

DESIGNING LATEX FOR CEMENT AND CONCRETE

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ABSTRACT

A latex may be composed of a base copolymer, a stabilization system and various functional monomers included in the polymer chain. The base copolymer is chosen in order to obtain the desired mechanical and physical properties, while the stabilization system is composed of a combination of emulsifiers and colloid stabilizers in order to prevent the polymer emulsion from coagulating when it is mixed with mortar or concrete. The functional monomer is chosen to give the base polymer special properties, for example by being capable of forming chemical bonds between the polymer chain and the cement minerals. The idea is that such interactions will render the latex modified mortar or concrete insensitive to wetting. Examples of such latexes are given together with their influence on mechanical and physical properties of mortars when 10 vol% of the cement gel is replaced with polymer at constant w/c-ratio.

Key-words: Polymer cement concrete, latex, polymer emulsion, flexural strength, durability, carbonation, capillary suction.



1 INTRODUCTION

Mortar and concrete made with Portland cement have been the most important construction materials for the past 160 years or more. Ordinary Portland cement concrete exhibit an excellent service performance if it is mixed correctly and placed in a non-aggressive environment. However, cement mortar and concrete have some disadvantages such as low tensile strength, substantial drying shrinkage and limited resistance towards certain chemicals. Many attempts involving polymers have been made to reduce these disadvantages, among them latex additions to the fresh mix. The first patent with the concept of latex modified cement mortar or concrete was published by Lefebure /1/ in 1924 and research in this field is still in progress. Ohama /2,3/ has recently given excellent reviews describing the status of latex-modified mortars

Curing scheme II = 2 days in the mould covered by wet burlap,
("dry-wet-dry") 12 days at 50% R.H.,
7 days submerged in water,
7 days at 50% R.H.

Curing scheme III = 2 days in the mould covered by wet burlap,
("dry-wet") 19 days at 50% R.H.,
7 days submerged in water

The common period of 2 days in the mould covered by wet burlap is to ensure good cement hydration, while the rest of curing scheme I is considered to give the best result for the polymer effect according to the principle of film-formation /3/. During the 14 first days of curing scheme I the weight-loss of the prisms are monitored as a measure of retained water. Curing scheme III will determine a possible loss of mechanical properties due to wetting, while curing scheme II shows if a loss of properties is reversible. In curing scheme III the prisms are weighed before and after submerging in water as a measure of water repellency. In addition to the 9 prisms (3 parallels), two cylinders ($d = 10$ cm, $h = 20$ cm) are cast. One for the carbonation test (storage in 3 vol % CO_2 in air, radial cleavage and application of phenolphthalein) and one for measurements of capillary suction (dried out disc placed with one surface just below water surface and measurement of the weight increase as a function of time).

3 RESULTS

3.1 Latex composition

As stated earlier, the latexes are composed of a base copolymer, a stabilisation system and a functional monomer giving the resulting terpolymer (3 monomers) particular properties. The selection of the three components are given in the following sections.

3.1.1 The base copolymer

There is a wide range of combination of monomers to chose from in order to give a suitable polymer backbone. Important considerations are that the chosen monomers are industrially available and undergo emulsion polymerisation readily at normal atmospheric pressures. Excessively toxic monomers should be avoided. The MFT of the copolymer may be varied within wide limits by copolymerisation of a "soft" (low glass-transition temperature) and "hard" (high glass-transition temperature) monomer.

Suitable "soft" monomers are n-butyl acrylate (BA) and 2-ethylhexyl acrylate (EHA), while "hard" monomers commonly used are methylmethacrylate (MMA) and styrene (St). A comparison of the polymers 60/40 EHA/MMA, 50/50 EHA/MMA, 60/40 BA/MMA and 50/50 BA/MMA showed that in spite of the similar glass-transition temperatures of BA and EHA the combination of BA/MMA gave better latex rheology and less sticking of the fresh mix to equipment, and was therefor selected. Thus the latexes are acrylate based.

3.1.2 The stabilisation system

The stabilisation system of the latex consist of one or more surfactants with optionally a protective colloid also present.

Surfactants may be of the anionic (A), cationic (C), or non-ionic (N) types. Anionic surfactants are universally used in emulsion polymerisation, while if the latex is to be used in a system of high ionic strength like a cement mortar, the stability will be greatly improved by the addition of a non-ionic type as well.

Various stabilisation systems (S1-S5) were tried out for a 50/50 BA/MMA backbone, with and without functional monomer. Rheological properties of cement mortars incorporating these latexes (at 10 % polymer) were tested and are listed in Table 1.

In addition, minor amounts of a defoaming agent were added to all latexes.

Table 1. Rheological properties for cement mortar modified with 10 % polymer (50/50 BA/MMA) with various stabilisers.

Latex number	Stab. system	Surfactant type	Func. monomer	Slump (cm)	Flow (%) [§]	Air content
103-03	S1	A	None	0.3	30	-
103-04	S1	A	2·A1*	0	-	-
109-03	S2	A/N	None	9.5	160 ^o 205 [§]	10.5
109-04	S2	A/N	2·A2*	10.0	200 ^o 225 [§]	6.2
110-01	S3	A	None	1.0	75	16.3
110-02	S3	A	2·A2*	0.5	100	18.8
111-03	S4	A/N	None	1.5	90	>25
111-04	S4	A/N	2·A2*	10.5	210 ^o	8.4
111-05	S5	A/N	None	0	-	-
111-06	S5	A/N	2·A2*	11.0	>225 ^o	10.4
Ref. mortar	-	-	-	3.2	145	3.7

*See section 3.1.3 Functional monomer.

§ % increase in diameter of a molded truncated cone specimen after jiggling 15 times. Deviations from 15 are given as upper numbers.

The results in table 1 reveals that the latexes are indeed very sensitive to the stabilisation system employed. The system S2 was chosen for the rest of the work since it was the only one stabilizing a polymer both with and without functional monomer, it gave excellent workability and it entrained least air. The latter property may be adjusted by adding more or less of a defoaming agent.

3.1.3 Functional monomers

The idea of the functional monomers is to act as a "chemical anchor" between the polymer and the cement gel and thereby render the resulting polymer cement composite insensitive to moist conditions, as visualized in figure 1. In addition, the functional monomers may couple together, either by self-reaction or through chelate formation with polyvalent elements from the cement. The latter mechanism, shown in figure 2, may form larger molecules and clusters and thus lead to further improvement in mechanical properties.

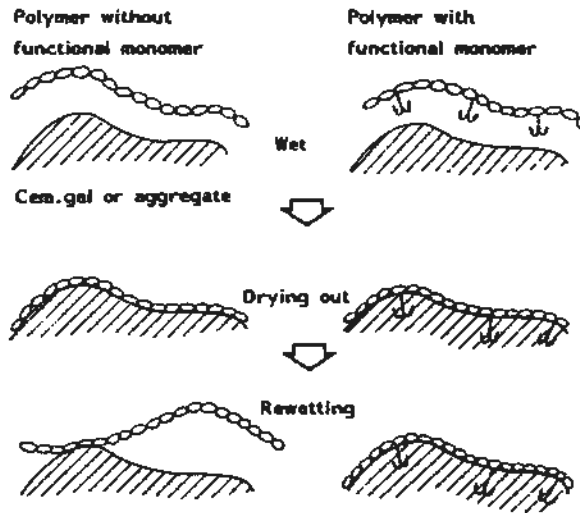


Fig 1. Principal sketch of the mechanism of functional monomers making latex modified cement mortar insensitive to moist conditions.

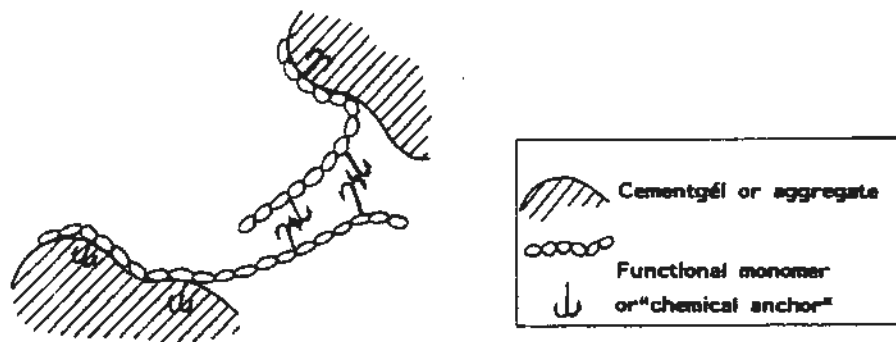


Fig 2. Principal sketch of cluster formation leading to giant molecules binding different particles together.

Taking into consideration commercial availability, there are five main categories of functional monomers available (A, B, C, D and E) and within each category there are a lot of individual compounds (A1, A2, ... etc). However, only a limited number of the most promising can be tried out. So far, the functional monomers A1, A2 and A4 have been tested. However, A1 was abandoned at an early stage due to a severe increase in viscosity of the latex with increasing amounts of A1.

3.2 Polymer cement mortars based on BA/MMA-latex without functional monomers

Latexes with the polymers 0/100, 50/50, 60/40 and 70/30 BA/MMA were made and polymer cement mortars, where 10 vol% of the binder was polymer, were cast and their properties are reported in the following sections. This series was made in order to study the influence of "hardness" or MFT on the properties of the composite and to serve as reference when the effect of functional monomers is evaluated.

3.2.1 Rheological properties

The rheological properties are given in table 2, together with a reference mortar, in which all the binder is cement paste with w/c = 0.55. To test the effect of the water phase alone two further mortars were prepared. One (124-A) consisted of surfactants and catalyst etc. which had been heated together under the same conditions as during polymerisation, while the other (124-B) contained only the surfactants. In both these cases the active substances are in the order of 0.3 % of the cement weight.

Table 2. Rheological properties for polymer cement mortars where 10 vol% of the binder is polymer of different BA/MMA-ratios.

Latex number	BA/MMA	Volume density (kg/l)	Air content (vol%)	Slump (cm)	Flow (%) [§]
123-03	0/100	2.201	4.3	9.8	160 ^o /225 ³
109-03	50/50	-	10.5	9.5	160 ^o /205 ⁶
123-01	60/40	2.084	9.0	7.5	55 ^o /145
123-02	70/30	2.035	10.2	5.5	55 ^o /140
124-A	Cat.+S2	2.078	10.8	7.5	105 ^o /200
124-B	S2 only	1.959	19	8.5	110 ^o /210
Ref.	None	-	3.7	3.2	145

[§] % increase in diameter of a molded truncated cone specimen after jiggling 15 times. Deviations from 15 are given as upper numbers.

The results show that the polymers entrain as much air as the catalyst/S2 system, except for the pure MMA latex which in fact defoams the mixture to a level close to the reference mortar. However, it is clear that the workability of the mix decreases with increasing BA in the polymer.

3.2.2 Mechanical properties

The absolute flexural and compressive strengths of the polymer cement mortars are given in Table 3, while the strengths relative to the reference mortar are depicted in Fig 3.

Table 3. Flexural- and compressive strength (MPa) of polymer cement mortars based on polymers with different BA/MMA-ratio

Latex number BA/MMA	123-03 0/100	109-03 50/50	123-01 60/40	123-02 70/30	124-A -	124-B -	Ref. mortar -
Curing Scheme I ("Dry")							
Weight (g)	550±8	-	525±8	514±8	517±4	498±2	570±2
Flexural	9.0±0.3	10.4±0.2	9.0±0.3	9.2±0.6	6.6±0.2	5.2±0.1	7.3±0.8
Compress.	45±2	33±1	34±1	28±1	30±1	23±1	34±1
Curing scheme II ("Dry-wet-dry")							
Weight (g)	557±10	-	535±11	518±6	533±3	508±3	583±5
Flexural	8.9±0.9	7.2±0.2	6.5±0.4	6.9±0.6	6.4±0.4	4.0±0.2	5.5±0.7
Compress.	49±1	29±3	32±1	27±1	35±1	25±1	43±3
Curing scheme III ("Dry-wet")							
Weight (g)	579±5	541±11	547±8	536±7	537±8	524±9	591±8
Flexural	7.0±0.5	7.0±0.3	6.0±0.1	5.7±0.2	5.6±0.3	4.3±0.1	5.7±0.6
Compress.	39±1	27±1	26±1	21±1	27±1	20±1	35±2

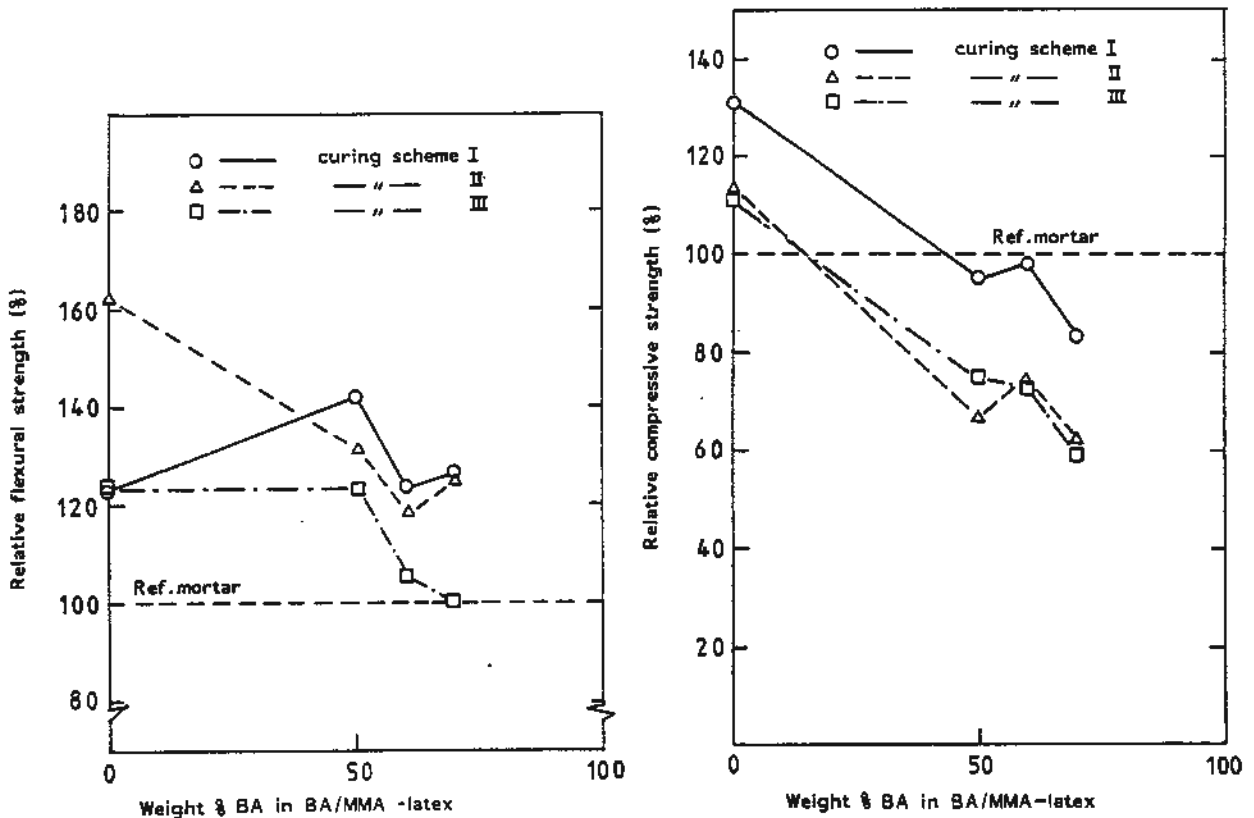


Fig 3. The relative flexural and compressive strengths of polymer cement mortars based on polymers with different BA/MMA-ratios

As seen from Table 3, all the polymer cement mortars lose much of their excess flexural strength upon wetting, while only the one based on pure MMA regains its strength after drying out again. However, values relative to ordinary cement mortar (Fig 3) show that all the polymer cement mortars regain their improvement in flexural strength after drying. The relative compressive strength (Fig 3) is equal for curing scheme II and III, while the relative strength for curing scheme I in general are 20 % higher.

Furthermore, the mechanical strength of polymer cement mortars declines with increasing amounts of BA in the polymer.

The mixtures 124-A, 124-B and reference mortar give an opportunity to find the effect of air-content on mechanical strength. The compressive strength seems to be reduced by 4 % for each additional 1 % air, while the flexural strength is reduced by 1-2 % for each 1 % up to 10 vol% air and then by 4 % at higher air contents.

3.2.3 Durability properties

3.2.3.1 Carbonation

Carbonation after 12 weeks with 3 vol% CO₂ was measured to 9, 7, 9, 14 mm for polymers with 0/100, 50/50, 60/40 and 70/30 BA/MMA-ratio and 10, 11 and 18 mm for the reference mortar, and mortars with 124-A and 124-B. The latter series reveals that the carbonation rate does not increase significantly until the air content exceeds 10 vol%. The first series shows that pure MMA seems to have no effect on carbonation rate (same vol% air as reference), while 50/50 BA/MMA leads to a small decrease. It appears that the protection decreases with increasing BA-content in the polymer.

3.3 Polymer cement mortars based on BA/MMA-latex with functional monomer A2

Extensive work has been carried out with polymers containing the functional monomer A2, since it is the most promising so far. Series with different contents of A2 in 50/50 BA/MMA-latexes, different BA/MMA-ratios with constant A2-content, and pure MMA-latex with various A2-contents have been tested to date.

3.3.1 Rheological properties

The rheological properties of the above series are shown in Table 4 together with an ordinary cement mortar (without polymer) and polymer cement mortar based on a commercial styrene-butadiene latex (SBR) as references.

The results reveal that the slump (Fig 4) and workability are at a maximum for 8·A2 in 50/50 BA/MMA. This polymer cement mortar was in fact close to self-leveling, with an excellent coherence.

Table 4. Rheological properties of polymer cement mortars based on BA/MMA-polymers with functional monomer A2

Latex number	BA/MMA	Rel. A2 cont.	Volume density (kg/l)	Air content (vol%)	Slump (cm)	Flow (%) [§]
109-03	50/50	0	-	10.5	9.5	160 ^o /205 ^o
109-04	50/50	2	-	6.2	10.0	200 ^o /225 ^o
115-05	50/50	4	2.076	13.3*	10.5	215 ^o
115-06	50/50	8	2.192	3.7	>11.5	>225 ^o
119-01	50/50	10	2.168	7.0	10.0	145 ^o /195
116-07	50/50	12	2.153	9.0 [@]	9.5	125 ^o /180
116-08	50/50	16	2.165	6.9	9.5	160 ^o /185
116-09	50/50	20	2.025	10.5 [@]	2.0	10 ^o / 80
119-01	50/50	10	2.168	7.0	10.0	145 ^o /195
119-02	60/40	10	2.063	9.5 [@]	6.0	90 ^o /155
119-03	65/35	10	2.128	7.2	6.5	110 ^o /160
119-04	70/30	10	2.079	8.0 [@]	3.0	60 ^o /135
123-03	0/100	0	2.201	4.3	9.8	160 ^o /225 ^o
128-01	0/100	4	2.187	4.4	9.5	160 ^o /225 ^o ¹²
128-02	0/100	8	2.188	4.7	9.2	145 ^o /225 ^o ¹²
Ref. mortar	-	-	-	3.7	3.2	145
SBR	-	-	-	8.0 [@]	9.5	220

[§] % increase in diameter of a molded truncated cone specimen after jiggling 15 times. Deviations from 15 are given as upper numbers.
 * Measured at 0.25 atm instead of 1.0 atm, result multiplied with 2.5.
 @ Measured at 0.50 atm instead of 1.0 atm, result multiplied with 1.5.

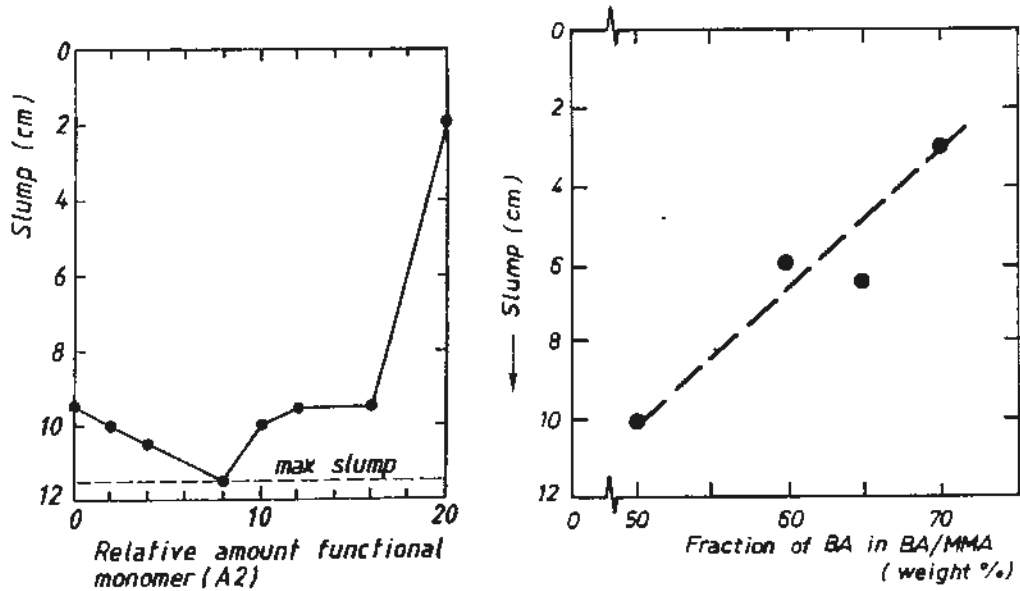


Fig 4. Slump for polymer cement mortars modified with 50/50 BA/MMA with different amounts of A2 (left) and with various BA/MMA-latexes with 10·A2

The serie with constant functional monomer (10·A2) shows that the slump (Fig 4) and workability decrease with increasing amount of BA in the polymer. The workability does not depend on the A2 content when the latex contains no BA.

3.3.2 Mechanical properties

The mechanical properties of the series with 50/50 BA/MMA-latex with variable content of functional monomer A2 is given in Table 5, while the flexural and compressive strengths relative to a reference mortar are depicted in Fig 5 and 6, respectively.

The series with polymer cement mortars based on latex with different BA/MMA-ratios with constant functional monomer (10·A2) has mechanical properties as listed in Table 6 and shown in Fig 7.

Table 7 indicates the absolute mechanical properties for polymer cement mortar based on MMA-latex with different amounts of A2.

As a comparison, a polymer cement mortar based on a commercial SBR-latex (10 vol % by replacement) exhibits relative flexural strengths compared with an ordinary cement mortar of 132, 144 and 114 % for curing scheme I, II and III, respectively. The similar values for the compressive strengths are 117, 94 and 96 %. This implies that the SBR-latex loses strength when wet, but regains its strength when drying out again as most commercial latexes.

Table 5. Flexural and compressive strength (MPa) of polymer cement mortars based on 50/50 BA/MMA-polymer with different contents of A2

Latex number Rel. A2	109-04 2	115-05 4	115-06 8	119-01 10	116-07 12	116-08 16	116-09 20
Curing scheme I ("Dry")							
Weight (g)	-	528±11	567±11	525±2	532±2	541±6	517±7
Flexural	9.3±0.1	9.9±0.2	10.8±0.5	10.3±0.2	10.2±0.6	12.3±0.2	10.8±0.5
Compress.	37±1	30±2	36±2	41±2	42±2	38±2	40±1
Curing scheme II ("Dry-wet-dry")							
Weight (g)	-	531±9	573±10	545±6	536±9	557±5	526±2
Flexural	6.4±0.1	6.4±0.8	5.7±0.3	7.0±0.7	7.0±0.3	6.5±0.6	5.6±0.5
Compress.	32±2	29±2	33±2	42±1	42±1	35±2	35±1
Curing scheme III ("Dry-wet")							
Weight (g)	577±12	554±6	576±4	548±9	540±4	554±3	548±10
Flexural	6.3±0.5	6.3±0.2	6.4±0.7	7.3±0.5	7.2±0.1	6.8±0.1	6.0±0.3
Compress.	28±2	22±1	30±2	32±1	34±1	27±2	28±1

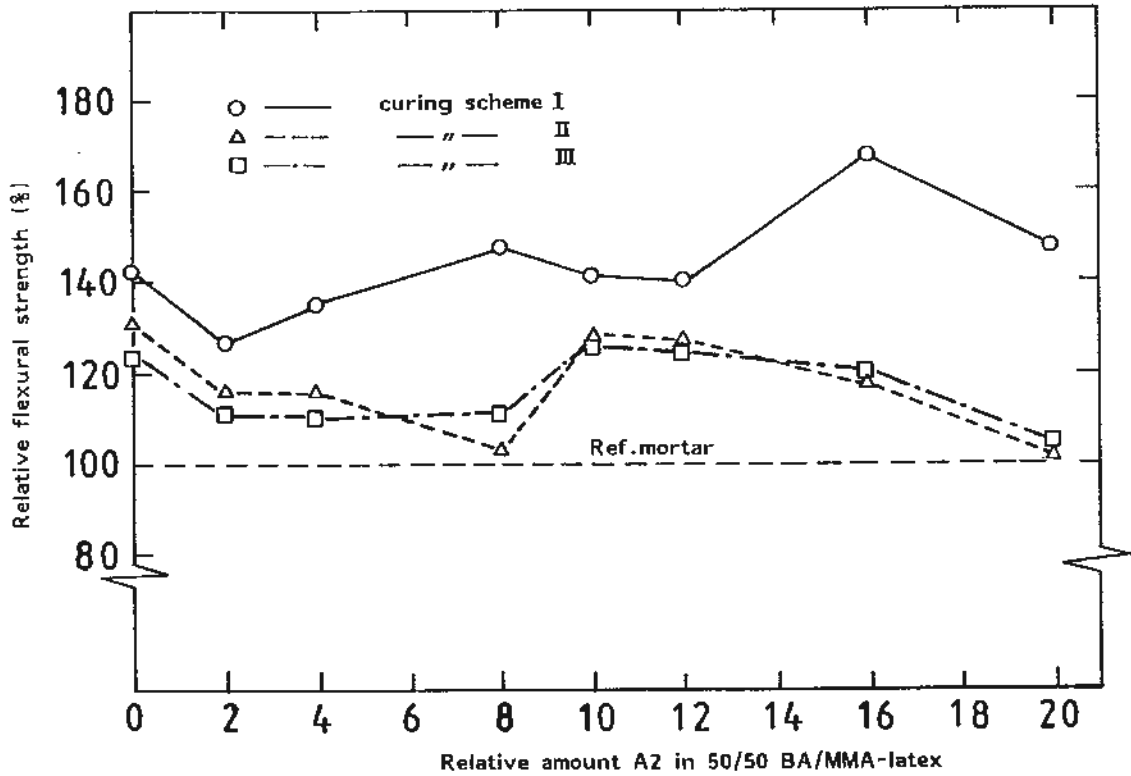


Fig 5. Relative flexural strength of polymer cement mortars based on 50/50 BA/MMA-polymer with various amount of A2

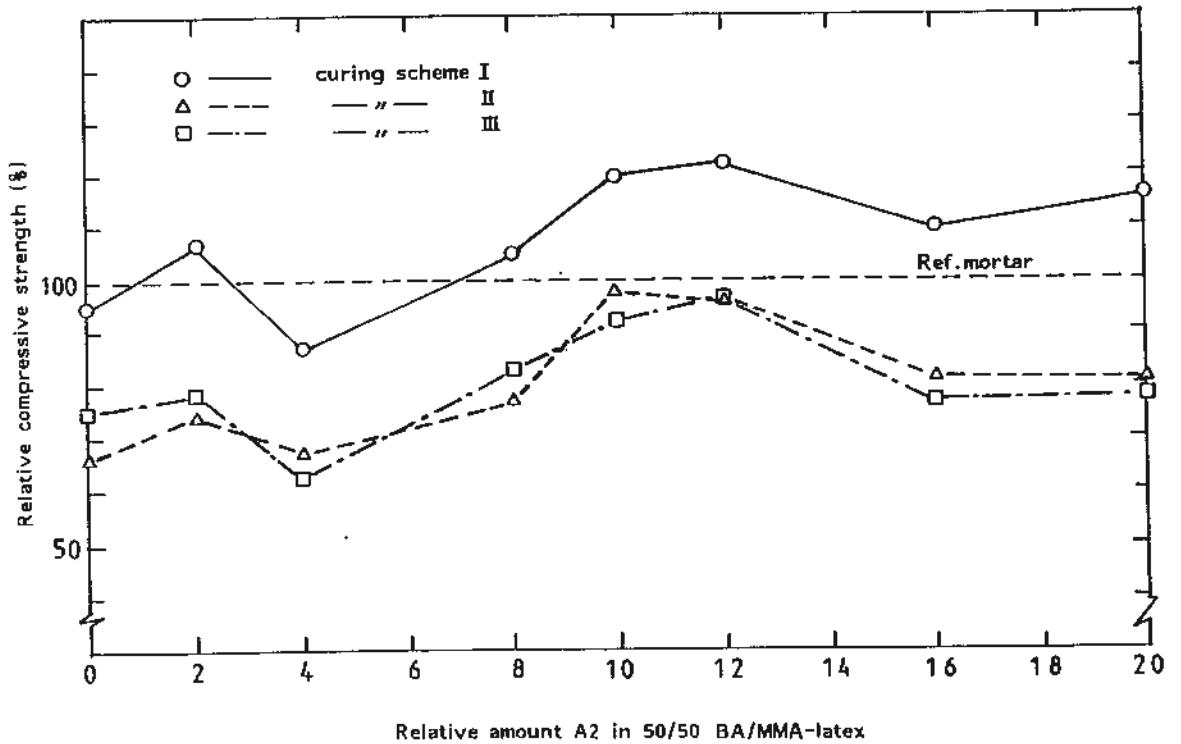


Fig 6. Relative compressive strength of polymer cement mortars based on 50/50 BA/MMA-polymers with various amount of A2

Table 6. Flexural and compressive strengths (MPa) of polymer cement mortars based on polymer with fixed amount functional monomer (10·A2) and various BA/MMA-ratios

Latex number BA/MMA	119-01 50/50	119-02 60/40	119-03 65/35	119-04 70/30	SBR -	Refer. mortar -
Curing scheme I ("Dry")						
Weight (g)	525±2	505±7	529±5	530±3	530±2	570±2
Flexural	10.3±0.2	10.1±0.4	10.7±0.5	10.7±0.5	9.6±0.2	7.3±0.8
Compress.	41±2	36±1	33±1	32±2	40±1	34±1
Curing scheme II ("Dry-wet-dry")						
Weight (g)	545±6	515±1	545±4	535±11	541±3	583±5
Flexural	7.0±0.7	6.2±0.2	7.3±0.2	6.6±0.6	7.9±0.3	5.5±0.7
Compress.	42±1	32±1	29±1	25±2	41±1	43±3
Curing scheme III ("Dry-wet")						
Weight (g)	548±9	529±5	553±7	540±8	556±5	591±8
Flexural	7.3±0.5	6.5±0.3	6.7±0.2	6.7±0.3	6.5±0.2	5.7±0.6
Compress.	32±1	27±1	23±2	22±1	34±1	35±2

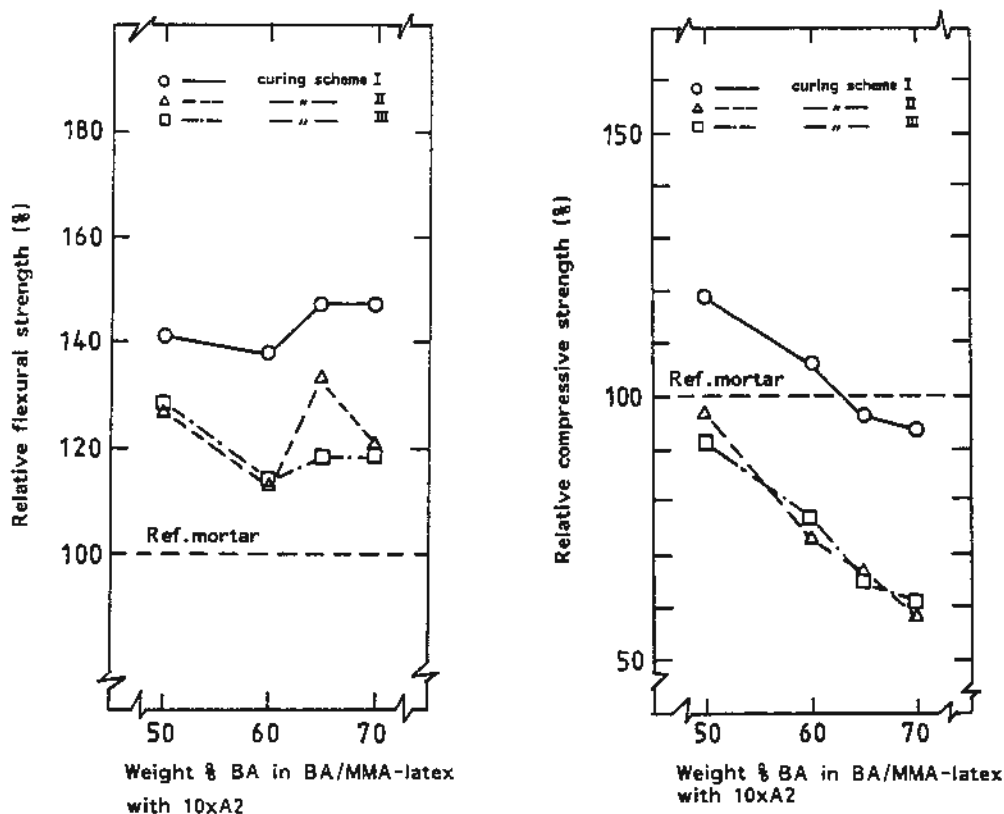


Fig 7. Relative flexural and compressive strength of polymer cement mortars based on polymers with a fixed amount of functional monomer (10·A2) and various BA/MMA-ratios

Table 7. Flexural and compressive strengths (MPa) of polymer cement mortars based on MMA with different amounts of A2

Latex number Rel. A2	123-03 0	128-01 4	128-02 8	SBR -	Ref. mortar -
Curing scheme I ("Dry")					
Weight (g)	550±8	552±7	547±4	530±2	570±2
Flexural	9.0±0.3	7.9±0.6	8.0±0.8	9.6±0.2	7.3±0.8
Compressive	45±2	38±2	41±1	40±1	34±1
Curing scheme II ("Dry-wet-dry")					
Weight (g)	557±10	556±7	560±7	541±3	583±5
Flexural	8.9±0.9	6.5±0.2	6.6±0.4	7.9±0.3	5.5±0.7
Compressive	49±1	45±2	46±1	41±1	43±3
Curing scheme III ("Dry-wet")					
Weight (g)	579±5	579±7	581±7	556±5	591±8
Flexural	7.0±0.5	6.8±0.1	6.7±0.5	6.5±0.2	5.7±0.6
Compressive	39±1	36±1	37±2	34±1	35±2

In the series of 50/50 BA/MMA latexes with variable A2 content, the polymer cement mortars based on latexes with 10 and 12 A2 exhibit the best mechanical properties, particularly after taking into account the aircontent. However, even though the relative strengths are vitually constant after curing scheme II and III, the values for curing scheme I are 10-20 % higher (see Fig 5/6).

The series of latexes with fixed amount of functional monomer (10·A2) and variable BA/MMA-ratios reveals the same effect of the curing schemes as the preceeding series. Furthermore, the compressive strength decreases considerably with increasing BA-content (see Fig 7).

The MMA-series with functional monomer A2 show decreasing strengths for the latexes with A2 in spite of constant air-content (see Table 7).

3.3.3 Durability properties

3.3.3.1 Carbonation

The carbonation of polymer cement mortars based on 50/50 BA/MMA-latex with different A2-content is shown in Fig 8. It appears that the resistance against carbonation increases with increasing A2-content. The carbonatization depth after 20 weeks for the best polymer cement mortars are only one third that of the control cement mortar. SBR-latex also reduces carbonation speed substantially.

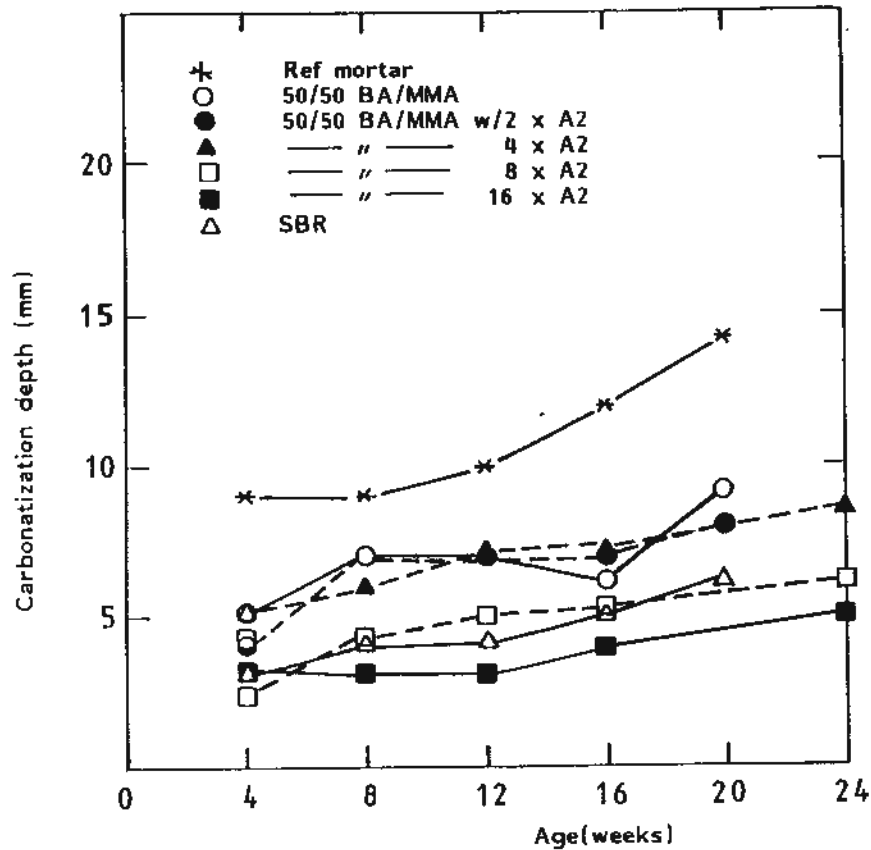


Fig 8. The carbonation depth of polymer cement mortars based on 50/50 BA/MMA-latex with variable A2-content.

3.3.3.2 Water transportation

The capillary suction of polymer cement mortar modified with 50/50 BA/MMA-latex with various A2-content is depicted in Fig 9. The tendency is toward lower absorption rate with increasing A2-content (when A2 > 4). Furthermore, the absorption rate is considerably lower than the cement mortar for all latexes.

The weight-loss of the polymer cement mortars is presented in Fig 10 as relative loss of the total water content in the specimen. This is taken as a measure of retained water. The retained water is 5 - 10 % higher than for the cement mortar, but the latexes do not seal the composite. The decrease in liquid water absorption is much greater than the decrease in evaporation, so the risk of water accumulation at outdoor exposure is minimal.

3.4 Polymer cement mortars based on BA/MMA-latex with functional monomer A4

Some initial work has been done for polymer cement mortars based on 60/40 BA/MMA-latex with various amounts of the functional monomer A4. However, after the rheological and mechanical properties were measured, the work was terminated since A4 apparently did not function as a "chemical anchor" (see section 3.4.2).

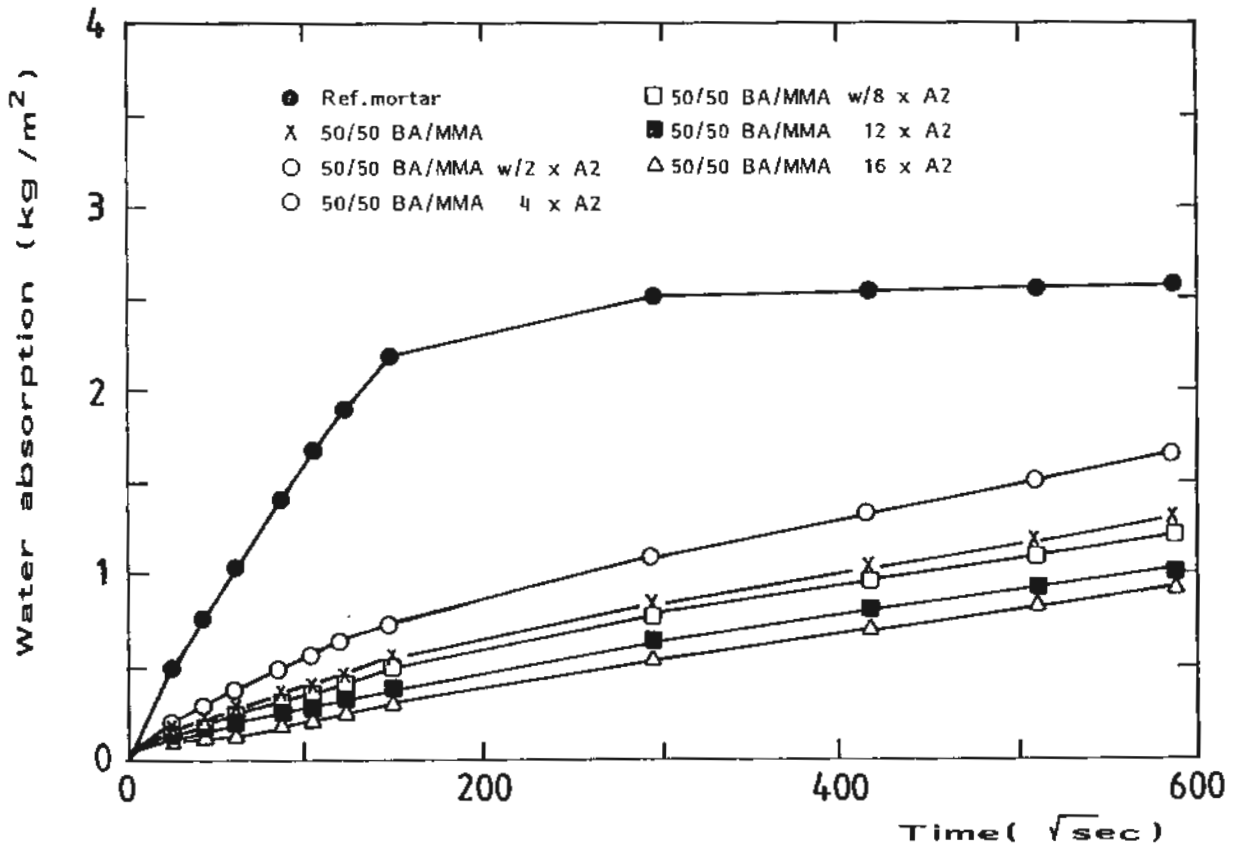


Fig 9. Capillary suction of polymer cement mortars based on 50/50 BA/MMA-latex with variable A2-content

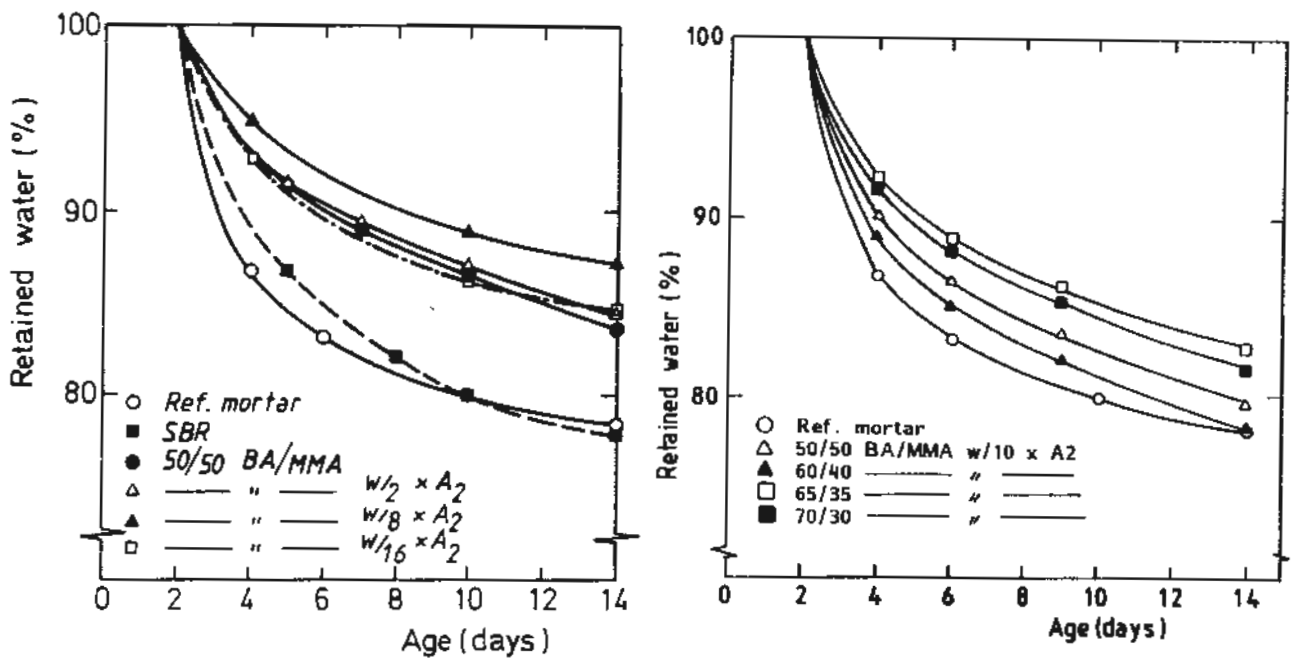


Fig 10. The retained water in polymer cement mortars based on different polymers

3.4.1 Rheological properties

The rheological properties of the above serie with A4 are given in Table 8 together with an ordinary cement mortar and a polymer cement mortar based on SBR-latex (10 vol % by replacement).

Table 8. Rheological properties of polymer cement mortars based on 60/40 BA/MMA-polymers with functional monomer A4

Latex number	Relative amount A4	Volume density (kg/l)	Air content (vol %)	Slump (cm)	Flow (%) [§]
123-01	0	2.191	9.0	7.5	55 ^o /145
122-02	2	2.107	8.7	10.5	220 ^o
122-03	3	2.008	9.4 [@]	8.5	10 ^o /100
122-04	4	1.954	10.9 [@]	7.0	10 ^o /100
SBR	-	-	8.0 [@]	9.5	220
Ref. mortar	-	-	3.7	3.2	145

[§] % increase in diameter of a molded truncated cone specimen after jiggling 15 times. Deviations from 15 are given as upper numbers.

[@] Measured at 0.5 atm instead of 1.0 atm, result multiplied with 1.5.

The results in Table 8 reveal that the air-content increases slightly and workability decreases with increasing A4-content, both of which are disadvantages. Repeatedly attempts to make a polymer cement mortar based on 60/40 BA/MMA-latex with 1·A4 gave mixtures impossible to cast (slump = 0).

3.4.2 Mechanical properties

The flexural and compressive strengths of the polymer cement mortars based on 60/40 BA/MMA-latex with functional monomer A4 are presented as relative values in Fig 11.

The results for the flexural strength (see Fig 11) show that the polymer cement mortars lose their strength when wet, but regain it after drying out again. This is a behaviour typical for a polymer without "chemical anchor" or when it does not function as intended. The reason why the strength after curing scheme II is not fully regained, is that the second drying periode was not long enough. However, an elongation of this periode would conflict with the total age for testing.

Furthermore, the mechanical strengths (see Fig 11) decrease with increasing amounts of functional monomer A4.

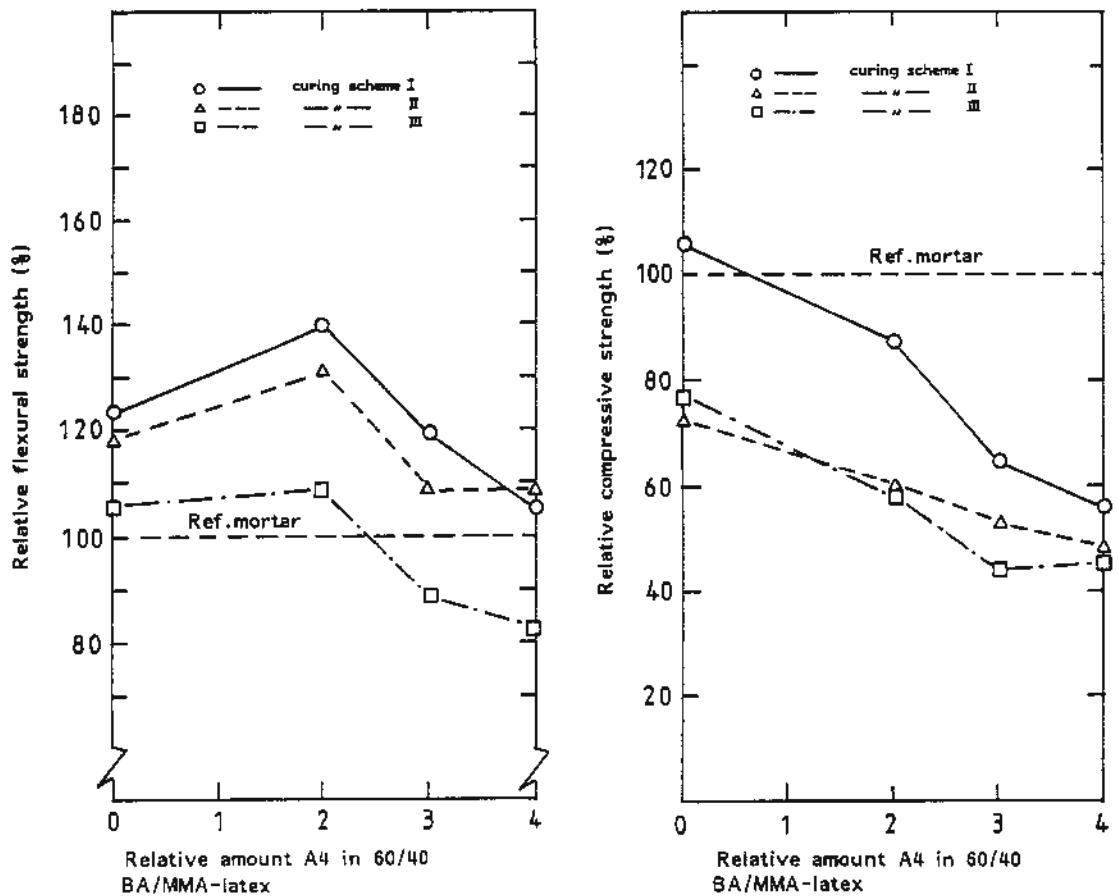


Fig 11. Relative flexural and compressive strengths of polymer cement mortars based on 60/40 BA/MMA-polymer with A4

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DISCUSSION

The main reason why increasing content of the functional monomer A4 leads to decreasing mechanical strength (Fig 11), while increasing amounts of A2 give constant or higher mechanical strength, is that A4 may be classified as a "soft" monomer and A2 as a "hard" monomer. In the series of 60/40 BA/MMA with A4, all latexes have a diffuse minimum film forming temperature (MFT) in the region 0 - 5°C. The MFT of 50/50 BA/MMA with 0, 4, 8, 10, 12, 16 and 20·A2, on the other hand, is 10, 24, 27, 28, 30, 36 and 42°C, respectively. The series of polymers with 10·A2 and variable BA/MMA-ratio has MFT 28, 16, 12 and 2 for a BA-content of 50, 60, 65 and 70, respectively. Since substantial improvement of the flexural strength for all polymer cement mortars, compared to a cement mortar, based on the above polymers has been observed, and the curing of all the composites have been performed at ambient temperatures (20 - 25°C), this implies that the mechanism of film formation as described by Ohama /3/ does not apply for these acrylates. In addition to the functional monomers, acrylate monomers themselves may interact strongly with the cement minerals, as stated by Chandra /4/. However, the film forming mechanism may apply for polymers like SBR, which do not contain functional groups that can interact with the cement minerals.

The preceding discussion means that MFT does not need to be considered when latexes are designed within the BA/MMA-system, and thus polymer compositions giving greater mechanical toughness may be utilized.

The observation in the series of 50/50 BA/MMA with different content of A2 that the improvement in flexural strength is the same after curing scheme II and III and higher after curing scheme I, is rather puzzling. If the functional monomer is not working as intended, as for A4, the flexural strength after curing scheme I and II should be the same and the flexural strength after curing scheme III should be lower. The only explanation is that an irreversible reaction occurs, involving the polymer, during the one week storage in water. The most likely type of reaction is that A2 does function as a "chemical anchor", and naturally such a reaction will imply a loss in flexural strength because of the more rigid (cross-linked) complex. Apparently the reaction needs a period with excessive pore water. Another type of reaction is a hydrolysis ("saponification") of the polymer, which also would give a stiffer polymer. However, in such a case one would expect the flexural strength after curing scheme III to be even lower than after curing scheme II, and, furthermore, both BA and MMA are known to be rather resistant towards an alkaline environment.

The minor increase in relative flexural strength with increasing A2 for 50/50 BA/MMA, as seen in Fig 5, may also be explained by an increasing stiffness with A2 in the polymer. However, the reason why the results are not improved much compared with 50/50 BA/MMA without A2 may only be understood if MMA itself can interact strongly with the cement minerals. In fact, this may be the explanation of why a pure PMMA latex surprisingly (hard spheres, MFT = 105 °C) improve the mechanical properties of an ordinary cement mortar (see Fig 3). A polymer cement mortar based on a polystyrene latex (hard non-reactive spheres, MFT = 100 °C) lead to a slight reduction of relative mechanical properties, and thus support the assumption of reactive MMA.

Another example of the significance of the flexibility of the polymer phase in the composite is seen in the serie of BA/MMA-latexes with constant functional monomer, 10·A2 (Fig 7), where the decrease in compressive strength is much steeper than the decrease in flexural strength with increasing BA-content. The decrease in compressive strength is due to a softer polymer, while the decrease in flexural strength is compensated somewhat by a simultaneous increase in the flexibility of the polymer.

The functional monomer A2 exhibits other positive effects also, such as increased workability (Fig 4). This effect is explained by the alteration of the charge of the particles in the fresh mix due to the polarity of the functional monomer A2 and MMA.

The diffusion rate of carbon dioxide is also reduced with increasing A2 (Fig 8). An explanation may be a lower diffusivity in a polymer - cement mineral complex than in a polymer, or, alternatively, an increase of the polarity of the polymer itself may lower the diffusion rate of non-polar gas molecules in general.

However, the first view is probably more correct, since the basical non-polar polymer SBR also is an efficient CO₂-block. Commercial acrylates have been shown by Ohama /3/ to give poor protection against carbonation of polymer cement mortars.

The reduction of the capillary suction (Fig 9) for polymer cement mortars support the view that the polymer complexes are concentrated in the poresystem /3/. The effect is explained by an alteration of the surface tension of the pore walls which creates a water repellancy. On the other hand, if the polymer is distributed in the matrix as inclusions, it will increase the termination of capillary pores and thereby reduce the speed of capillary suction. The inclusion theory is supported by the observation of decreasing relative compressive strength with increasing softness of the polymer (Fig 3 and 7). This had not been the case if the polymer strictly had filled up the capillary pores in the cement paste, especially not in a mortar so rich in cement paste.

5 CONCLUSION

It is possible to design polymers (latexes) that will improve the flexural strength of cement mortars and concrete regardless of the moisture conditions by the means of functional monomers. Combinations of n-butylacrylate (BA), methylmethacrylate (MMA) and a functional monomer A2 reveal that the improvements are not dependent on having a MFT lower than the curing temperature. Thus, polymers of higher mechanical toughness may be utilized.

In addition to improving mechanical strength, the functional monomers also affect the durability of the composite (e.g carbonation and capillary suction) and the rheological properties.

Making the mechanical properties of the polymer-ement composite unaffected by the moisture conditions is crucial for the utilization of mechanical improvements in outdoor constructions. Furthermore, durability properties will then also be insensitive to moist conditions. This is confirmed by chloride permeability tests, which will be published later in a larger durability context. Thus, the latexes described here are also advantageous in protective layers (e.g. bridge decks) and in repair mortars.

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