Available online at www.sciencedirect.com

ScienceDirect

Construction and Building Materials 21 (2007) 379–383

Construction and Building MATERIALS

www.elsevier.com/locate/conbuildmat

Properties of polymer-modified mortars using epoxy and acrylic emulsions

L.K. Aggarwal *, P.C. Thapliyal, S.R. Karade

Central Building Research Institute, Roorkee-247667, India

Received 10 December 2004; received in revised form 9 August 2005; accepted 10 August 2005
Available online 27 September 2005

Abstract

Water based polymer systems are often used for improvement in the properties of plain cement mortar or concrete. Presently, latexes of a single or combinations of polymers like polyvinyl acetate, copolymers of vinyl acetate–ethylene, styrene–butadiene, styrene–acrylic, and acrylic and styrene butadiene rubber emulsions are generally used. One of the limitations of these polymer systems is that they may re-emulsify in humid alkaline conditions. To overcome this problem, an epoxy emulsion based polymer system has been developed. In this paper the properties of the cement mortar modified with this newly developed epoxy emulsion are compared with those of the acrylic-modified mortar. The results showed that the mortars with the newly developed system have superior strength properties and better resistance to the penetration of chloride ions and carbon dioxide.

Keywords: Polymer; Epoxy emulsion; Acrylic emulsion; Mortar; Repair

1. Introduction

In modern concrete construction and repair works the role of polymers is increasing day by day. Polymers are either incorporated in a cement–aggregate mix or used as a single binder. The composites made by using polymer along with cement and aggregates are called polymer-modified mortars (PMM) or polymer-modified concrete (PMC), while composites made with polymer and aggregates are called polymer mortar (PM) or polymer concrete (PC). Since polymers are costly the former type of application is preferred over the latter in most of the situations. The incorporation of polymers greatly improves strength, adhesion, resilience, impermeability, chemical resistance and durability properties of mortars and concrete [1–3]. These properties make PMM a suitable material for making various structural and non-structural pre-cast products, repair of structural members, waterproofing, anticorrosive and decorative finishes, overlay of pavements, bridges and industrial floors [1,4]. A number of thermoplastic or thermosetting polymers are used in modifying mortars and concrete. These are used in various forms like: liquid resins, latexes, redispersible powders and water-soluble homopolymers or copolymers [5]. The choice of the polymer depends upon the intended use, and requirement of performances like strength, durability and chemical resistance. Moreover, the polymer systems can also be modified by use of additives like surfactants, stabilisers, antifoaming agents and colouring pigments [1].

Polymer latexes are dispersion of polymer particles of size 0.05–5.00 μm in water [5]. For making PMM, most of the researchers use latexes of a single or combinations of polymers like polyvinyl acetate, copolymers of vinyl acetate–ethylene, styrene–butadiene, styrene–acrylic, and acrylic [1,5,6]. Latex can also be made by using epoxy resin, which comes under the non re-emulsifiable category. The non re-emulsifiable latexes are expected to have greater resistant to chemical, alkaline and humid environment. However, very little information is available on the use of epoxy emulsion in making PMM. In view of this, an experimental study was conducted to develop PMM based on

* Corresponding author. Tel.: +91 1332 283354; fax: +91 1332 272272.
E-mail address: lka_cbri@rediffmail.com (L.K. Aggarwal).

0950-0618/$ - see front matter
doi:10.1016/j.conbuildmat.2005.08.007

epoxy emulsion. The outcomes of this study are reported in this paper. The properties of epoxy-modified mortar are compared with those of unmodified cement mortar and acrylic-modified mortar.

2. Materials and methods

Epoxy emulsion was prepared by emulsifying epoxy resin, based on diglycidyl ether of bisphenol-A, and amino-amide based hardener in water by using a non-ionic surfactant. Additives like defoaming, wetting and anti-catering agents, and fillers were also used. For both, epoxy emulsion and acrylic emulsion, similar dosages of additives were used. The prepared epoxy emulsion had density of 1.00–1.05 g/cm^3, epoxide equivalent value of 200–300 g eq and total solids of 60 ± 2%; while acrylic emulsion had density of 1.05–1.10 g/cm^3 and total solids 38 ± 2%.

Ordinary Portland cement, grade 43, and quartz sand No. 10 were used for making the PMM test specimens. Properties of the cement and sieve analysis of the sand used in this study are reported in Tables 1 and 2, respectively. To study the effect of polymer–cement ratio on various properties specimens were prepared by varying the polymer–cement ratio from 0% to 30% by mass of cement. A cement–sand ratio of 1:3 by mass was kept constant for all the specimens. For all the mixes the water–cement ratio (w/c) was adjusted to maintain a constant flow between 110 and 120 mm.

Five specimens of 40 mm × 40 mm × 160 mm size were prepared for three-point flexure test. After flexural test the specimens were cut from the ends, i.e., from the uncracked portion of the specimens to obtain cubes of size 40 mm × 40 mm × 40 mm for determining compressive strength and water absorption. For carbonation and chloride ion penetration tests three prisms of 40 mm × 40 mm × 80 mm size for each test were moulded. After moulding, the specimens were allowed to cure in the mould for first 24 h. During this period the moulds were covered with wet cloth and polyethylene sheet. The specimens were then kept in the laboratory conditions, 20 ± 2 °C and 50 ± 5% relative humidity (RH) for the next 27 d. It is known that the water curing degrades the mechanical strength of polymer modified cementitious mortars [2,7]. Hence, water curing was eliminated for PMM specimens, while one set of control specimens, i.e., specimens without polymer was water cured and another was air cured. Water absorption, flexural and compressive strength tests were carried out according to JIS A 1171–2000 and JIS A 6203–2000 [8,9].

In the carbonation test, the finished and bottom surfaces and two ends of the cured mortar samples were coated with epoxy resin based paint. The specimens were then placed in a test chamber for 14 d at a CO_2 gas concentration of 5%, temperature 30 °C and 60% RH. The carbonated samples were then split into two pieces by using a splitting-tensile device. Immediately after splitting a 2% alcoholic solution of phenolphthalein was sprayed on the newly exposed inner surfaces of the specimens. The depth of each cross-section without colour change was measured as carbonation depth. For the chloride-ion penetration test, the cured samples were immersed in a 2.5% sodium chloride solution at 25 °C for 7 d. The samples were split after the test and the split cross-sections were sprayed with 0.1% sodium fluorescein and 0.1 N silver nitrate solution. The depth of the rim of each cross-section changed to white was measured as chloride ion penetration depth.

3. Results and discussion

The effect of polymer addition on water–cement ratio required to maintain the desired flow (110–120 mm) is shown in Fig. 1. The required quantity of water decreases with the addition of both polymers. However, the decrease is relatively more in case of acrylic emulsion. A reduction in

Table 1
Properties of cement used

Property	Value
Density (g/cm^3)	3.08
Specific surface area (cm^2/g)	2540
Chemical analysis (%)	
Silica, SiO_2	21.40
Lime, CaO	62.25
Alumina, Al_2O_3	8.95
Iron Oxide, Fe_2O_3	2.80
Magnesia, MgO	1.46
Loss on ignition	1.52

Table 2
Sieve analysis of quartz sand

I.S. sieve size	Mass retained (%)	Cumulative mass retained (%)
4.75 mm	–	–
2.36 mm	–	–
1.18 mm	–	–
600 μm	40	40
300 μm	30	70
150 μm	30	100

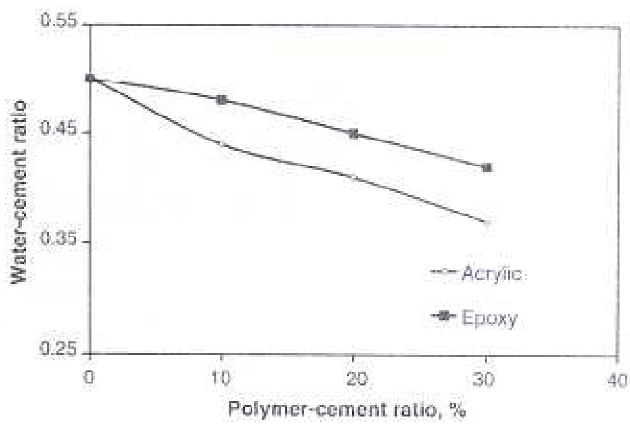

Fig. 1. Effect of polymer addition on water–cement ratio required to maintain flow.

water requirement was expected not only due to the presence of surfactants in the polymers but also due to the lower surface tension of polymer molecules, which facilitates better flow of the mix at the same water content. The results of polymer addition on compressive strength of the mortar at 28 and 90 d are shown in Figs. 2 and 3, respectively. The compressive strength of unmodified water cured mortar specimen is 39.5 MPa at 28 d and 45.0 MPa at 90 d curing. It can be seen that both 28 and 90 d compressive strengths of the mortar increase with polymer–cement ratio. However, the compressive strength of PMM is less than that of water cured control specimens when the polymer–cement ratio is less than 20%. Nevertheless, the 90 d compressive strength is higher than water cured specimens when the polymer–cement ratio is more than 20% for both the polymer systems (Fig. 3). While comparing the 28 and 90 d strength of PMM and water cured control specimens it appears that in water cured specimens most of the hydration is completed within 28 d; whereas in PMM the process of hydration/polymerisation continues till around 90 d. However, this period may vary depending upon various parameters such as type of polymer, additives and their dosages. Nevertheless, the slow rate of strength gain of PMM is not expected to affect the performance, because the strength development can continue without any external aid. The results also show that at the same polymer–cement ratio the epoxy emulsion modified mortars have better compressive strength than acrylic modified mortars (Figs. 2 and 3).

The effect of polymer–cement ratio on 28 d flexural strength of different compositions is shown in Fig. 4. It can be seen that the flexural strength of the unmodified water cured mortar is 7.8 MPa and that the flexural strength of air cured PMM specimens is less than water cured unmodified mortar samples when polymer–cement ratio is less than 20%. However, for both polymer systems the flexural strength is better than that of the water cured control specimens at 30% polymer–cement ratio. The flexural strength of epoxy modified mortar samples with 30% polymer–cement ratio is about 10% higher as compared to wet cured samples. In case of air cured samples, the increase in strength of acrylic modified mortars is up to 40% as compared to unmodified mortar samples while it is about 60% for epoxy modified mortar samples. This shows

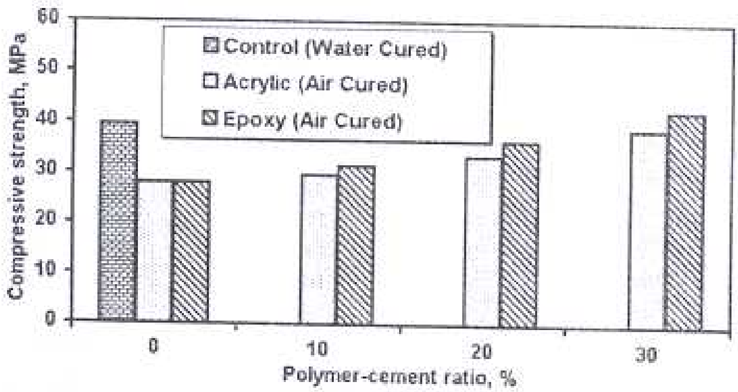

Fig. 2. Comparison of 28-d compressive strength of control specimens and PMM with different polymer–cement ratios.

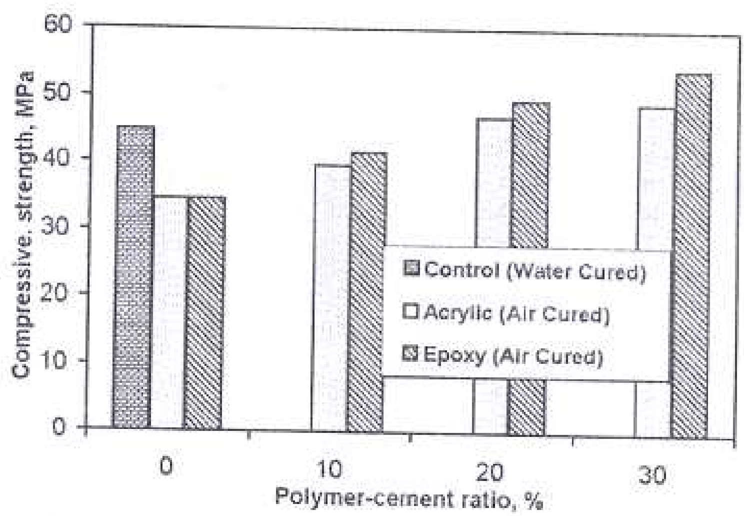

Fig. 3. Comparison of 90-d compressive strength of control specimens and PMM with different polymer–cement ratios.

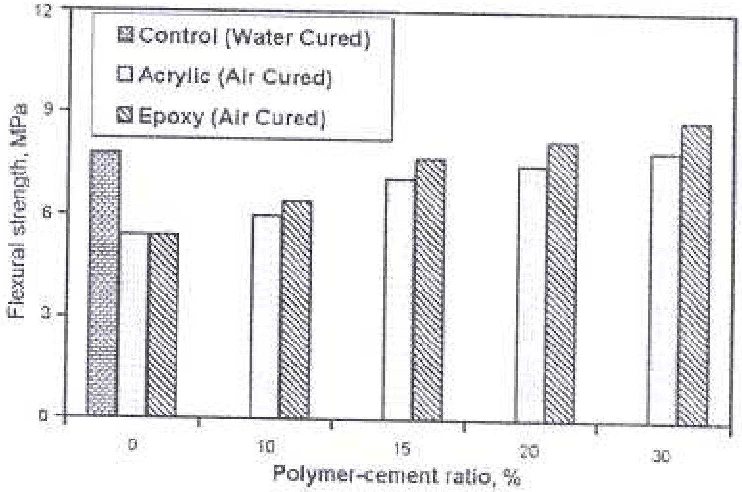

Fig. 4. Comparison of 28-d flexural strength of control specimens and PMM with different polymer–cement ratios.

that epoxy modified mortars should behave better than acrylic modified mortars under flexural loading.

From Figs. 2–4, it can be noted that the effect of increase in polymer–cement ratio is more pronounced in flexural strength than in compression strength. The improvement in strength properties of air cured PMM can be exploited for advantage in repair applications at the locations where access is difficult for water curing. Besides enhancing strength, polymer modifications can significantly improve toughness of the mortars. From the stress strain curve shown in Fig. 5, it can be seen that the addition of both epoxy and acrylic latex increases the toughness. It can be noted that the area under the stress–strain curve of epoxy emulsion based PMM is about three times the area of the controlled specimen.

Epoxy based mortar showed better resistance to penetration of carbon dioxide (Fig. 6). For example, at 10% polymer–cement ratio the epoxy emulsion based mortar showed 45% reduction in carbonation, while it was 28% for acrylic based mortar. At 20% loading of epoxy emulsion

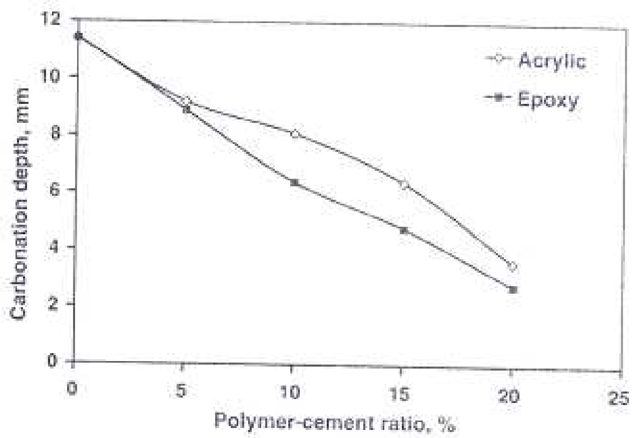

Fig. 6. Effect of polymer addition on depth of carbonation.

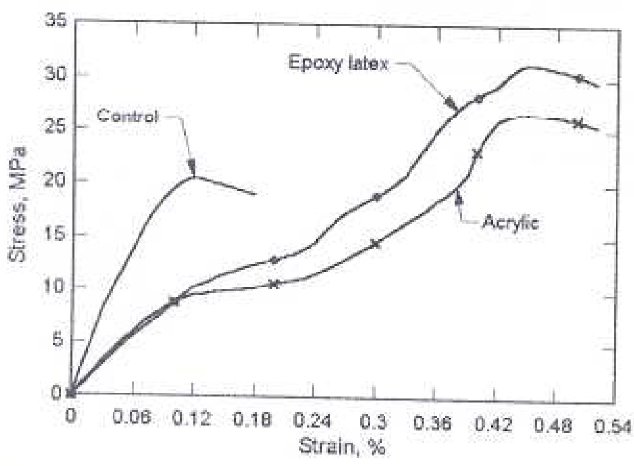

Fig. 5. Stress–strain behaviour of control specimens and PMM (10% polymer cement ratio) in compression.

the carbonation depth greatly decreases (by about 75%). Similarly, chloride ion penetration also decreases with the addition of polymer in the polymer–cement mix (Fig. 7). In the present investigations, the reduction is up to 60% at 20% epoxy loading in the mix. The reduction in chloride ion penetration is about 40% at 10% epoxy or 20% acrylic latex loading in the mix. This indicates that epoxy emulsion mortar should have more resistant towards chloride ion attack. The increased resistance to penetration of CO_2 and chloride ions make PMM very useful in application in corrosion prone areas.

The effect of polymer–cement ratio on water absorption of mortars is shown in Fig. 8. It is evident from the figure that the water absorption reduces with the increase in polymer–cement ratio irrespective of the type and amount of polymer. At 30% polymer–cement ratio, the decrease in water absorption is about 45% and 55% for acrylic and epoxy emulsion modified mix, respectively. This indicates that the polymer addition results in reduction of the porosity of the mortar. Other studies also showed that the polymer fills the voids in the cement matrix [2,10]. Polymer

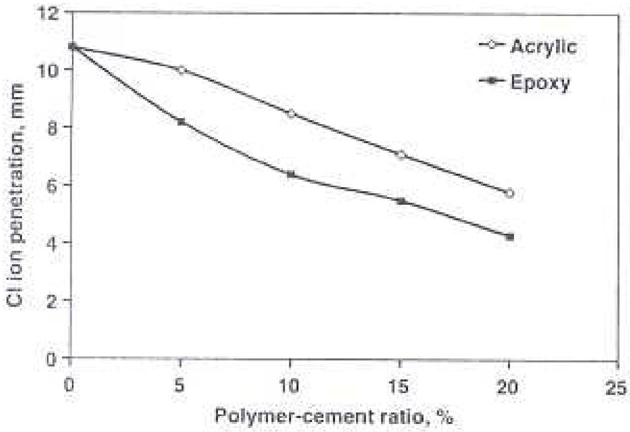

Fig. 7. Effect of polymer addition on chloride ion penetration.

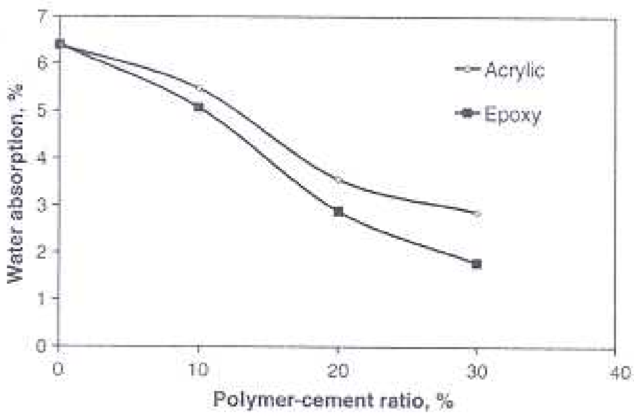

Fig. 8. Effect of polymer addition on water absorption.

modified cementitious mortars are therefore expected to be more resistant towards humid environments than plain cement mortar.

Most of the results of the tests conducted during this study show that epoxy emulsion has greater effect on improvement of properties of the mortar than the acrylic. Moreover, epoxy emulsion is considered non re-emulsifiable latex and therefore it should not destabilise under humid and alkaline environment, but acrylic based mortar can. Thus, polymer modified cementitious mortars based on epoxy emulsion shall be more suitable for use in structures exposed to high humid conditions or immersed in water. The epoxy emulsion based cementitious mortars also have some advantages over solvent based epoxy mortars such as these can be applied on wet substrates, i.e., bone dried substrate will not be essential requirement as in the case solvent based polymer mortars. The other advantages include ease in cleaning of tools and equipment after use, minimum health hazard and cost saving as there is no use of organic solvents. Thus, epoxy emulsion is more environment-friendly than the solvent based epoxy.

4. Conclusions

The results of this study showed that the addition of polymer to cement mortar improves workability, increases flexural and compressive strengths, and decreases water absorption, carbonation and chloride ion penetration. However, at the same amount of polymer–cement ratio epoxy emulsion showed slightly better properties than acrylic emulsion. In addition, the epoxy emulsion based mortars have several advantages over solvent-based epoxy mortars. Thus, epoxy emulsion based mortar is a potential material that can be used for repair works in humid and industrial environments.

Acknowledgment

The paper is published with the kind permission of the Director, Central Building Research Institute, Roorkee, India.

References

[1] ACI 548.3R-95. State of the art report on polymer-modified concrete. In: ACI Manual of Concrete Practice, Part-5. Farmington Hills, USA: American Concrete Institute; 2000. p. 548.3R-1–548.3R-47.
[2] Ohama Y. Principle of latex modification and some typical properties of latex modified mortar and concrete. ACI Mater J 1987;86(Nov–Dec):511–8.
[3] Mirza J, Mirza MS, Lapointe R. Laboratory and field performance of polymer-modified cement-based repair mortars in cold climates. Constr Build Mater 2002;16:365–74.
[4] Mehta PK, Monteiro PJM. Concrete: structure, properties and materials. 2nd ed. Englewood Cliffs, NJ: Prentice Hall; 1993. p. 418–23.
[5] Ohama Y. Polymer-based admixtures. Cement Concrete Compos 1998;20:189–212.
[6] Ohama Y, Demura K, Hamatsu M, Kakegawa M. Properties of polymer-modified mortars using styrene–butyl acrylate latexes with various monomer ratios. ACI Mater J 1990;88(2):55–61.
[7] Popovic S. Strength losses of polymer modified concrete under wet conditions. In: David WF, editor. Polymer modified concrete. ACI SP-99, 1987. p. 165–89.
[8] Test methods for polymer-modified mortar. JIS A 1171 2000, Japanese Industrial Standard, Tokyo, Japan.
[9] Polymer dispersions and redispersible polymer powders for cement modifiers. JIS A 6203–2000. Japanese Industrial Standard, Tokyo, Japan.
[10] Shaker FA, El-Dieb AS, Reda MM. Durability of styrene butadiene latex modified concrete. Cement Concrete Res 1997;27(5):711–20.