CEMENT BASED BONDING MATERIAL FOR FRP

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ABSTRACT

Strengthening and rehabilitation of structures are major issues worldwide. In most situations, strengthening is required when there is an increase in the applied load, human error in initial construction, legal requirement to comply with updated versions of existing codes, or as a result of the loss of strength due to deterioration over time. Fibre Reinforced Polymer 'FRP' strengthening systems are enjoying a great deal of popularity as a result of the unique properties of FRPs, namely, being lightweight, fatigue resistant and non-corrosive in addition to their ease of application.

As the major bonding agent used in current applications are organic adhesives with low glass transition temperatures, it would be very beneficial if they are replaced with a cementitious (mineral) based bonding agents such as modified concrete in order to produce fire resistant strengthening system.

Pilot testing conducted by the authors have shown that excellent bonding properties can be achieved using many types of cement based adhesives. The mixes generally include Ordinary Portland Cement with a Silica based very fine filler to reduce cement dosage and superplasticizer to achieve the required workability. Three different mixes have been used including silica fume, latex modified adhesive containing SBR latex, and Micro-cement.

KEYWORDS

FRP; rehabilitation; cement based adhesives; mortar.

INTRODUCTION

The deterioration of the concrete structures coupled with usage beyond anticipated design loads has led to a considerable increase in repair and strengthening works worldwide. Over £500 million per annum is spent on concrete repairs in the united kingdom, while nearly %40 of the bridges in the United States are structurally deficient or obsolete (Dunker and Rabbat 1993).

Fibre Reinforced Polymer 'FRP' strengthening systems are enjoying a great deal of popularity as a result of the unique properties of FRPs, namely, being lightweight, fatigue resistant and non-corrosive in addition to their ease of application. As FRPs are becoming available at lower prices, a tendency toward using them as a substitute or in conjunction with steel plating (the favourite strengthening method of the 90s) is gaining momentum.

Limitations of using epoxy in frp strengthening

Application of Epoxy and other resins as an adhesive agent has got serious problems in certain conditions such as in fire danger due to sensitivity to high temperature exposure with glass transition threshold only slightly above the high end of the ambient temperature rang under normal environmental exposures. Furthermore, emission of toxic fumes, moisture impermeability and flammability are critical issues related to polymer matrix composites, as well as emission of the steroids during the curing phase (Kolsch 1998; B. Taljsten 2007). It also creates a sealed surface(diffusion-closed) that may imply freeze/thaw problems for concrete structures (Taljsten and Blanksvard 2007).

The glass transition temperature T_g is a very important property of polymers. It is the temperature around which a sudden drop happens in properties of the polymer. The study done by Gamage confirms the drastic drop in mechanical properties of composite section using epoxy. The test included single lap shear test on FRP strengthened blocks. It has been reported that the failure mode of composite section was concrete rupture up to temperature of 50˚C; however, beyond this temperature the failure mode changed to bond delamination. Furthermore, the loss of strength was reported at temperature range of 60˚C to 70˚C (Gamage et al. 2005). Saafi also reported such change in properties of polymers around T_g from a relatively stiff material to a viscous material (Saafi 2002). Several investigations have been done to determine the glass transition temperature. It has been reported to be in order of 50 to 60˚C (Barnes and Fidell 2006), while ACI 440.2R reported the temperature of 65 to 150˚C as the threshold of change in polymer matrix to viscous and rubbery.

In addition, FRP displays drastically different behaviour at high-temperature, compared to concrete or steel. The degradation in tensile strength and elastic modulus of FRP materials at elevated temperatures has been reported in several studies (Blontrock et al. 2001; Barnes and Fidell 2006; Rafi and Ali 2007). Rafi found that as the temperature increased up to 250˚C, the tensile strength of the FRP laminates decreased around 20%, that caused by degradation in resin component of the plate.; however, there was a small decrease in the ambient modulus of elasticity. Barnes, also, reported that the adhesive and the resin component of the CFRP plate had been destroyed although the carbon fibers were still intact and appeared undamaged at a temperature of up to 950˚C (Barnes and Fidell 2006).

Cement-based adhesives an alternative for epoxy in frp strengthening

The limitation of the epoxy resins, mentioned in last parts, lead some researchers to substitute it with another adhesive agent to eliminate such harms. They considered that mineral based material must have specific characteristics. It can prepare an environment for the fabrics in which they can be dense in order to achieve a high-volume fraction of reinforcing material within the overlay. The requirements for the matrix material are as followed.

- Sufficient mechanical properties for load transfer.
- Correct consistency, good penetration of the fabrics, and good bond characteristics for embedded fabrics.
- Thermal and chemical compatibility of the fibers and the substrate and thermal and fire resistance.
- Workability on site (applicability to large vertical surfaces, open-ended time period for application).
- The demand of environment acceptability.

Since the polymer improves the bonding properties of the concrete as well as reducing the water to binder ratio, the polymer modified mortar has been practiced as the cement based adhesive in FRP strengthening (Wiberg 2003; Bournas et al. 2007; Bousias et al. 2007). Nevertheless, the polymer modified mortar has a few drawbacks. The polymer decreases the permeability of the adhesive matrices and obstructs moisture transition from substrate concrete to the environment.

Silica fume is another additive that can improve the properties of mortar by densifying the cement based matrices. Although some research has been conducted on this type of mortar (Wiberg 2003; Wu and Sun 2005; Taljsten and Blanksvard 2007), more in depth investigation is needed.

Experimental study

The research has been focused on investigation of flexural behaviour of FRP strengthened beams using different type of mortars as bonding agent. The specimens included un-reinforced concrete beams that have been reinforced by FRP sheets and grids. Figure1 and 2 illustrates the beam dimensions and load-setup configuration respectively. It should be mentioned that the FRP sheet is 610mm long and the beam is un-reinforced 70mm from each end. Four types of mortar were used for FRP strengthening of the concrete substrate. The mixing ratios are presented at table 1.

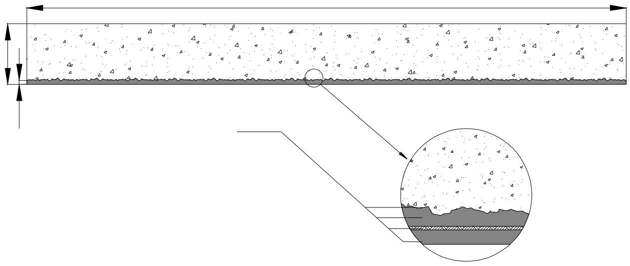

Figure 15 Beam dimension

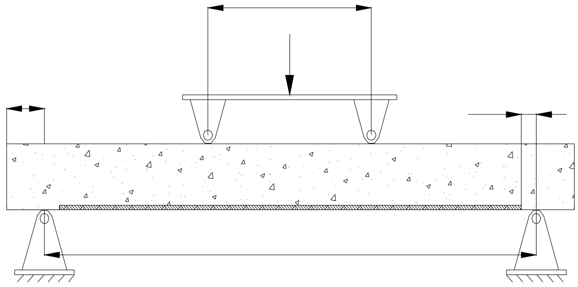

Figure 16 Load setup configuration

Table 8. Mix ratios of concrete and mortar

Type	*C[1](Kg)*	*MC[2](Kg)*	*CA[3](Kg)*	*FA[4](Kg)*	*W[5](litre)*	*F[6](Kg)*	*SF[7](Kg)*	*SBR[8](Kg)*	*SP[9](Kg)*
Concrete	306	-	1275	685	177	-	-	-	-
OC[10]	888	-	-	-	426	754.8	-	-	8.9
OS[11]	813	-	-	-	406	691	81.3	-	40.6
OL[12]	776	-	-	-	310	659	-	194	3.9
MS[13]	613	153	-	-	437	651.5	76.7	-	42.2

1.Ordinary Portland Cement
2. Micro-cement
3.Coarse aggregate
4.Fine aggregate
5.Water
6.Filler (Silica 200G)
7. Silica fume
8. SBR Latex (Barra Emolsion 157)
9. Superplacticizer (Viscocrete5-500)
10. Cement based mortar without any other additives
11. Silica-fume incorporated mortar
12. Latex modified mortar
13. Micro-cement added to OS mortar

Specimen preparation was as follows:

Having been cast and cured for 14 days, the concrete substrate was sand blasted to provide rough surface for FRP application and remove laitance. Then the concrete was remoulded and first layer of mortar was poured followed by FRP sheet and then second layer of FRP applied.

Figure 17 Sandblasted concrete substrate

Figure 18 The laid FRP on fresh mortar

RESULT AND DISCUSSION

There was a clear reinforcement action which was achieved by application of FRP sheet with different types of mortar. Comparing the un-reinforced plain concrete with FRP reinforced same beam, it can be seen that the load carrying capacity from 1.6KN has been increased about 60-200% for different types of mortar. Test results are shown in table 2.

Table 9 Test results

Type	*FRP type*	*maximum Load(KN)*	*σ_{frp} (MPa)*	*ε_{frp} (μs)*	*FRP efficiency(%)*	*σ_c (MPa)*
OCS	sheet	3.51	810	4050	20	21
OSS	sheet	3.83	887	4437	23	24
OLS	sheet	2.53	585	2926	15	16
OST	textile	4.73	1096	5479	29	29
MSS	sheet	4.13	956	4782	25	26

The silica fume incorporated mortar (OS) had a better performance compared to ordinary Portland cement mortar (OC) and polymer modified mortar (OL). It shows the higher level of peak load as well as more ductile behaviour. Also, it was concluded that replacing 20% of Ordinary Portland cement with micro-cement in silica-fume incorporated mortar, has improved the flexural performance of FRP strengthened member by increasing peak load and maximum deflection. As it illustrates in figure 5, the FRP textile strengthened member (OST) has better performance than FRP sheet strengthened member (OSS) using the same mortar as bonding material.

In addition, the failure mode of FRP strengthened members were FRP debonding in all specimens using different types of mortar except silica-fume incorporated one (OSS) in which FRP rupture happened, shown in figure6. The number of cracks also implies the ductile behaviour of composite members which was a few for ordinary Portland cement mortar (OCS), shown in figure 7. In contrast, several number of cracks distributed in MSS and OST sample, shown in figure 8.

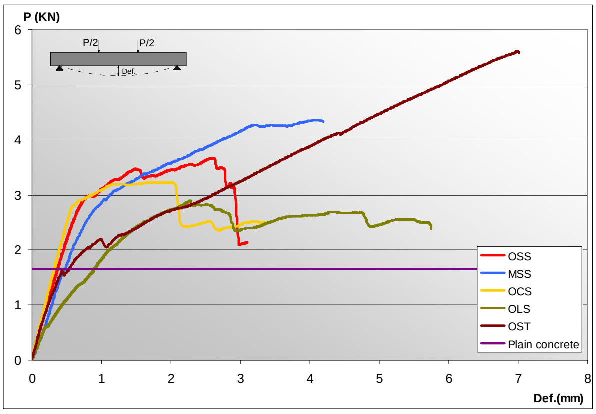

Figure 19 Flexural performance of FRP strengthened beam with different mortars

Figure 20 FRP rupture at OSS sample

Figure 21 OCS specimen failure

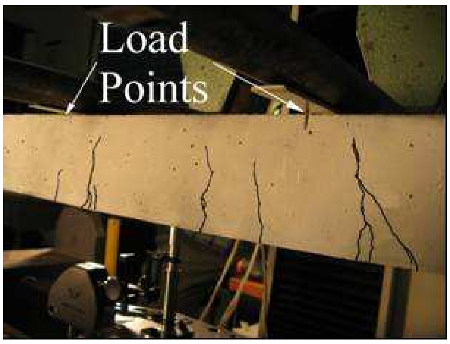

Figure 22 OST sample failure

CONCLUSION AND DISCUSSION

It can be concluded that all types of mortars that were used as a bonding material can effectively contribute to increase load carrying capacity and ductility of structural member. Since, higher level of capacity can be achieved by OC mortar without any substantial additives, compared to latex modified mortar (OL), it is not economical to add SBR latex to the mix. Furthermore, using the same strengthening material of FRP sheets, the best flexural performance from the micro-cement added mortar (MS), was obtained. The MSS specimens showed a ductile behaviour and the load carrying capacity has increased up to 2.5 times of un-reinforced concrete. Although such increase has been achieved, the efficiency of FRP material was about 25% of its full capacity. Moreover, the OST specimens, strengthened with FRP textile, presented higher capacity compared to FRP sheets which is due to better mortar penetration through the tows.

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