PERFORMANCE OF EXTERNALLY BONDED REINFORCED CONCRETE STRUCTURES USING CARBON FIBER REINFORCED POLYMER IN TROPICAL CLIMATE

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Abstract

The emerging field of renewal engineering or sustainable infrastructure may best describe the role of FRP composite in civil engineering application. FRP itself is very durable due to its non-corrodible characteristics as compared to steel. Strengthening of existing concrete structures may be necessary in order to overcome the increase in loading capacity and also environmental effect. The main objective of the current research is to determine the structural behavior of concrete structures by using externally bonded Carbon FRP fabric and plate for flexural strengthening due to tropical climate exposure. Tropical climate countries which experience high average annual temperature, humidity, rainfall and relatively constant ultra violet ray may have detrimental effect on the usage of FRP composite over long period of time. At present, the amount of information on the durability of FRP subjected to environmental condition especially in the tropical climate environment is very limited. It is crucial to study the tropical climate effect of using FRP and its matrix material in structures element in order to gain acceptance in a related country. This is essential because many of the applications of FRP as strengthening or repair materials are for outdoor environment. The study focused on reinforced concrete beams and concrete prisms externally bonded with FRP and expose to numerous environmental conditions. The preliminary results show that the exposure to aggressive environment has an effect on the FRP bonded system.

Keywords: Fiber reinforced polymer, strengthening, repair, sustainable infrastructure, durability, tropical climate.

1. Introduction

Strengthening of existing concrete structures may be necessary in order to overcome the increase in loading capacity and also environmental effect. Durability and ductility are essential to the long-term sustainable service life of FRP material and concrete structural members with FRP reinforcement. Structural reliability and durability implies good performance of material that are able to resist degradation and capable to avoid structural damage. The strengthening of concrete structures through the used of externally bonded FRP composite system raises concern on the durability of the FRP materials at two locations. The first ones is the durability of the FRP material itself and the other one the durability between FRP material and the concrete substrate. The renewal of structural inventory is best summarized into (i) rehabilitation that include the application to repair, strengthening and retrofit structures and (ii) new construction with all FRP or new (Van Den Einde et al., 2003).

Tropical climate of countries which experience high average annual temperature, humidity, rainfall and relatively constant ultra violet ray (UV) may have detrimental effect on the usage of FRP composite either externally or internally retrofitted. The rainy season or the most rainfall is experienced by East Malaysia in the October through February with annual rainfall of 5080 mm compared to 2500 mm of annual rainfall for the Peninsular Malaysia. Even tough, the temperature is quite consistent throughout the year, the temperature records in Malaysia for the last fifty years has shown a warming trend (Zhao et al., 2005).

The amount of information on the durability of FRP subjected to environmental condition especially in the tropical climate environment is still very limited in the literature. Concluded researches show inconsistencies in the results on the degradation effect. It is crucial to study the tropical climate effect of using FRP and its matrix material in structures element in order to gain acceptance in a country which is experiencing tremendous wet and dry cycle through rain, moisture and dry season. This is essential because many of the applications of FRP as strengthening or repair materials are for outdoor environment. However, there is another concern of using FRP as external strengthening materials which is interfacial fracture along the bonded joints that can limit the strengthening performance of FRP materials. It is essential for the long term behavior of the structural bonded joints in civil engineering structures be guaranteed between 50 to 100 years for the acceptance of this bonded system in the construction industry (Täljsten, 2006).

1.1 Interfacial bond

In either flexural or shear strengthening cases, the interface bonding is critical by providing the effective shear stress transfer from the concrete to the externally bonded FRP (Ueda et al., 2005). So, the composite action of structures being externally bonded with FRP material should be preserved during the loading until failure by having a capable and efficient adhesive to transfer stresses between adhesive concrete and adhesive plate bonding (Swamy et al., 1995). The completed research evaluated several interfacial characteristic involving strain development, average and maximum shear bond stress, effective bond length, interfacial energy, and local bond stress-slip relationship.

A study observed three types of failure modes of a GFRP plate bonded to concrete surface subjected to long term aggressive environmental exposure namely (i) cohesive failure in the adhesive layer (ii) adhesion failure and (iii) concrete shearing failure (Mukhopadhyaya et al., 1998). Results of works carried out by two other researchers showed that failure modes by debonding occurred in concrete adjacent to the adhesive concrete interface with noticeable thin layer of concrete attached to the FRP strips after failures (Sharma et al., 2006; Yao et al., 2005). Applied load was observed to be related to strain distribution in which as the load was gradually increased, the strain distribution decreased starting from the loaded end area (Bizindavyi et al., 1999). An investigation showed that the load transfer from plate to concrete at lower loads level is fairly linear and occurred at uniform rate (Mukhopadhyaya et al., 1998). Observation made by a related research indicated that the shear stress is larger at the area of nearest to the loaded end and reach a peak value at normalized load before going for decreasing trend (Sharma et al., 2006). The decreasing trend indicated the initiation of plate debonding and initial cracking at the most stressed region. A very important conclusion made from testing the bonded joints between FRP-adhesive-concrete systems is the existent of effective bond length in which beyond certain bond length the ultimate load experienced no noticeable variation. A larger bond length is only anticipated to cause a longer deformation process as debonding propagates along the interface. Other important conclusion has been made by another study in which the effective bond length is related to FRP stiffness (Nakaba et al., 2001).

Important issues that need deeper consideration in understanding interfacial bond strength in using externally plated FRP reinforcement is concrete surface preparation because of the bonding failure that happen within the concrete layer beneath the adhesive (Ueda et al., 2005). It is necessary to carry out some surface treatment to have a satisfactory bond between the adherents. This is also highlighted as very important because test results in debonding failure modes, and ultimate load are different due to less stringent specimen preparation (Yao et al., 2005). A study carried out earlier also confirmed the important of surface preparation for significant improvement of bonding between FRP and concrete (Toutanji et al., 2001).

1.1 Durability of FRP reinforced Structures in Tropical Climate

Most of the above studies concern with different climate environment which is dominated by severe cold weather condition or extreme temperature of Middle Eastern region and also durability upon exposure to water and solution. Studies on FRP durability on tropical climate environment involved the used of GFRP compare to CFRP with the concern on the improvement of mechanical properties of glass fiber. An experimental research demonstrated that reinforced concrete beam strengthened with CFRP plate under load and exposed to tropical climate for a duration of six months had higher stiffness compared to the strengthened and unexposed beam (Mohd.Sam et al., 2005). This maybe due to better bonding between

CFRP plate and concrete subjected to fully cured adhesive upon outdoor exposure. A durability study to investigate the effect of tropical climate on engineering properties of GFRP laminates bonded to RC beam as a mechanism of external beam strengthening found that tensile and bond strength of GFRP laminates decreased as the results of outdoor exposure (Liew et al., 2003).

A similar test was also carried out to investigate the long-term performance of reinforced concrete structures strengthened with externally bonded fiber reinforced polymer system with combined effect of sustained loading and the impact of weathering (Saha et al., 2005). The experiment results showed that beams subjected to sustained loading exhibited larger deflection and cracks widths when subjected to longer period of weathering exposure. The beams subjected to outdoor weathering showed larger deflection and larger crack width compared to specimen under ambient laboratory condition. Both strength and ductility of beam kept under accelerated weathering decreased with longer weathering period.

2. Experimental Program and Results

This present research is motivated to study the effect tropical climate exposure as well as salt solution on the performance of externally bonded FRP fabric and plate on reinforced concrete structures. Research on durability of FRP material has been initiated at Universiti Teknologi Malaysia, Skudai for couple of years for exposure duration of six months. Study is currently being carried on a longer duration period between 6 to 18 months to further access the performance of CFRP material as strengthening material under tropical climate. Specimen in form of short prism having dimension of 100 x 100 x 300 mm were prepared from concrete of grade 50 N/mm^2. The concrete prisms were bonded with CFRP plate on two sides and subjected to environmental condition of outside weather and salt solution. Eventually, the prism will be subjected to bonding test by double shear test to access the strain and stress distribution. Reinforced concrete beams strengthened with CFRP plate and fabric having dimension of 120 x 180 x 2400 mm are also prepared for tropical climate exposure and tested for flexural investigation under four point load test. The preliminary results of the durability and sustainability studies due to tropical climate and salt solution affected the bond performance. The following sections describe the investigations.

2.1 Interfacial bond study

A research to study the effect of tropical climate on the bonding behavior of external reinforced FRP to concrete was carried out at Unibversiti Teknologi Malaysia, Skudai (AbuHassan, 2006) . Concrete prisms were fabricated for having dimension of 100 x 100 x 300mm and compressive strength of 47 MPa at 28 day test. The dimension of CFRP plate adopted for this study was 1.5 x 50 x 550 mm. The laboratory test on the mechanical properties indicated that tensile strength and tensile modulus was 2400 MPa and 135 GPa respectively. Structural adhesive brand Sikadur 30 was used as the bonding material for FRP and concrete. Electrical strain gauges, LVDTs, and Demec disc were installed on the plate and prism for related measurement during loading. The complete dimension set-up of the testing was shown in Figure 1. The stress is created between the plate and concrete, by applying a tensile force onto the CFRP plate end tabs that resulted for the face of the top concrete surface came into contact with the bearing plate which produced bearing stress and was finally transmitted to the concrete prism. The specimens were subjected to various environmental condition of laboratory air, outside air, and water and salt solution.

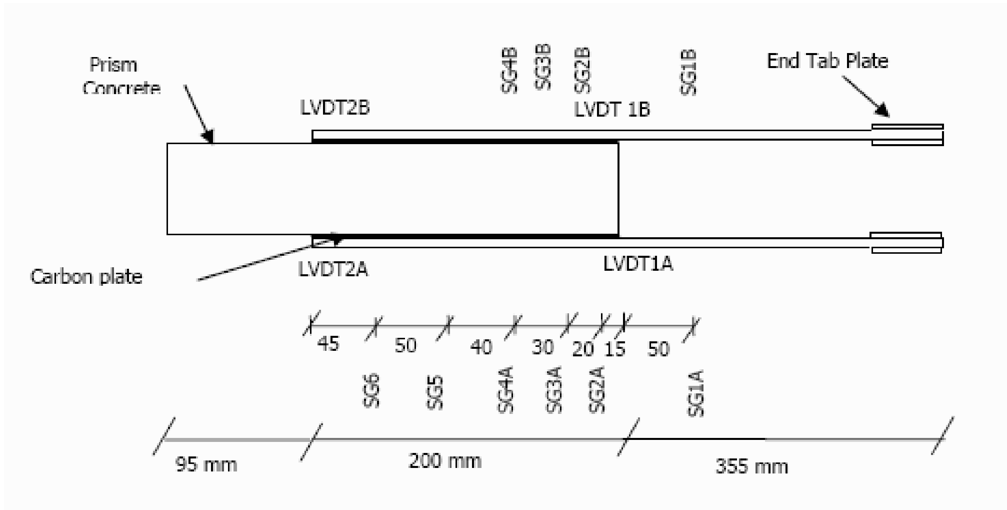

Figure 1 Dimension and instrumentation arrangement (AbuHassan, 2006)

The investigation showed that the bond transfer force from CFRP plate to concrete at low load level was fairly linear, while bond transfer force became non-uniform at higher load. Low level loads also resulted in shorter force transfer length compared to higher load level. Crack can be observed at the loaded end. The full bonded length occurred at 60% of ultimate failure load. The maximum local bond stress occurred in the region of most stress areas near the loaded end. The failure and stress shifted to adjacent and towards the free end region as load was increasing. The results of investigation showed that the exposure regime influenced the bond-slips and time to failure of the samples.

2.2 Flexural Strengthening

An experimental research was carried out to study the performance of reinforced concrete beam strengthened with CFRP plate under load and exposed to tropical climate. The investigation was carried out by focusing on the ultimate load, load deflection behavior, and mode of failure of the beams and compared with the control beam. Four reinforced concrete beams were casted and tested under four-point load to study the flexural behavior of the strengthened beam by externally bonded CFRP plate. The sizes of the beams used were 100 x 150 x 2300 mm for the width, depth, and length with concrete cover of 20 mm. The beams were provided with two 12 mm diameter high tensile reinforcement steel and 6 mm diameter steel for stirrups. Three of the beams were strengthened with CFRP plate and one beam was used as a control beam. Two of the strengthened beams were exposed to the outdoor environment for six months as shown in Figure 2 (Mohd.Sam et al., 2005). The other strengthened beam was not exposed, but tested after 28 days with the control beam. The results of testing after 28 days showed that the strengthened beam was able to carry higher load by about 96% compared with control beam which shows the effectiveness of the plate bonding with CFRP. However, the ultimate load of the exposed beams and the control strengthened beam was about the same at 38.7 kN on the average (Figure 3). This showed that the performance of strengthened beams upon exposure for six months to tropical climate has no significant effect. However, the experimental works showed that the stiffness of the strengthened and exposed beam was higher than the strengthened and unexposed beam.

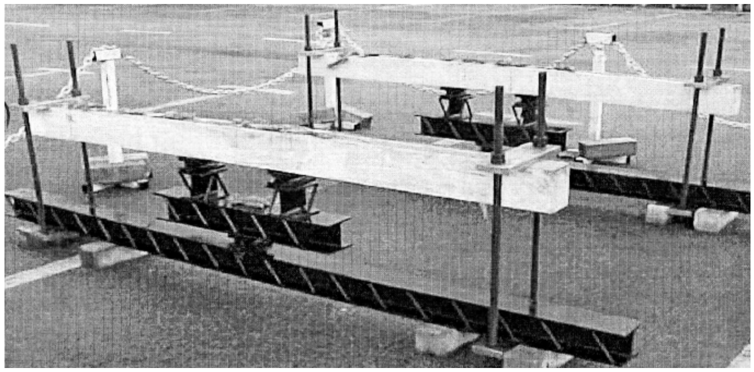

Fig 2. Strengthened beams exposed to tropical weather

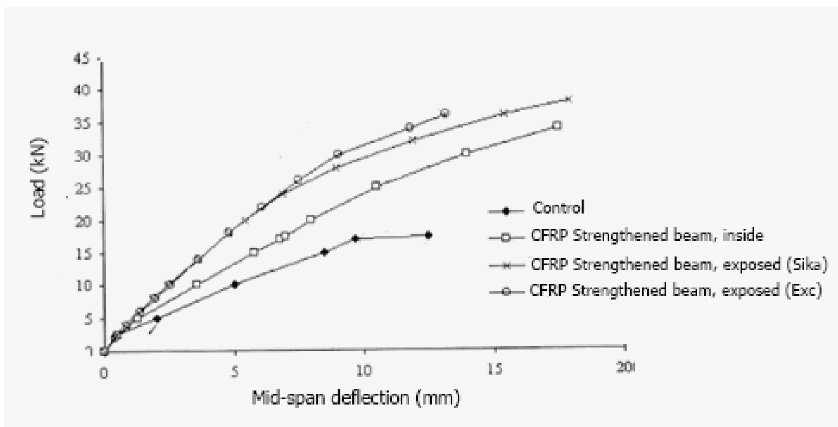

Fig 3. Load deflection of strengthened beam (Mohd.Sam et al., 2005)

3. Discussion

The successful performance of a bonded joint between construction members such as FRP and concrete through the used of adhesion is dependent upon adequate adhesion between the members in the system. Not only should the adhesive used have adequate cohesive strength, but also the extent of adhesion to the bonding surface is required factors to ensure providing strength to the bonded joints. One of the negative aspects of adhesive bonding is that the surfaces need to be clean in order to remove contamination and weak surface layers and to change the substrate surface geometry for eventual satisfactory degree of contact (Täljsten, 2006). The assumption of perfect bonding between the FRP and concrete by using adhesive was adopted in both of the investigations. As such, the bonding failure was found to be on the concrete surface. Important parameters to be considered in measuring the durability of FRP plate bonded system are the bond slip and time to failure. This is significant in studying the critical region of the plate bonded system. The expose beams in flexural strength studies may indicate a fully cured adhesive after the duration of exposure.

4. Conclusion

1. The use of CFRP as strengthening material in concrete structure improves the flexural performance of reinforced concrete beams. However, the exposure to tropical climate seems to produce very minimal impact on the structural performance of the strengthened beam.

2. The interfacial bonding study provided some signs on the failure of bond durability as shown on the stress characteristics behavior. Bond slip characteristics of the strengthened concrete structures can be used to measure the durability of the FRP system.

However, the ongoing research is expected to provide better understanding on interfacial bonding and flexural performance of reinforced concrete structures strengthened with CFRP plate or fabrics. Hence, the use of FRP materials can gain wide acceptance in tropical climate countries for its structural effectiveness for the development of sustainable infrastructures.

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