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Durability of Concrete Beam Strengthened with Fibwrap ® System and Fiber Composite Laminate

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Abstract

Externally bonded fiber-resinforced polymer is a common solution for strengthening and rehabilitating the existing structures. However, the concerning also raised a bout the effect of different environment to the durability of FRP composite system and its bonding performance to concrete substrate. In this paper, the deterioration strength of concrete beam strengthened with glass fiber-reinforced polymer (CBF) and glass fiber-reinforced polymer composite laminate (FC) after being exposed with outdoor, under submersion and wet-dry cycle condition with water, sea-liked water and sodium sulfate solution with a duration of 1000h, 2000h, 3000h, 5000h and 10000h were observed. The microscope also used to examine the physical changes of the external and rupture surface of the FC specimens. The results showed that the wet-dry cycle and submersion in water were associated with swelling and cracking of epoxy resin on FC and could shift the failure mechanism of the bonding interface of FRP-concrete. Submersion in sea-liked water and Na_2SO_4 caused considerable degradation of concrete strength while the GFRP composite seems to protect the concrete substrate from these solubles diffusions. The initiation of the spalling of resin was observed on specimens exposed to these solution.However, the capacity strength of all specimens is still higher than the controlled specimen but decrease gradualy if compare with specimens at the initial exposure duration.

Keywords

Submersion, Wet-dry cycle, Concrete beam, GFRP, Exposure condition, Durability

Introduction

Externally bonded of fiber-reinforced polymer (FRP) as a composite method is increasingly being conducted to repair and strengthening the concrete structures in civil infrastructure application. Although FRP composite provided an effective method to strengthening the concrete structure, this system also shown degradation after being exposed to the aggressive environmental condition. Many research have been conducted to study on the durability of FRP composite and bonding behavior of FRP composite with the concrete structure under various simulated exposure condition and the result shown greatly different between each experimental study due to the exposure mode and durtion. The relationships of exposure time and tensile strength of the FRP composite have been reported by the researchers (Silva et al., 2013, Dawood & Rizkalla, 2010). The result exhibited that the tensile strength of FRP composite could be increase strength after short term exposure due to the post-curing of the epoxy resins. However, the tensile strength of the long-term exposure above the threshold value exhibited a decreased in strength of the FRP composite which cause by attributed to the damage to the fiber-matrix interface.

In case of FRP-concrete externally bonded system, FRP, adhesive and FRP-concrete interfacial are the important components. Many study have been performed to investigate the longterm behavior of FRP in various environmental. Benzarti et al., (2011); Maljaee et al., (2016) reported that moisture has a slight effect on the compressive strength of the concrete. Regarding the FRP composite, moisture has a degradation effect on the matrix that connects the fibers with each other in the laminate and also has a damaging effect on glass reinforce too. Regarding to these finding, some researchers like Sethi and Ray, (2015) believe that moisture conditions could lead more deteriorate on matrix dominated properties, such as interlinear shear. For the effect of moisture to adhesive matrix, moisture diffuse into the polymers result to change the mechanical, chemical and thermophysical. In addition, Fonseca et al., (2018) reported that moisture can cause plasticization, swelling, hydrolysis and cracking that vanish after drying which lead to substantial loss of the fracture toughness of the interface.The effect of FRP-to-concrete interface under marine environment is a synergistic action, which may be caused the degradation of fibers, polymeric resin matrix, adhesive epoxy resin and concrete interfacial. Li et al., (2021) conducted a critical review on the effect of aging in seawater on performance of GFRP/BFRP composite and they concluded that the result of quasi-static tensile strength and dynamic tensile performance of the GFRP composite decrease with immersion time and the degradation rate accelerated at due to the high temperature exposure. The immersion in seawater cause a significantly affected due to the debonding along the fiber-resin matrix interface due to difference in moisture expansion rate and plasticization effect in the resin matrix. An other study of Zhou et al., (2015) reported that, after 150 days of dry-wet cycling with high temperature as 40 °C in sulfate solution, the bond capacities of the CFRP-concrete and GFRP-concrete bond interfaces decreased gradually by 14% and 14.5%, respectively. Consequently, the mechanical performance of the adhesive was slightly reduced while the compressive strength of concrete decreased sharply after sulfate corrosion. In addition, GFRP composite laminate were exposed to dry-wet cycling of sulfates in order to study its tensile strength. After 120 and 150 days of exposure, the tensile strength of GFRP changed relatively significantly and decreased by 2.5% and 6.6%, respectively. They also found that dry-wet cycling of sulfate solutions can hardly affect the elasticity modulus of both CFRP and GFRP.The effect of outdoor exposure test is an important way to understand the durability of the constituent materials. Nishizaki and Kato, (2011), a CFRP sheets were exposed to a natural environment for a period of 14 years, varying types of primer, putty, adhesive, and FRPs among the samples. Generally, a loss in strength is observed and failure planes lie within the concrete layer, with the authors indicating a selection of very durable adhesives. However, contributing to these failure modes would also be the use of low-grade concrete; this cannot be confirmed as concrete compressive strength have not been reported.

Methodology

Material properties and specimen preparation

A compressive strength of 20 MPa in cylinder of concrete was use to cast the concrete beam by casting in the mould with dimension 10cm width, 20cm depth and 120cm length and then strengthened by externally bonded GFRP at the tension face of concrete beam. The GFRP sheet was also cut in to dimension 1.5cm width and 35cm length to fabricate the GFRP composite laminate specimens.

A unidirectional glass fabric, Tyfo® SHE-25A, and the epoxy matrix with two components A and B, Tyfo® S, were use for FRP strengthening system and the material properties were dicribed in Tab. 1 and Tab. 2 respectively.

Table 1. Composite gross laminate properties (Fyfe Co. LLC, 2005)

Properties	Test Value	Design Value
Tensile strength at 0°	521 MPa	417 MPa
Tensile modulus	26.1 GPa	20.9 GPa
Elongation at break	2.0 %	1.76 %
Laminate thickness	0.50 mm	0.50 mm

Table 2. Properties of Tyfo® S Epoxy (AEGION, 2015)

Properties	Test Value
Tensile strength	72.4 MPa

Tensile modulus	3.18 GPa
Elongation at break	5.0 %
Flexural strength	123.4 MPa
Flexural modulus	3.12 GPa

Exposure condition

The concrete beam specimens and fiber composite laminate specimens were exposed to different environment such as water, sea liked water and sodium sulfate solution with duration 1000h, 2000h, 3000h, 5000h and 10000h. The chemical composition for preparing the solution were based on ASTM D1141-98 (2003) and ASTM C1010-04 to prepared the sea-liked water solution and solution of sodium sulfate (Na_2SO_4), respectively. For the wet-dry cyclic exposure, the specimens were wet 12 hours and dry 12 hours. The unconditioned specimens, strengthened concrete beam (CBF) and GFRP composite laminate (FC) were also prepared. Symbols were also used to represent the identification of other specimen is shown in Tab. 3.

Table 3. Symbol of Specimens

Environmental Exposure	Wet-dry Cycle	Submersion	Outdoor
CBF exposed oudoor	-	-	BA
CBF exposed to water	CBE	SBE	-
CBF exposed to sea-liked water solutionn	CBM	SBM	-
CBF exposed to sodium sulfate solution	CBS	SBS	-
FC exposed oudoor	-	-	FA
FC exposed to water	CFE	SFE	-
FC exposed to sea-liked water solution	CFM	SFM	-
FC exposed to sodium sulfate solution	CFS	SFS	-

Specimens testing set-up

After the proposed exposure duration was reached, the specimens were then taken to conduct the corresponding test , by the three-points bending test and uniaxial tensile test were utilized to test on the ultimate load carrying capacity of CBF specimens and on tensile strength of fiber composite laminate laminate specimens, respectively, as shown in Fig. 1. Moreover, before and after the tensile test, the microscope image also conduct to capture any visible sign of degradation on the external surface and rupture surface of GFRP composite laminate .

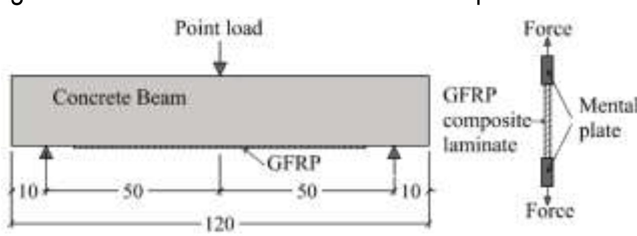


Figure 1. Specimen testing set up (dimension in centimeters)

Results and Discussion

Concrete beam strengthened with glass fiber-reinforced polymer

The load carrying capacity of unconditioned specimens is used to compare with the conditioned spacimens. The testing results was used to study the behavior of CBF after being exposed to different environmental conditions. The intermediate crack induce interfacial debonding was observed for all concree beam specimen and the debonding fracture planes after debonding failure of specimen were observed after the test as showed in Fig 2.

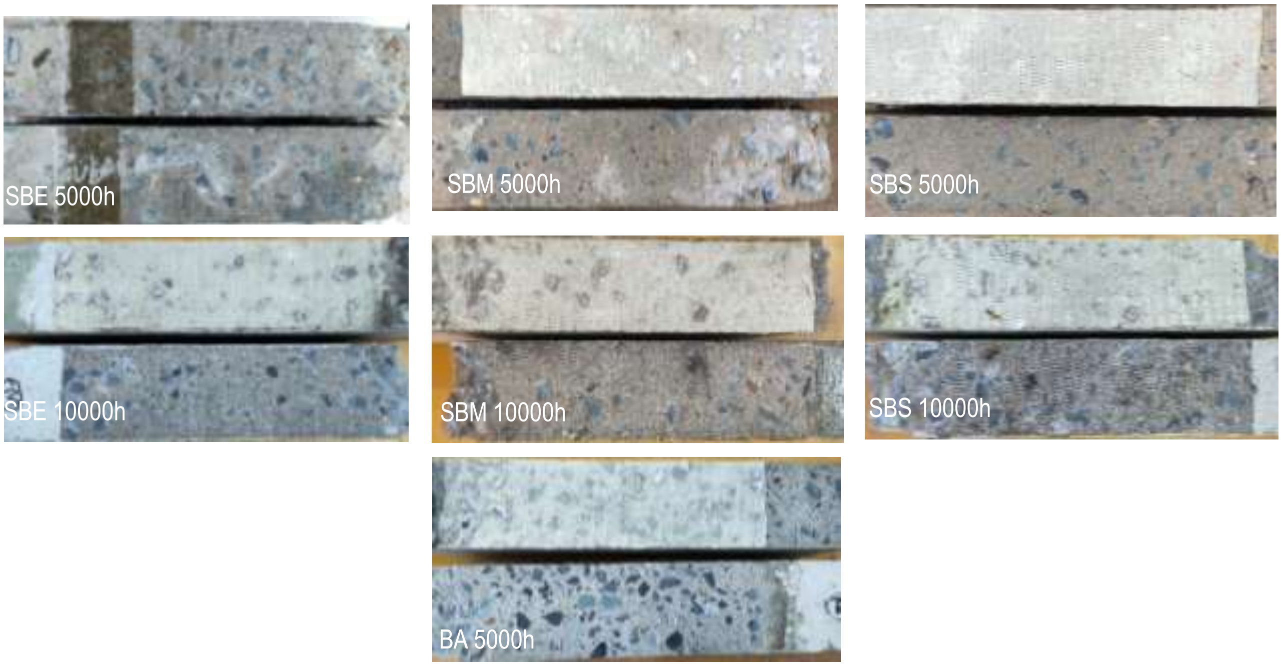


Figure 2. Fracture planes of concrete beam strengthened with glass fiber-reinforced polymer

The main observation are showed bellow:

- At a duration of 1000 hours, the concrete beam specimens exhibited an increase in failure load due to the post-curing of epoxy resin which could improve the bonding interfacial of FRP-concrete.
- At the duration of 5000 hours and 10000 hours, the failure load of the strengthened concrete beam was still higher than the controlled specimen, though the concrete strength has been degraded and lower than the controlled value. The FRP composite seems to protect the concrete substrate from outside environmental exposure by preventing the solution diffusion to the concrete due to the good bond between concrete and resin.
- Moist could shift the failure mechanism from concrete substrate failure to dual-interface failure which is the combination of FRP-resin failure and concrete substrate failure. The shifting of failure mechanism mode is caused by the effect of plasticization, swelling and cracking of epoxy resin due to the moist diffusion.
- Submerged in sodium sulfate solution is the most negative effect on concrete strength rather than FRP composite. This solution could significantly decrease the compressive strength of the concrete and degrade the bonding interfacial of FRP-concrete.

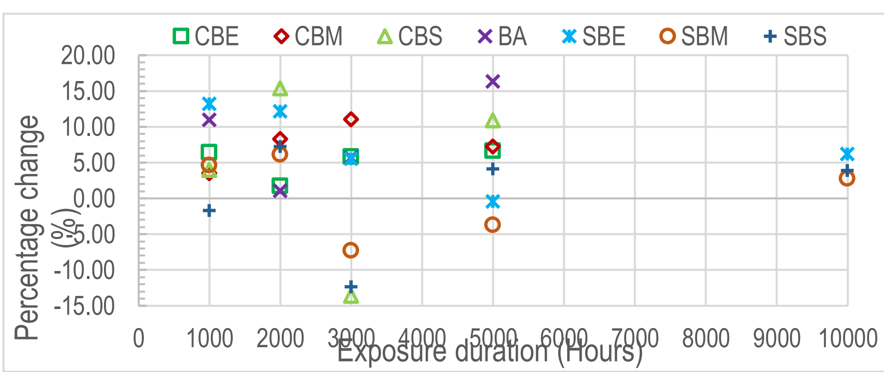


Figure 3. Percentage change of load-carrying capacity of strengthened concrete beam comparred to contolled specimen

Glass fiber composite laminate

The glass fiber composite laminate were used to study on its tensile strength after being exposed to different environmental conditions. The tensile strengghte of unconditioned specimen was used to compare with the conditioned specimen as shown in fig.5. The gauge length rupture failure at different location were observed on all of specimens and the microscope image of the external and ructure surface of the specimens are shown in Fig. 4.

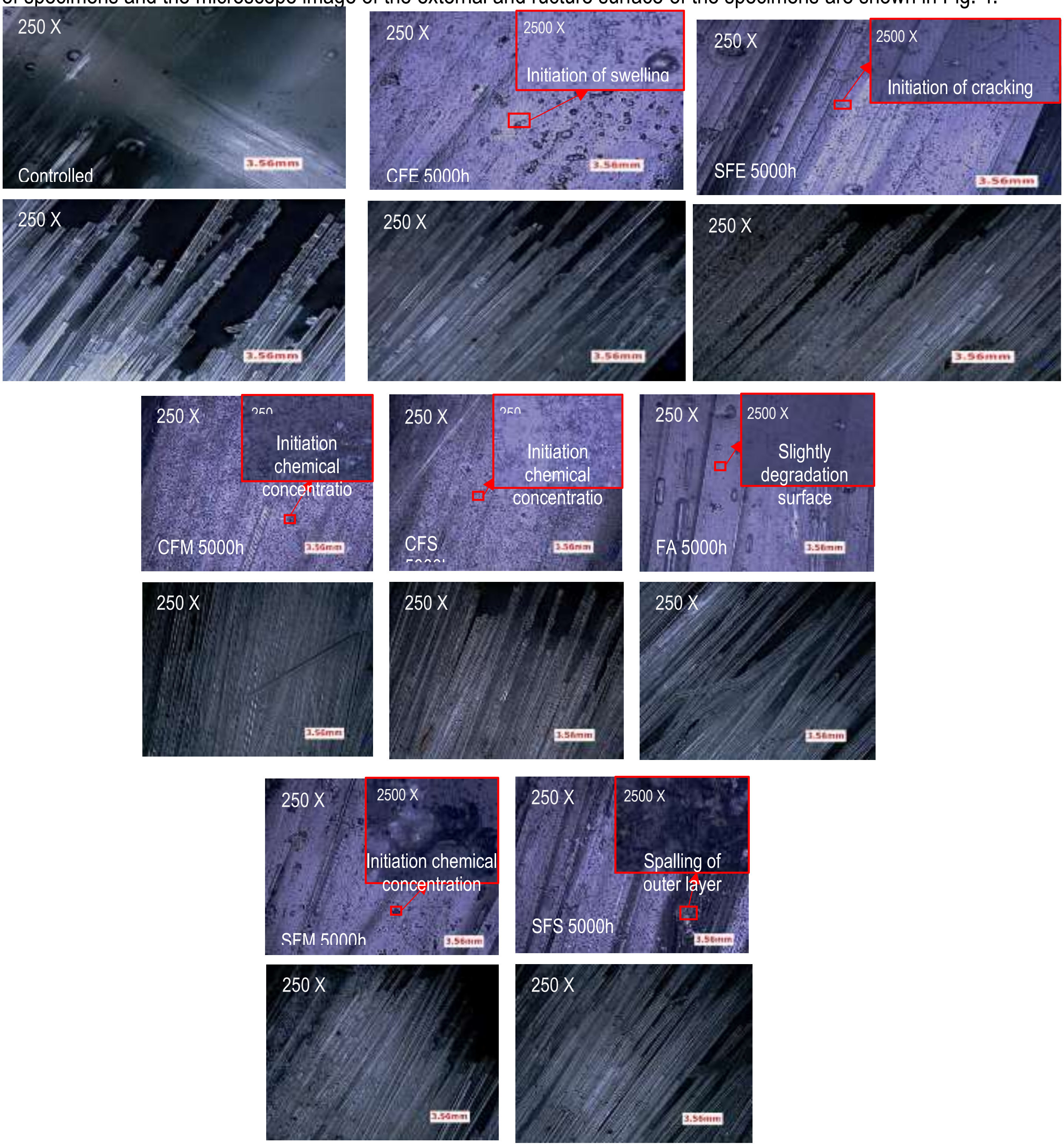
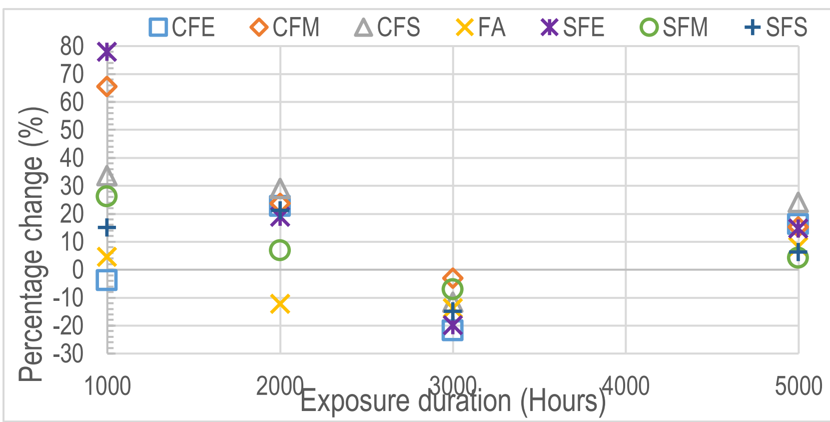


Figure 4. The microscope imate of external surface and rupture surfae of glass fiber composite laminate

The main observation after testing showed as bellow:

- The GFRP composite laminate still improve the tensile at a duration of 1000 hours and started to decrease at duration up to 2000 hours. This could be the result of the post-curing of epoxy resin. The post-curing process has maximized the physical and mechanical properties of the resin.
- The percentage change of GFRP composite laminate exposed to different environmental conditions at a duration of 5000 hours was still higher than the control specimen about 4.32% to 24.12% but the specimens exhibited a slight decrease in tensile strength if compare to the exposed specimens at duration of 1000 hours and 2000 hours. This could be the effect of environmental exposure conditions at a duration of 5000 hours not yet reached the threshold value of duration which could lower the tensile strength of GFRP composite laminate. However, the microscope images showed a surface degradation of the GFRP composite specimen after being exposed to different environmental conditions.
- At a duration of 5000 hours, the GFRP specimen exposed to water under wet-dry cycle and submersion conditions showed a visible swelling and cracking of the resin, respectively. Moreover, the chemical concentration of the NaCl and Na_2SO_4 could cause spalling to the outer layer of the resin on GFRP composite laminate.
- The outdoor environment of the tropical season seems to have no negative effect on the GFRP composite laminate at the exposure duration of 5000 hours. The dropped in tensile strength at a duration of 2000 hours and 3000 hours could not explain since at a duration of 5000 hours, the specimen showed an increase in tensile strength. The microscope image also showed only a slight degradation on the external surface of the



specimen. The longer exposure duration will need to explain for this condition.

Figure 5. Percentage change of tensile strength of glass fiber composite laminate comparred to contolled specimen

Conclusions

In conclusion, at a duration of 1000 hours, the strengthening system exhibited increase in strength capacity due to the effect of post curing of resin and at duration of 5000 hours and 10000 hours, only a slight decrease in strength capacity were observed. Sea-liked water and sodium surfate solution could cause considerable deterioration of the bonding interface between the GFRP composite plate and concrete due to the deterioration strength of concrete and a visible spalling of the external surface of resin on the GFRP composite laminate. Moist could shift the failure mechanism of the strengthening system from concrete substrate failure to mixed of FRP-resin failure and concrete substrate failure. The visible initiation of cracking and swelling of resin was observed by microscope image which was caused by moist diffusion.

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