DEBONDING BEHAVIOR OF GFRP SHEET REINFORCED CONCRETE

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ABSTRACT

The fiber reinforced polymer (FRP) has been applied to many purposes for civil engineering structures not only for new structures but also for strengthening of the deteriorated structures. Many researches have been done as an effort to apply the FRP materials for strengthening, particularly due to an increase on load requirement, a change of use or due to a degradation problem or some design/construction defects. However, widely application is still questionable until a fundamental understanding of bonding behavior is clearly available. This paper is mainly focused on the study of the debonding behavior of FRP sheet patched on the tensile fiber of concrete beam. A series of GFRP sheet reinforced concrete beams with various length and width of GFRP sheet was prepared. For the purpose of purely investigation on the GFRP sheet as reinforcement, all beams were not reinforced by steel bars. The beams were loaded under four points bending test. Results indicated that debonding of GFRP sheet started on the flexural cracks and it was propagated to the sheet end.

Keywords: Bonding capacity, debonding, FRP sheet, and flexural beams

1. INTRODUCTION

Many reinforced concrete structures such as buildings and highway bridges were built more than 20 years ago and are still used until present day. Due to the change of the life demands, the structuresmay be experiencing changes in the function and an increase in service load so that the structures is no longer safe for use and it may cause a damage on the structural elements. Beams performance may decrease due to age and or increasing of the service loads as well as due to disasters. Due to service load, a compression as well as tension stress occur which indicated by the deformation of the beam. Tension stress may cause a cracking on the beam. As the result the cracking may decrease the beam performance due to corrosion and or loss of bonding.

Deterioration of the structures may result to the demolishing of the structures. Rebuilding of structures is costly and high time consumption. At certain condition, the structure element may be repaired and or strengthened. Many strengthened method have been developed from using of the conventional steel material to the application of the advance material such as non-corrosive Fiber Reinforced Polymer (FRP) (Nakamura et. a. (1996), Christos, et.al., 2009 and Mahmoud et. al., 2000).

One alternative is the retrofitting of structural repairs to the structure by covering the damaged concrete with steel reinforcement and new concrete, but its weakness is the concrete and reinforcing steel will increase the dead load of structure, reduce space and difficult in application (Mehdi et. al., 2011) and Saadatmanesh et. al. 1991).Recently, technology developmenthas provided a new challenging in strengthening method of structural elements without having to do the demolition. Uncorrosive materials such as carbon, glass and aramid has been developed. Application of that material to structures is being done by many researchers in many fields. The repair of damaged reinforced concrete members by external bonding of fiber reinforced polymer (FRP) is becoming increasingly popular in the construction industry. The use of FRP for this application offers several desirable attributes, such as resistance to corrosion,high strength, light weight, and ease ofhandling.

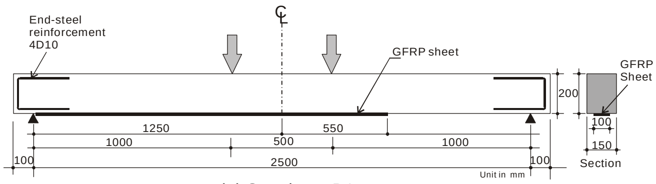
Flexure strengthening of concrete beams is accomplished by epoxy bonding the FRP material to the beam on the web or the tension face, and for shear strengthening the FRP are bonded to the web. The tensile force resisted by FRP materials bonded on the concrete surface is transferred to the beam by interfacial shear. When this shear stress exceeds the shear strength of the interface, debonding occurs. Debonding failures generally occur in the concrete, which is also assumed in the design theory. This is because, with the strong adhesives currently available and with appropriate surface preparation for the concrete substrate, debonding failures along the physical interfaces between the adhesive and the concrete and between the adhesive and the FRP plate are generally not critical. Debonding may initiate at a flexural or flexural-shear crack in the high moment region and then propagate towards one of the plate ends. Debonding of the FRP sheet may cause the decreasing of the flexural capacity with more brittle failure mode. Figure 1 shows a debonding of GFRP sheet on concrete beam. A good understanding of the bond behavior between the FRP plate andthesubstrate

Figure 1 Debonding failure of GFRP sheet on a concrete beam

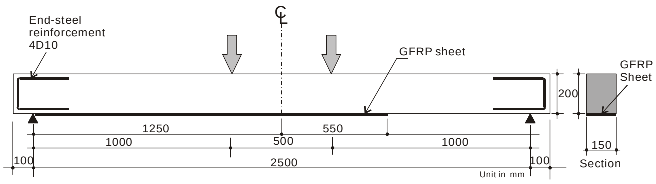
Concrete is important for understanding and predictingthe debonding behavior of FRP-plated RC beams.Bondbehaviorbetween FRP and concrete has been widely studied experimentally usingsimple pull-off tests or using theoretical/finite element models (e.g. Chenand Teng, 2001; Wu et al., 2002; Yuan et al., 2004; Yao et al., 2005).This paper is mainly focused on the study of the debonding behavior of FRP sheet patched on the tensile fiber of concrete beam due to flexural loading. A series of GFRP sheet reinforced concrete beams with various length and width of GFRP sheet was prepared. For the purpose of purely investigation on the GFRP sheet as reinforcement, all beams were not reinforced by steel bars.

2. SPECIMEN AND TEST SETUP

Three types of concrete beams with the dimension of 150 x 200 x 2700 mm as showsn in Figure 2 were prepared with the parameter of the length and the width of the GFRP. Glass fiber laminate used in this study was Type G manufactured by Fyfe. Material properties of the Glass fiber laminate and the GFRPare shown in Table 1. Type B1 are concrete beams reinforced by GFRP sheet with length of 550 from center line to the left side of beams with a width of 2/3 of beam width. Specimens type B2 are concrete beams reinforced by FRP sheet with length of 550 mm from span center line on left side of beam with entire width of beam. Specimens type B3 are concrete beams reinforced by FRP sheet on entire bottom surface of beams. The un-balance length of sheet had a purpose to allow the bonding stress concentration on only one side for easy monitoring and investigation. To ensure debonding occured on the observed left side, a higher bonding capacity was prepared on the opposite side. A notch was also prepared as an initial crack on each beams at the span center. All beams were constructed at the laboratory and curing for 28 days. Material properties of the concrete is shown in Table 2.



(a) Specimen B1



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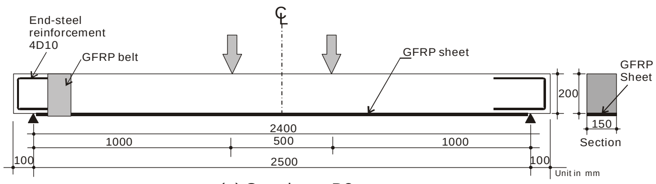

(c) Specimen B3

Figure 2 Specimen Detail

Table 1 Material Properties of Glass Fiber and GFRP composite

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Table 2 Material Properties of Concrete

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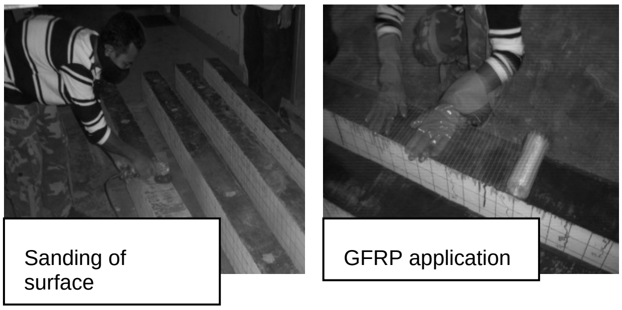

Figure 3 Application of GFRP Sheet

The concrete surface for the specimens to be strengthened with GFRP sheet was then prepared by either sanding the bottom surface. The first technique was a light surface cleaning performed by dredging and then sanded it using sand papers to complete the surface preparation as on the designated. The sheetswere applied following thespecifications of the material system manufacturers. This included compliance with resin proportioning, mixing, application and curing. The typical sequence of operation for manual layup was: application of a surface primer, application of the first layer of impregnating resin, application of the sheet (ply), layering resin, and application of the second layer of impregnating resin.

All specimens were tested under four points bending test with the span of 2500 mm. The load was applied by two concentrated load with the distance of 500 mm. Figure 4 shows the test setup of specimen. For easy crack propagation monitoring, the grid lines with distance of 50mm was drawn on the one side of the beams. The measurements were done on the deflection and the applied load. Three deflection dials were placed at the span center point, and at the both left and right of loading points, respectively. The load was applied from a hydraulic jack. The beams were loaded incrementally with the rate *of 0.5* kN per steps. The test was divided into three loading steps which are loading up to first cracking, loading up to concrete crushing, and then loading up to debonding or final failure, respectively. The cracks propagation and the debonding of GFRP sheet as well as the load-deflection behavior were monitored and noted.

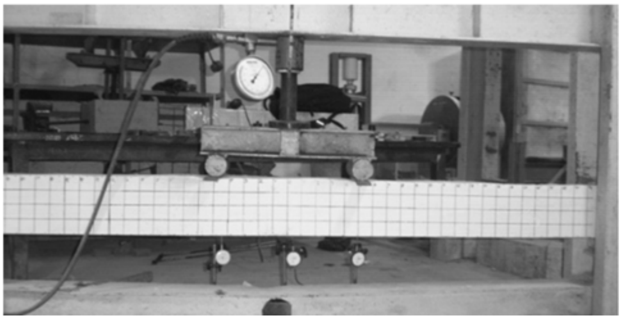

Figure 4 Setup of beam specimen

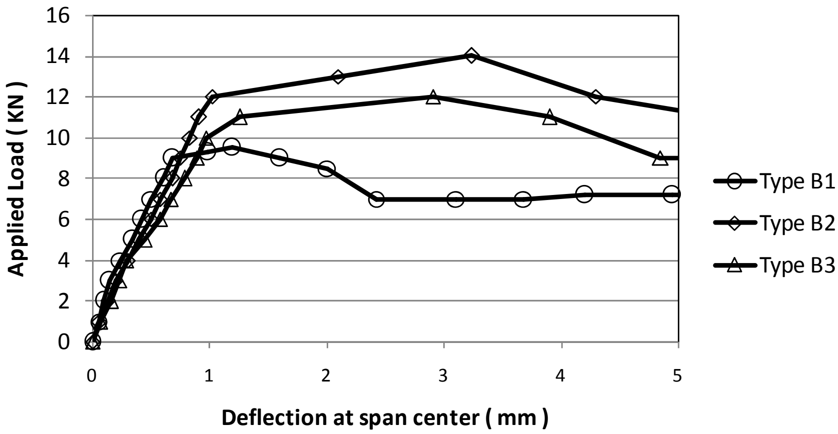

Figure5 Load-deflection relationship up to Maximum load

3. RESULTS AND DISCUSSION

3.1. Load-Deflection Behaviour

Figure5 shows a relationship between the applied load and the deflection at span center for the loading step up to the concrete crushing. At initial stage of loading, the beams were un-cracked beam. The concrete resisted both compression and tension force. When the applied load reached to the rupture strength of the concrete, the concrete started to crack at approximately 4 kN of applied load. This caused a decreasing of beam flexural stiffnes. Once the tension zone of concrete cracked, its tensile force resistance becomes negligible. The tensile force due to external load was primarily carried by GFRP sheet reinforcement. Interaction betwen GFRP reinforcement with the concrete is only due to interfacial bonding. Further loading caused the cracks propagated toward to the top of beams. This caused a crushing of concrete. On the specimen B1, the concrete crushed when the applied load achieved to 9 kN. On the specimen type B2, concrete crushing occured at appoximately 11 kN of applied load, while concrete crushing of specimen type B3 occured when the applied load achieved to appoximately 12 kN, repectively. Load-deflection behaviour up to maximum load showed a typical over reinforced concrete load-deflection behavior Further loading, the beam continued to deflect without significant increasing of the applied load. Faster crack propagation on the specimen was caused by the lower elastic modulus of the GFRP composite and the lower shear modulus of interfacial epoxy resin.

Figure 6 presents the entire load-deflection relationship of the specimens up to final failure due to debonding. Crushing of concrete did not cause the beam loss its moment capacity. The plastic hinge on the compression fiber was still acting together with the GFRP sheet to resist the applied load. Therefore, eventhough the load decreased but the deformation of the beam still propagated. On the specimens type B1, deflection of beam propagated with slightly increasing of appliced load up to approximately 15 mm and then debonding occured. On the specimens type B2, debonding occured when the deformation propagated up to 50 mm with also slightly increased of applied load. On the specimens type B3, deflection of the beam was approximately 25 mm when the debonding occured. Specimens type B3 had widest bonding area than the others. It was noted that debonding was started on the crack point within constant moment region. Cracks on the bonding line between GFRP and concrete tended to force the occurrence of debonding. Therefore the interfacial strength between GFRP sheet to concrete plays an important role in debonding process.

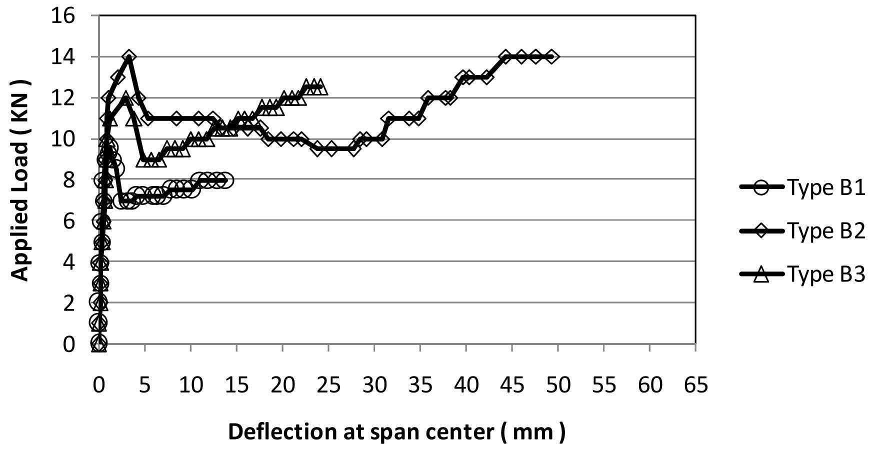

Figure6 Load-deflection relationship up to final debonding

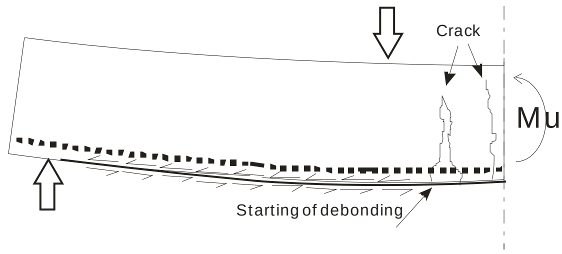

Figure 7 Interfacial debonding started on a major flexural crack

3.2. Interfacial debonding

Figure 7 illustrates the crack affecting the initiation of the localized debonding of GFRP sheet. All beams were a concrete beam (without steel reinforcement within the concrete). Therefore, all beams cracked under single major crack. When a major flexural or flexural-shear crack was formed in the concrete, theneed to accommodate the large local strain concentration at the crack leadsto immediate but very localized debonding of the GFRP from the concretein the close vicinity of the crack, but this localized debonding was notyet able topropagate. The tensile stresses released by the cracked concrete were transferred to the GFRP sheet, so high local interfacialstresses between the GFRP sheet and the concrete were induced near the crack.As the applied loading increases further, the tensile stresses in the GFRP andhence the interfacial stressesbetween the GFRP sheet and the concrete nearthe crack also increased. When these stresses reach criticalvalues, then, debondingstarted to propagate towards one of the sheet ends, generally the nearerend. A thin layer of concrete remains attached to the sheet, which suggeststhat failure occurred in the concrete, adjacent to the adhesive-toconcreteinterface. Figure 8 shows the typical failed specimens type B1, B2 and B3, respectively. The figure also shows major cracks where the debonding initiated. This point has high local interfacial stresses between GFRP sheet and the concrete.

(a) Typical for Type B1 (b) Typical for Type B2 (c) Typical for Type B3

Figure 8 Typical major cracks of specimens

Table 3 Average bonding stress of GFRP sheet to Concrete surface

Beam	Bonding area (mm2)	Moment arm (z) (mm)	Maximum Momen (kN.mm)	Tensile force on GFRP (kN)	Bond stress (Average) (N/mm2)
B1	55000	200	5000	25.0	0.455
B2	82500	200	6000	30.0	0.364
B3	187500	200	7000	35.0	0.187

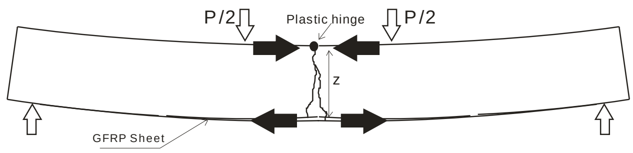

Figure 9 Illustration of the couple moment action after concrete crushing

1.1. Average Bonding Stress

Table 3 presents average bonding stress along the GFRP sheet calculated using couple moment of cross section at the span center as illustrated in Figure 9. The moment arm was taken from the plastic hinge of concete at compression fibers to the GFRP sheet at the bottom of beams. Results indicated that the avarage bonding stress decreased as the increasing of the bonding area. It should be noted here that bonding strength of the epoxy as well as cohessif bonding strength of concrete calculated in Table 3 is an average bonding stress. The debonding occured when the bonding stress achieved a critical bonding stress near the crack points as a trigger for final debonding.

4. CONCLUSIONS

(1) Load-deflection behaviour up to maximum load is a typical of an over reinforced concrete load-deflection behavior. After concrete crushing, the beam continued to deflect without significant increasing of the applied load due to plactic hinge action.

(2) Debonding initiated on the major crack point within constant moment region. Cracks on the bonding line between GFRP and concrete tended to force the occurrence of the debonding. Therefore the interfacial strength between GFRP sheet to concrete plays an important role in debonding process.

(3) The tensile stresses released by the cracked concrete were transferred to the GFRP sheet, so high local interfacialstresses between the GFRP sheet and the concrete were induced near the crack.As the applied loading increased further, the tensile stresses in the GFRP andhence the interfacial stressesbetween the GFRP sheet and the concrete nearthe crack also increasedwhen these stresses reach criticalvalues, then, debondingstarted to propagate towards to the nearerend.

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