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EFFECT OF FLY ASH CONTENT IN MBC BONDER FOR SUSTAINABLE CFRP RETROFIT

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The rehabilitation and strengthening of reinforced concrete structures have been attracting increasing attention due to various factors including increase in traffic volume and weight, structural aging and environmental impact. Various techniques such as grouting, guniting and external post-tensioning are being used to retrofit or strengthen deteriorated members. With recent developments in the application of fiber composites in structural engineering, externally bonded Fiber Reinforced Polymer (FRP) system has become one widely used repair techniques because of its durability and long-term cost-effectiveness. In the FRP bonded retrofit technique, epoxy is often used as the bonding material. Because of environmental impact and health issues, construction sector is always looking for sustainable alternative bonding materials for FRP retrofit. A new trend on using Mineral Based Composites (MBC) has garnered the attention for a possible alternative to replace the use of harmful epoxy in FRP retrofit. MBC is formed by mixing the cement with some other minerals together and some concrete admixtures. As a part of a project to investigate optimum mix for the MBC, a series of tests were carried out to study the effect of fly ash content in the MBC mix as a partial replacement of cement. This paper discusses the results from this experimental program and evaluates the optimum fly ash content for the MBC and its associated properties.

Keywords: Fiber reinforced composites, Rehabilitation, Bonding material, Epoxy, mineral composites, Damaged concrete, Strengthening.

1 INTRODUCTION

Like all types of modern day infrastructure concrete structures are also subject to structural deterioration over their design life as a result of a numerous factors such as corrosion, weathering and "wear-and-tear". Structural retrofitting has become an increasingly popular method for treating structures for economic, environmental and social reasons; since retrofitting is usually far cheaper option than replacing the structure limiting the potential for waste while reducing the operational downtime of the structure during repair. Due to its cost effectiveness and high strength-to-weight ratio, Fiber Reinforced Polymer (FRP) retrofitting has become the preferred option for most structural defects. Until recent years, epoxy is used as common bonding agent for most of the FRP retrofits. However, due health issues associated with the epoxy, researchers are looking for an alternative bonding agent for such retrofitting. Mineral Based Composite (MBC), which is a cement based mortar, is another form of sustainable bonding material that can be used as an alternative for the epoxy. This paper presents experimental results that investigates the effect of fly ash amount in the bonding strength in the sustainable MBC bonder.

2 METHODOLOGY

2.1 Mineral Based Composites (Cement Based Bonders) for FRP Strengthening

MBC bonders are those such as mortar and concrete in which the main component is a mineral material such as cement and fly ash. MBC are widely being trialed and adopted as the more sustainable alternative to epoxy resins for use in retrofitting. By using MBC bonders, the harmful effects on humans directly related to exposure to epoxy resins are eliminated. It is a system in which a FRP grid is applied to the outermost surface of a structure which has to be strengthened using an MBC bonding agent, as shown in Figure 1. Fine grained MBC bonders are an appropriate option to be used since it is economical and has good workability, while also being compatible with the FRP material and being able to bond with the existing concrete surface.

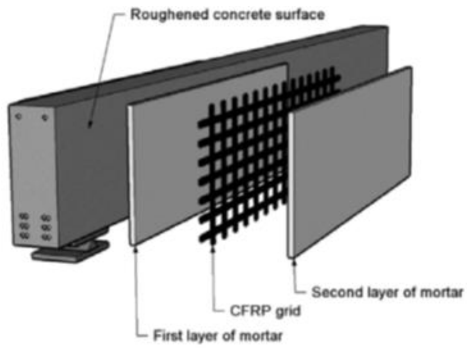

Figure 1. Overview of MBC Strengthening System.

Mahal (2013) conducted tests using beams retrofitted with Carbon Fiber Reinforced Composites (CFRC) and Carbon Fiber Reinforced Polymer (CFRP) to determine the mechanical behavior of the FRP material at different stress levels. As seen in Figure 2, the fatigue resistance of the CFRC and CFRP retrofitted beams significantly increased compared to control beams. The CFRP peak is followed by a sharp decrease indicating that beams failed due to delamination. The CFRC on the other hand shows a more gradual slope indicating that the FRP sheeting has ruptured as opposed to the adhesive failure in the CFRP.

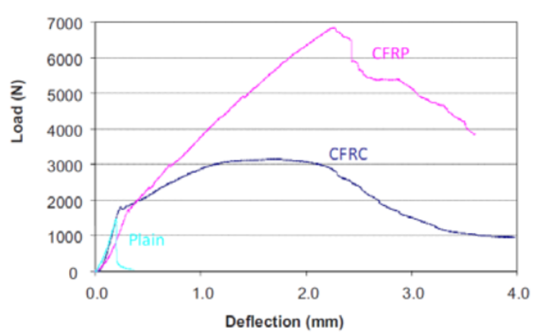

Figure 2. Flexural response of plain, CFRC and CFRP Retrofit.

Raghavendra *et al.* (2016) conducted tests to compare the bonding strength of FRP retrofitting with both epoxy and MBC. Figure 3 shows the experimental results for both bonders in which the specimens were single wrapped (SW) with Glass Fiber Reinforced Polymer (GFRP) sheeting. The retrofitting was applied to specimens, which had reached fully failed (FF) and first-crack stages.

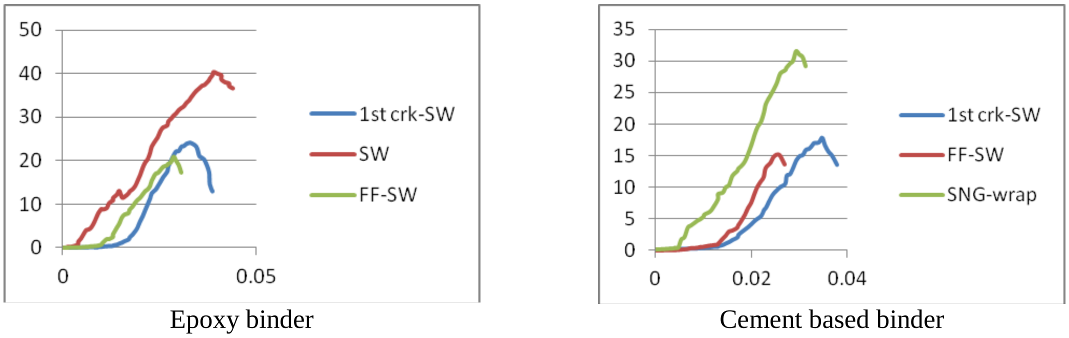

Figure 3. Compression Testing Results [On x-axis strain and on y-axis stress in MPa].

The results proved that the strength between the epoxy and MBC bonder differed, however, they behaved relatively similar. Epoxy in comparison with MBC gives higher strength increases, but it was noted that there are also demerits associated with epoxy that includes higher cost, hazardous to work with and had special requirements for its usage.

With regards to the performance of FRP with cement based bonders and epoxy bonders, Hashemi (2012) performed single-lap shear and flexural test to analyse the bond strength. CFRP retrofitting was used and the bond slip response identified during testing proved that the cement based bonder performs better than epoxy in hot regions or regions subjected to higher temperatures, as the ultimate load reached was 80% greater than the CFRP retrofitting with epoxy bonding.

2.2 Fly Ash as a Sustainable Cement Replacement in MBC Bonder

Fly ash is an industrial by-product of coal combustion which commonly occurs in power stations. It also can be used as a mineral admixture to improve the overall performance and quality of concrete. It improves workability, reduces water demand thus increasing strength, controls bleeding and lowers the heat of hydration. Fly ash also increases strength development at later ages, reduces corrosion of reinforcing steel and generally improves resistance to chemical attack and mobility through a reduction in pore size and, therefore, permeability.

Jian *et al*. (2002) conducted tests on high-performance concrete containing ultra-pulverized fly ash composite and super plasticizer. The results proved that the double effects of pulverized fly ash and super plasticizer enhances concrete performance in terms of excellent workability, lower drying shrinkage, better durability and higher mechanical properties. Yijin *et al.* (2004) investigated the effect of fineness and replacement levels of fly ash on the fluidity of cement paste, mortar, and concrete. The incorporation of ultra-fine fly ash may increase the setting time of cement paste, slump and also decrease the water demand ratio due to its fineness. Ozbay *et al.* (2009) studied an optimal design for blended mortars and the results revealed that 30% fly ash optimizes water permeability/water absorption and 15% of fly ash enhances splitting tensile strength and compressive strength. In order to achieve a sustainable and innovative MBC bonder for FRP retrofitting, it is appropriate to use recycled pozzolanic materials where possible and appropriate. An increase in the utilization of fly ash as an alternative to cement will result in a range of benefits such as wider use of recycled materials, environmental protection and sustainable future construction.

3 METHODOLOGY

3.1 Concrete Specimens

Standard size concrete cylinders (Φ150 × 300 mm) were prepared using Grade 32 concrete in the laboratory and allowed at least 28day for curing under control room temperature with plastic wrap. After the curing, a sample surface was prepared to ensure good and consistent bonding of the FRP sheets was carried-out. The surface preparation involves grouting of small holes, washing off fine particles and sanding the contact surfaces.

3.2 MBC Bonder

In this experimental program, the mineral bonder mix used by Raghavendra *et al*. (2016) is used as control mix for the MBC bonder. It consists of cement, metakaolin, Viscous Modifying Agent (VMA), and super plasticizer. The cement used was Portland Pozzolona cement with controlled amounts fly ash. Metakaolin is a supplementary material to be used as strengthening agent for cement. Glenium B233 is a light brown liquid and a kind of polycarboxylic ether with specific gravity 1.08. This acts as a super plasticizer (water reducing agent) for the cement based bonder and is compatible with all types of cement. Glenium Stream 2 admixture is a colorless liquid with specific gravity 1.01, which exhibits superior stability and controlled bleeding characteristics. It is used as a viscous modifying agent as it increases the resistance to segregation and facilitates concrete placement. The detail of the mineral based bonder mix is given in Table 1.

Table 1. Mineral based bonder mix detail.

Component	**Amount (g)**
Cement	1000
Metakaolin	100
Super Plasticizer	30
Fly Ash (variation)	10%, 20%, 30%, 40% replacement to the amount of cement
VMA	0.4

3.3 Specimen Preparation

There was a total of 16 different specifications were considered in the specimen and these parameters are summarized in Table 2. All specimens will be prepared and cured at similar condition as much as practically possible to reduce any variation due to preparation and curing process. All specimens were retrofitted with single FRP wrap.

Table 2. Test parameters.

Parameters	**Variation**			
Amount of fly ash replacement (%)	10	20	30	40
Condition prior to the retrofit	No cracks		Full failure	
Test	Compression test		Split tensile test	

3.3.1 *Control and failure specimens*

The control specimens are standard specimens which would be subjected to retrofitting without any damages in it. After specimens were cured for 28 days, they were tested in a compression testing machine at a constant loading rate of 20 MPa/min (AS 1012.9: 2014) until failure. The same set of experiments will be carried out using full failure specimens.

3.3.2 *Wrapping procedure*

The fully failed specimens were again outer-surface prepared before retrofitting. To do this, the specimens were sun-dried to make it free from moisture, then the surface was smoothened with a sand paper and the loose particles were removed using a brush, where the holes and imperfections on the surface are filled with cement grout and cured for a week. The specimens are then wrapped with FRP material. One coat of MBC bonder was applied to the surface of the cylinder. CFRP has been used in this project as it has excellent mechanical and thermal properties when compared with other fiber and it is compatible with MBC bonding materials. CFRP fabric was used for wrapping the cylinders after a layer of bonder is applied. The wrapping has an overlap of 75mm to avoid failure in the overlap region. Then a second layer of bonder coating was applied over the FRP surface to seal it properly. The wrapped specimens will then be cured for a further 7 days. After the CFRP wrapping is completed and left to cure for a week, compression testing and split tensile testing will be conducted on these specimens.

4 RESULTS AND DISCUSSION

Both compressive strength testing and split tensile testing results for CFRP retrofitted control and full failure specimens are summarized in Table 3.

Table 3. Performance of MBC bonder with varying fly ash amount.

Fly ash amount (%)	Increase in Strength (%)			
	Compression Test		Tensile Test	
	New Specimen	Failed Specimen	New Specimen	Failed Specimen
10	26.50	95.95	19.68	164.76
20	17.89	81.22	11.52	128.96
30	27.65	105.06	31.38	249.18
40	21.18	90.74	9.79	134.15

From Table 3, it can be seen that the amount of fly ash in the MBC bonder have substantial effect in the strength increases in all different test conditions. However, there is a peak in the performance of specimens in both compressive and split tensile testing with 30% fly ash replacement. From the results, it can be seen that up to 32% of the tensile strength increases can be achievable with the 30% flash replacement for uncracked specimens while this value can go up to 250% in the case of the fully failed specimen.

Similar strength increases are also seen in compression test results. In an uncracked specimen, up to 28% increase was observed while it went up to 105% for full failure specimens. This suggests that the fly ash can be used to replace the cement in the MBC retrofit by 30%. That will save significant cost for MBC retrofit while making use of industrial waste, which otherwise could end up in the landfill.

5 CONCLUDING REMARKS

From the experimental results obtained the following concluding remarks could be made.

- Fly ash admixture in MBC bonder gives substantial strength increases and is compatible with CFRP sheet retrofit.
- It can be suggested that 30% cement replacement can be the optimum fly ash content in the MBC bonder.
- Tensile strength results observed that tensile strength responded the best to the fly ash admixture with strength increases about 250% for full failure specimens and up to 32% for control specimens. Compressive strength increased also about 105% increase for full failure specimens and up to 28% for control specimens.
- Since a common failure mode for most concrete structural members such as beams is usually a tensile strength failure as a result of bending from applied loads, these results are encouraging for field applications.

This suggests that the fly ash can successfully replace the cement by up to 30%. However, it should be noted that these tests were performed for cylinders with circumferential wrapping. For in-situ structural members with only three faces exposed, further investigation needs to be accomplished to study the effective wrapping procedure.

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