World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:6, No:12, 2012

Grooving Method to Postpone Debonding of FRP Sheets Used for Shear Strengthening

Davood Mostofinejad, Seyed Amirali Mostafavizadeh, and Amirhomayoon Tabatabaei Kashani

Abstract**—**One of the most common practices for strengthening the reinforced concrete structures is the application of FRP (Fiber Reinforce Plastic) sheets to increase the flexural and shear strengths of the member. The elastic modulus of FRP is considerably higher than that of concrete. This will result in debonding between the FRP sheets and concrete surface. With conventional surface preparation of concrete, the ultimate capacity of the FRP sheets can hardly be achieved. New methods for preparation of the bonding surface have shown improvements in reducing the premature debonding of FRP sheets from concrete surface. The present experimental study focuses on the application of grooving method to postpone debonding of the FRP sheets attached to the side faces of concrete beams for shear strengthening. Comparison has also been made with conventional surface preparation method. This study clearly shows the efficiency of grooving method compared to surface preparation method, in preventing the debonding phenomenon and in increasing the load carrying capacity of FRP.

Keywords**—**FRP composite, grooving, rehabilitation, reinforced concrete, shear strengthening, surface preparation.

I. Introduction

STRENGTHENING and rehabilitating concrete structures has been one of the active fields in a construction sector. Application of fiber polymers is known as an effective solution and proper substitution for traditional methods in strengthening of concrete structures [1].

The conventional method for concrete surface preparation is to eliminate the weak near surface layers of concrete which may result in a deficient connection. In this method the outer layers of concrete is removed until the surface composes of both hardened cement and aggregates. This will result in a better bonding between the FRP sheet and concrete surface. Appropriate implementing of this method will result in proper transfer of shear stresses between the concrete surface and the FRP composite [2].

Various studies have been conducted on the effect of surface preparation and treatment for bonding FRP sheets. Toutanji and Ortez [3] have investigated the effect of concrete surface preparation for FRP sheets in flexural strengthening. For this study different specimens were cast with different preparation methods such as water jet and sandblast. They concluded that various surface preparation methods will result in different flexural strength in specimens. The specimens prepared with water jet demonstrated 50 percent higher failure load than the rest. This was due to higher smoothness of concrete surface resulted in this method in comparison with other methods.

Another technique for bonding FRP sheets to the concrete substrate is near surface mounted (NSM) method, which is of great interest due to ease of application and low costs. The major advantage of this method is reducing the probability of premature deboning and also preserving the FRP from environmental attacks [4].

Rizzo and Lorenzis have investigated the effect of NSM, externally bonded reinforcement (EBR), distance between the FRP sheets and angle of the fibers on the behavior and failure mode of concrete beams. They concluded that the EBR strengthening method would increase the shear capacity of the beams by 16 percent while the NSM method would increase it by 22 to 44 percent. Finally because of optimum usage of composite materials in tension and reducing the risk of debonding, they suggested the NSM method to be more efficient than EBR [5].

The latest study conducted by Mostofinejad and Mahmoudabadi regarding the connection between CFRP sheets and the concrete surface for flexural strengthening of reinforced concrete beams has showed that grooving method (GM) in form of application of longitudinal grooves would increase the maximum strain in the FRP sheets up to their ultimate state and rapture. Grooves with 10 mm depth showed increase of the flexural capacity of the beams by 100 percent [6].

This article studies the effect of grooving method on the shear strength of reinforced concrete beams. Four concrete small scale beams are tested with the EBR and grooving methods and the results are compared with a non-strengthened reinforced concrete beam.

II. Materials

Casting specimens with compression strength of 25 MPa was conducted, while the mix design was performed according to ACI 211.1-91 [7]. Portland cement from Esfahan cement factory was used for testing purpose. For evaluating compression strength, three cubic specimens with dimension of 150×150×150 mm were cast during the concrete mixture. One of the three cubic specimens was tested for evaluating compression strength after 28 days of curing. Two other cubic specimens were maintained until the principal tests. In this experiment, composite sheets made of carbon with

F. D. Mostofinejad Prof. at Civil Department, Isfahan University of Technology, Isfahan, Iran (phone: (+98) 311 3913818; fax: (+98) 311 3912700; e-mail: dmostofi@cc.iut.ac.ir).

S. S. A. Mostafavizadeh Ardestani undergraduate student, Civil Department of Isfahan University of Technology, Isfahan, Iran (e-mail: amirali-mostafavizadeh@hotmail.com).

T. A. Tabatabaei Kashani graduate student, Civil Department of Isfahan University of Technology, Isfahan, Iran (e-mail: amirhomayoont@yahoo.com).

commercial name of Sika Warp Hex-230C were applied. The properties of the FRP sheets are shown in Table I. The yield stress of steel bars applied in this experiment was 382 MPa and the ultimate stress was 614 MPa.

TABLE I
CFRP MECHANICAL PROPERTIES

Ultimate strain (%)	Thickness (mm)	Ultimate tensile capacity (MPa)	Tensile modulus (GPa)
1.7	0.12	4100	231

III. SPECIMENS CHARACTERISTICS

The testing specimens included 4 reinforced concrete beams with dimension of 570×85×70 mm. Steel bars were applied for reinforcing beams; the arrangement of the bars are shown in Fig. 1. Due to the fact that it was impossible to anchor the bars used in concrete beams with specified dimension, a plate with thickness of 12 mm was applied as a mechanical anchor in order to prevent the bars from slipping within the concrete beams. The details of the anchor are shown in Fig. 2. With the aim of strengthening shear capacity of the beams, the CFRP sheets were applied with dimension of 85×40×0.12 mm. Total number of eight FRP patches were applied to the sides of the test beams. The center-to-center distance between the sheets was 55 mm. The details of spaces between the sheets are shown in Fig. 3.

IV. SPECIMENS CLASSIFICATION

Four test specimens were cast for this experiment, labeled as T13-1, T13-2, T13-4 and T13-5. Specifications of these specimens are as follows;

No strengthening was applied on the beam T13-1 and it was considered as reference specimen. Beam T13-2 was strengthened with surface preparation method, while beams T13-4 and T13-5 were strengthened with the grooving method by laying two grooves with width of 5 mm and depth of 10 mm beneath each FRP sheet.

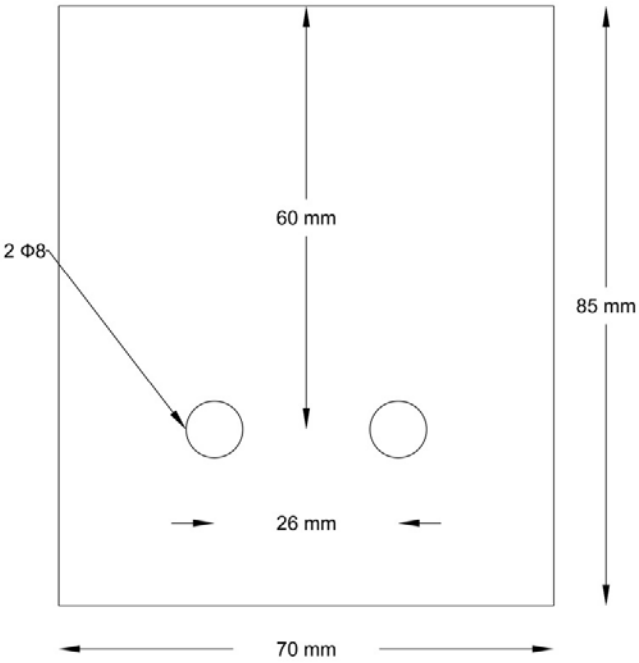

Fig. 1 Beam section

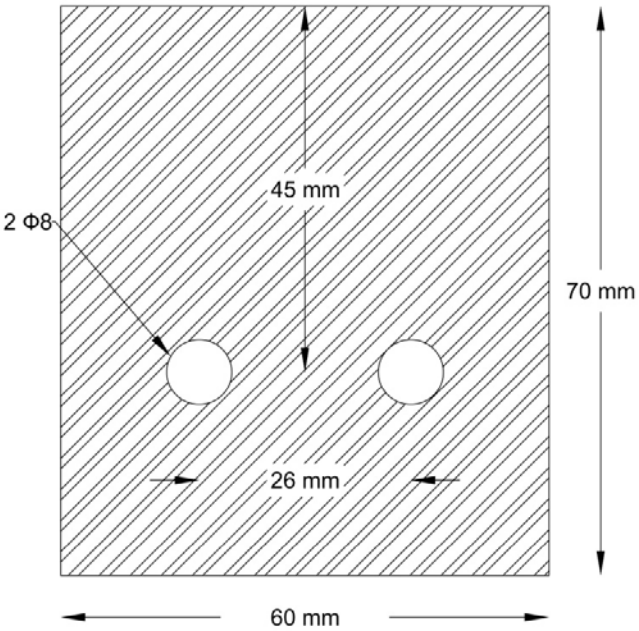

Fig. 2 Plate details

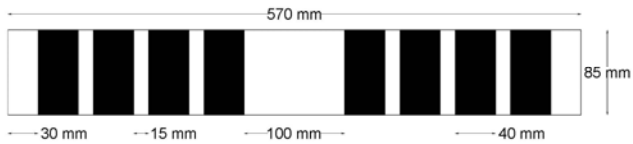

Fig. 3 Arrangement of FRP sheets

V. TESTING PROCEDURE

In order to investigate the efficacy of grooving method in shear strengthening, the prepared specimens were tested by four-point flexural test. The loads and corresponding

displacements at midspan were collected during the test. The testing device is displayed in Fig. 4. The ultimate load and displacement at midspan of the beam were measured.

Fig. 4 Testing Device

VI. Results

The failure load of the specimens, the failure mode and the growth rate of ultimate load in comparison with the reference specimen are shown in Table II. Figs. 5, 6, 7 and 8 illustrate the failure mode of the tested beams.

TABLE II
Test Results

Specimen	Load (kN)	Failure mode	Growth Rate (%)
T13-1	21.91	Shear	-
T13-2	24.95	debonding	14
T13-4	26.98	Flexural	23
T13-5	26.30	Flexural	20

Fig. 5 Reference specimen

Fig. 6 Specimen prepared with surface preparation

Fig. 7 Specimen prepared with grooving method

Fig. 8 Specimen prepared with grooving method

As it is shown in the figures, the reference beam was failed with a diagonal crack starting from the loading point towards supports, which clearly shows that the failure mode is shear failure. The beam prepared with surface preparation underwent higher load compared to the reference beam. This beam showed 13 percent increase in ultimate load capacity. The failure mode of T13-2 was debonding of CFRP sheets from concrete surface because of weakness in the connection of CFRP and concrete surface.

The grooving method was very effective in shear strengthening of T13-4 and T13-5 specimens. The ultimate failure loads of T13-4 and T13-5 beams showed an average of 21 percent increase compared to reference specimen. No shear failing was observed and no sign of debonding was detected. The failure mode was flexural, while the other beams were failed in shear mode. The results demonstrated that the grooving method had eliminated shear weakness completely in these specimens.

The load-displacement diagrams of the specimens are presented in Fig. 9. The abrupt decrease of the forces applied against displacements in T13-1 and T13-2 is the result of the shear failure in these specimens. Although the T13-2 beam had a higher load and displacement compared to reference specimen, its failure showed brittle behavior. The amount of load increased by 21 percent in T13-4 and T13-5, then became constant in a way that the displacement at midspan of the beam increased approximately 34 percent. These results demonstrate the ductile behavior of beam strengthened with grooving method. As it is illustrated in the figures, the T13-4 and T13-5 beams were failed in flexural mode.

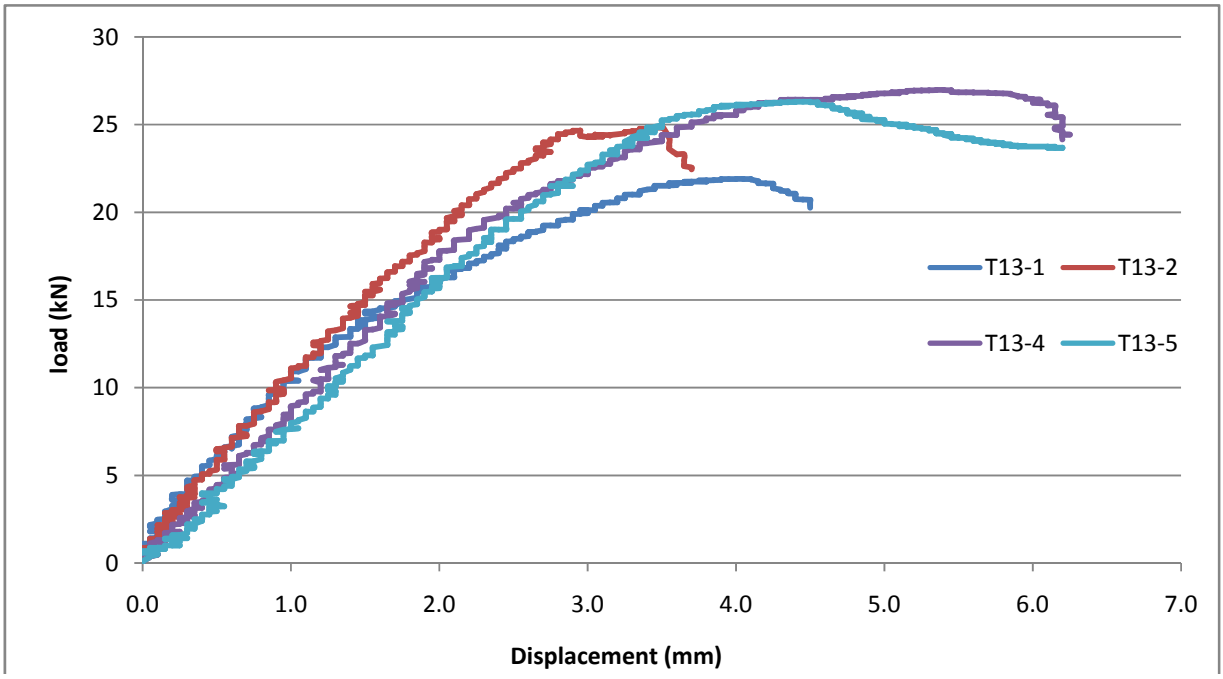

Fig. 9 Load-Displacement diagrams of tested specimens

VII. Conclusion

The aim of this study was to investigate the effect of grooving method (GM) compared to conventional surface preparation for bonding FRP sheets to concrete surface. The experiment was carried out by performing flexural bending tests over two groups of CFRP reinforced concrete beams. In the first group, conventional surface preparation method was applied to attach the CFRP sheets to concrete surface, while in the second group; grooving method was applied for this purpose. The following conclusions are inferred from shear strengthening of beams under flexural loads.

1. Having prepared the surface concrete by eliminating the weak layer and filling in the pores and cracks, resulted in 13 percent increase in the flexural strength compared to reference specimen, but the surface treatment could not eventually prevent debonding and the failure of beam was brittle.

Having the CFRP sheets attached to the concrete surface with grooving method resulted in a 23 percent increase in the flexural strength of the beams compared to reference specimen. This increase in the strengthening with grooving method was associated with the increase of contact surface between the epoxy and the concrete surface, specially the inner layer. In addition, GM method eliminated the premature debonding and altered the failure mode from shear to flexural failure with ductile behavior.

References

[1] ACI 440R, (2004), State-of-the-art report on fiber reinforced plastic reinforcement for concrete structures, American Concrete Institute Committee 440.

[2] Karbhari, V. M., and Zhao, L. (1998), Issues related to composite plating and environmental exposure effects on composite-concrete interface in external strengthening, Composite Structures, Vol. 40, No. 3, pp. 293-304.

[3] Toutanji, H., and Ortez, G., (2001), “The effect of surface preparation on bond interface between sheets and concrete members,” Composite structures, Vol. 53, pp. 457-462.

[4] De Lorenzis, L. and Teng, J.G., (2007), “Near-surface mounted FRP reinforcement:An emerging technique for strengthening structures,” Composites, part B, Vol. 38, pp. 119-143.

[5] Rizzo, A. and De Lorenzis, L., (2009), “Behavior and capacity of RC beams strengthened in shear with NSM FRP reinforcement,” Construction and Building Materials, Vol. 23, pp. 1555-1567.

[6] Mostofinejad, D., and Mahmoudabadi, E., (2010), “Grooving as Alternative of Surface Preparation to Postpone Debonding of FRP Lamination in Concrete Beams,” Journal of Composites for Construction, Vol. 14, No. 6, pp. 804-811.

[7] ACI Committee 211,” Standard Practice for Selecting Proportions for Normal, Heavyweight, Mass concrete”, Farmington Hills, MI: American Concrete Institute; 2009.