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PERFORMANCE OF CARBON FIBRE REINFORCED POLYMER-CONCRETE BONDING SYSTEM IN TROPICAL CLIMATE

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Abstract**—** Many infrastructures such as buildings, bridges, dams, highways and others were constructed and built using reinforced concrete. However, upon exposure to aggressive environments the structures will be deteriorated and with the changes to the function of the structure, a repair and even strengthening process is required to ensure the serviceability of the structures. In this respect, Carbon Fibre Reinforced Polymer (CFRP) concrete bonding system is seen to be one of the effective alternatives for the strengthening process. This paper briefly looks into the performance of CFRP-concrete bonding system exposed to laboratory, plain water, saltwater and outdoor or tropical climate conditions for the duration up to 6 months. A number of samples of CFRP plate for tensile strength test and CFRP plate bonded to concrete prism were prepared, exposed and tested under compression-tension to determine the bonding performance of the system. The results of the tensile test indicated that exposure to salt water to some extent decreased the tensile strength of the CFRP plate indicating the effect of moisture. Furthermore, the ultimate load of the bonded CFRP-concrete prism was also found to be slightly affected by the exposure in which the ultimate load was less than the control sample in the range of 2 to 8 % upon exposure to various conditions. The failure shows that the bonding between CFRP plate and concrete was relatively very good.

Keywords: *Carbon Fibre Reinforced Polymer, strengthening, bonding, outdoor, tropical climate, strength*

1.0 INTRODUCTION

Nowadays, Carbon Fibre Reinforced Polymer (CFRP) composites have started to be used in civil engineering application such as in enhancing or upgrading the existing reinforced concrete structures by external plate-bonded system. The CFRP composites are considered to be suitable and more durable than steel in such applications due to the resistance in most aggressive environments such as polluted industrial area and near seawater. In addition, some of the advantages of using CFRP compared to the existing conventional technique of using steel plates are that the CFRP is lighter than steel and also immune to atmospheric and to electrochemical corrosion [1]. This will reduce the use of heavy machinery during application.

It is also known that various Fibre Reinforced Polymer (FRP) composites system is sensitive to moisture absorption, swelling and dissolution which will have a serious implication on its long-term mechanical properties. Thus, durability is an important factor that will affect the long-term sustainable service life of structural system having FRP-concrete relation [2]. However, the use of CFRP-Concrete bonding system requires understanding among others on two main issues, namely, the durability of the FRP material itself and the durability or performance of bonding between the FRP material and concrete substrate that can limit the strengthening performance of FRP materials [3-5].

The FRP plate-concrete bonding system is relatively new in the construction industry compared to steel for similar application. Therefore, there are still many areas of material and structural implications arising from the use of FRP composite bonded system that need further research especially in the area of its long-term durability performances under tropical environment. Furthermore, most of the durability studies and findings were conducted in Japan, Europe, Canada and the United States of America, which cannot directly be translated to tropical climates due to various dissimilar climatic patterns. At present, the experimental data on the CFRP-concrete bonding system exposed to tropical climate is very limited. A study conducted on strengthening of reinforced concrete beam exposed to tropical climates surprisingly revealed that the strengthened beam exposed to outdoor had higher stiffness compared to the control beam [6]. Other study also indicated the potential applicability of the CFRP-concrete bonded system in tropical countries [7].

The epoxy synthetic based adhesive systems that have been developed by various manufacturers have shown excellent mechanical and physical properties when being applied to steel or concrete in most load tests conducted by most known researchers around the globe. Most of the researches focused on studying the short-term rather long-term performances. Thus, the increasing use of structural adhesive in strengthening or upgrading the reinforced concrete, steel or wood structures needs to be well understood by engineers in account for the durability factors in their design works.

2.0 EXPERIMENTAL PROGRAMME

The experimental work carried out in the study include test on CFRP plate and CFRP-Concrete bonding system under tension-compression upon exposure to various conditions. A number of samples were prepared, exposed and tested. The samples were exposed to laboratory environment (LB), outdoor (OD), plain water (PW), and salt water (SW) for the duration of six months. The main aim is to investigate the effect of different environments on the CFRP plate itself and the bonding performance between the CFRP plate and concrete prism.

2.1 Materials

Concrete – Concrete grade 45 was used throughout the study. The concrete mix was designed according to the DoE method with water-cement ratio of 0.47. Crushed granite with nominal size of 10 mm was used together with fine aggregate and Ordinary Portland cement as the binding material.

CFRP - The CFRP plate used was Selfix Carbofibre supplied by the Exchem company with the tensile strength and tensile modulus of 2800 MPa and 150 GPa, respectively. The overall cross-sections of the CFRP plate used in this study were 1.5 mm thick and 50 mm width.

Adhesive – The type of adhesive used to bond between the CFRP plate and concrete prism was Sikadur 30 supplied by Sika Kimia. The adhesive will act as the medium to transfer the load from concrete to the CFRP plate.

2.2 Preparation of samples and experiment

The overall sizes of the CFRP plate samples to be exposed to the designated environments were 1.5 x 15 x 250 mm. An end tabs using steel plate were provided on both ends of the CFRP plate for the gripping purposes during tensile test. This is to ensure that there will be no premature failure on the grip so that the failure will be along the gauge length of the sample. In this study, the samples were divided into two categories namely pre-stressed (P) and unstressed (U). The samples were pre-stressed to 50% of the ultimate load with the intention to create micro-cracks in the resin before exposure in order to study the effect of moisture on the CFRP plate itself. The main purpose of introducing micro-cracks is to allow moisture to penetrate into the CFRP sample.

The overall dimensions of the CFRP plate sample used to be bonded to the concrete prism were 1.5 x 50 x 555 mm. One end of the plate was provided with end tab. The end tab was made using steel plate and then drilled to create a hole for the load application during testing.

The concrete prism samples were cast and prepared in a mould with the dimensions of 100x100x300 mm. The concrete samples were well compacted and cured to ensure the required concrete compressive strength is achieved. After 14 days, the surface of the concrete to be bonded with the CFRP plate was roughened using Air Tool hammer in order to ensure perfect or good bonding between the CFRP plate and concrete as shown in Figure 1. The prepared samples of CFRP-concrete bonding system were divided into two categories similar to the CFRP plate, i.e. stressed (S) and unstressed (U). The samples of the CFRP-concrete prism were stressed up to 40% of the failure load and the load was maintained throughout the study. This was to investigate the effect of stress and moisture on the bonding performance of the CFRP-concrete samples. In the study the stress applied may cause micro-cracks on the adhesive that enable moisture to penetrate into the bonding system. Figure 2 shows the special test rig manufactured and used for the preparation of the CFRP-concrete prism to ensure the bonded CFRP plates were aligned properly. After exposure to the designated environmental conditions, the sample was tested under tension-compression as shown schematically in Figure 3. Figure 4 shows the actual test conducted on the bonded CFRP-concrete sample. This type of test arrangement will cause shear stress on the CFRP-adhesive-concrete system that will show the bonding capacity of the system..

Figure 1: The roughened surface of concrete prism

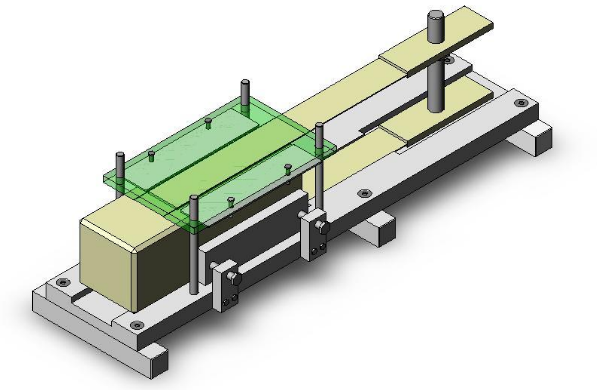

Figure 2: Test rig for the CFRP-concrete bonding

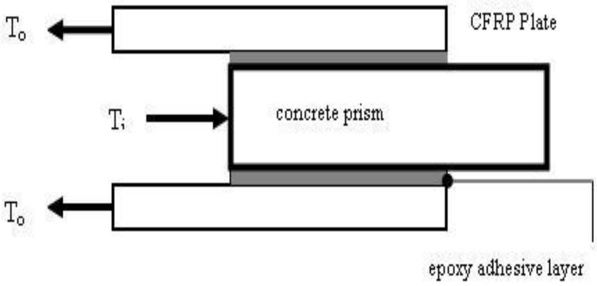

Figure 3: Schematic diagram of tension-compression test

Figure 4: Testing of CFRP-Concrete prism

3.0 RESULTS AND DISCUSSIONS

The following sections discuss the results gathered from the experiment. The evaluation of the experimental work was based on effect of different environments on the tensile strength of the CFRP plate, ultimate load of the CFRP-concrete bonding system, and mode of failure of the samples tested.

3.1 CFRP plate samples

The results of the tensile strength of the CFRP plate after exposure are shown in Table 1. It can be seen from the table that the pre-stressed samples was less affected by the different exposures compared with the un-stressed samples. The reduction on the tensile strength for the CFRP plate exposed to saltwater for the un-stress and pre-stressed samples were in the range of 1 to 15% and 0 to 11%, respectively. The highest strength reduction was for the un-stressed sample exposed to plain water which was around 14.3%. The results indicate that the effect of moisture was more pronounced on the un-stressed compared to the pre-stressed samples. Thus, pre-stressing the samples may not actually create the micro-cracks as initially expected probably due to load applied was less than the actual load that will cause micro-cracks.

Table 1: Tensile test results of exposed CRP plate

Sample	Failure Load (KN)	Difference (%)	Tensile strength (MPa)
Control	56	-	2489
CULB	55	1.8	2444
CUOD	54	3.6	2400
CUPW	48	14.3	2133
CUSW	51	9.8	2267
CPLB	56	0.0	2489
CPOD	56	0.0	2489
CPPW	52	7.1	2311
CPSW	50	10.7	2222

All the samples tested failed in an expected manner along the gauge length which was sudden, with loud cracking sound and broom type failure. The general mode of failure of the sample after tensile test is shown in Figure 5.

Figure 5: Mode of failure of the CFRP plate

2.2. CFRP-Concrete prism samples

The results of the tension-compression test on the CFRP-concrete prisms are shown in Table 2. The experimental results indicated that the un-stressed samples experienced higher load reduction compared to the stressed samples. The un-stressed sample exposed to outdoor (CCUOD) recorded 8.7% less ultimate strength than the control sample. Samples exposed to plain water (CCUPW) and salt water (CCUSW) recorded lower strength than control sample by only 1.8% and 1.5%, respectively. However, stressed sample exposed to salt water (CCSSW) was found to have lower strength than the un-stressed sample with the same exposure condition by about 1.3%. The variation and differences of result between samples might be due to the sample itself. However, the results show that moisture, to some extent, has an effect on the bonding performance of the CFRP-concrete bonding system.

Table 2: Results of CFRP-concrete prism test

Sample	Ultimate Load (KN)	Difference (%)
CCULB	61.7	-
CCUOD	56.3	8.7
CCUPW	60.6	1.8
CCUSW	60.8	1.5
CCSLB	61.2	-
CCSOD	59.7	2.5
CCSPW	61.2	0
CCSSW	59.5	2.8

The general mode of failure of the CFRP plate bonded to the concrete prism is shown in Figure 6. The failure shows that the bonding between the CFRP plate and concrete prism was very good. This can be seen from the figure that the failure was on the concrete surface not on the adhesive indicating a perfect bonding between the adhesive-CFRP plate and adhesive-concrete prism. One of the main critical factors that will affect the CFRP-concrete bonding system is the preparation of the concrete surface. The concrete surface has to be roughened, in this study roughening the surface using Air Tool hammer as discussed earlier, and free from loose particles to ensure good bonding between the adhesive and concrete. The result in this study indicated that the effect of moisture was more likely on the concrete rather than the bonding between adhesive and concrete or adhesive and CFRP plate as shown by the mode of failure.

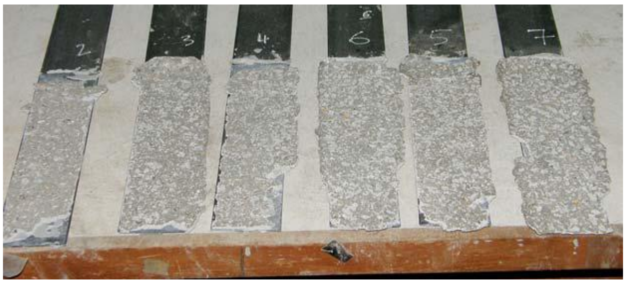

Figure 6: Mode of failure of the CFRP bonded to concrete

Figure 7 shows the cross section of the CFRP plate sample bonded to concrete after failure showing the interlocking mechanism between the adhesive (top part) and concrete (bottom part). It can be seen that roughening the concrete surface is very important since it will enhanced the bonding performance between the adhesive and concrete that will affect the whole performance of the CFRP-concrete bonding system.

Figure 7: Cross-section of adhesive-concrete bonding

4.0 CONCLUSIONS

The results of the study indicated that exposure to moisture, plain water and salt water, will have an effect on the tensile properties of the CFRP plate. Similar finding also can was recorded for the CFRP-concrete prism bonding performance. The outdoor or tropical climate exposure to some extent has an effect on the bonding performance of the CFRP-concrete prism. The failure of the samples revealed that the bonding between CFRP and concrete was very good as a result the failure of the bonding system occurred on the concrete.

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