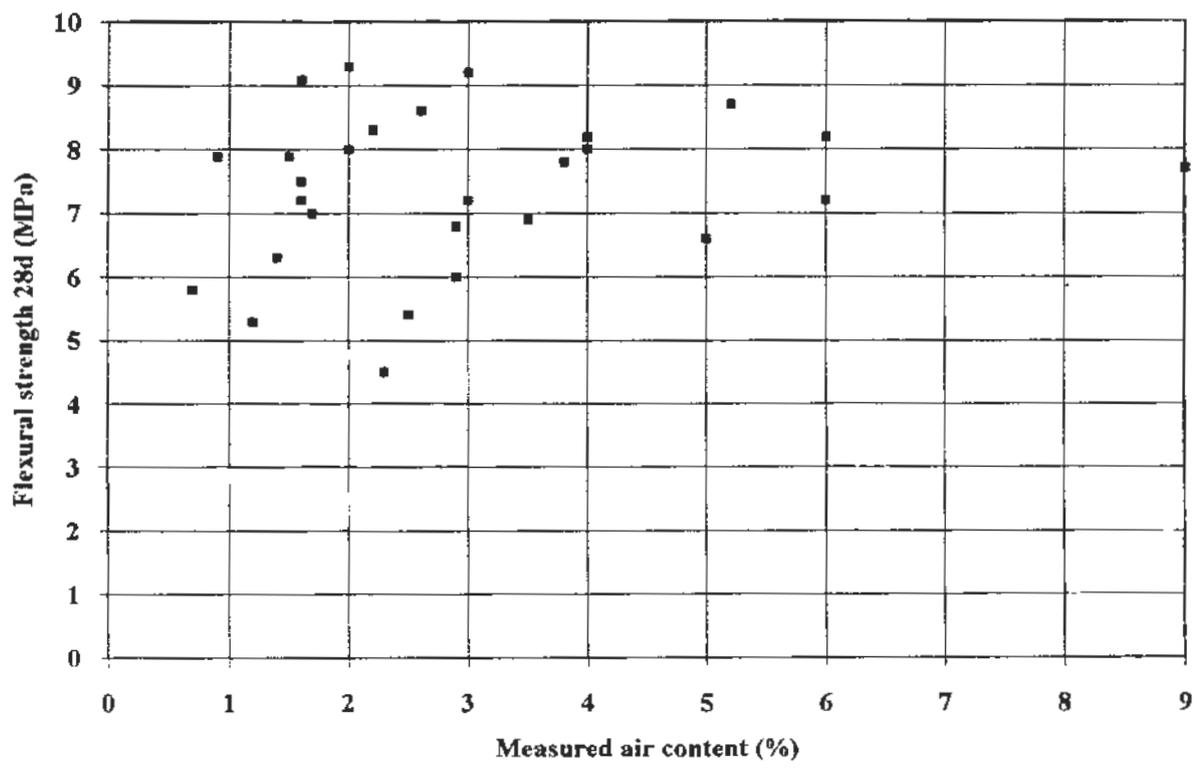

Figure 9. Flexural strength versus air content of the polymer cement concretes.
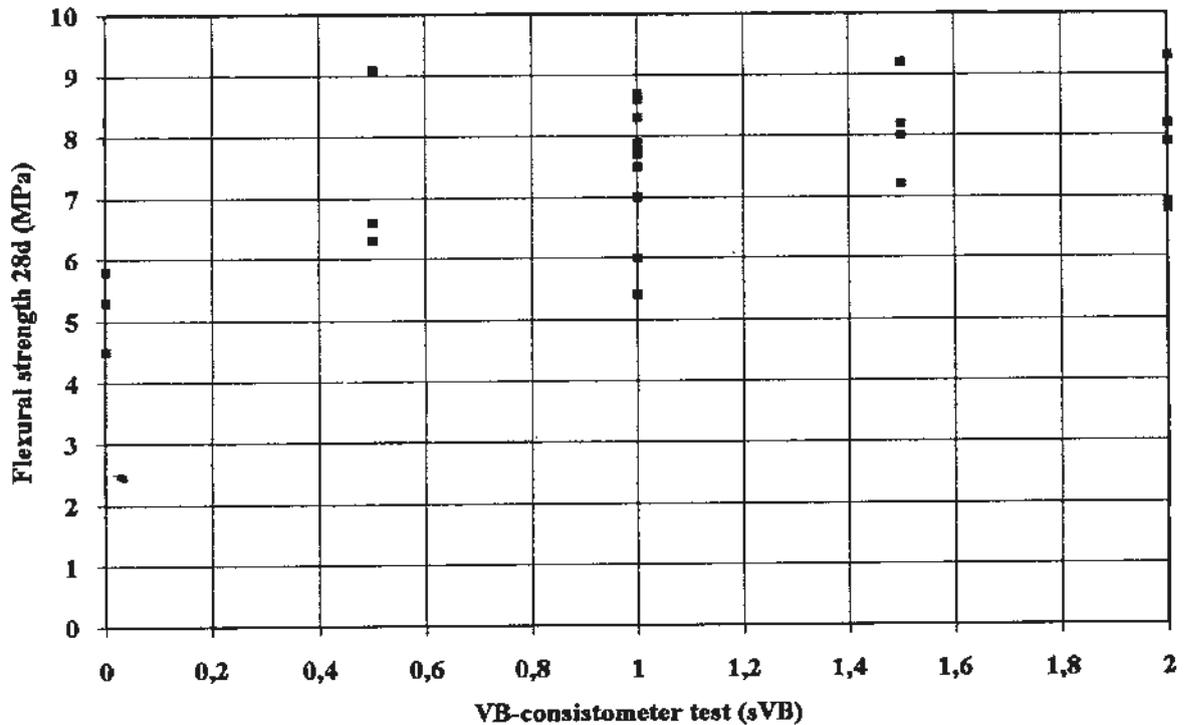
Figure 10. Flexural strength versus consistency of the polymer cement concretes.

Testing

The bending test where two line loads are applied gives smaller flexural strength values compared to the method with one line load because the area of maximum moment is longer in the first mentioned method. According to the results of this project one line load method gives about 25 % better flexural strength values. Also the specimen size and maximum aggregate size have a strong effect on the obtained flexural strength values, smaller prisms give always higher strengths than larger concrete beams. Flexural strengths of the mortar prisms (40*40*100 mm^3) having 2 mm maximum aggregate size were 27 % in the average higher compared to the concrete beams (100*100*500 mm^3) produced with 16 mm maximum aggregate size at the age of 28 days.

Polymers

The studied polymers caused quite diverse effects on the strength properties of the test concretes. Similarly consistency, air content, setting times and other fresh concrete properties changed adversively depending on the used polymer type. Compressive strengths of SBR concretes and comparison concretes were quite similar and the use of SBR latexes reduced the compressive strength only slightly. Thermoplastic latexes (PAE, PVAC, S-A) diminished compressive strengths rather much although the flexural strength was very good compared to the compressive strength. Thermoplastic latex concretes increased the ratio between flexural

and compressive strengths, this ratio ranged from 0,16 to 0,22. The compressive strengths of thermoplastic latex concretes ranged from 33,7 to 52,2 MPa.

Thermosetting latex (epoxy) did not increase the strength of tested mortars as much as for example SBR latexes. There were some hardening problems with powdered polymers but they possessed fairly good flexural strengths. The use of powdered polymers caused some shrinkage cracks in the specimens after the moist curing.

Binders and polymers

Sulfate resistant portland cement P40/28 SR seemed to work best in polymer cement concretes. With this cement type flexural strengths developed reasonably well from the first day to 28 days. However, one of the best flexural strength values was achieved with extra rapid hardening Portland cement P40/3 and silica fume. This test was the only one where silica fume caused a clear increase in flexural strength. Usually with P40/3 cements not very good flexural strengths were achieved at the age of 28 days. The use of P40/3 caused flexural strengths to decrease slightly from the first day results compared to 7 day results but strength always recovered at the age of 28 days.

Not surprisingly the cement amount correlated well with the achieved flexural strengths at least up to 400 kg/m³. Similarly when the latex amount is between 0 - 30 % of the cement amount, increase in the latex amount always increased flexural strength of polymer cement concretes. The inefficiency of large 20 % silica fume dosages in enhancing the flexural strength of polymer cement concretes can be explained by the blocking action that polymers have on calcium hydroxide formation in the cement paste.

Curing

According to the tests air curing after one day in the mold is the best curing method for polymer cement concretes. Best curing method might vary if the polymer cement concrete contains smaller latex amounts than used in these tests. When latex amount is as high as 30 % of the cement amount polymer properties have a dominating influence on concrete behavior.

Aggregates and superplasticizers

Polymer cement concretes produced by gabro aggregates increased somewhat the flexural strengths compared to typical granite based polymer cement concretes. Normal grading curve with small amount of fine aggregates gave better flexural strength results than polymer cement concretes where larger amounts of fine aggregates were used. All polymer cement concretes containing superplasticizers had better flexural strength values compared to the same concretes without superplasticizers.

Mixing procedures, air content and consistency

It seems that mixing procedures have very small effects on the strength properties of polymer cement concretes. Air content did not seem to have any effect on flexural strengths, a batch containing more than 9 % of air had a flexural strength of 7,7 MPa at the age of 28 days and

the same batch containing only 1,6 % of air had a flexural strength of 7,2 MPa at the same age. These polymer cement concretes were made with almost the same mix proportions. In Figure 9 the flexural strength dependence on air content is presented. There is no correlation between flexural strength at the age of 28 days and the air content values. Consistency of the fresh concretes seems to affect flexural strengths. The best flexural strength values were obtained when consistency was between 1,0 - 1,5 sVB. Batches having fluid consistency and when the consistency exceeded 2 sVB did not achieve as high flexural strength values. Reason for this was probably in the efficiency of the available compaction techniques.

5 CONCLUSIONS

The best flexural strength achieved with the larger concrete beams was 9,3 MPa at the age of 28 days when styrene butadiene rubber latex was used. Solid polymer content was 15 % of the 400 kg/m^3 cement amount. Cement type was sulfate resistant, normally hardening Portland cement P40/28 SR. Gabro based aggregates and lignosulfonate based superplasticizer were used in this test concrete and it had a compressive strength of 72,2 MPa at the age of 28 days. Almost as good flexural strength of 9,2 MPa was achieved using 10 % silica fume of the cement amount and extra rapid hardening Portland cement P40/3 350 kg/m^3. In this concrete latex was also styrene butadiene rubber and normal granite based aggregates were used. A sulfonated naphthalene formaldehyde condensate was used as superplasticizer and its dosage was 2,5 % of the cement amount. Comparison concrete batches without polymers achieved only 5,2 MPa and 5,4 MPa flexural strength values but their compressive strengths were 70 MPa.

The best flexural strength achieved with mortar prisms was 16,7 MPa when the batch had a very dry consistency. The applied polymer was styrene butadiene rubber. When the consistency of the batch was fluid the best flexural strength achieved was 14,3 MPa with styrene-acrylate powder having a dosage of 15 % of the cement amount. Cement type was sulfate resistant Portland cement P40/28 SR and cement content was 500 kg/m^3. Lignosulfate based superplasticizer had a dosage of 2,5 % of the cement amount. Good flexural strength value was also achieved with the use of styrene butadiene rubber 15 % (solid) of the cement amount together with superplasticizer based on sulfonated naphthalene formaldehyde condensate with the dosage of 2,5 % of the cement amount. This mix proportioning gave 11,6 MPa flexural strength at the age of 28 days. Cement type was P40/28 SR and cement content was 500 kg/m^3. Comparison mortar batch without polymers achieved only 5,9 MPa flexural strength at the age of 28 days.

The carbon distribution in the phase map of Figure 1 shows that the polymer component concentrates into the cement paste phases where Ca/Si-ratio is smallest. Similarly the percentual weight concentrations of metal, sulphur, and alkali components increase in the phases that are situated at longer distances from the unhydrated cement particles. During the hydration process AFt, AFm, and alkali components grow or migrate to the more porous regions between the cement particles or to the transition zone near the aggregate particles.

6 ACKNOWLEDGEMENTS

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