Modification of Cement Mortars by Polymer Latex

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ABSTRACT: The polymer systems of vinyl latex, epoxy latex/resin, and phenol formaldehyde were used to modify sand-cement mortar at room temperature. The compressive strength increased with an increase of the latex/resin concentration, with the addition of $CaCl_2$ or $CaCO_3$, and with the addition of superplasticizer. Tensile and flexural strengths also increased with polymer incorporation. The porosity of the modified mortar decreased with the addition of resin. The percentage of water absorption and acid solubility were found to decrease for the latex/resin modified samples. © 1997 John Wiley & Sons, Inc. J Appl Polym Sci **63:** 1251-1257, 1997

INTRODUCTION

With the advancement of structural engineering, efforts have been made to improve the characteristics of conventional concrete to more efficiently suit specialized constructions. An important development in this direction is the use of polymers to improve the properties of concrete.[1] Polymers generally are highly durable and strong, and thus concrete made with polymers would have superior properties to conventional concrete. Polymer concrete is made by mixing either a monomer or polymer in a dispersed, powdery, or liquid form with fresh concrete mixtures and subsequently curing it.

The first large-scale trial of epoxy resins as road surfacing materials was carried out in the 1950s.[2,3] The advantages of using epoxy resins were: the resin had excellent adhesion properties to bond sharp hard aggregates to improve skid resistance[4]; the epoxy layer was an effective barrier to moisture and moisture vapor; and the resistance of the surface to chemicals, oil, and grease was high.

The workability of the cement composites increased when modified with latex, and hence a reduction in the total water content was recommended. The properties of the latex combined with low water cement ratio produced a concrete that had improved flexural, tensile, and bond strength, lower modulus of elasticity, increased freeze–thaw durability,[5] and reduced permeability characteristics. Although an increase in compressive strength of cement mortar with increasing latex content[6] was reported, there were also reports of no reduction or a marginal decrease in compressive strength. Various latex materials like vinylidine chloride, styrene butadiene, polyvinyl acetate, and acrylics have been developed and marketed for several years.

In many respects $CaCl_2$ has been found to be an ideal additive to cement mortar. The rate of hardening of cement is still increased by the addition of $CaCl_2$ or format (an optimum quantity being 1.5%, because higher amounts cause corrosion of embedded steel).[7] This is especially useful in cold weather. Hence in the present work the effect of $CaCl_2$ on the strengths of unmodified and modified mortars was also studied.

Prescon is a new generation of melamine based superplasticizer.[8] When added to concrete (about 0.5–2%), Prescon imparts a very high workability as well as an increase in the 28-day compressive strength. So the combined effect of Prescon and the latex on the mortar compressive strength were studied.

The literature shows that a lot of work has been done in the field of polymer modified ce-

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ment composites; but most of the studies have been patented and detailed information is not available.[9–15] It was found that not much work has been done with epoxy and phenol-formaldehyde resins, and no work has been reported with vinyl latex modification of cement mortars. Therefore, in this work results of the studies carried out on the effect of vinyl latex, epoxy latex/resin, and phenol-formaldehyde resin on the properties of cement mortar are discussed.

EXPERIMENTAL

Chemicals and Other Materials

Vinyl latex [(Chemplast, Madras) an aqueous emulsion of vinyl chloride-acrylic acid copolymer with an emulsifier; specific gravity, 1.09], epoxy resin (EPG 120, Anabond), the nonionic emulsifier ethylene oxide condensate (SD Fine Chemicals Ltd.), phenol-formaldehyde resin in salicylic acid solution (70% solid, Namaste Polymers Pvt. Ltd.), diethylene triamine hardener (Fluka), superplasticizer (Prescon), calcium carbonate and calcium chloride salts (E. Merck), commercially available portland cement, river sand, 5% (v/v) HCl in water, and double distilled water were used to carry out the present work.

Preparation of Epoxy Latex

One hundred grams of the epoxy resin, 100 g of water, and 1 g of the emulsifier (ethylene oxide condensate) were placed in a flat bottomed flask and stirred vigorously for about 3 hours, at which time an emulsion of the water based epoxy resin was formed.

Preparation of Mortar

The cement and sand used for the preparation of the mortar were weighed out in the ratio of 1 : 3 or 1 : 1 after drying in an air oven. Calculated quantities of the polymer latex (resin), water, and other additives were added and mixed thoroughly to a workable slump. This mixture of cement, sand, and admixtures is known as the mortar.

Moldings

Cylindrical molds (2-in. height and diameter) for measuring compressive strength, 25 × 2.5 × 2.5 cm beams for flexural strength, a wooden briquet

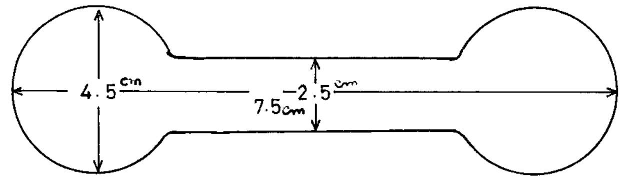

Figure 1 Wooden briquet model for tensile strength.

model (Fig. 1) for tensile strength, and a cylinder (1-in. diameter and height) for porosity measurements were made. A mold releaser was used to release the moldings easily. The moldings were water cured for 3 days, then air cured for 28 days. The following tests were performed.

Compressive strength was measured using a Universal testing machine model FUT-10, which has a capacity of 10 tons. The test specimen in the form of cylinders were loaded in direct compression until failure occurred. Flexural strength was measured using the Universal testing machine, and the strength was expressed as the modulus of rupture in kilograms per square centimeter. The load was applied so that fracture occurred in the middle of the span length. The modulus of rupture was obtained using the formula $R = PL/bd^3$ where R is the modulus of rupture, P is the maximum load indicated by the testing machine, L is the span length, b is the average width of the specimen, and d is the average depth of the specimen. Tensile strength was measured using a Hounsfield Tensometer. The porosity was determined by immersing the molding in water for 72 h at room temperature. The surface water was wiped off and the weight of the pat was taken. It was then dried in an air oven and its weight recorded. Porosity was calculated using the formula

$$\begin{array}{c}\text{porosity}\\ \text{(\% absorption of water)}\end{array} = \frac{\text{wt difference}}{\text{vol of pat}} \times 100.$$

Acid resistivity was determined by immersing the preweighed specimen for 14 days in a dilute acid at room temperature. Then the specimen was washed thoroughly with water, the surface water wiped off, dried in an air oven, and weighed.

$$\text{acid resistivity} = 100 - \frac{\text{wt loss}}{\text{actual wt}} \times 100.$$

RESULTS AND DISCUSSION

In the present study, vinyl latex, epoxy latex/resin, and phenol-formaldehyde in salicylic acid

Table I Comparison of Compressive Strengths of Epoxy Modified Mortars

Effect of Mortar	Emulsion (mL)	Water (mL)	Hardener (g)	Total Water[a] (mL)	Compressive Strength (kg/cm^2)
Latex concn					
C_1	—	42.5	—	42.5	75.0
$ELMM_1$	5.0	28.5	0.7	31.6	105.6
$ELMM_2$	20.0	14.0	1.4	26.0	115.7
$ELMM_3$	45.0	0.0	2.8	27.0	185.9
$CaCl_2$ (g)					
C_1	—	42.5	0.0	0.0	75.0
C_2	—	42.5	0.0	1.0	123.0
$ELMM_4$	10.0	24.0	1.4	1.0	250.3
Superplasticizer Prescon (g)					
C_1	0.0	42.5	0.00	0.0	75.0
C_3	0.0	42.5	0.00	2.0	84.8
$ELMM_5$	20.0	14.0	2.51	0.0	113.0
$ELMM_6$	20.0	14.0	2.51	2.0	183.7
Hardener					
$ELMM_7$	20.0	14.0	1.25	—	94.2
$ELMM_2$	20.0	14.0	1.40	—	115.7
$ELMM_5$	20.0	14.0	2.51	—	113.0

[a] From emulsion and added water.

solution were used to modify the portland cement mortar. Preliminary work revealed that the nonionic ethylene oxide condensate was found to be an excellent dispersing agent for the aquoepoxy resin and was used for the preparation of the epoxy latex modified mortars.

Effect of Latex Concentration

The compressive strength increased with the increase of epoxy latex concentration (Table I, Fig. 2) as expected. It can be considered that the water/cement ratio controls the compressive strength of the mortar. As the consumption of water decreased with the addition of latex to the cement sand mixture, the strength of the sample also increased. Samples $ELMM_2$ and $ELMM_3$ had more or less the same water/cement ratio; but the latter had a higher compressive strength than the former, suggesting that the incorporation of the polymer in the mortars may have also helped to enhance the strength of the same. Such large strength developments were found to be one of the advantages of latex mortar over ordinary cement mortar.[16]

In the present study with vinyl latex mortars, the compressive strength decreased with increasing water curing days (Fig. 3). It should be noted that this is opposite from that observed with unmodified mortar, where optimum strength properties are achieved by rigorous wet curing techniques. One of the reasons for this difference is that for the latex to beneficially modify the cement, it must be allowed to coalesce and form a film. The loss of water is a key step in this film formation process. So based on the above observa-

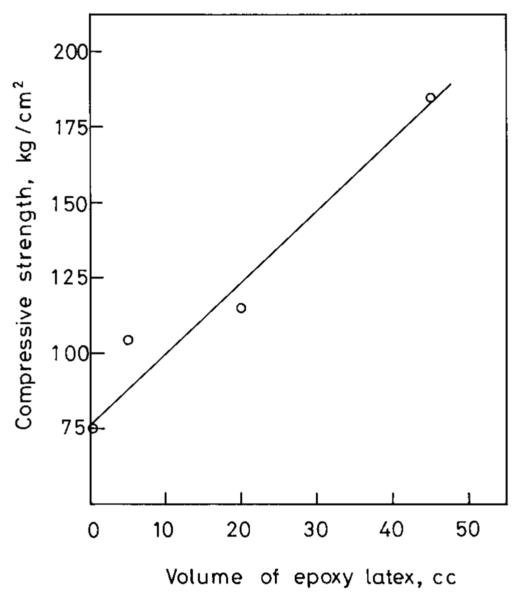

Figure 2 Effect of epoxy latex concentration on the compressive strength of the mortar.

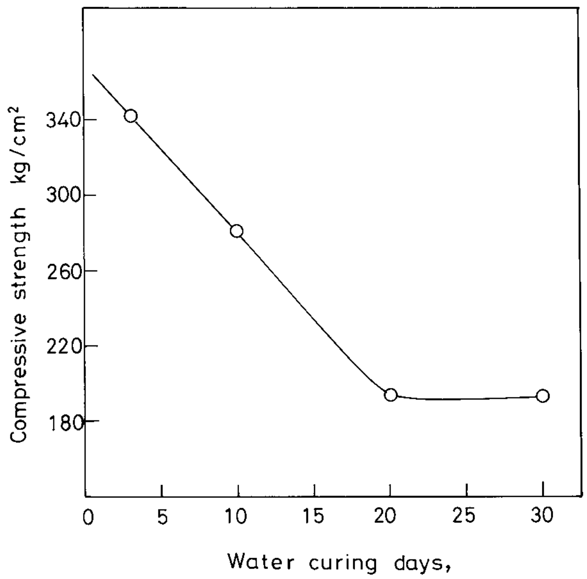

Figure 3 Effect of water curing on the compressive strength of the vinyl latex modified mortar.

tions, in the present study the modified mortars were wet cured for 3 days and air cured for 28 days to obtain full strength. Similar observations were made by Lavelle[17] who found that if the latex modified mortars that were wet cured were allowed to dry, eventually full strength was achieved.

Effect of $CaCl_2$ and $CaCO_3$

The inclusion of $CaCl_2$ in the mortar definitely increased the compressive strength of both the control and the latex modified samples (Table I). A similar observation was made by other authors[18,19] also. According to Rosenberg,[19] inclusion of 2% $CaCl_2$ decreased the set time from 225 to 75 min and increased the early strength.

The addition of $CaCO_3$ invariably increased the strength of the mortar (Tables II–IV) with both fine and coarse sand as well as with cement : sand ratios of 1 : 1 and 1 : 3 in the case of epoxy and vinyl latices. When the latex was present along with the above salt, the strength of the mortar was reduced considerably [e.g., $C_1S \rightarrow C_1LS$ and $C_2S \rightarrow C_2LS$ in Table II, $F_1S \rightarrow F_1L_ES$ in Table III, and $F_1S \rightarrow F_1L_VS$ in Table IV]. This large reduction of strength of the mortars was attributed to the interference of the additives (latex) with the reinforcing action of $CaCO_3$.[20,21]

Effect of Superplasticizer

Usually a superplasticizer is added to increase the workability of the slump. Apart from this benefit a slight increase in the strength of the mortar was also observed in certain cases. These were linear polymers containing sulfonic acid groups attached to the polymer backbone at regular intervals, for example, sulfonated melamine formaldehyde condensate; normally Na, Mg, Ca, and ammonium formulations are used.[20]

In normal concrete mixes the particles of cement tend to form small clusters because of a lack of mutual electrostatic repulsion of particles. As a result the cement particles are not fully broken up during the mixing process; however, plasticizers have a strong action, dispersing the individual

Table II Formulations for Epoxy Latex Modified Mortars (with Coarse Sand) and Their Compressive Strength

	Cement/Sand Ratio							
	1 : 1				1 : 3			
Composition	C_1	C_1S	C_1L	C_1LS	C_2	C_2S	C_2L	C_2LS
Portland cement (g)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
River sand unseived (g)	100.0	100.0	100.0	100.0	300.0	300.0	300.0	100.0
Water (mL)	28.0	28.0	20.0	19.0	35.0	35.0	24.0	27.5
Epoxy latex (mL)	—	—	10.0	10.0	—	—	10.0	10.0
Hardener (g)	—	—	1.4	1.4	—	—	1.4	1.4
Calcium carbonate (g)	—	1.0	—	1.0	—	1.0	—	1.0
Compressive strength (kg/cm^2)	283.0	380.0	341.6	203.0	120.0	178.0	246.0	161.0

Table III Formulations for Epoxy Latex Modified Mortars (with Fine Sand) and Their Compressive Strength

	Cement/Sand Ratio						
	1 : 3			1 : 1			
Composition	F_2	F_2S	F_2L_ES	F_1	F_1S	F_1L_ES	F_1R_ES
Cement (g)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sand (g)	300.0	300.0	300.0	100.0	100.0	100.0	100.0
Water (mL)	28.0	21.7	28.0	28.0	28.0	7.1	28.0
Latex (mL)	—	—	10.0	—	—	10.0	1.14[a]
Hardener (g)	—	—	1.4	—	—	1.4	1.14
Calcium carbonate (g)	—	1.0	1.0	—	1.0	1.0	1.0
Compressive strength (kg/cm^2)	86.2	120.0	148.0	246.3	346.0	200.0	290.0

[a] Epoxy resin in grams.

particles and forming clusters. They have a much more effective action, giving greatly improved workability, but at the same time they have a cohesive effect that prevents segregation. The dispersive action allows more surface area of the cement to be in contact with the water. Therefore, once the plasticizing effect of superplasticizers subsides, hydration of cement can take place more rapidly, resulting in higher early strength development. The fluidity effect of superplasticizers depends on several factors, such as the nature and concentration of the admixture, the composition and temperature of the fresh mix, the mixing procedure, and so on.

In the present work, a 62% increase in the compressive strength was noticed with the latex modified mortar whereas only a 13% increase was observed with the unmodified sample (Table I). This showed the involvement of the superplasticizer in the formation of the comatrix along with the polymer in the cement matrix. In the case of vinyl latex modified mortars, Prescon increased the compressive strength of the mortar by only 10% (Table IV).

Effect of Hardener

An increase in the amount of hardener increased the compressive strength of the mortar (Table I).

Effect of Binder (Cement)

When the binder was present in comparatively large amounts (cement/sand ratio 1 : 1), the probability of the polymer entering the matrix may have been less, leading to only a marginal increase or decrease in the strength. At the same time, when the binder was present in lower quan-

Table IV Formulations for Vinyl Latex Modified Mortars (with Sieved Fine Sand) and Their Compressive Strength

	Cement/Sand Ratio						
	1 : 1				1 : 3		
Composition	F_1	F_1S	F_1L_V	F_1L_VS	F_2	F_2P	F_2PL_V
Cement (g)	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sand (g)	100.0	100.0	100.0	100.0	300.0	300.0	300.0
Water (mL)	28.0	28.0	28.0	28.0	28.0	28.0	28.0
Latex (mL)	—	—	2.5	2.5	—	—	2.5
$CaCO_3$ (g)	—	1.0	—	1.0	—	—	—
Prescon	—	—	—	—	—	2.0	2.0
Compressive strength (kg/cm^2)	246.3	346.0	342.9	254.8	86.2	100.8	95.0

Table V Percentage of Absorption of Water and Acid Resistivity of Epoxy Modified Mortars

Mortar	Water Absorption (%)	Acid Resistivity
C_1[a,b]	—	87.9
C_1L[a,b]	—	93.7
C_2[a,c]	10.1	83.6
C_2L[a,c]	7.1	92.1
F_1SL[b,d]	—	96.9
F_2SL[b,c]	—	93.9

[a] Unsieved sand.
[b] Cement/sand ratio 1 : 1.
[c] Cement/sand ratio 1 : 3.
[d] Sieved sand.

Table VII Comparison of Properties of Phenol-Formaldehyde Resin Solution Modified Mortars

Mortar	Compressive Strength (kg/cm^2)	Tensile Strength (kg/cm^2)	Flexural Strength (kg/cm^2)
C_1[a]	75.0	8.2	38.0
C_4[b]	37.7	—	—
$PFMM_1$[b,c]	94.2	—	38.0
$PFMM_2$[b,d]	66.8	16.0	—

[a] Water cured.
[b] Air cured.
[c] 100 mL resin.
[d] 50 mL resin.

tities (cement/sand ratio 1 : 3), there may have been more chances of polymer molecules getting into the network structure, hence producing a large increase in compressive strength. This possibility was greater in the fine sand as shown in Table III. In the case of fine sand, addition salt alone to the control mortar increased the compressive strength by 39.2% ($F_2 \rightarrow F_2S$) whereas the addition of latex increased the compressive strength by 71.7% ($F_2 \rightarrow F_2LS$) when the cement : sand ratio was kept at 1 : 3. At a ratio of 1 : 1 addition of latex decreased the compressive strength by 19%. When cement was present in large amounts (1 : 1 ratio), it removed the water from the latex, which resulted in sudden coagulation of the latex that caused less strength of the mortar.

The acid solubility and water absorption decreased for the latex modified samples. This decrease was found to be marked in the case of mortars containing fine sand. The polymer film formed may have sealed the pores and protected it from the penetration of water and acid (Table V).

The tensile and flexural strengths of epoxy latex modified mortars were higher than that of the control samples (Table VI). In general latex modified mortar and concrete showed a noticeable increase in the tensile and flexural strengths. This may have been due to the high tensile strength of the polymer itself and an overall improvement in the cement aggregate bond. The porosity of the modified mortar usually decreases with the addition of resin to the cement matrix due to the pores in the hardened concrete being filled up with the polymer. In the present study a similar observation was made when epoxy latex was added to the cement mortar (Table VI).

Phenol-Formaldehyde Resin Solution

Phenol-formaldehyde resin increased the compressive and tensile strength of the modified mortar. The increase in the amount of the resin in the mortar increased the compressive strength (Table VII, Fig. 4). A twofold increase in the amount of resin increased the compressive strength by about 50%. The flexural strength was not different from that of the control sample. The samples were air

Table VI Comparison of Properties of Epoxy Latex Modified Mortars

Mortar	Compressive Strength (kg/cm^2)	Tensile Strength (kg/cm^2)	Porosity (%)	Flexural Strength (kg/cm^2)
C_1	75.0	8.2	26.8	38.0
$ELMM_1$	105.6	—	—	—
$ELMM_2$	115.7	—	—	—
$ELMM_3$	185.9	16.6	15.5	61.4
$ELMM_4$	250.3	—	—	153.6
$ELMM_5$	113.0	—	—	—
$ELMM_6$	183.7	—	—	—
$ELMM_7$	94.2	—	—	—

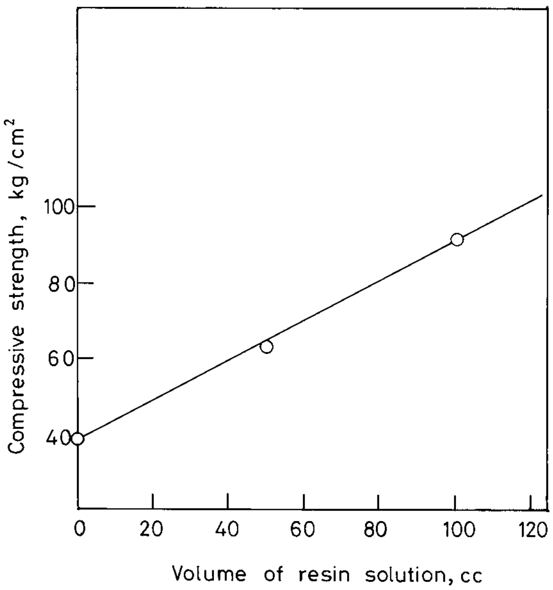

Figure 4 Effect of phenol-formaldehyde resin concentration on the compressive strength of the mortar.

cured at 80°C for 2 days, because water curing cannot be done for this resin.

Mortar and concrete made with portland cement have disadvantages such as delayed hardening, low tensile strength, large drying shrinkage, and low chemical resistance. The polymer modified mortar and concrete had a comatrix in which the organic polymer matrix and the cement gel matrix were homogenized. In the systems modified with latices and other polymer systems, the drainage of water from them along with the cement hydration led to film formation. The properties of the polymer modified mortar and concrete were characterized by the comatrix. When the matrix was homogeneous, better properties were obtained; when there was heterogenity, poor properties were shown.

CONCLUSIONS

The systems studied, namely, epoxy resin/latex, vinyl latex, and phenol-formaldehyde solution, gave better properties, such as compressive, tensile, and flexural strengths, to the mortars modified by them. It may be concluded that the latex/resin solution helped homogenization of the polymer–cement monolithic comatrix. The few admixtures that were used improved the compressive strength of mortar when present alone. When they were present along with latex, they showed poor properties in the mortar. It may be concluded that the addition of admixtures along with latex might have failed to provide homogeneity in the polymer cement network.

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