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MECHANICAL PROPERTIES OF REINFORCED CONCRETE BEAM AND COLUMN STRENGTHENED BY FIBRWRAP ®SYSTEM AFTER BEING SUBMERGED TO DIFFERENT EXPOSURE SOLUTIONS

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Abstract: *Fiber Reinforced Polymer (FRP) external bonding system is a popular technique that is used to strengthen and repair existing structural elements due to its high strength to weight ratio, fatigue resistance, non-corrosiveness and ease of handling and application at the site. In this research, the focus is on the behavior of FRP external bonding system use to strengthen Reinforced Concrete (RC) beam and column when subjected to be exposed to out-door climate, submersion in tap water, sea-liked water and high concentration of sodium sulfate (Na_2SO_4) solution. This area of work has not yet fully explored in Cambodia. This research project is attempting to fulfill that gap. The scope of work for this research divided into 3 categories such as RC beam-column specimen strengthened externally by one layer of Glass Fiber Reinforced Polymer (GFRP) sheet that expose into different exposures with duration of 1000, 2000, and 3000 hours. The GFRP in the form of sheet roll was used as material to strengthen on tension face of RC beam in order to improve the flexural strength and wrapped around RC column in order to increase the compressive strength. The result, FRP external bonding system maintained its capacity after exposure to aggressive degradation agents in the scope of 1000 and 2000 hours. However, after being submerged for 3000 hours in tap water, strengthened RC column specimens started to decrease the ultimate load due to degradation on GFRP sheet. The most aggressive exposure condition was tap water during this scope period of work.*

Keywords: GFRP, Durability, Degradation, FRP system, Submersion

1. INTRODUCTION

In the past decade, the popularity of the external bonding of Fiber Reinforced Polymer (FRP) to Reinforced Concrete (RC) structures has increased. There has been much research attention on this strengthening technique (Miguel, 2015). FRP external bonded system was used by civil engineer in order to stabilize both historical and new buildings as well as to cope with the problem such as changing function of the buildings and renovation without demolition. It was developed and started its practical applications in the 1980s (Sathishkumar, 2014). The benefits of FRP external bonded system are ease of installation, minimal labor costs, lightweight, and effective durability. FRP is the material with good mechanical performance, resistance to corrosion and lightweight. Its application has become globally recognized because of its effectiveness (Alberto, 2013). Shokrieh et al. (2016) conducted an experiment on E-glass fiber exposed to sulfuric acid environment. In this research, the investigation of strength behavior and crack-formation mechanism of E-glass fiber exposed to sulfuric acid environment was examined by quantitative X-ray fluorescence method. The result illustrated the deterioration of E-glass fiber occurred by the removal of Al, Ca, and Fe ions from the fibers. It was observed that by increasing the immersion time in acid, the shrinkage of E-glass fiber

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surface caused axial cracks in fibers. Bavarian et al, 1996, reported on the effects of elevated temperatures on the S-glass embedded in polyester resin and Kevlar-29 embedded in epoxy resin. These repairs were applied to standard concrete cylinders and exposed to elevated temperatures of 49ºC and salt fog application for a period of 28 days. The result, there was no significant loss of strengthening capability. Soudki and Green, 1996, tested 42 circular concrete columns (152 x 305 mm), 28 columns were wrapped with carbon fiber reinforced polymer (CFRP) sheets in either one or two layers. Carbon sheets were applied to the concrete columns, impregnated with epoxy, and allowed to cure for one week at room temperature before testing. Six columns were submerged under water for 200 days, six columns were kept at a temperature of -18ºC for 200 days, 15 columns were kept at a temperature of 20ºC for 200 days, and 15 columns were subjected to 200 freeze/thaw cycles. The result showed that carbon wraps provided more strength, stiffness, and ductility than for control columns subjected to the same environment. Bavarian et al, 1996, investigated the effect of salt spray exposure on the durability of concrete cylinders wrapped with two in wide S-glass and Kevlar fiber tape. The glass strips were applied with polyester resin and the Kevlar strips were applied with epoxy resin. The result, compression tests on the conditioned cylinders did not show damage or loss of strength. Lixin Wu et al, 2003, conducted a research on the effects of water on the curing and properties of epoxy adhesive used for bonding FRP composite sheet to concrete. The result was epoxy adhesives cured in the presence of water are significantly different from neat epoxy adhesives in terms of curing reaction, mechanical properties, and durability. A small amount of water (2%) accelerates the curing rate, increases the degree of cure, flexural modulus, and bonding strength, while it decreases water uptake and rate of degradation of the flexural modulus.

The objective of this research is to study the mechanical properties of FRP external bonding system that used one layer of GFRP sheet to strengthen the structural elements such as RC beam and column. The RC beam and column specimens were subjected to be exposed to outdoor climate and to be submerged in different exposure solutions include submersion in tap water, high concentration of sodium sulfate (Na_2SO_4) solution and sea-liked water in the scope of 1000 hours, 2000 hours, and 3000 hours in terms of flexural and compressive strength respectively.

2. EXPERIMENTAL PROCEDURE

2.1 Specimens and Materials Properties

For RC beam, the steel longitudinal reinforcement was 4DB12 and RB6.5 was used as 50mm spacing for stirrup. For RC column had steel longitudinal reinforcement of 4DB10 and RB6.5 was used as stirrup with 200mm spacing. The dimension of concrete beam was 1200 mm length, 100 mm width and 200 mm depth as shown in Fig.1. For dimension of column was 600 mm height and square section (100x100 mm) as shown in Fig.2. The concrete mix design that used was to cast concrete beam and column for the design compressive strength of cylinder 20 MPa as shown in Table 1.

The FRP material used in this experimental study was glass fiber unidirectional (Tyfo® SHE-25A). One-way GFRP is considered as one of the most economical for reinforcement among other unidirectional FRP materials, beneficially by its higher modulus of traction and tensile strength. The main features of this GFRP are described in the Table 2.

The Tyfo® S Epoxy as shown in Table.3 was used to bond interface between concrete surface and GFRP. The epoxy was prepared by mixing between A-component and B-component epoxy until uniformly blended. The mixing ratio of epoxy is 100 component A to 42 component B by volume or 100 component A to 34.5 component B by weight.

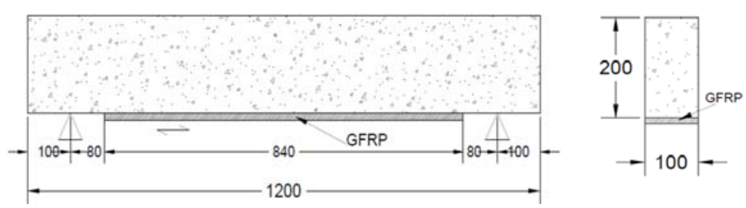

Fig.1. Dimension of RC beam specimens

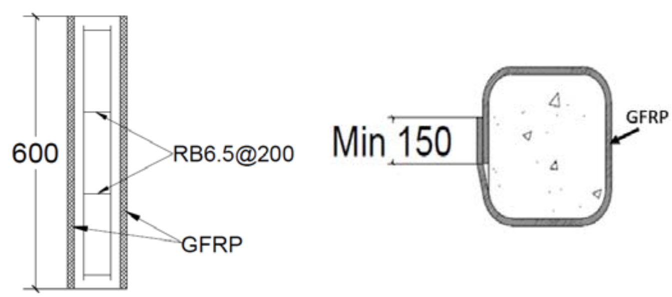

Fig.2. Dimension of RC column specimens

Table 1. Concrete mix design

Property	Concrete mix
Gravel (kg/m^3)	1050
Sand (kg/m^3)	832
Cement (kg/m^3)	274
Water (kg/m^3)	190

Table 2. Properties of Tyfo® SHE-25A fabric

Property	Tyfo® SHE-25A
Ultimate tensile strength (MPA)	417
Tensile modulus (GPa)	20.9
Thickness (mm)	0.5
Elongation at break (%)	1.76

Table 3. Properties of Tyfo® S Epoxy

Property	Tyfo® S Epoxy
Tensile strength (MPA)	72.4
Tensile modulus (GPa)	3.18
Flexural strength (MPa)	123.4
Flexural modulus (GPa)	3.12
Elongation at break (%)	5

2.2 Exposure Condition

There were two types of controlled samples such as unstrengthen and strengthened sample. First, three controlled RC beams and three controlled RC columns were casted and cured for 28 days before testing. Second, 28 days cured RC beams and RC columns were strengthened by one layer of GFRP sheet and were left for 5 days until epoxy dried and hardened before testing. Furthermore, there were four typical exposure conditions on specimen strengthened by one layer of GFRP sheet such as exposed to outdoor climate, submerged in sea-liked water, in sodium sulfate solution (Na_2SO_4) solution, and in tap water with different durations of 1000, 2000, and 3000 hours. Each type of exposure test was prepared by three specimens and the specimens were left for 5 days until epoxy dried and hardened before each exposure. Symbols were used to represent the identification of specimens as shown in Table 4. For outdoor climate exposure, the specimens were placed outside the room. For the submersion condition, the specimens were immersed into tap water, sea-liked water and sodium sulfate solution with chemical composition as shown in Table 5. Each type of solution was accompany by three concrete cubes (15x15x15cm) in order to determine the effect agents.

Table 4. List of symbols' specimens

Property	Symbols
Controlled Specimens	C.
Controlled Specimens with FRP	C.FRP
Beam	B
Column	C
Exposed to climate	A
Submerged under Sea-like water solution	SN
Submerged under Na_2SO_4 Solution	SS
Submerged under Tap water	SW

Table 5. The chemical composition for salt solution

Constituent	Sea-liked water	Sodium sulfate solution
NaCl (g/L)	24.53	-
Na_2SO_4 (g/L)	4.09	50

2.3 Testing Specimens

The specimens were tested in laboratory of civil engineering at Institute of Technology of Cambodia (ITC) after each exposure condition was completed. The three-load point flexural test was used to test the flexural capacity of strengthened beam as shown in Fig.3. For column, specimens were tested their compressive strength by manually operated compressive machine and were recorded as shown in Fig.4.

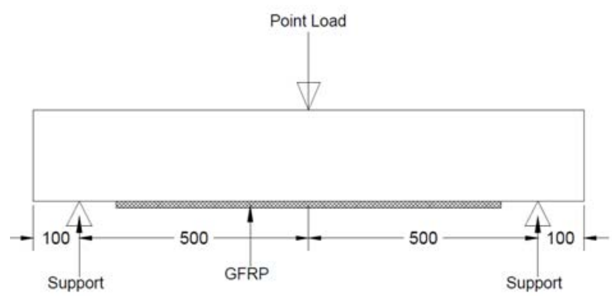

Fig.3. Three point flexural test of RC beams specimens

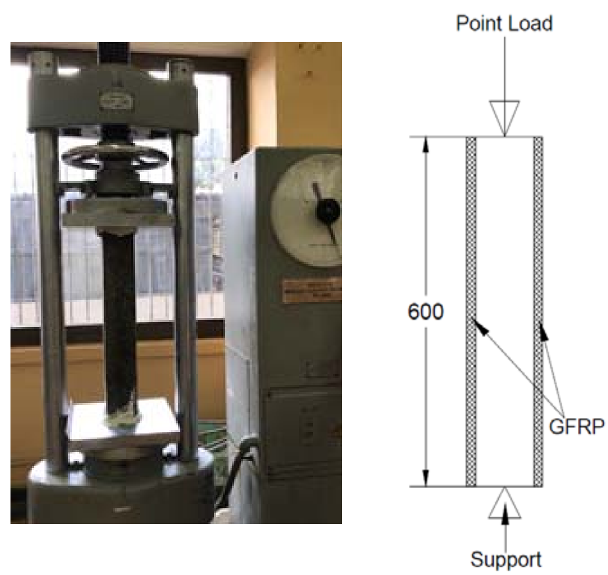

Fig.4. Compressive test of RC column specimens

3. RESULTS AND DISCUSSION

In this section, the experimental result of specimens such as RC column and beam is presented and discussed.

3.1 Column specimens result

Column specimens were taken out and left to dry for at least 2 days before compressive test by machine in order to eliminate the issue that could cause by moisture content. During the period of 1000 hours as shown in Fig.5, the bar charts illustrated that all the categories have higher compressive strength compare with the unstrengthen controlled samples and have lower compressive strength than controlled samples strengthened by GFRP sheet. The specimens exposed to climate has the highest compressive strength stood at 311 kN. During the period of 2000 hours, the specimens exposed to climate and to solution Na_2SO4 have the higher compressive strength, stood at 326.33 kN and 315.83 kN respectively. The specimen submerged in sea-liked water was the lowest that stood at 290.83 kN in this period. During the period of 3000, the specimens submerged in tap water has the lowest compression strength, stood at 297 kN.

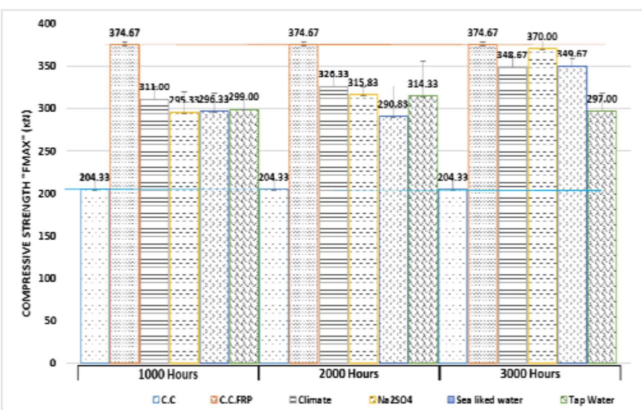

Fig.5. Compressive strength bar chart column specimens

The result from the compression machine for column indicated that:

- The externally bonded with GFRP sheet on the surface of unexposed column could increase 83 % of ultimate load compare with the unstrengthen column as shown in Fig.6.
- Column strengthened by GFRP had failure by compression at top and bottom as shown in Fig.7.
- FRP external bonded system strength continued to increase during the scope of work. All ultimate force of exposed column specimens increased to 44%-81% compared with unexposed column.
- According to the overall trend indicated that apart from tap water specimen during 3000 hours period the entire specimen was increasing throughout the period of 1000, 2000, and 3000 hours. The entire specimen had the compressive strength higher than that of controlled RC specimen without strengthening with GFRP sheet.
- For tap water, GFRP sheet could start to degrade during 3000 hours of exposure. This could be caused by water being the most penetrable degradation agent compare to other solutions. The viscosity of water is lesser than that of Na_2SO_4 and sea-liked water (these solutions have more salinity). Thus, during the scope of 1000, 2000, 3000 hours, tap water could penetrate GFRP sheet more easily and in high amount of moisture content compare to other solutions. (According to (CEB, 2001) of experimentation indicate that moisture present in FRP external bonded system could decrease its strength capacity). Thus, the FRP external bonded system could be degraded by tap water more than other solution during this scope of 1000, 2000, and 3000 hours.

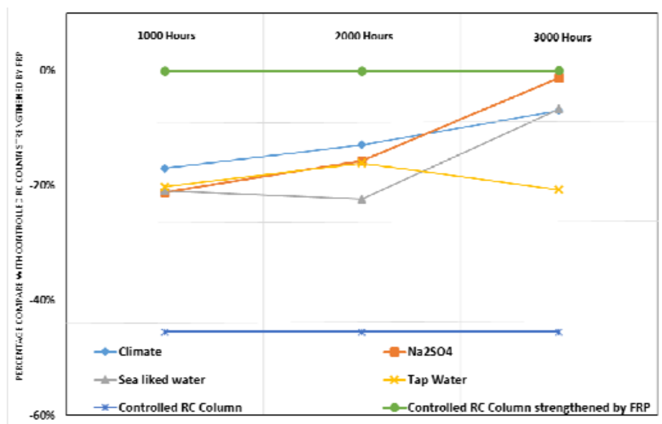

Fig.6. Line graph of column specimens under compression compare with controlled specimen strengthened by GFRP

Fig.7. Failure by compression at top and bottom

3.2 Beam specimens result

Beam specimens were taken out and left to dry for at least 5 days before flexural test by machine in order to eliminate the issue that could be caused by moisture content. In all 3 periods as shown in Fig.8, the bar charts illustrated that all the categories have higher flexural strength compare with the unstrengthen controlled samples. During the period of 1000 hours, the specimens submerged in sea-liked water, had the highest flexural strength and stood at 91.53 kN. During the period of 2000 hours, the specimens exposed to climate and to solution Na_2SO_4 have the higher flexural strength and stood at 94.68 kN and 94.49 kN respectively while specimens exposed to sea-liked water had the lowest flexural strength at 81.63 kN. During the period of 3000 hours, the specimens exposed to climate has the highest flexural strength 96.26 kN.

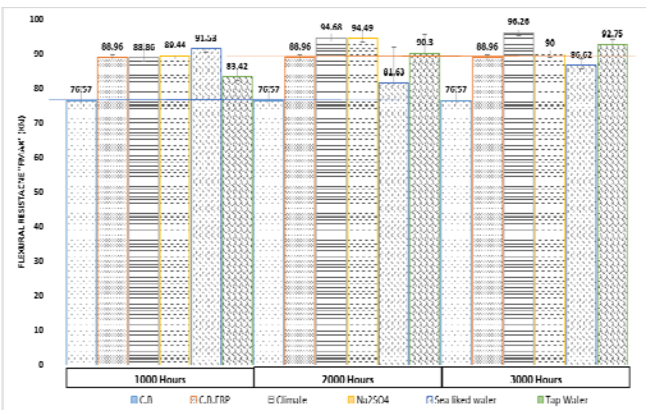

Fig.8. Flexural strength bar chart of 1000 hours beam specimens

The result from the machine indicated that:

- The externally bonded system with GFRP sheet on the tension surface of unexposed beam could increase 16 % of ultimate load compare with the unstrengthen beam as shown in Fig.9.
- Beam strengthened by GFRP sheet had failure by concrete cover separation as shown in Fig.10.
- FRP system strength continued to increase during the scope of work. All ultimate load of exposed column specimens increased to 6%-25% compared with unexposed beam.
- The specimen submerged under sea-liked water decrease its capacity by 8 % during the 2000 hours exposure while specimen exposed to climate stood at 6% and 8% during 2000 and 3000 hours. The specimen exposed to climate has the highest capacity than all of the submersion categories and specimen submerged under sea-liked water has the lowest capacity as shown in Fig.9.
- However, according to the overall trend, FRP external bonded system strengthened beam by 16% while FRP external bonded system strengthened column by 83%. The increase in strength of column specimens is 5 times stronger than the increase in strength of beam specimens. This could indicate that: even if GFRP sheet degraded during 3000 hours of exposure had no significant effect on the overall trend of the flexural strength. Because the variation in percentage was just around ±8% which is relatively small to be noticed.

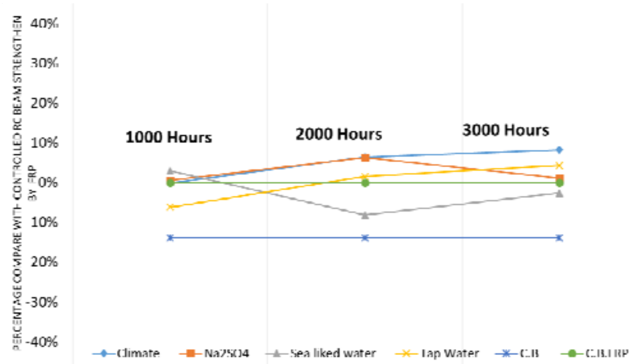

Fig.9. Line graph of beam specimens under flexural

Fig.10. Rupture along direction of GFRP of strengthened beam in the mode of cover separation

4. CONCLUSIONS

In conclusion, after the testing of the RC element strengthened by FRP subjected to submerged under different solutions, the objectives of the project were obtained:

(i). For column, GFRP sheet in tap water could start to degrade during 3000 hours of exposure. This could be caused by water being the most penetrable degradation agent compare to other solutions. The viscosity of water is lesser than that of Na_2SO_4 and sea-liked water (these solutions have higher salinity). Thus, during the period of 1000, 2000, and 3000 hours, tap water could penetrate GFRP sheet more easily and in high amount of moisture content compare to other solutions. (According to CEB, 2001 indicated that moisture present in FRP external bonded system could decrease its strength capacity).

(ii). For beam, even if GFRP sheet degraded during 3000 hours of exposure, it had no significant effect on the overall trend of the flexural strength. Because the variation in percentage is around ±8% which is relatively small to be noticed.

(iii). For FRP external bonding system, GFRP sheet remained strengthening RC beam under flexural condition and RC column under compressive condition even after exposed into different solutions during the scope of 1000, 2000, and 3000 hours.

In the future, comparison between other type of FRP materials such as Carbon or Aramid is crucial for the better understanding of this composite material in order for the economics of the usage and effectiveness. There are still a lot of things for the next generation of student to find concerning the FRP external bonding system. A further study of these material mechanical properties is necessary for the future of the advancement of Cambodian's infrastructure.

- The period of experiment should be increased to longer period of exposure.
- X-ray or microscope should examine the study of material's microstructure such as GFRP in order to identify the degradation of GFRP in detail.
- The concrete must be monitored its compressive strength, as well the speed control of the testing machine while applying load on the specimen during testing of the specimens.

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