Jurnal Teknik Sipil & Perencanaan 21 (2) (2019) p. 54 – 61

JURNAL TEKNIK SIPIL & PERENCANAAN

10.15294/jtsp.v21i2.19927

Debonding Behavior of Conventional Concrete Strengthened with Anchored FRP and Staked

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Abstract. Concrete structures can be damaged or deteriorate due to various reasons such as errors in planning, implementation factors, getting overload burden, decreased capacity and quality of structures, and changes in structural functions. Thus, to strengthen the damaged structures, there is a need for an investigation regarding the damage to the existing concrete structures. Retrofitting FRP (Fiber Reinforced Polymer) to the damaged structures can be a reinforcement alternative. The bond shear between FRP and concrete need to be considered in using FRP to solve the damaged structure. Shear behavior on the bonded structures greatly affects the condition of the structure. Therefore, this study aimed to examine the effect of anchors and stakes on FRP debonding behavior. This study was carried out experimentally to obtain the results and data on the effects of the anchors and stakes. This study used 9 specimens with a size of 150 mm x 150 mm x 300 mm. From those 9 specimens, 3 specimens were specimens without reinforcement (FR), 3 specimens were reinforced with anchor (FRA), and 3 specimens were reinforced with anchor and stake (FRAP). The test method used in this study referred to ASTM D5379 concerning the Standard Test Method for Shear Properties of Composite Materials. From the bond shear test of each FR, FRA, and FRAP specimens, it was found that the average maximum shear load was 19.405 kN, 28.465 kN, and 29.699 kN, consecutively.

Keywords: Structural Strengthening, Fiber Reinforced Polymer, Anchor, Stake.

INTRODUCTION

Damage and deteriorate of a concrete structure can be caused by errors in planning, implementation factors, receiving exceeded loads from the planned load (overload), decreased capacity and quality, changes in structural functions, and changes in requirements in meeting new regulations. This condition causes the need for an investigation regarding the damage to the existing concrete structure in order to carry out reinforcement and repairs.

The external reinforcement method proves to be a practical and effective way to improve the performance of reinforced concrete structures [1]. Several reinforcement methods and repair methods are adding a layer of concrete, reinforced with a steel plate, external prestressing, and using FRP (Fiber Reinforced Polymer) [2]. The commonly used FRP (Fiber Reinforced Polymer) is CFRP (Carbon Fiber Reinforced Polymer) and GFRP (Glass Fiber Polymer) [3].

In short, the alternative reinforcement that can be used is external reinforcement using FRP. Reinforced concrete beam structures with FRP without special roughness bounding on concrete surface can experience debonding failure [4]. Debonding failure resulted in the ability of FRP reinforcement to concrete beams not optimal. The bonding method on the concrete surface, the type of epoxy adhesive used, and the adhesion dimensions greatly influence the bond between FRP and concrete [5], [6], [7].

Retrofitting concrete surface by grinding the entire surface area with a depth of 4 mm (plain type), grinding longitudinal direction with a grinding depth of 2mm (longitudinal type), grinding upright/transverse with a grinding depth of 2 mm (transversal type), grinding in the same direction diagonally with a grinding depth of 2mm (diagonal type), and cross grinding with a 2 mm grinding depth (cross-type). The roughness bounding provides an increase in shear behavior compared to the plain type. For example, the longitudinal type increases

23%, the transversal type increases 27%, the diagonal type increases 30%, and the cross-type increases 36% shear force [8].

The use of anchor can be useful to avoid or delay final debonding failure in reinforced concrete elements externally bonded with FRP material [9]. The attachment of FRP using U-jacket can increase load capacity and ductility that occur in reinforced concrete beams [10]. Referring to the above problems, this study was carried out to overcome the debonding problem in reinforced concrete using FRP by adding anchors and stakes.

METHODOLOGY

This study used 9 concrete blocks with dimensions of 150 mm x 150 mm x 300 mm as the specimens. Those specimens consisted of 3 control specimens (FR), 3 anchored CFRP specimens (FRA), and 3 anchored and staked CFRP specimens (FRAP). FRP materials used were 3 layers of CFRP Sheet, anchor made from Carbone Fiber Reinforced Polymer with a diameter of 10 mm with a depth of 50 mm, and stakes made from rebar with a diameter of 6 mm with a length of 50 mm. The specimens were illustrated in Figure 1.

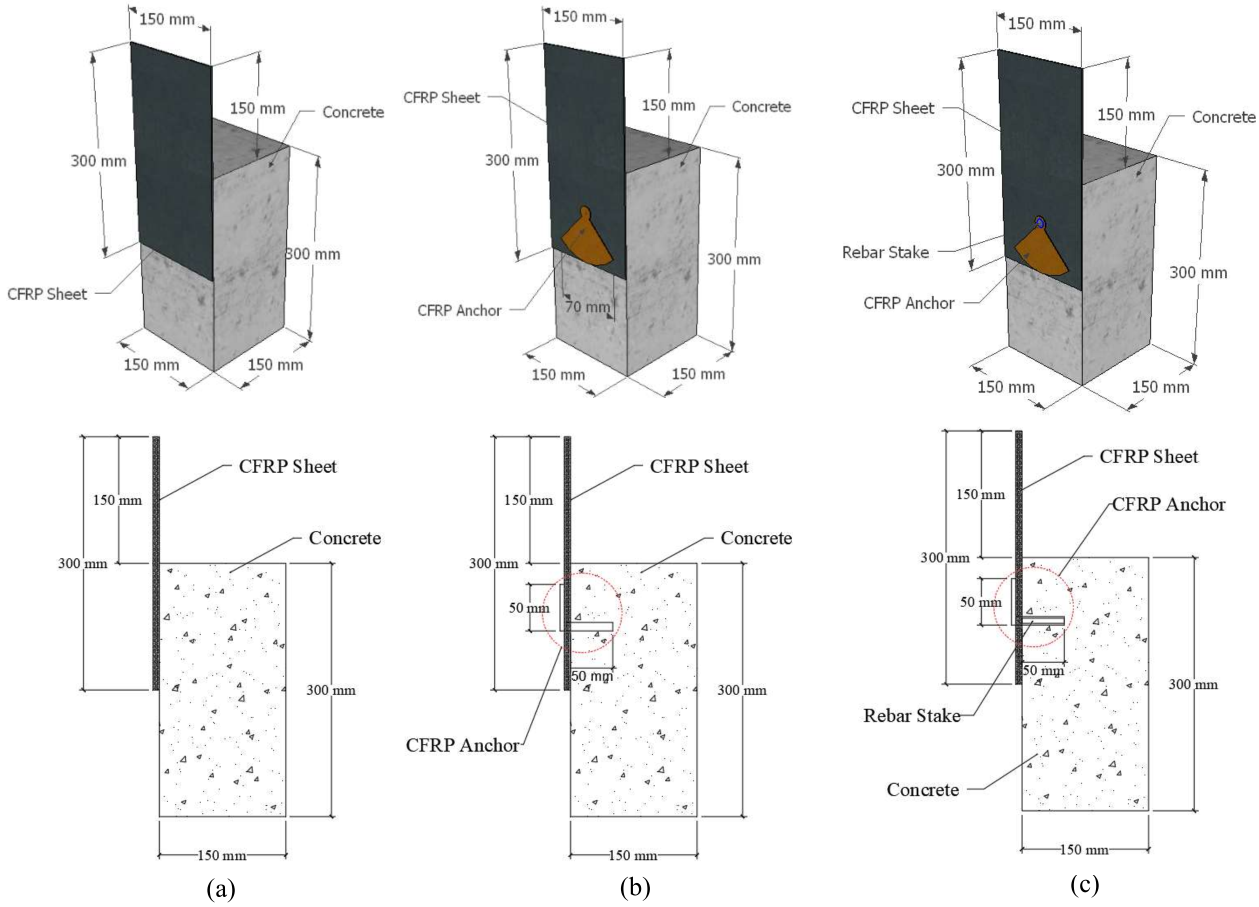


FIGURE 1. (a) Control Specimens (FR); (b) Strengthening Specimens with anchor (FRA); (c) Strengthening Specimens with anchor and stake (FRAP)

The Installation of CFRP sheet, Anchored CFRP, and Anchored CFRP and Staked

The hardened specimens were treated in water for 28 days. After 28 days, the CFRP Sheet, anchors, and stakes were installed on the specimens by:

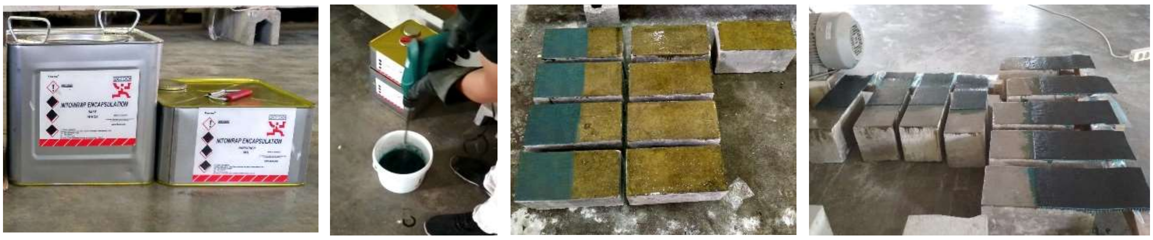
1. Flattening and cleaning the concrete surface by grinding and other instruments that can clean the concrete surface (figure 2(a)).
2. Mixing Nitowrap Primer adhesive materials for approximately 3 minutes with a mixer speed of 500 rpm (figure 2(b), 2(c)).

3. Priming Nitowrap Primer on the concrete surface by using a role brush before leaving it dry for 24 hours. The liquid or primary mixture functioned as adhesive/cohesive between CFRP and Encapsulation Resin as well as between CFRP and concrete (figure 2(d)).

(a) (b) (c) (d)

FIGURE 2. The process of Nitowrap Primer application

4. Mixing adhesive Encapsulation Resin for 3 minutes (figure 3(a), 3(b)). After applying the Nitowrap Encapsulation, CFRP was immediately installed on the concrete surface. Then, CFRP was pressed into the surface using a hard rubber roll in order to make Encapsulation Resin able to absorb CFRP (figure 3(c), 3(d)).
5. The installation of the next layer of CFRP by letting it dry for the first 30 minutes or at a maximum of 3 hours. After that, Encapsulation Resin was reapplied on the installed CFRP surface. CFRP was immediately attached to the surface that had been applied with Encapsulation Resin and so on.



(a) (b) (c) (d)

FIGURE 3. The process of Installing CFRP

6. After the installation of CFRP Sheet was complete and had hardened, holes were made for anchor by drilling on the specimens with a diameter of 10 mm and a depth of 50 mm. After drilling, the holes were cleaned (figure 4(a), 4(b)).
7. Mixing Nitobond EC Adhesive for at least 3 minutes with the ratio of two mixture materials between hardener and base of 1/5 (figure 4(c)). The Material of Epoxy Anchor Adhesive (Nitobond EC Adhesive) was an adhesive material in the form of paste which served as cohesive/adhesive anchor
8. After the mixing process of the anchor adhesive (Nitobond EC) was complete, the adhesive was immediately poured into the anchor hole (figure 4(d)) and anchored CFRP was installed (figure 4(e), 4(f)). Then, it was left to dry for about 3 hours.
9. In general, the installation of specimens reinforced with anchored and staked CFRP was carried out in the same manner from step 1 to step 8. However, there was an additional stake with a diameter of 6 mm in diameter with a length of 50 mm planted on anchor (figure 5(b)).
10. During the installation process of anchor, the stake was immediately pressed in order to make it embedded in the anchor hole.

(a) (b) (c)

(d) (e) (f)

FIGURE 4. The installation process of anchored and staked CFRP

The anchored CFRP and anchored and staked CFRP models used in this study can be seen in Figure 5.

(a) (b)

FIGURE 5. (a) Anchored CFRP; (b) Anchored and Staked CFRP

The test objects in this study were tested using a method that refers to ASTM D5379 concerning the Standard Test Method for Shear Properties of Composite Materials, using UTM (Universal Testing Machine). The number of Maximum Load (P_{max}) was then analyzed. Equipment Set-up and bond shear test are visualized in Figure 6.

FIGURE 6. Equipment Set-Up and Bonding Test

RESULTS AND DISCUSSION

Bond Shear Test Results

The results of the CFRP bond test with an area of 22,500 mm^2 (150 mm x 150 mm) conducted showed an increase of maximum shear load value. The average maximum shear load that occurred was 19.405 kN on the control specimens (FR) and 28.465 kN on the anchored CFRP specimens (FRA). Meanwhile, the average maximum shear load of anchored and staked CFRP specimens was 29.699 kN. The bond shear test results can be seen in table 1.

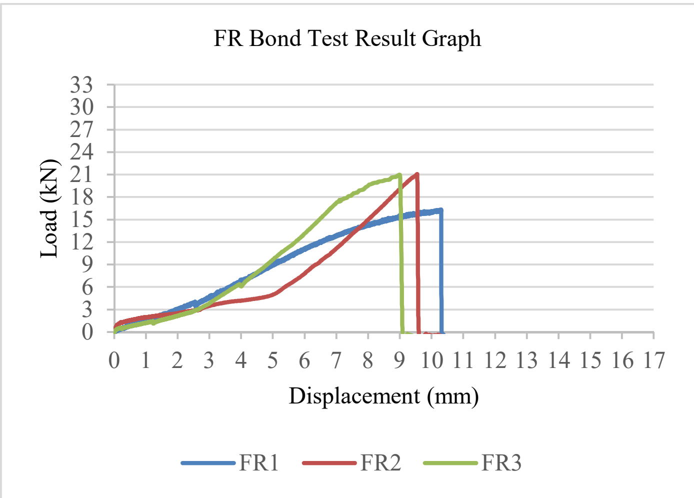
TABLE 1. Shear Force

Test Object	Bond Extent (mm^2)	First Shear Load (kN)	Maximum Shear Load (kN)
Control specimen (FR1)	22.500	3,083	16,344*
Control specimen (FR2)	22.500	2,950	20,950
Control specimen (FR2)	22.500	1,395	20,922
Average Bonding Strength			**19,405**
Strengthening with anchor (FRA1)	22.500	3,726	28,441
Strengthening with anchor (FRA2)	22.500	3,852	28,448
Strengthening with anchor (FRA3)	22.500	2,197	28,507
Average Bonding Strength			**28,465**
Strengthening with anchors and stakes (FRAP1)	22.500	4,232	28,083
Strengthening with anchors and stakes (FRAP2)	22.500	3,695	29,991
Strengthening with anchors and stakes (FRAP3)	22.500	4,251	31,022
Average Bonding Strength			**29,699**

*note: During the testing process, the specimen received the load, there was an error in setting up the UTM instrument. Thus, the test was temporarily suspended. After that, the testing process was resumed from the beginning. The maximum shear load had decreased and significant graph difference could be seen.

Bond Shear Test on the Control Specimens (FR)

Figure 7 shows the bond shear test results on the control specimens (FR).



(a)

(b)

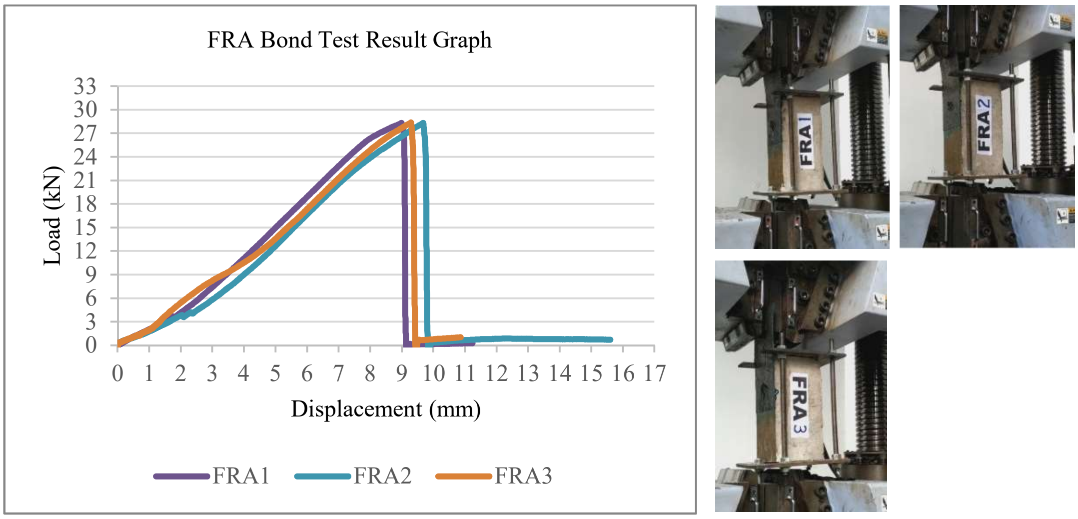
FIGURE 7. (a) Relationship graph of *Load–Displacement* on FR; (b) FR bond shear test

Figure 7 shows the results of the bond test of control specimen (FR). The first test object (FR1) experienced the first shear load of 3.083 kN. Thus, there was a graphical change from the elastic area to the plastic area.

During the testing, the control specimen continued to experience energy absorption which caused an ascending graph to reach peak load (maximum shear load). The maximum shear load that occurred in FR2 test object was 16.344 kN with a displacement of 10.308 mm. Meanwhile, the second specimen (FR2) had the first shear load of 2.950 kN and the maximum shear load of 20.950 kN with a displacement of 9.362 mm. Whereas for the third test object (FR3), the first shear load was 1.395 kN and the maximum shear load was 20.922 kN with a displacement of 9.072 mm.

Bond Shear Test on Strengthening Specimens with Anchor (FRA)

CFRP strengthened with anchor (FRA) bond shear test results presented in Figure 8.



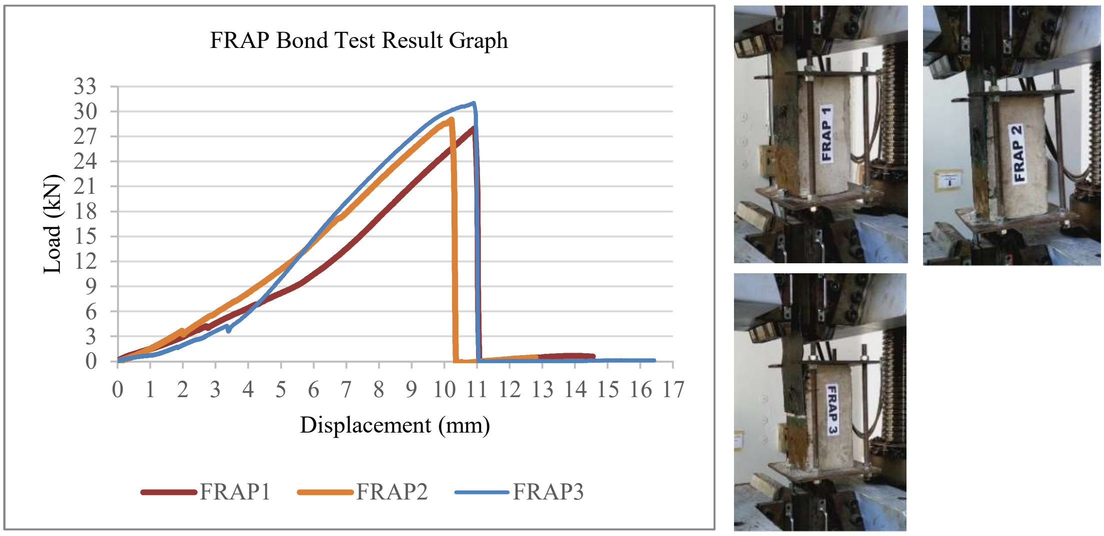
(a) (b)

FIGURE 8. (a) Relationship graph of Load-Displacement of FRA Test Objects; (b) Bond Shear of the Test Objects FRA

Figure 8 shows the results of adhesive failure test on the CFRP Strengthening with Anchor (FRA). During the test, there was a change in the graph from the elastic area to the plastic area. The change indicated the position of first shear load value. The first shear load on the first object (FRA1) was 3.726 kN. The test object continued to experience energy absorption which caused an increase in the graph (ascending) until it reached peak load (maximum shear load). The maximum shear load of FRA1 test object was 28.441 kN with a displacement of 9.132 mm. Meanwhile, the third test object (FRA3) had the first shear load of 2.197 kN, the maximum shear load of 28.507 kN, and a displacement of 9.488 mm.

Bond Shear Test on Strengthening Specimens with Anchors and Stakes (FRAP)

The results of bond shear test on the CFRP reinforced with anchor and stake (FRAP) were shown in Figure 9. During the testing process on the CFRP Strengthening with Anchors and Stakes (FRAP), there was a change in the shape of the graph from the elastic area to the plastic area indicating the position of first shear load value. The first shear load on the first test object (FRAP1) was 4.232 kN. The test object continued experiencing energy absorption during the test which caused an ascending graph to reach peak load (maximum shear load). The maximum shear load in FRAP1 test object was 28.083 kN with a displacement of 11.048 mm. The second test object (FRAP2) experienced the first shear load of 3.695 kN and the maximum shear load of 29.991 kN with a displacement of 10.118 mm. Meanwhile, the third test object (FRAP3) experienced the first shear load of 4.251 kN and the maximum shear load of 31.022 kN with a displacement of 10.900 mm (figure 9).



(a) (b)

FIGURE 9. (a) Graph of relationship between load-displacement and FRAP Test Objects; (b) Bond Shear of the Test Objects FRAP

Data Analysis

The bond test results present a shear load ranging from 16.344 kN to 31.022 kN. In the bond test, there was an increase of bond in each type of specimens which was strengthened compared to those control specimen (FR) (FR). For example, specimens reinforced with anchor and stake (FRAP) increased by 46.689% while specimens reinforced by anchor and stake (FRAP) increased by 53.046%. Compared to the type of specimens reinforced with anchor and stakes, specimens reinforced with anchor only (FRA) increased by 4.334%.

Reducing the bonded length, L_b, from 150 to 100 mm and for the same FRP width (Bf =100 mm, Bf /B = 0.67), the effectiveness of the anchorage devices was greater: a strength increment of about 54% for the CFRP fan, 48% for the CFRP bar, and 24% for the CFRP transverse strip was attained. Thus, in the case of Bf / B = 0.67 and for L_b = 100 and 150 mm, the CFRP fan type anchor is the most effective system and has a thicker concrete cover [9].

The damage that occurred in all specimens was debonding. The damage to each test specimens can be seen in Figure 10.

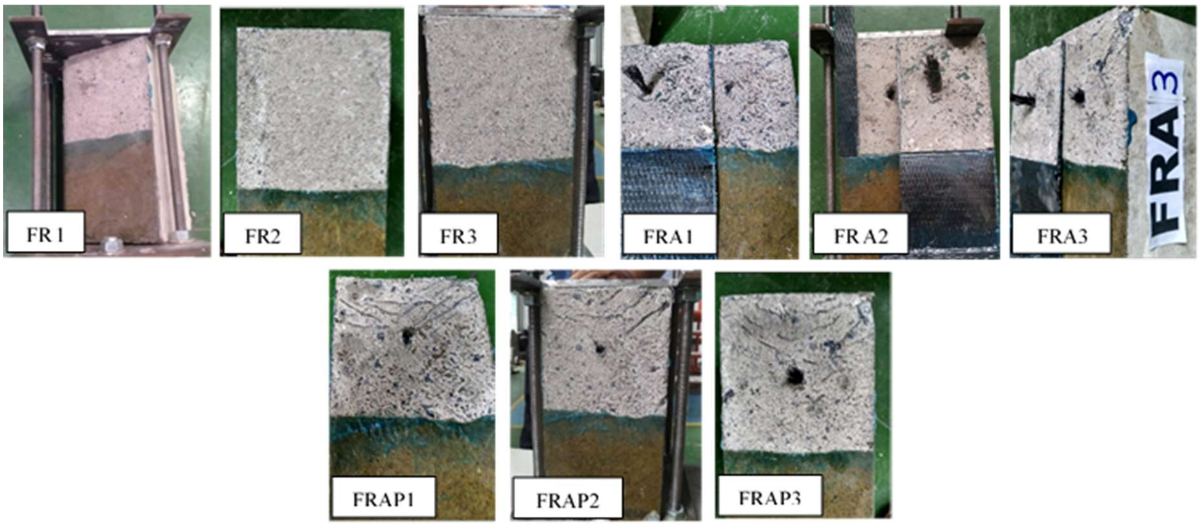


FIGURE 10. The damage to each test specimens

CONCLUSION

This study proved that the type of specimen without special treatment on FRP was easier to get debonding failure. Therefore, adding retrofitting on FRP reinforcement can reduce the occurrence of debonding between FRP and concrete. He shear test results showed that retrofitting on FRP reinforcement provided more effective results compared to those without retrofitting. Thus, the application of reinforcement using FRP needs to use applicable retrofit. In conclusion, the addition of roughness treatment on the concrete surface can reduce the occurrence of debonding between FRP and concrete [8].

ACKNOWLEDGMENTS

The authors would like to express their gratitude to PT. Fosroc Indonesia for providing FRP and epoxy materials. The authors also would like to thank the Technology Research and Development Center for Road and Bridges (*PUSJATAN*) which have supported and assisted the authors in carrying out the tests in this study.

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