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Evaluation of Polymer Modified Mortar and Bonding Agent for Structural Repair

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Abstract: Polymer modified mortar is found to be suitable for structural repair and strengthening of damage structural elements. Conventional mortar is not preferred in repair of concrete since it has inferior mechanical property and durability performance. Polymer based mortar is an alternative to conventional mortar with enhanced mechanical properties. However, there are limited specifications and guidelines available for specifying PMM mixes for structural repair work. The research work aims to evaluate the mechanical performance of polymer based mortar with varying concentration of styrene butadiene rubber latex at laboratory scale. Another aspect in repair of corrosion damage structures is the bond between the substrate concrete and repair mortar. In order to study the effectiveness of bonding agents, the performance evaluation of bonding agents has been evaluated using slant shear test and pull-off test as per ASTM C 882 and EN 1542 respectively. Findings of study indicates that at 8-10 percent concentration of dry polymer solid by cement mass in polymer based mortar is the optimum dosage. Styrene-butadiene rubber based polymer mortar showed improvement in flow in comparison to normal mortar however, mixes with crushed sand shows decrease in flow which is due to presence of more fines. Slant shear and pull-off test method shows epoxy bonding agent give better bond strength as compared to SBR latex.

Keywords: Polymer modified mortar, SBR latex, Epoxy, bond strength, shrinkage.

1. Introduction

The last few decades have witnessed significant research on the application of polymer based mortars for concrete repair. In order to generate confidence in decision making among practicing engineers and to freeze the accurate specifications for concrete repair using different polymer based mortar along with bonding agent, there is need to evaluate both these materials scientifically. The type, & dosage of the polymers incorporated in modified composite, usually depends on the purpose of application, such as improving some engineering properties like workability [1], bending strength [2,3], bonding of composites [3], adhesion to concrete substrate [4], waterproofing [5], shrinkage [6] and chemical resistance [2]. Styrene butadiene rubber and styrene-acrylic are most widely used latex. G. Baruenga & Hernandez-Olivares [2], Walter [5], Joachim Schules [3] ACI 548.3R [1], Dennis L. Bean, Tony B. Husbands [6] showed that the polymer modification of concrete using styrene-butadiene rubber improved workability, flexural strength, bonding strength, permeability resistance, and ductility. Barluenga & Hernandez-Olivares [2], highlighted that bond between cement to polymer is less strong in comparison to cement to cement. With increase in concentration of polymer in polymer based mortar there is reduction in strength due to formation of large number of polymer to cement bonds. Drying shrinkage reduces in polymer based mortar due to decrease in water to binder ratio [6]. Polymer based mortar possesses better rheological property due to water reducing ability in polymer surface active system [1]. The appropriate concentration of polymer is needed to achieve the desired mechanical performance and durable repair. Based on various work done by various researcher, the optimum degree of polymer modification are 7.5 to 20% [1], 20 to 30% [4], 8 to 10% [7] & 15% [6] dry polymer solids by cement proportion. In order to avoid failure between old and new concrete or its bond, the role of bonding agent becomes crucial to avoid failure from both repaired mortar or bond. Bond strength depends upon the formation of monolithic polymer cementitious matrix at the interface which bridges pore development and crack formation at bond [8]. D J Cleland, M Naderi & A E long [9]

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performed "Limpet test" by applying epoxy resins, acrylic latex& SBR latex system and concluded that epoxy resins system give maximum bond strength, the increment is about 50% as compared to plain cement/mortar system.

Durability performance of polymer based mortar studied in past at 5 to 20% polymer concentration at every 2.5 % interval concluded that 10 percent polymer concentration affected the initiation of cracks while 12.5 % polymer concentration led to improved stress redistribution during crack formation [10]. Past study [11] has indicated that formation of extensive polymer network leads to increase in flexural strength of polymer based mortar beams. Past studies [12-14] highlighted that acrylic based polymer system reduces water demand in comparison to epoxy based mortar as acrylic polymer forms extensive boundary surface acting agent due to lower surface tension. The study on mortar made with the powder obtained from the aerated block shows higher risk of cracking in comparison to mortar made with brick powder at a lower water content [15]. The research work aims to evaluate the mechanical performance of polymer based mortar with varying concentration of styrene butadiene rubber latex at laboratory scale. In order to study the effectiveness of bonding agents, the performance evaluation of bonding agents has been evaluated using slant shear test and pull-off test.

2. Research significance

There are limited specifications and guidelines available for specifying polymer modified mortar mixes for structural repair work. Research is intended to study the optimum dosage of SBR latex in polymer modified mortars and the effectiveness of structural bonding agent, which can help practicing engineers in better decision making for effective and durable structural repair.

3. Experimental Program

3.1 Constituent Materials

Material used study includes Ordinary Portland Cement (OPC) 43 Grade satisfying the specification of IS: 269-2015 [16], Portland Pozzolona Cement (PPC) satisfying the specifications of IS, Fine aggregate (Natural zone-III & Crushed zone II) and coarse aggregates satisfying the specifications as per IS: 383-2016 [17], Potable water, styrene butadiene rubber Latex (satisfying type-I as per ASTM C 1059 [18] with solid content of 40%) and Epoxy (satisfying Type-II as per ASTM C 881 [19]. The engineering properties of the selected material are evaluated at Lab which was maintained at 27±2°C and 65±5% RH.

The properties of bonding agent styrene butadiene rubber latex selected for study is given in Table 1. Results indicates that compressive strength satisfy the requirement which is 70% minimum of reference mixture/control at 28 days age as per ASTM C 1438 [20]. The reference mixture/control compressive strength is 32 MPa. The bond strength is more than minimum requirement for type-I latex as per ASTM C 1059 [18]. Solid content met the requirement as per manufacturers Technical Data Sheet (TDS). The chloride content in % by mass is 0.003 and pH is 8.33. The properties of epoxy bonding agent is given in Table 2. The test results indicates that 07 days compressive strength and 14 days bond strength of epoxy bonding agent selected for the study confirms to type-II of ASTM C 881-13 [19]

Table 1 – Properties of bonding agent styrene butadiene rubber latex selected for study

Sl.No.	Properties	Reference code	SBR latex	Remarks
Physical Properties				
1	Compressive strength in MPa	ASTM C 1438	28.20	Control compressive strength is 32.00MPa
2	Bond Strength (Slant shear) in MPa	ASTM C 1059	5.66	Min. 2.80 MPa
3	Flow in %	IS 4031 (part7)	115	
Chemical properties				
4	Solid content in %	TDS	39.51	Technical Data Sheet (TDS)

Table 2 – Properties of epoxy bonding selected for study

Bond Strength at 14 days age tested with reference to procedure given in ASTM C882-13 in MPa		Compressive strength at 07 days age in MPa	
Result Obtained	Min. Requirement as per ASTM C 881-13	Result Obtained	Min. Requirement as per ASTM C 881-13
11.37	10	86.07	35

3.2 Optimization of SBR latex content

Optimization of SBR latex content in Polymer-modified cement mortars study was carried out by varying SRB latex's solid content (0, 8, 10, & 15%) by weight of cement, crushed and natural fine aggregate, two types of cement, & with a constant water/cement mass ratio of 0.35 and cement/fine aggregate in 1:3 proportion. Cement mortar were mixed in an electrical driven mechanical mixer with a stainless steel mixing bowls and mixer blade. The stainless steel mixing bowl of 5 liters capacity and mixing blade were thoroughly cleaned before mixing. The interior faces of the molds were cleaned and oiled appropriately. A typical mix proportion for PMM with 8% latex solid content by weight of cement is given in Table 3.

Table 3 – Mix Proportion for PMM

Mix Constituents	Mix Proportion
w/c ratio	0.35
Cement (grams)	100
Fine aggregate (grams)	300
Cement: Fine aggregate	1:3
SBR Latex (ml)	20ml (20% Latex by mass of cement) [40% of 20 ml is solid and 60% liquid]
Net Quantity of water added (ml) after doing water correction for SBR latex	23 ml (35ml-12ml)

The performance of PMM on the selected engineering properties evaluated are flow table test as per IS 4031(part-7) [21], compressive strength as per ASTM C 109-16 [22], Static modulus of elasticity tests as per IS 516-1959 [23]. Flexural strength was as per IS 4031(part-8) [24]. Drying Shrinkage test as per IS 4031 (part-10) [25]. Dry/air curing was adopted PMM test specimen. The specimens were kept in laboratory condition which is maintained at 27±2^{o}C and 65±5% RH till the test day

3.3 Evaluation of structural Bonding agent

Locally available one type of Epoxy and SBR latex were selected to evaluate their performances. Mixing proportion, procedures, coverage area & procedures of applications was carried out as per manufacturer's technical data sheets. Bond strength of bonding agent was carried out by slant shear test method and pull-off test method [26]. For pull-off strength test method, 50mm thick overlays of repair mortar was placed over substrate base concrete. Casting, preparation, curing & grit blasting of substrate based concrete was done as per EN 1766-17 [27]. Measured roughness index of substrate base concrete was 1745mm. Substrate mix proportion is given in Table 4.

Pull-off test was also carried on with and without bonding agent at bond on concrete overlays and substrate. Mix proportioning of concrete grade selected for the study was carried out as per the procedure given in IS 10262-2009 [28].

Table 4 – Mix Proportion for concrete mix as Substrate

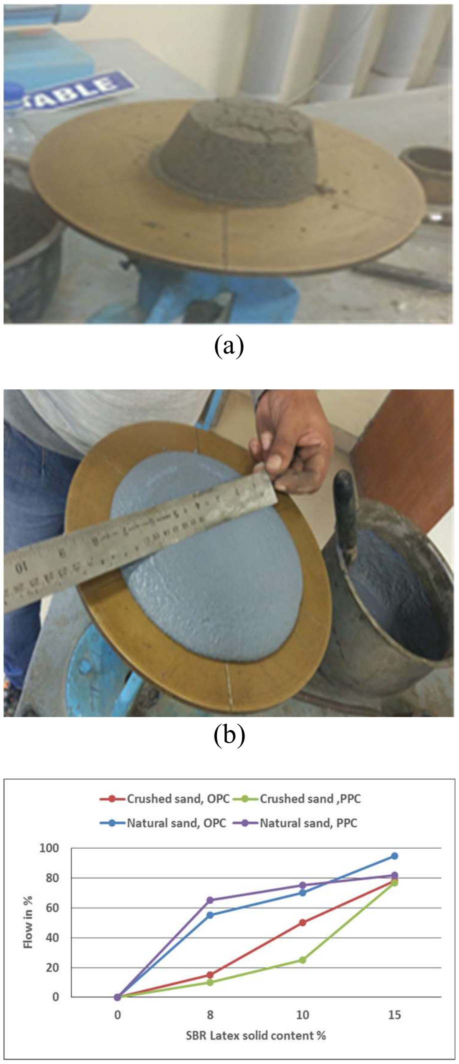
Mix Constituents	Mix Proportion
w/c ratio	0.32
Cement (kg/m^3)	450
Coarse Aggregate (10 mm) (kg/m^3)	859
Fine aggregate (kg/m^3)	1041
Water (kg/m^3)	144
28 days compressive strength (MPa)	58.91

4. Result & Discussion

4.1 Optimization of SBR latex content in Polymer modified mortar (PMM)

4.1.1 Flow

Flow test of Polymer Modified Mortar was done as per the procedure of IS 4031 [21]. Flow of mortar measured by flow table test is shown in Fig. 1(a) and Fig. 1(b). The test results (Fig. 1(c)) indicate that SBR latex based polymer mortar flow increases with increase in latex content due to the formation of extensive surface acting agent in system [1]. Mixes with crushed sand shows decrease in flow which is due to presence of more fines. The crushed sand with more angular shape and pointed edge hinders cement paste and particle movements causing reduction in flowability [29].



(a)

(b)

(c)

Fig. 1 – (a) Flow of 0% latex solid content by flow table test, (b) Flow of 15% latex solid content by flow table test, (c) – Flow of repair mortar by flow table test

4.1.2 Compressive strength

Compressive strength test of Polymer Modified Mortar was done as per the procedure of ASTM C-109 [22]. The result of compressive strength at 28 days age is shown in Fig. 2. Test result indicates the compressive strength of mixes modified with SBR latex is less compared to unmodified mortar. However, among PMM mixes, the mix with 10% latex solid content shows maximum increment in compressive strength (Fig. 2). After further addition beyond 10% latex solid content there is reduction in strength due to formation of several polymer cement bond as the increase in polymer content causes cover to hydrated cement and aggregates.

4.1.3 Flexural strength

Flexural strength test of Polymer Modified Mortar was done as per the procedure of IS 4031 [24]. As shown in Fig. 3, addition of SBR latex improves flexural strength. The mix with 8% latex solid content shows maximum increment in flexural strength which may be due to SBR latex form strands that bridges micro cracks inside the mix, thereby increasing the flexural strength [1]. The performance of the polymer based mortar improves as the polymer dosage increases from 5% to 15% incase of SBR latex but type of fine aggregate and type of cement also has effect on the flexural strength along with percentage of latex solid content.

4.1.4 Static Modulus of elasticity (MOE)

Static Modulus of elasticity (MOE) test of Polymer based Mortar was done as per the procedure of IS 516 [23]. From Fig. 4, the inclusion of SBR latex produced an improvement in the modulus of elasticity of PMM. The study indicates that the improvement was achieved with the dosage of 8 to 10% latex solid content by weight of cement. In order to have an effective repair, modulus of elasticity of substrate and repair mortar shall be in the same range.

4.1.5 Drying Shrinkage

Drying shrinkage test of Polymer Modified Mortar was done as per the procedure of IS 4031 [25]. As shown in Fig-5, significant decrease in drying shrinkage is observed with addition of SBR latex into the mix where in optimum dosage of water also plays an important role to control the drying shrinkage. The mixes correspond to 8% SBR latex solid content mixes shows maximum decrement which could be due to latex emulsion forming a barrier at the surface of the mix thereby preventing rapid loss of moisture [6]. Not much variation in drying shrinkage results are seen when percentage of SBR latex solid content is increased from 8 % to 15 % which indicates that increase in polymer concentration does not affect drying shrinkage.

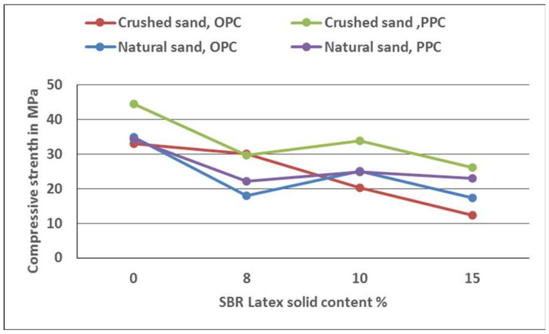


Fig. 2 – Compressive strength at 28 day's age

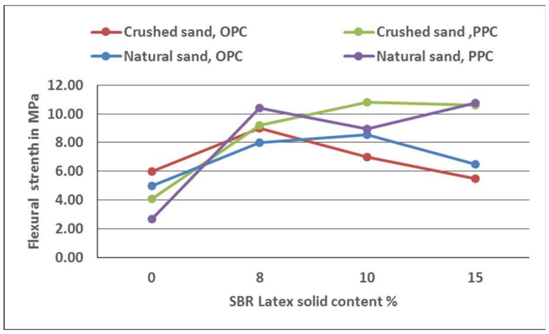


Fig. 3 – Flexural strength at 28 day's age

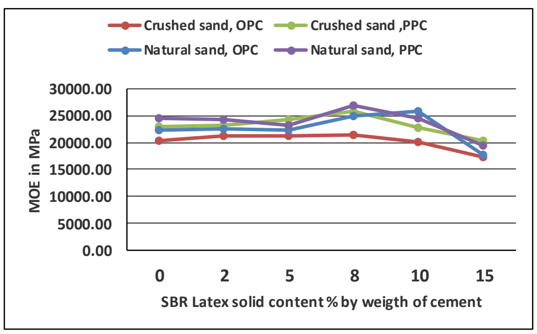


Table 5 indicates significant increment in bond strength when epoxy bonding agent is used as compared to SBR latex. As per slant shear test results, epoxy bonding agent tensile bond strength is more than SBR latex by 50%.

The improvement in tensile bond strength by pull-off test method, of Polymer Modified Mortar overlays with concrete substrate, shows 46 % increment when epoxy bonding is used at the interface when compared to SBR latex bonding agent. Tensile bond test was also conducted using concrete as overlays (M65) and substrates (M25). The bond strength using epoxy bonding agent applied at the interface shows 51 % increment as compared to bond strength without any bonding agent. The test results indicated that there is improvement in bond strength when Epoxy bonding agent was applied at the interface as compared to concrete without epoxy bonding agent.

Fig. 4 – Modulus of elasticity (MOE) at 28 days' age

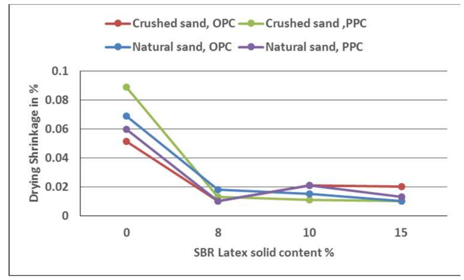


Fig. 5 – Drying shrinkage at 28 day's age

4.2 Evaluation of structural Bonding agent

Bond test by slant shear test method was carried out with reference to procedure given in relevant ASTM C 882-13 [30] (Fig. 6 and Fig. 7). The slant shear test was carried out on 250kN CTM with reference to the procedure given in ASTM C 39 with 0.25MPa/s as rate of loading till failure. Whereas, bond strength test by pull-off test method was carried out with reference to procedure given in EN 1542-99 [26] (Fig. 8 and Fig. 9). The pull off equipment along with accessories were then placed concentrically over the dolly to the cored surface at a loading rate of 0.05 MPa/s until failure occurs. The load at failure was recorded and then the mean diameter of the specimen at the failure face was measured using Vernier calipers.

Bond strength test result from

Fig. 6 – Slant shear test set up

Fig. 7 –Test specimen after slant shear test

Fig. 8 –Pull-off test set up

Fig. 9 –Test specimen after pull-off test

Table 5 – Bond strength test by slant- shear & pull-off test method

SI No	Bonding agent at interface	Substrate mortar/ concrete compressive strength in N/mm^2		Overlays mortar/concrete compressive strength in N/mm^2		Average bond strength in N/mm^2	
		Mortar	Concrete	Mortar	Concrete	Result obtained	Remarks
1.0	Slant shear test method						
1.1	SBR latex	31	-	31	-	5.66	-
1.2	Epoxy resin	31	-	31	-	10.71	-
2.0	Pull-off strength test method						
2.1	SBR Latex	-	58.19		-	1.06	Overlay is PMM with 8% latex solid content
2.2	Epoxy	-	58.19		-	1.98	
2.4	Epoxy with No bonding agent	-	M25	-	M65	1.17	Overlay is concrete with 20 MSA
2.5	Epoxy with bonding agent	-	M25	-	M65	2.39	

5 Conclusion

Findings of study indicates that at 8-10 percent concentration of dry polymer solid by cement mass in polymer based mortar is the optimum dosage. Styrene-butadiene rubber based polymer mortar showed improvement in flow in comparison to normal mortar however, mixes with crushed sand shows decrease in flow which is due to presence of more fines. Optimal polymer content of the research is related to enhancing flexural strength, static modulus of elasticity & decrement in drying shrinkage of mortar while achieving adequate strength and flow. The improvement in tensile bond strength by pull-off test method incase of Polymer Modified Mortar overlays with concrete substrate, shows 46 % increment when epoxy bonding is used at the interface when compared to SBR latex bonding agent. The bond strength using epoxy bonding agent applied at the interface shows 51 % increment as compared to bond strength without any bonding agent which highlights the importance of application of bonding agent at the interface. Slant shear and pull-off test method shows epoxy bonding agent give better bond strength as compared to SBR latex.

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