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The Innovative Performance of Polymer Modified Cement Systems for Use in Infrastructure Applications

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Abstract: This paper discusses the innovative performance of polymer modified cement mortar in comparison with conventional cement mortar particularly when exposed to severe environmental conditions. The effect of cyclic exposure to air and salt water environment increases deterioration process resulting in a high cost of maintenance and repair. The use of ordinary Portland cement system alone in severe environmental condition may not be effective, and cannot provide long term solutions because the problems of concrete deterioration will exist after a shorter period of time. Hence, there is the need to consider alternative modifications, and the polymer modified cement system can offer not only enhanced engineering properties but also high durability performance. The research have shows that, the polymer modified cement mortars have been found to improve not only the flexural strength of the mortar matrix, but also enhance the durability characteristics of the material by reducing the water absorption, shrinkage and expansion, modulus of elasticity and chloride permeability
Keywords: Polymer modified cement mortar, engineering properties, durability performance, flexural strength, modulus of elasticity, chloride permeability.

I. INTRODUCTION

Deterioration of concrete structures as a result of chemical attack and corrosion of reinforcement is mainly attributed to the ingress of chlorides, sulphates and other aggressive substances into concrete. The use of ordinary Portland cement systems alone in severe environmental conditions may not be effective and cannot provide long term solutions because the problems of deteriorations will exist after a shorter period of time. To reduce these disadvantages, polymers have been utilized as an additive (Ohama et al, 2001). Polymer-modified or polymer cement mortar and concrete are the materials which are made by partially replacing the cement hydrate binders of conventional cement mortar or concrete, with polymers. The concept of polymer modification for cement mortar and concrete is not new, since considerable research and development of polymer modification have been performed for the past 70 years or more (Ohama, 1998). As a result, many effective polymer modification systems for cement and concrete have been developed, and currently are used in various applications in the construction industry (Fowler, 1999).

A polymer-based admixture, also called a cement modifier, is defined as an admixture which consists of a polymeric compound as a main ingredient effective at modifying or improving the properties such as strength, deformability, adhesion, waterproof ness and durability of cement mortar and concrete (Morlat, 1999). Such a polymeric compound is a polymer latex, redispersible polymer powder, water-soluble polymer or liquid polymer. The cement mortar and concrete which are made by mixing with the polymer-based admixtures are called polymer-modified mortar and concrete, respectively (Beeldens et al., 2001). Polymer addition is found to improve flexural strength and other engineering properties of mortars by reducing shrinkage and chloride permeability has been reported by Ramli et al, 2000). A high resistance to chloride ion penetration has been reported by Mehta, (1986) from tests on acrylic latex-modified mortar and concrete ponded with 3% sodium chloride for a period of 60 days. These results also indicate a low penetration of water and salt into the polymer-modified cement systems and thus play a significant role in enhancing the durable performance of concrete construction (Swamy, 1995).

Based on this, to achieve desired concrete properties, experimental research on certain types of polymer admixture is necessary. Through researching and finding the optimal admixture quantity, concrete properties can be significantly improved. The wide applications of polymer modification for cement mortar and concrete urges researcher to carry out extensive work in order to establish a good base for this development. The purpose of this research is to study of innovative performance of various polymer-modified cement systems in concrete construction. This includes study of the behavior of various polymer-modified mixes, the effect of different curing conditions on its mechanical properties, dimensional stability, impermeability characteristics and water absorption.

Research significance

This paper provides a comparative study of three polymer admixtures type, namely styrene butadiene rubber latex, SBR (10 percent by weight of cement), natural rubber latex, NR (10 percent by weight of cement) and epoxy resin, ER (10 percent by weight of cement), in their ability to increase the bond strength between concrete and reinforcement.

II. EXPERIMENTAL PROCEDURE

The research was conducted through an experimental program with mortar samples, different in size and shape. Therefore, the influence of the polymer admixture participation in percentages was studied concerning compressive strength, flexural strength, modulus of elasticity, as well as bond between reinforcement and concrete. Additionally, the following were also studied: water absorption, chloride permeability, shrinkage and influence of various curing conditions on polymer modified cement mortars. The experiments were conducted in the laboratories at the School of Housing, Building and Planning, Universiti Sains Malaysia. Three polymer admixtures type, were selected for this study. The material properties are listed in Table 1.

Table 1. Material properties of polymers

Property	SBR	NR	ER
Total solid, %	46.6	61.52	100
pH	10.4	10.56	-

Ordinary Portland cement of ASTM type I was used. The cement had a specific surface of 350 kg/m^2 and a compound composition C_3S 54.3%, C_2S 17.6%, C_3A 11.6% and C_4Af 6.4%. The sodium oxide equivalent of the cement was 0.59%, while the silica and iron modulus were 2.62% and 2.71% respectively. The fine aggregate was a graded river sand with 5.0mm maximum size and complied with the grading limit of zone F of BS 882. The sand has a specific gravity of 2.65, absorption of 0.80%, and a fineness modulus of 2.46. The mortar mix proportions used in this study were cement: sand: 1:3, all by weight with a water-cement (w/c) ratio of 0.45 for the initial mixes. Irrespective of the final w/c ratio used, all the mixes were designed for a slump of 90-120 mm.

The amount of cement content used in the mortar mix is therefore, designed based on the following expression (Paillere, 1985).

$$C = \frac{700}{\sqrt[5]{D}}$$

Where,

C is the cement proportion in kg/m^3.

D is the maximum size of aggregate in mm.

If the maximum size of fine aggregate in the mix proportion is 5.0 mm, then the cement content should be used are about 506 kg/m^3. The mix proportion is shown in Table 2.

Table 2. Design mixes for mortar specimens

Type of mortar	CON	SBR	NR	ER
Cement (Kg/m^3)	506	506	506	506
Sand (Kg/m^3)	1518	1518	1518	1518
W/c	0.45	0.35	0.45	0.45
Polymer (%)	-	10	10	10
Super plasticizer (%)	1.5	-	1.5	1.5
Slump (mm)	115	115	120	110

When designing the mix, the percentage of water present in the polymer dispersion was taken into account for determining the mixing water. A superplasticiser, sulphonated naphthalene condensate, was used 1.5% by weight of cement. All mortar specimens were cast in steel moulds, an external vibrator was used to facilitate compaction and decrease the amount of air bubbles. The samples were demoulded after 24 hours and then cured in water at room temperature of 20 ± 2 °C and relative humidity 75% for 28 days. Once demoulded, the specimens were further cured at 2 different curing conditions; air curing and salt water curing until the date of test.

III. RESULTS AND DISCUSSION

3.1 Compressive strength

The compressive strength of the mortars specimens was determined from method specified in BS 1881: part 119: 1983. The compressive strength results of all the mixes tested up to 90 days are presented in Fig. 1 and Fig. 2, respectively for the two different curing regimes. From the results, the compressive strength development of polymer modified cement mortars was great enhanced by initial air curing compared to initial salt water curing. Under these conditions, polymer modified mortars attained lower compressive strength than unmodified mixes.

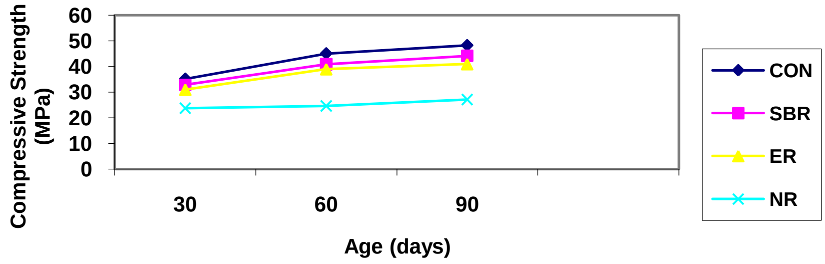

Figure 1. Compressive strength of polymer-modified mortars cured for 28 days in water followed by air-curing

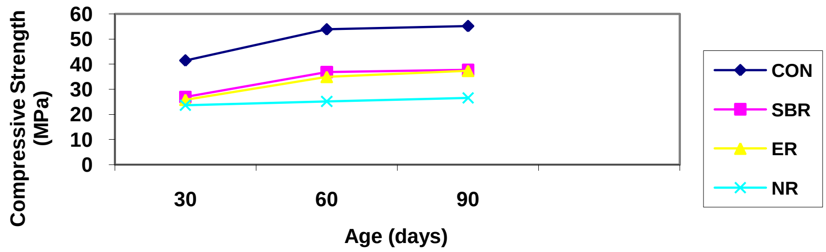

Figure 2. Compressive strength of polymer-modified mortars cured for 28 days in water followed by salt water-curing

3.2 Flexural strength

The flexural strength is carried out in accordance with British Standard BS 1881: Part 118: 1983 "Method of determination of flexural strength". The flexural strength result of the mixes tested in this study under two different curing conditions is presented in Fig. 3 and Fig. 4. From these results, the flexural strength of mortar specimens is significantly improved by addition of polymer latexes especially by initial air curing. However, flexural strength values under salt water curing show a lower flexural strength than the unmodified mortars.

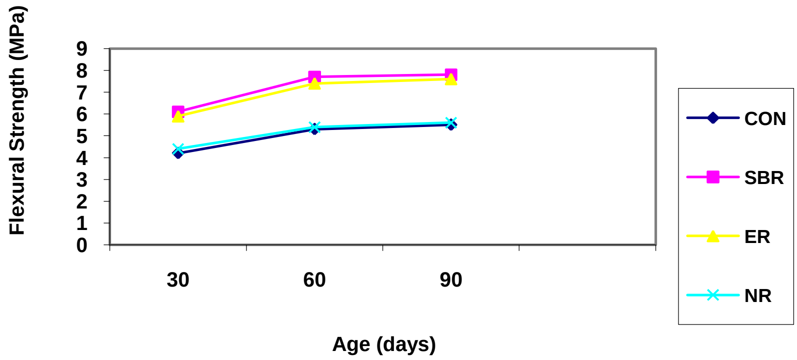

Figure 3. Flexural strength of polymer-modified mortars cured for 28 days in water followed by air-curing

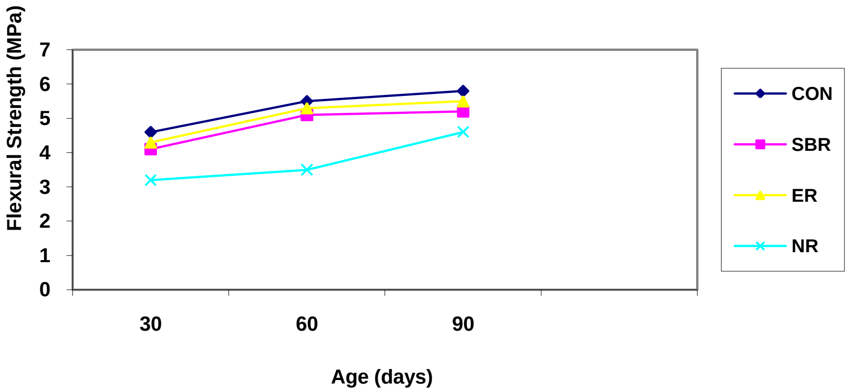

Figure 4. Flexural strength of polymer-modified mortars cured for 28 days in water followed by salt water-curing

This is interpreted in terms of the contribution of high tensile strength by the polymers themselves and an overall improvement in cement hydrate-aggregate bond. The strength properties of the polymer modified mortars are influenced by various factors that tend to interact with each other.

3.3 Water absorption

The water absorption is calculated from the increase in mass of the specimen and expressed as a percentage of dry specimen multiply by a correction factor derived from the expression following BS 1881 : Part 122 : 1983 as follow:

$$Correction\,Factor = \frac{Volume\left(mm^2\right)}{Surfacearea\left(mm^2\right)\times 12.5}$$

The results are presented in Fig. 5 and Fig. 6, for two different curing conditions. From these results, all polymer modified cement mortars show lower water absorption compared with the unmodified mortars. This because polymer modified mortars have a structure in which the microspores and voids normally occurring in Portland cement systems are partially filled with polymers or sealed by continuous polymer film that forms during curing. This is one of the most important factors affecting the corrosion of reinforcing steel in concrete structure.

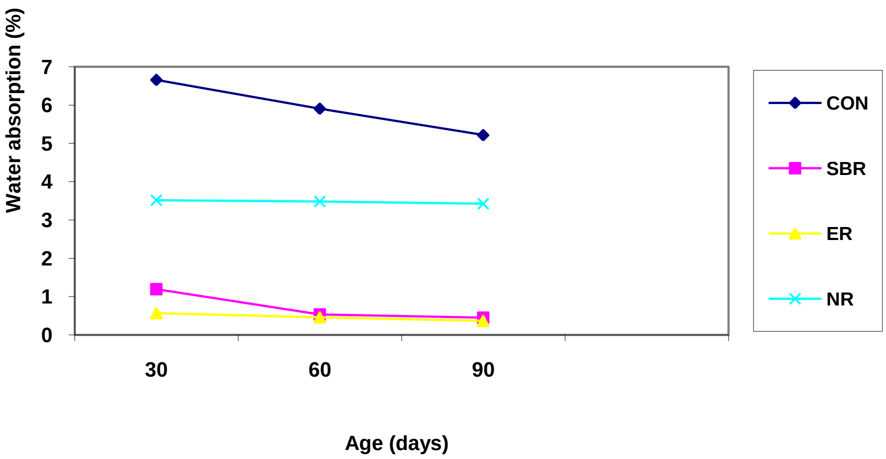

Figure 5. Water absorption of polymer-modified mortars cured for 28 days in water followed by air-curing

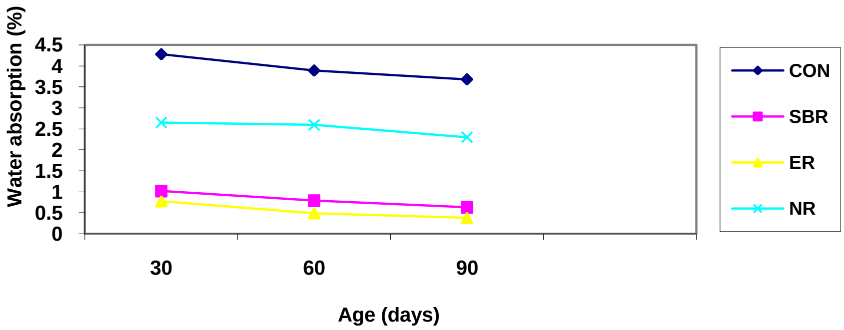

Figure 6. Water absorption of polymer-modified mortars cured for 28 days in water followed by salt water-curing

3.4 Modulus of elasticity

The modulus of elasticity may be estimated from emphirical formulas, given in the British code for design of concrete structure, BS 8110: 1985 is: E_c (static modulus) = 1.25 E_d - 19. When it is required to relate the dynamic modulus (E_d) to strength and density, the static modulus was estimated from the following expression as given by CP 110:1972 : $E_c = 0.85\ \rho^2 f_{cu}^{\ 1/2}\ x\ 10^{-6}$. Where; ρ = density (kg/m^3) and f_{cu} = cube crushing strength (N/mm^2). The modulus of elasticity results for all the mixes are presented in Fig. 7 and Fig. 8. The polymer modified mortars generally show a lower modulus of elasticity than the unmodified mortars, their magnitude depending on the polymer type and polymer cement ratio (Ramli, 1998). This behavior has great advantages to structural concrete since a lower modulus of elasticity would induce lower stress for the same strain. The modulus of elasticity is not affected by the curing condition adopted.

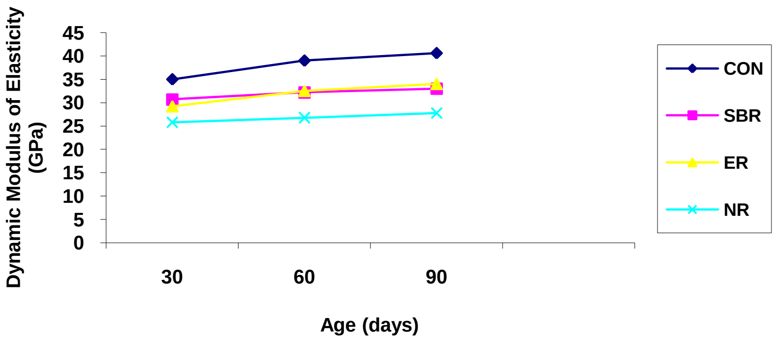

Figure 7. Modulus of elasticity of polymer modified mortars cured for 28 days in water followed by air-curing

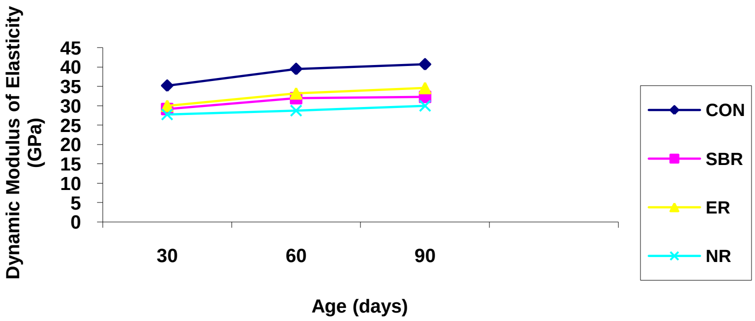

Figure 8. Modulus of elasticity of polymer-modified mortars cured for 28 daysin water followed by salt water curing

3.5 Shrinkage and expansion

The shrinkage and expansion are carried out in accordance with British Standard BS 1881: Part 206: 1986. The result is presented in Fig. 9. All the specimens are subjected to air-curing after 28 days of immersion in water. From the test resulted, the polymer modified mortars show much lower shrinkage than the unmodified mortar specimens. These properties can be an asset to concrete construction in aggressive environments since low shrinkage and expansion will also reduce the developments of micro cracks.

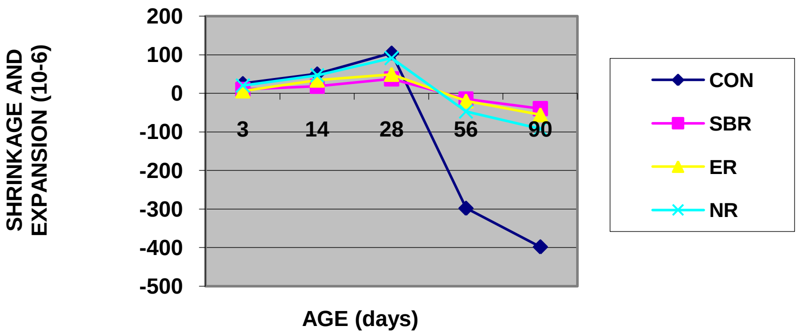

Figure 9. Drying shrinkage and wetting expansion of specimens

3.6 Permeability

The permeability of the unmodified controls and polymer modified specimens was determined from a 50 mm diameter mortar sample with an average depth of 40 mm, using the Leeds cell permeameter developed by Cabrera and Lynsdale (1986). Prior to testing of permeability, the specimens were conditioned by drying in an oven at a temperature of 105 ± 5 ° C for a period of 24 hours. On removal of the samples from the oven, they were allowed to cool for a minimum period of 24 hours before testing. The permeability of the samples is calculated from this expression (Lawrence, 1986):

$$K = \frac{4.04xP_2{}^2 xRxL10^{-16}}{ax\left(P_1{}^2 - P_2{}^2\right)}$$

Where; K = intrinsic permeability (m^2), R = flow rate (cm^3/s), L = length of specimen (m), a = cross-sectional area of specimen (m^2), P_1 = absolute pressure (bar), and P_2 = pressure at which the flow rate is measured.

From the Fig. 10, the polymer modified specimen's exhibits superior performance compared with the unmodified mortar. Polymer modified cement mortars have been found to reduce the permeability of the cement matrix, and significantly reduce the depth of penetration of chloride ions into the mortars. As the cement hydration process continues, the polymer particles coalesce to form a continuous layer of polymer film which surround the aggregates, and coats the gel resulting in a less porous and a less permeable mortar matrix. This system should have high durability performance against chloride penetration, chemical attacks and other form of structural deteriorations.

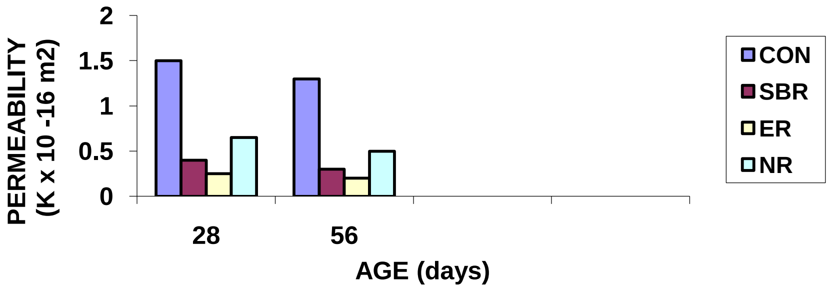

Figure 10. Permeability of polymer modified and unmodified mortars

IV. Conclusions

From the test results and the analysis of the experimental work carried out in this study the following are the main conclusions and recommendations:

1. The addition of polymers emulsions improves significantly the flexural properties of the mortars. The drying shrinkage and expansion, permeability are greatly reduced, whilst the modulus of elasticity is slightly reduced.
2. The polymer modified cement mortars have great advantages to structural since a lower modulus of elasticity would induce lower stress for the same strain. This is quite useful in pavement construction such as car parks and airport runaways, which are subjected to high-induced stresses and temperature variation.
3. The costs of producing the polymer modified cement mortars should not be compared to the cost of the production of unmodified on short run. Although, polymer modified cement mortars has higher initial production cost it should be compared with the sum of the initial production cost of unmodified plus the cost of the expected repair works during the service life of the structures, especially those exposed the severe aggressive environment.
4. More research work is required to investigate the effect of the sulphate attack on the polymer modified cement mortars, and also the effect of using different cement types on the performance of the polymer modified cement mortars.

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