

# Effect of High Temperature and Marine Corrosion on Mineral Bonder in Fibre Retrofit Over Epoxy Resin

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## Abstract

**Objectives:** This project investigates the performance of mineral based composite in fibre retrofit under saline water corrosion as well as its behaviour at high temperatures in comparison to epoxy bonder. **Methods/Experimental Analysis:** Three types Fibre Reinforced Polymer (FRP) materials were used in retrofitting standard cylindrical concrete specimens subjected to various damage levels prior to its retrofit. The specimens were wrapped using epoxy resin and Mineral Based Composite (MBC) bonders before they were tested for their mechanical properties under high temperature. Apart from that, the carbon fibre samples were placed in marine conditions in order to investigate the effect of corrosion. **Findings:** Carbon fibre proved to be the most efficient retrofit with mineral bonder under various levels of pre-existing damage followed by aramid and e-glass fibres. Further, the MBC mix proportions were varied to accommodate industrial by-products such as class F flyash and metakaolin. The ideal mix proportions was later determined after a series of compressive tests and the finalized ratio was used in FRP retrofits under high temperature (100°C) alongside offshore environmental conditions. Epoxy had detrimental effects and lost its bonding capacity under these conditions whereas mineral composite established itself as a superior bonder. Around 205% strength development was observed in the tensile behaviour of carbon fibre retrofit and 30% replacement of cement with flyash seemed to perform optimally. Under severe temperature and marine corrosion, MBC bonded CFRP retrofit proved to be most durable. Thus, the significance of rehabilitating damaged concrete structures can be carried out globally using mineral based FRP strengthening technique which is sustainable solution. **Application:** From all the findings, it can be suggested that mineral bonding admixture can be adopted as a potential replacement for harmful epoxy resin under increased deterioration levels.

**Keywords:** Epoxy, FRP Retrofit, Rehabilitation, Sustainability, Temperature, MBC

## 1. Introduction

Concrete disintegration due to various natural and induced phenomena undoubtedly impacts the structural integrity and may result in complete failure under extreme circumstances. By any means, the predominant framework is subjected to loss of strength so that it should undergo some kind of repairs immediately. Based on the degree of damage, the infrastructure may be subjected to minor or major rehabilitation considering the detainment of its operational service life. There have been extensive

studies undertaken on various bonding techniques for FRP retrofit as it is one of the widely used restoration techniques in recent years. Conventionally epoxy has been used as the bonding agent in the FRP retrofit. However, as epoxy releases toxic fumes at higher temperatures and has the potential to cause adverse health impacts for the people working with them, this project shifts its focus on green materials. Post the success in development of a high-performance cement-based mineral bonder, the elimination of harmful epoxy resin can be contained. Most importantly, the mineral based composite can be

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generated in-situ and also aids sustainability. The main objective of this project would be to investigate the effect of temperature and salt water corrosion on the bonding potency with respect to epoxy and MBC<sup>1-5</sup>.

## 2. Comprehensive Literature Study

The following literature review provides a brief overview of the environmental and human impacts due to epoxy resins thereby signifying the research background and implementation of sustainable alternatives.

### 2.1 Potential Health Concerns due to Epoxy Resin

Even though epoxy and its associated resins are considered to be the primary bonding component in structural reformation activities for many years, it involves a few demerits in practice. Firstly, it is a highly volatile liquid, vulnerable to freeze-thaw conditions as well as higher temperatures. Secondly, these polymers are classified to impose associated risks and adverse health impacts as it fumes toxic gases if the temperature rises above its glass transition temperature. Moreover, it is not susceptible to wet or moisture conditions.

### 2.2 Robustness of FRP Rehabilitation with Mineral Aided Bonding Composites

There is different type of FRPs available commercially with mechanical properties listed<sup>6</sup> in Table 1 and Carbon Fibre Reinforced Polymer posing excellent tensile resistance and durability<sup>7</sup>. Glass fibres are also categorized in three groups: E-glass, S-glass, and C-glass, with the first group being the most common type for civil applications<sup>8</sup>. The experiments conducted by Mahal<sup>9</sup> using beams retrofitted with Carbon Fibre Reinforced Polymer (CFRP) under diverse stress levels to determine the FRP's mechanical behaviour reported that the fatigue resistivity of both beams were critically inflated when compared to the control beams and had failed as a result of delamination. On the contrary, Carbon Fibre Reinforced Composites (CFRC) displayed a more gradual slope illustrating that rupture followed by opposition to adhesive failure that had eventuated<sup>9</sup>. In order to overcome the health and environmental impacts of epoxy, research is being carried out on other alternate sustainable bonding solutions and MBCs are one such recent advancement.

**Table 1.** Mechanical properties of FRPs used in experimental procedure<sup>6</sup>

Properties	GFRP (E-glass)	AFRP (Kevlar-29)	CFRP (Carbon)
Density (g/cm <sup>3</sup> )	2.60	1.44	1.90
Elastic modulus (GPa)	72	83-100	370
Tensile strength (GPa)	1.72	2.27	1.79
Elongation (%)	2.4	2.8	0.5

Experimental study was conducted to compare the bonding strength of FRP retrofitting with both epoxy and MBC<sup>7</sup>. All specimens were retrofitted with single wrapped (SW) using Glass Fibre Reinforced Polymer (GFRP) and Aramid Fibre Reinforced Polymer (AFRP). The results exhibited lower bonding performance when compared to CFRP<sup>6,7</sup> regardless of bonder. This proved that the strength of the epoxy and MBC bonder differed, however, they behaved relatively similar. Epoxy in comparison with MBC gives higher strength even though it has demerits such as higher cost, hazardous to work with and had requires special arrangements for its usage. With regards to the performance of FRP with cement based bonders and epoxy bonders, single-lap shear test and flexural test were performed to evaluate the bond strength<sup>10</sup>. CFRP retrofitting was used and the bond slip response identified during testing proved that the cement based bonder performs better than epoxy in regions subjected to higher temperatures, as the ultimate load reached was 80% greater than the CFRP retrofitting with epoxy bonding<sup>11</sup>. Kevlar-29 and Kevlar-49 are the most frequent types of aramid fibres for civil engineering applications. Aramid, unlike the other two fibre types, suffers from a low compressive to tensile strength ratio<sup>12</sup>. Thus, the proper selection of material and hybrid bonding of FRPs to reinforce damaged concrete members play a vital role in preserving the structure's integrity and promotes extended lifespan<sup>13</sup>.

### 2.3 Characteristic Behaviour of Induced Industrial By-Products in MBC Mix Proportion

The key strategy is to reduce the impact on environment by recycling the industrial waste into concrete industry<sup>14</sup>. Fly ash seems to have a profound impact on strength development at later stages, reduces the risk of steel corrosion and naturally improves the intervention of chemical attack through reduced permeability<sup>15</sup>. In a

research project involving induced industrial waste, tests were conducted on high-performance concrete containing ultra-pulverized fly ash composite and superplasticizer<sup>16</sup>. 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. A study undertaken by Sainsbury et al, to introduce fly ash in various proportions to the prevailing admix proportion<sup>15</sup>, shows that 30% amount of fly ash in the MBC bonder had a substantial effect on the strength increases under all test conditions. Likewise, metakaolin is a finer clay powder when compared to cement. The quality and reactivity of this mineral are strongly dependent on characteristic of the raw material treated<sup>17</sup>. In order to achieve a low impact innovative MBC bonder for FRP retrofits, it is appropriate to use recycled pozzolanic materials wherever feasible. It was reported that the development of a metakaolin based geopolymeric mortar for the external strengthening of RC beams<sup>18</sup>. Four-points bending tests revealed the enhanced mechanical resistance, with the failure load of the reinforced beams roughly twice that of the control beam. This undoubtedly recognizes the excellent strengthening capability of metakaolin used with any mortar throughout the time. Profuse incorporation of fly ash and metakaolin as an alternative to cement will result in a range of benefits such as wider use of recycled materials, cost effectiveness and sustainable future construction<sup>15</sup>. This will save significant cost for MBC retrofit while making use of industrial waste, which otherwise could end up in the landfill.

#### 2.4 Effect of FRP Bonders under Elevated Temperatures and Corrosion

One of the vital goals of this research is to investigate the effect of epoxy and mineral bonder under prolonged severe conditions. In regards to that, the loss of compressive strength in FRP system under prolonged extreme temperature was tested<sup>19</sup>. Exposure of epoxy retrofitted CFRP and GFRP samples subjected to elevated temperatures were found to adversely impact on residual strength and stress-strain relationship<sup>20</sup>. As epoxy adhesion is not recommended for environments above glass transition temperature (55 to 60° C), mineral-based composites were acknowledged to examine the bond strength. From the investigative data obtained, it is well established that cement-based bonding material possesses

a strictly high behaviour response where there is a danger of fire outbreak<sup>11</sup>. Similarly, the consequences of carbon fibre retrofitted with epoxy resin in a steel member was exposed to harsh environments<sup>21</sup> such as sea water and cyclic temperature to find the reduction in stiffness of the member at various time intervals of a calendar year. It was prominent that epoxy had an eminent reduction in the bonding rate after 9 months of surviving under severe conditions. Moreover, the mechanical performance of CFRP bonded joints critically degraded due to the humidity<sup>22</sup> and resulting in catastrophic failure due to sulphate attack of FRP confined concrete<sup>23</sup>.

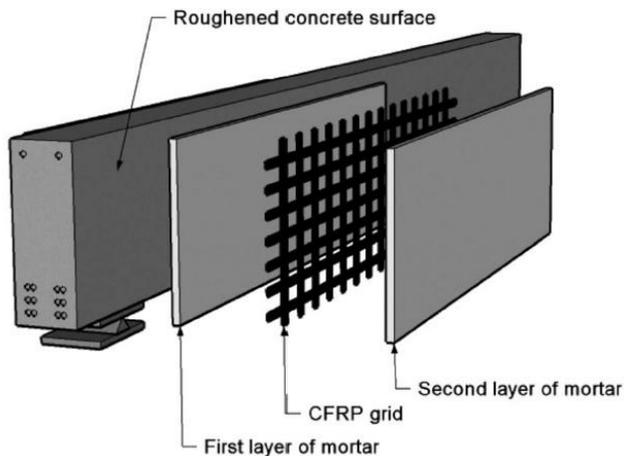
As discussed in this section, it is important to develop a sustainable mineral adhesive bonder as an alternative for epoxy in any form of the construction sector. Further down the line, the use of heat and corrosion resistant FRP bonding retrofit techniques may be highly regarded in the near future for various construction activities.

### 3. Experimental Methodology

#### 3.1 Specimen Design, Damage Parameters and Wrapping Technique

A number of cylindrical ( $\Phi 100 \times 200$  mm) specimens were cast using M32 mix design (Cement: w/c ratio: Manufactured sand: Medium Sand: 10mm aggregate: 20mm aggregate is 1:0.58:0.18:1.77:0.66:2.47) prepared in structures laboratory as per Australian standards<sup>24</sup> AS 1012.1:2014. There were three individual damage levels adopted for each type of testing involved. The foremost was the control specimen without pre-induced damage used for setting high compressive benchmark. Auxiliary to the control (uncracked) specimen; partially damaged specimen that was preloaded by about 70% of the ultimate capacity to induce minor damage was accounted. Thirdly, the fully failed specimens that attained negative peak and those subjected to complete loss of strength were a part of the test setup. Once the progression of casting and 28 days of curing were successful, the specimens were subjected to failure loads as quoted earlier. Thereafter, the outer surface was grinded to perfection to perform the rehabilitation process<sup>5</sup> as presented in Figure 1. An epoxy or MBC bonder coat is applied over the surface and the bi-directional CFRP encases the specimen leaving a fail-safe overlap of 75mm. The same procedure was executed for GFRP, CFRP and AFRP in terms of thermal tests. But,

carbon fibre was prioritized over other retrofits in case of corrosion testing because of its high tensile strength and excellent elastic modulus. In addition to that, CFRP has very high corrosion resistivity, compatible with most of the resins and ideal for multi-layer solutions. All cylindrical specimens were subjected to single wrap retrofit. Later, a second layer of bonder coating is provided to seal the surface properly and allowed to cure for 7 days.



**Figure 1.** Overview of the FRP structural retrofit methodology<sup>5</sup>.

### 3.2 Essentialities for Designing a Fibre Retrofit Mineral Bonder

The basic ideology of the project is to develop an alternate mineral bonder and analyse its performance to that of epoxy. The pre-determined epoxy polymer (Sikadur) incorporates Part-A and Part-B components applied over consecutive days and having a mix ratio of 1:3. As far as the proposed mineral bonder is concerned, the primary elements should procreate strength, durability and viscosity distinctively. Therefore, pozzolanic cement was premeditated as the fundamental constituent, high reactivity metakaolin (Metamax) as an accomplice strengthening agent, Class F fly ash from power station waste to control the water demand and bleeding characteristics, Viscocrete PC HRF-2 as superplasticizer (SP) that works on most cement types and finally Sika VMA (Viscosity Modifying Agent) to control the rheology against particle segregation. Initially, there was a number of trial and error experiments accounted in relation to the contemporary mineral bonder developed. As the mix proportions of the crucial bonding elements were revised

in every opportunity, its mechanical appropriateness with e-glass fibre was tested in contrast to high tensile carbon fibre retrofits. On obtaining the base optimal mix proportion consisting of cement, water, metakaolin, SP and VMA in the ratio 1: 0.37: 0.1: 0.03: 0.0004 per cylinder wrapping allowing for 5% wastage. It is observed that the viscosity constraining reagents are used in very minimal proportion just to aid workability. Later, this composite is applied over FRP materials as illustrated in Figure 2 and their failure modes are obtained.



**Figure 2.** Failure mode of mineral bonder retrofit to e-glass, carbon and aramid fibres.

### 3.3 Refinement of MBC Admix with Varying Proportions of Industrial By-Products

From the compressive and tensile bonding observations, the original MBC mix design was subjected to three types of modifications. Firstly, a part of cement was replaced by flyash and tested for its mechanical properties followed by varied metakaolin influence on the latter mix. Thirdly, with the optimum flyash substitution remaining a constant, the bonding performance of metakaolin varied admixture was investigated. Figure 3 shows the delamination failure due to addition of the substantial amounts of flyash to compensate the cement in single wrap CFRP-MBC mix proportion. In another experimental investigation, similar tests were performed with regards to addition of varying proportions of high reactivity metakaolin into the mix. It is to be noted that there was 10% metakaolin in the pre-defined mix design but the analyses included compensating amounts starting from 5% up to 50% and the experimental data was retrieved admixture.



**Figure 3.** Flyash retrofitted samples alongside dry MBC.

### 3.4 Calfaction Treatment and Thermal Recordings

In order to investigate the bonding performance of mineral composite over epoxy under elevated temperatures, the CFRP retrofitted cylindrical samples were assembled at a constant temperature of 100°C for at least 24 hours prior to testing. Out of the 72 samples subjected to testing there was one sample under each bonder that had a K-type thermocouple embedded into the bonding layer whilst wrapping. Moreover, an Infrared thermometer that could detect the surface temperature using laser induced blackbody radiation principle was in operation as well. Amidst the entire duration of the experimental procedure, the thermal drop was constantly monitored at various stages and also pertaining to the insulated transportation of specimens. The other end of the thermocouple was pinned to a VOM multimeter in order to acquire accuracy in thermal recordings. The pictorial representation of testing methodology is represented in Figure 4.



**Figure 4.** Hot sampling oven and temperature monitoring during analysis.

## 4. Experimental Outcomes and Discussion

### 4.1 Mechanical Properties Comparison for GFRP, CFRP and AFRP Bonders

Table 2 distinguishes the percentage gain in mechanical properties of every epoxy test parameter that was initially proposed. Standard error and deviation values were also formulated for each retrofit with regard to measuring the accuracy of sampling population. There are no such standardized limits for a good or maximal standard deviation. The important aspect to be noted based on our data meeting the assumptions of the model being used. A smaller SD value represents results close to the mean value but larger SD represents more variance in the results. In fact, the globally accepted value states, 68% of all data points should be within  $\pm 1SD$  from the mean, 95% of all data points should be within  $\pm 2SD$  from the mean, and 99% of all data points should be within  $\pm 3SD$ .

The inference was distinctive towards epoxy as it displayed lower standard error values even though MBC exhibited quite a variation. However, it is to be noted that MBC samples for AFRP, CFRP and GFRP retrofits had the error value range well under the accepted limits and demonstrated little variation. Figure 5 emphasizes the effect of bonding performance obtained in FRP retrofits due to mineral based adhesives, especially the improved performance of carbon fibre (189% strength increase) on

**Table 2.** Strength comparison in FRP fibre composites for accuracy

Retrofit material	Initial damage level	Strength obtained with epoxy retrofit				Standard error	
		Compressive testing		Tensile testing		Epoxy	MBC
		MPa	(%) increase	MPa	(%) increase		
GFRP	Nil	74.3	65.1	5.8	11.7	0.552	2.219
	70%	44.56	48.8	5.8	28.9	0.983	2.628
	100%	21.7	8.4	3.04	41.9	0.949	1.148
CFRP	Nil	77.7	72.5	10.1	92.5	1.30	0.27
	70%	67.7	124.6	9.7	115.8	2.29	0.37
	100%	56.4	188.8	6.2	200.9	1.79	4.44
AFRP	Nil	66.44	4.75	7.34	40.0	0.899	1.705
	70%	61.9	105.4	6.34	40.2	0.660	4.745
	100%	48.1	140.0	4.5	116.9	0.831	3.190

MBC single wrap retrofit resulting in unexpectedly high compression resistance for full failure specimens. Further, the characteristic strength of carbon and aramid fibre retrofitted MBC had upsurged 1.5 times in contrast to epoxy during an indirect tensile test as provided in Figure 6. This suggests that MBC retrofit is not impacted by increased deterioration levels unlike control and partial failures. From the standard error data, it is seen that GFRP has a relatively higher range of accuracy when compared to CFRP or AFRP. The average standard error for MBC maintained a range of 2.31 on average and within the reasonably acceptable limit but was higher than 0.9 for epoxy.

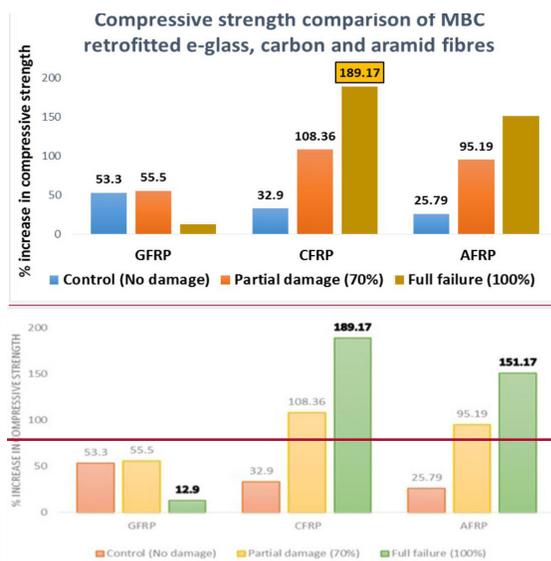


Figure 5. Compressive evaluation of MBC retrofitted GFRP, CFRP and AFRP specimens retrofit which showed greater accuracy.

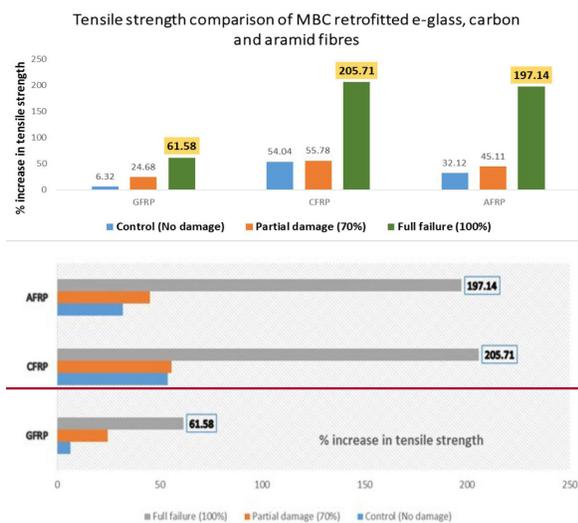
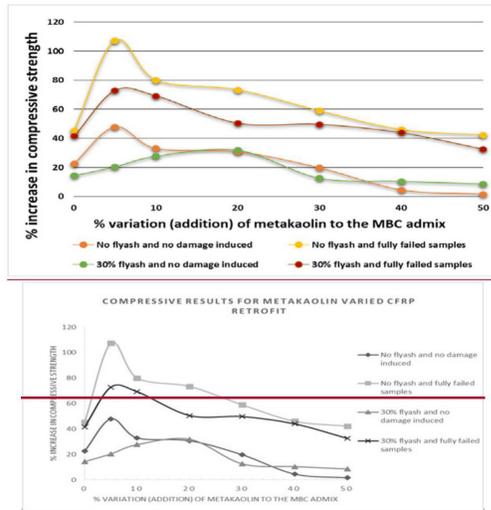


Figure 6. Tensile strength increase in three different FRP retrofitted MBC specimens.

## 4.2 Compensation of Cement with Varying Flyash and Metakaolin Proportions

From the results obtained, the MBC mortar refinement was trailed with varying amounts of flyash in compensating the MBC cement content. After arriving with a desired mix proportion for the sustainable cement-based bonder as mentioned previously, the idea was to obtain a cost-effective replacement for cement without compensating its bonding performance. As pozzolanic cement consists of pre-meditated flyash in it, further addition of flyash content to this cement had the potential to significantly weaken its bonding characteristics. This experiment was performed earlier to obtain the ideal flyash percentage that could possibly be added to bring about a cost-effective solution for the initial admixture. From the results obtained<sup>15</sup>, 30% of flyash replacement works better in terms of sustainability and curtailing the material expenses that are required to fulfil the admix proportions. Furthermore, it also proves that Portland pozzolana cement can accommodate for some flyash supplement without compensating on its bonding performance. Therefore, the new mineral admixes proportions were worked out to be in the ratio 0.7: 0.37: 0.3: 0.1: 0.03: 0.0004 for cement, w/c ratio, flyash, metakaolin, SP and VMA. The maximum strength attainment was when 30% cement was restored with Class F flyash. This parameter was fixed and the resulting experiment continued with altering the percentage of metakaolin introduced into the admixture. After trailing with 5% to 50% reinstatement, the results were exemplary for 20% addition of metakaolin for the pre-treated 30% fly ash restored cement. Based on the commendable results obtained (compressive strength of 59.42 MPa with 31.9% overall strength improvement), a new set of 12 samples were predominantly retrofitted using both bonders. It was identified from the testing outcomes that 5% of metakaolin in relation to the initial mix containing 10% provides excellent bonding behaviour. Moreover, the data represents diminishing performance as the amount of metakaolin is upsurged proving the fact that lesser addition of metakaolin to cement admixture provides greater strength and durability. Therefore, it is critical in using the correct amount of industrial by-products to the bonding admixture for enhanced behaviour. Figure 7 quantifies the competency of supplemental flyash (30%) in mineral based composite developed along with 20% metakaolin as the ideal recycled bonder to obtain the best bonding proficiency products.



**Figure 7.** Graphical results of CFRP retrofit with varying ratio of industrial by-products.

### 4.3 Effect of Elevated Temperature in Evaluating Bonding Performance

Control and full damage criteria were taken into account as an average of 3 samples for each CFRP retrofit and

placed at 100°C all the time and constantly observed for any discrepancy. Table 3 provides a detailed specification of the recorded surface and bonding temperatures as outlined by Infra-red thermometer and thermocouple propelled volt-ohm-milliammeter (VOM) measuring type multimeter.

The test was completed in less than 3 minutes from the time of sample seizure from the oven until the borderline when compressive failure occurred. Both control and fully failed specimens showed an identical response to the bonding and surface temperature variations. Table 4 shows the vital information on how the increase in temperature can affect adhesion competency in various single wrap FRP retrofitted epoxy and MBC samples.

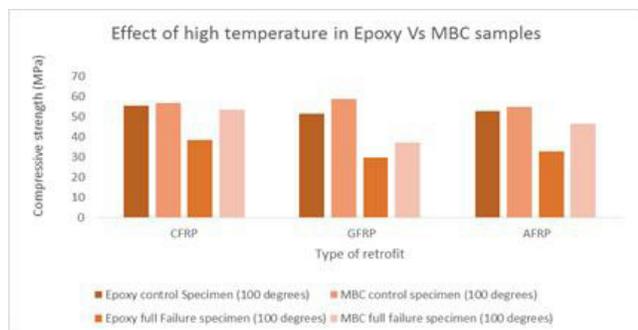
The critical data gathered accomplishes the failure relation of epoxy adhering to a drastic thermal inflation from 27 to 100 degrees (in terms of Celsius heat representation). Likewise, Figure 8 correlates the high temperature behaviour inspection from CFRP, GFRP and AFRP samples by examining the compressive strength graph attained through epoxy and MBC bonders conjointly.

**Table 3.** Temperature recordings at different test points

Sample test condition	Surface temp (°C)		Bonding temp (°C)		Time taken to test (sec)	
	Epoxy	MBC	Epoxy	MBC	Control	Full failure
Inside oven	98.7	95.0	97.4	96.6	0	0
On placement in CTM	66.5	77	85.2	88.2	30	30
On peak load	72.8	79.5	87.6	90.1	167-171	86-107
Post failure removal	72.1	77.3	87.0	85.5	175-179	94-115

**Table 4.** Bonding performance of FRP retrofits at low and high temperature levels

Retrofit Type	Initial damage level	Compressive strength at room temperature (27°C)		Compressive strength at elevated temperature (100°C)	
		Epoxy (MPa)	MBC (MPa)	Epoxy (MPa)	MBC (MPa)
GFRP	Nil	64.33	59.87	51.54	58.74
	100%	32.45	40.54	29.77	36.97
CFRP	Nil	77.7	64.52	55.52	56.81
	100%	56.44	55.92	38.34	53.34
AFRP	Nil	66.43	56.67	52.65	54.89
	100%	50.31	48.06	32.82	46.41



**Figure 8.** Thermal efficiency of single wrap samples for carbon, e-glass and aramid fibres.

The resulting outcomes from Table 4 amounted towards 20% strength reduction in both uncracked and fully failed epoxy retrofitted samples at high temperatures. On the contrary, an approximate loss of 5% strength for control MBC specimen and only 2% with full failure specimen were observed in CFRP retrofit. It was obvious that the outright results evidenced the supreme bonding efficacy of mineral composites over epoxy at elevated temperatures.

#### 4.4 Effect of Marine Corrosion in Epoxy and MBC Retrofitted CFRP Samples

Since, CFRP retrofit had the maximum performance from the previous testing data; the offshore corrosion investigation was performed for single and double wrapped samples. Epoxy resin was subjected to testing along with the optimized MBC bonder and the 48 test specimens were placed underwater for a period of 6 months and 1 year under natural conditions. The marine environment constituted of periodic high and low tides apart from the seasonal effect. Further, algae were noticed on the surface of the samples making it hard to handle. With utmost precaution, the samples were compressive tested in order to study their properties as listed in Table 5. Though, it can be seen that epoxy overrules MBC bonders for a short span of marine corrosion with 10% increase in strength for control specimens, the fully failed samples seemingly behave similar. On the other hand, double wrap control specimens surprisingly increase their performance being underwater for both types of retrofit bonders. The only occasion when epoxy fails desperately is when the double wrapping loses its bonding capacity after 12 months of subjugation to sea water corrosion. It is understandable that cement and concrete will increase their strength due to ageing and the strength increase may be due to the same fact for control specimen testing.

**Table 5.** Bonding performance of FRP retrofits at low and high temperature levels

Retrofit type	Type of wrap	Initial damage level	Time period of sample under marine condition	Compressive strength (MPa)	
				Epoxy	MBC
	Single	Nil	6 months	77.47	69.18
	Single	100%	6 months	70.53	67.03
	Double	Nil	6 months	102.00	86.34
CFRP	Double	100%	6 months	82.06	78.56
	Single	Nil	12 months	75.54	66.04
	Single	100%	12 months	70.04	60.39
	Double	Nil	12 months	89.35	84.95
	Double	100%	12 months	46.22	72.52

### 5. Conclusive Remarks

Based on the literature study and the experimental results, a thorough analysis was undertaken and the following inferences can be drawn:

Both carbon and aramid fibre retrofits had a direct effect on withholding the bond resistance in correspondence to damage induced when compared to lower bonding efficiency of glass fibre. This states that the mineral based bonders tend to improvise their performance in direct proportion to the degree of damage.

It was re-established that CFRP retrofit performance is much better compared to other FRPs due to its excellent material properties. Even though the initial cost of installation material would be higher than glass or aramid fibre, the longevity and bonding potency would compensate for it.

Initial testing demonstrated 80% strength improvement in compression and more than 200% in tensile behaviour for full failure samples. Later the bonding admixture was refined by replacing 30% cement with fly ash and further 20% addition of metakaolin to the original mix ratio to obtain optimization. The peak is found to be when 30% of PPC is replaced with class F flyash and the graph then starts to descent. Since metakaolin is finer than that of cement and lesser in weight, further addition of metakaolin can negatively modify the adhesion of MBC admixture to a greater extent.

All these results were justified as MBC specimens maintained to perform remarkably well at elevated temperatures without significant loss of strength, in

contrast to that of epoxy. The common mode of failure observed for epoxy retrofitted sample was rupture and it was delamination in case of MBC. Moreover, all the cylindrical test specimens could accommodate for complete wrapping. But in practice, most of structural RC members only allows 3 wrapping faces and further investigation on this is recommended.

Also, the double wrap CFRP specimen placed in marine corrosive environment proved to be the most efficient in terms of around 30MPa strength increase for MBC retrofit over epoxy after 12 months' time. This can be subjected to future research prospects on durability of FRP bonders and retrofits on offshore structural rehabilitation.

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