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A Study on the Shear Behaviour of Reinforced Concrete Beams Embedded with Glass Fibre Reinforced Polymer Plates

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Abstract

Fibre reinforced polymer (FRP) has been widely as a substitute for steel reinforcement in reinforced concrete (RC) structures or to retrofit existing structural members as a result of its high tensile strength and anti-corrosive characteristics. Most of FRP products are designed to enhance the flexural strength of structural members in the form of FRP rebars and sheets. In this paper, a new type of glass fibre reinforced polymer (GFRP) plates with openings is proposed to improve the shear strength of RC beams and its effectiveness was experimentally examined. Totally, six specimens were manufactured by embedding the proposed GFRP plates into concrete beams with steel longitudinal reinforcement instead of typical steel stirrups. All the test specimens had the shear span ratio of 2.8 and test variables include the sectional area of the GFRP plate and its width and thickness. The test results indicate that the RC beams with the proposed GFRP shear reinforcement can retain the shear strength approximately up to 3.5 times higher than the one with conventional steel stirrups and the shear strength increases as the width of the GFRP plate increases.

Keywords: glass fibre reinforced polymer, stirrup, plate, reinforced concrete beam

1 Introduction

The shear behaviour of reinforced concrete beams is diverse and irregular because of the interrelation between concrete and reinforcement bars (rebars). As shear reinforcements, steel stirrups play the role of preventing the brittle failure of concrete due to shear cracks and the ability to withstand an even greater load while resisting cracks. When a strong shear force acts on the members, the steel stirrup bar arrangement becomes dense and either the self weight increases or aggregates are arranged unevenly, thus causing the performance reduction of structures. Unlike reinforcement steel, fibre-reinforced plastics (FRP) have advantages, such as high corrosion resistance and being light weight, and are therefore widely used as reinforcements instead of reinforcement steel.[1]~[5] However, studies on the application of FRP as replacement materials for steel stirrups are rare. In order to understand the application of carbon fibre-reinforced plastics (CFRP) in the form of rebars as stirrups, Ahmed et al. [6] studied the bond strength (based on the diameter and the embedment length) and the shear reinforcement performance of CFRP stirrups on concrete beams. Ahmed et al. [7] also conducted the shear test after reinforcement with stirrups in the form of CFRP rebars instead of steel stirrups and compared empirical equations and prediction equations in terms of the shear's strength. Dinh et al. [8] studied the shear behaviour after reinforcement with high-strength reinforcement steel fibre stiffeners instead of steel stirrups.

The present study proposes a way of using, as shear reinforcements, manufacturing glass fibre-reinforced polymers (GFRP) by manufacturing them in the form of plates, and embedding GFRP plates, instead of steel stirrups, in concrete beams, as shown in Figure 1. The purpose of the present study thus lies in grasping the structural behavior of the new shear reinforcement shapes and evaluating the shear behavior of concrete beams to which these new shapes have been applied.

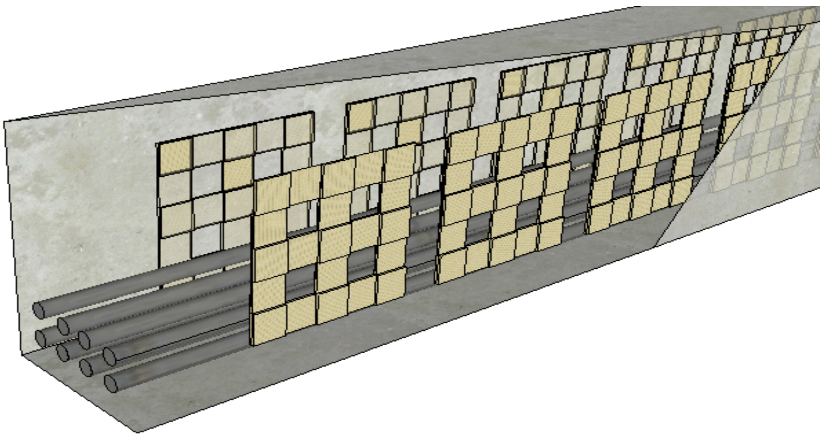


Figure 1: Reinforced concrete beam with GFRP plates

2 Experimental Program

2.1 Material

The standard design compressive strength of the concrete used in manufacturing the test specimens was 45 MPa and the mixing ratio shown in Table 1 was used. According to the standards in KS F 2405, the compressive strength was measured after aging for 28 days, and an average compressive strength of 42.7 MPa was confirmed. As for the tension reinforcements, deformed bars with a diameter of 29 mm were used, and as for the stirrups, deformed bars with a diameter of 10 mm were used. Table 2 shows the material properties of the reinforcement steel and GFRP used in the experiments.

Component	Value
Compressive Strength	45 MPa
Water Cement Ratio	31.4 %
Sand to Aggregate Ratio	45.5 %
Coarse Aggregate Size	25 mm
Slump	600 mm
Water Content	145 kg/m³
Cement Content	492 kg/m³
Fly Ash Content	43 kg/m³
Fine Aggregate Content	786 kg/m³
Coarse Aggregate Content	872 kg/m³
AE Water Reducer Content	6.42 kg/m³

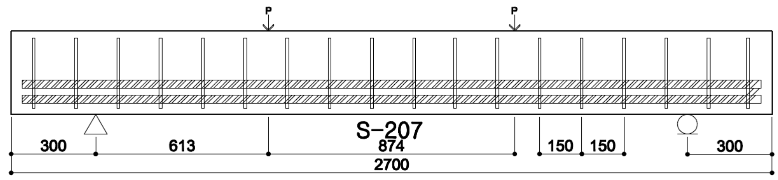
Table 1: Concrete mix proportions

	Diameter (mm)	Area (mm²)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)
Tensile Reinforcement	28.7	642.4	500	200
Stirrup	9.5	71.3	500	200
GFRP	-	-	480	50

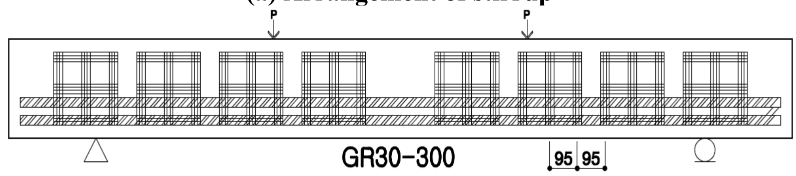
Table 2: Properties of steels & GFRP

2.2 Specimens, Plans, and Variables

5 test specimens shear reinforced with GFRP plates and 1 test specimen reinforced with steel stirrups were manufactured, respectively, and the shear test was conducted on a total of 6 test specimens. The general arrangement patterns of steel stirrups and GFRP plates are shown in Figure 2. As for the test specimens, the total length was 2,700 mm and the clear span was 2,100 mm, respectively, and the development length of 300 mm was placed from the point to both ends. The cover's thickness was set to 40 mm. As for the test specimens, the effective depth was 218.9 mm and the shear span to depth ratio was 2.8, respectively. All test specimens were designed to prevent flexural failure and to cause shear failure. The GFRP plate reinforcement area was the same and the effect of the thickness and the width of reinforcements were selected as the experimental variables. A survey of the test specimens is shown in Table 3.



(a) Arrangement of stirrup



(b) Arrangement of GFRP plate

Figure 2: Type of shear reinforcements

Specimens	f_y or f_{yt} (MPa)	Type of shear reinforcement	Width of reinforcement (mm)	Thickness of reinforcement (mm)	Reinforcement Area (mm²)
S-207	500	Steel	-	-	207
G15-45	480	GFRP	15	1.5	45
G30-300	480	GFRP	30	2.5	300
G25-300	480	GFRP	25	3	300
G50-300	480	GFRP	50	1.5	300
G30-525	480	GFRP	30	2.5	525
※ Specimens Notation –G15-45 G : Type of shear Reinforcements (G–Glass Fibre Reinforced Polymer, S–Steel) 15 : Width of Reinforcement (15mm, 25mm 30mm) 45 : Reinforcement Area (45mm², 207mm², 300mm², 525mm²)					

Table 3: Characteristics of specimens

2.3 Test Setup and Procedures

Test specimens were simply supported and subjected to load using a hydraulic UTM with the maximum capacity of 5000 kN at the average velocity of 5 kN/min. At load points 613 mm from both points, two points were subjected to load, and a linear variable differential transformer (LVDT) was installed at the bottom center of the test specimens to measure the specimens' vertical displacement. To grasp whether concrete reached the maximum strain, the strain of concrete was measured by attaching the strain gauges to the top and bottom of the center of the test specimens.

In addition, to determine the yield of the tension reinforcements, the strain of the reinforcement steel was measured by attaching strain gauges to the bottom center of the tension reinforcements. Strain gauges were attached to the axis of abscissa and the axis of ordinate of GFRP plates to measure the strain on the axis of abscissa and the axis of ordinate of GFRP plates. By using UCAM-500A, the data on load, deflection, and strain were collected. The test specimen settings and the locations at which strain gauges were attached are diagrammatized in Figure 3.

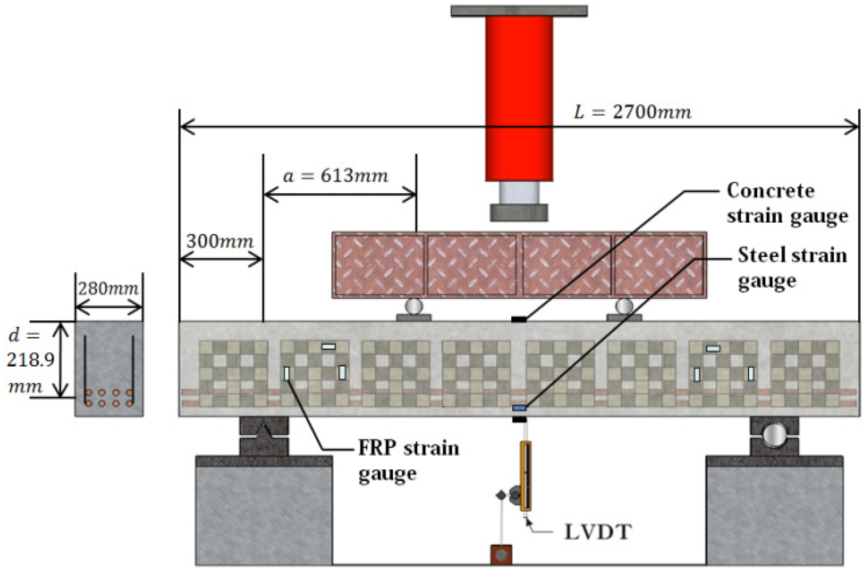


Figure 3: Specimens setting and strain gauge

3 Test Results

3.1 Failure Modes

In cases where GFRP plates were either fractured or not fractured according to the shear reinforcement area, there were two types of failure. The two types are presented in Figure 4 and Figure 5, respectively. Table 4 shows the results of experiments on reinforced concrete beams reinforced with GFRP plates. The case where fracture had occurred on GFRP plates was basic grid-type G15-45, where the shear strength of the experiments increased by approximately 99% in comparison to the design shear strength. This seems to be because GFRP plates exhibited adequate strength before their fracture, thus contributing to shear performance improvement. On the contrary, when GFRP plates had not been fractured, the experimental shear strength was similar to, or lower than, the design shear strength. This seems to be because, due to the high reinforcement area, brittle fracture caused by concrete crushing occurred first before GFRP plates reached the maximum strength.

Figure 4: Fracture of GFRP plates

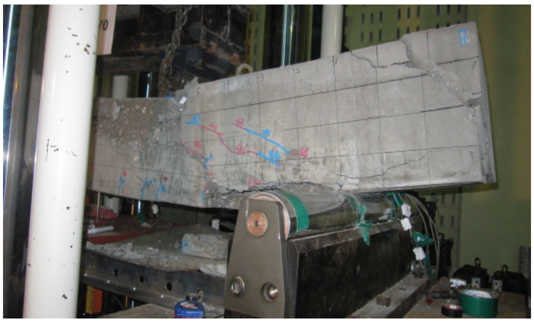


Figure 5: Shear compression failure

Specimens	V_{exp} (kN)	V_{cal} (kN)	Failure Mode
S-207	297.90	200.65	Shear
G15-45	236.39	118.64	Shear
G30-300	264.38	241.04	Shear
G25-300	227.60	241.04	Shear
G50-300	248.31	241.04	Shear
G30-525	300.22	349.04	Shear

Table 4: Test results

3.2 Load-Deflection

3.2.1 Load-Deflection of Steel Stirrups and GFRP Plates

The load-deflection curve of beams reinforced with GFRP plates and those reinforced with steel stirrups is presented in Figure 6. The reinforcement area of S-207 reinforced with steel stirrups was 207 mm², while that of G15-45 reinforced with GFRP plates was 45 mm². When the shear strength per unit reinforcement area was compared, beams reinforced with GFRP plates were 3.5 times superior to those reinforced with steel stirrups. Consequently, if GFRP plates exhibit adequate shear performance, they will be more effective than steel stirrups for improving shear performance.

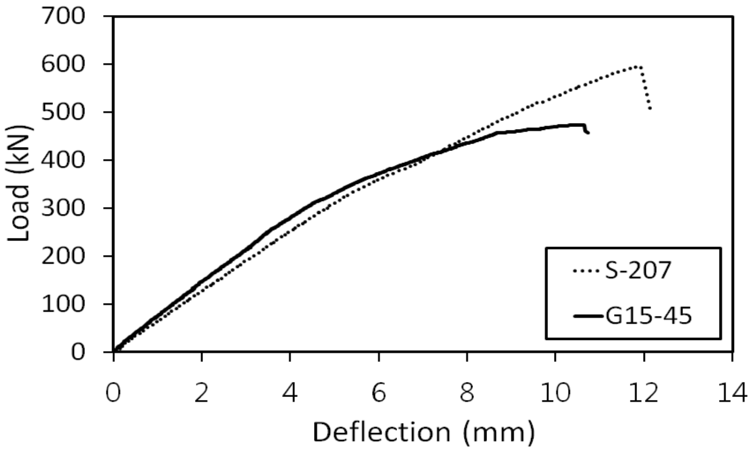


Figure 6: Load-deflection curve (Type of shear reinforcements)

3.2.2 Load-Deflection According to the Reinforcement Area of GFRP Plates

Characteristics due to the reinforcement area of GFRP plates are represented as a load-deflection curve in Figure 7. As the reinforcement area increased, so did the shear strength. When G30-300 and G30-525 test specimens, where all variables were identical and only the reinforcement area differed, were compared in terms of the shear strength, the shear strength increased by approximately 14% while the reinforcement area increased by approximately 75%,. Through this, it was possible to confirm that the increase in the shear strength was not as great as that in the reinforcement area. This seems to be because even when the reinforcement area increases, brittle fracture occurs due to concrete crushing before GFRP plates reach the maximum strength.

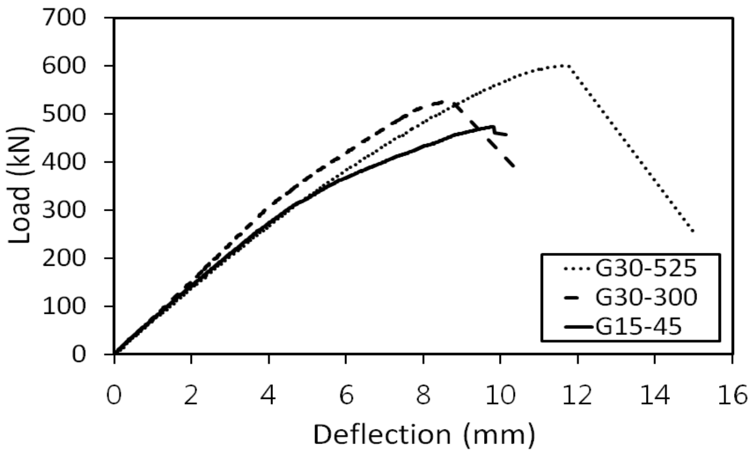


Figure 7: Load-deflection curve (Reinforcement area)

3.2.3 Load-Deflection According to the Width and the Thickness of GFRP Plates

The load-deflection curves for G30-300, G25-300, and G50-300 with the identical reinforcement area are presented in Figure 8. In Figure 8, all 3 test specimens exhibited identical behavior before the initial cracks occur. After the initial cracks, differences in the stiffness gradually developed, and, after the shear cracks, those differences became more pronounced. With G30-300 as the standard, in the case of G25-300, where the reinforcements decreased in the width but increased in the thickness, adequate strength was not exhibited before GFRP plates reached the maximum strength due to brittle fracture caused by concrete crushing. On the contrary, in the case of G50-300, where the reinforcements decreased in the thickness but increased in the width, adequate maximum strength was exhibited. Due to the fact that with the identical reinforcement area, GFRP plates failed to reach the maximum strength due to concrete crushing only in G25-300, an increase in the thickness was limited. In addition, as the width of the reinforcements increases, the contact surface that can resist shear cracks increases, so that it is more effective in checking shear cracks. Consequently, to secure high shear strength, it is more effective to secure the width of a certain scale that is greater than the thickness.

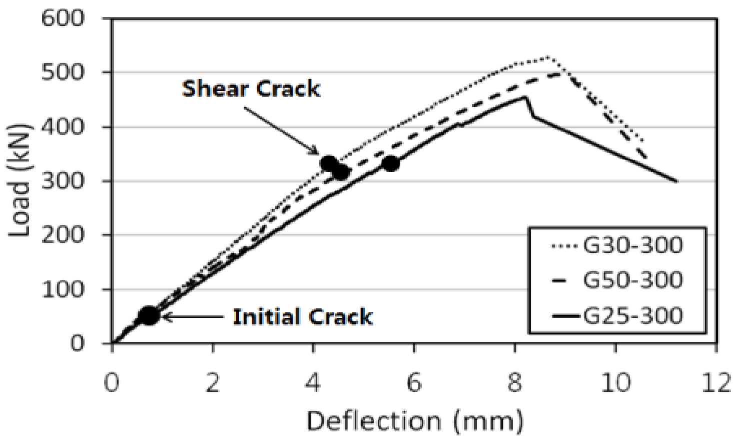


Figure 8: Load-deflection curve (Thickness & Width)

3.3 Strain

Figure 9 shows the strain of GFRP plates in intervals where shear cracks occurred. The strain of GFRP plates remained in the elastic state until the initial shear cracks occured, but as the working load increased, shear cracks occurred. Afterwards, the strain increased considerably at the point of the occurrence of shear cracks. Judging from the fact that, as shown in Figure 9, the strain of the axis of abscissa of GFRP plates is in the elastic state, the capacity to withstand shear force is negligible. Consequently, when GFRP plates are used as shear reinforcements, the axis of ordinate of GFRP plates seems to contribute to shear performance.

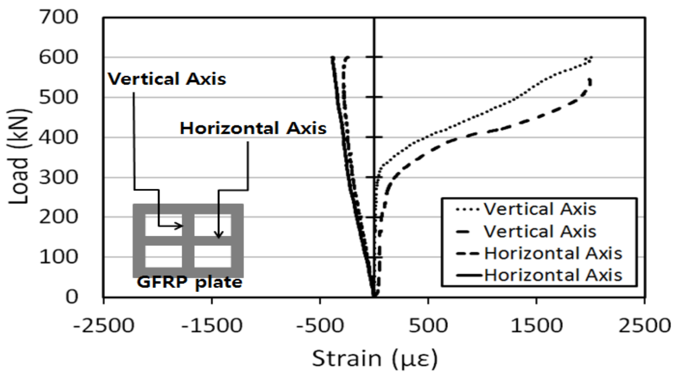


Figure 9: Load-strain curve (G30-525)

4 Conclusion

In the present study, to analyze the shear behaviour of reinforced concrete beams shear reinforced with embedded-type GFRP plates, which are replacement materials for steel stirrups, experiments were conducted with the GFRP reinforcement area and the effect of the thickness and width of reinforcements as the variables. The results were analyzed and led to the following conclusions:

1) When steel stirrups and GFRP plates were compared in terms of the shear strength per unit reinforcement area, beams reinforced with GFRP plates were 3.5 times better. When the shear strength was compared according to the reinforcement area of GFRP plates, as the reinforcement area increased, so did the shear strength.
2) When the effects of the thickness and the width of GFRP plates were analyzed, an increase in the width, rather than in the thickness of reinforcements, was more effective. This seems to be because an increase in the contact surface that can resist shear cracks is more effective for checking shear cracks.
3) When the axis of abscissa and the axis of ordinate of GFRP plates were compared in terms of the strain, judging from the fact that the axis of abscissa remained in the elastic state, there was nearly no effect on the capacity to withstand shear force. Consequently, the contribution of the axis of abscissa of GFRP plates to shear performance seems to be negligible.

Acknowledgements

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