Flexural Behavior of Concrete Beam Reinforced with GFRP Bars Compared to Concrete Beam Reinforced with Conventional Steel Reinforcements

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This research presents an experimental study on the flexural behavior of concrete beams reinforced with glass fiber-reinforced polymer (GFRP) bars and concrete beams reinforced with conventional steel reinforcements. A total of six full-scale beams (beam dimension of 150x250x2500 mm) reinforced with either steel or GFRP bars is investigated. The test variables include the tension reinforcement type (steel reinforcement grade [SD30 and SD40], GFRP bars). The flexural behavior including the load-deflection relationship, the flexural capacity, the stiffness, and mode of failure is investigated under a four-point loading test. The experimental results show that the maximum load of concrete reinforced with steel bars tended to increase as the steel strength increased. The maximum load of the concrete beams reinforced with GFRP bars was higher than the beams reinforced with steel bars up to 98%. However, the stiffness of the concrete beams reinforced with GFRP bars reduced when compared to the ones reinforced with steel bars.

Keywords: Concrete beams, Flexural behavior, Flexural strength, Composite beams, GFRP bar

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1. Introduction

Nowadays, a decrease in the durability of reinforced concrete structures caused by corrosion of steel reinforcement has become an essential problem widely in construction industries. Such a problem can significantly reduce the service life of the reinforced concrete structures. To repair and retrofit these damaging structures, the process of renovation is quite costly expensive. Several methods to strengthen the damaging structures can be employed to repair and retrofit these structures by using ferrocement [1–5], fiber-reinforced polymer (FRP) materials [6–19], steel jacket, or steel angle/strips [20–22], etc. An alternative and effective solution is that a reinforcement bar with other strong and durable materials can be employed instead of using a pure steel bar. The fiber-reinforced polymer (FRP) bar is a favorite reinforcement to replace steel bars, which has been routinely used in construction industries. There are several types of FRP bars made from fibers such as glass, carbon, or aramid and combined with resin either epoxy, polyester, or vinyl-ester [23]. Rafi et al. [24] has performed experimental testing of concrete beams reinforced with carbon fiber-reinforced polymer (CFRP) bars by focusing on the flexural behavior of these specimens in terms of stress-strain, load-carrying capacity, mode of failure, deflection behavior, and cracking pattern. Four specimens were tested with two different reinforcement materials, which are steel and CFRP bars. The CFRP-reinforced concrete beams were designed to be over-reinforced using a reinforcement ratio greater than a balanced reinforcement ratio. The mode failure on CFRP-reinforced concrete beams failed in compression. The CFRP bars show a good and consistent bond with the concrete with no sign of bond failure. Ashour and Habeeb [25] have reported the testing of three continuously and two simply supported concrete beams reinforced with CFRP bars in flexural capacity to investigate the use of CFRP bars as longitudinal reinforcement for continuous concrete beams. Ashour and Habeeb [25] found that all beams failed upon with the rupture of the CFRP bar. In addition, the use of CFRP reinforcement at the bottom layer of simply and continuously supported beams has a significant factor in improving the load capacity and controlling deflection while the use of CFRP reinforcement at the top layer had a slight effect or no effect on reducing the deflection of concrete beams. Zhang et al. [26] presented an experimental study of the flexural capacity of concrete beams reinforced with basalt fiber-reinforced polymer (BFRP) bars. Numerical simulations using the sectional analysis method and spatial FEM are performed. A total of seven specimens were designed by flexure to achieve different failure modes with one of these that was reinforced with steel bars. Therefore, six specimens were selected to be investigated in this study. The results showed that all the BFRP-reinforced concrete beams experienced either rupture or concrete crushing. Elgabbas et al. [27] performed an experimental study that aimed at investigating the flexural behavior and serviceability performance of concrete beams reinforced with ribbed BFRP bars. The study also evaluated the performance of BFRP-reinforced concrete beams compared to beams reinforced with steel bars. It could be observed from Elgabbas et al. [27] that axial stiffness of the flexural reinforcement had significantly influenced the behavior of concrete beams reinforced with BFRP bars. Ovitigala et al. [28] performed an experimental studied on the flexural properties of concrete beams reinforced with BFRP bars to investigate the serviceability requirements and ultimate load behavior of the beam. The beams were divided into three categories with different reinforcement ratios including low, moderate, and high. They found that all RC beam failed by concrete crushing on the compression face which were directly related to the reinforcement and balanced reinforcement ratio. Liu et al. [29] focused on flexural capacity and deflection of fiber-reinforced lightweight aggregate concrete beams reinforced with GFRP bars. In their study, the stress and strain conditions of FRP-reinforced lightweight aggregate concrete (LWC) beams with and without fibers at ultimate load level were specified to study the influence of steel fibers and FRP reinforcement ratio. Crushing of lightweight aggregates (LWAs) was observed at the fractured surface in the compression zone, owing to their low compressive strength. In addition, increasing the reinforcement ratio and adding steel fibers could restrain the deformation of the FRP bars, indicating their benefit achieved in flexural stiffness of the beams.

This research mainly focuses on glass fiber-reinforced polymer (GFRP) materials. The mechanical properties of the GFRP bars are better than those of steel bars in several ways. For example, the GFRP bars are more lightweight, nonmagnetic, non-conductive, and free from corrosion [30–38]. In addition, the tensile strength of the GFRP bar is also comparable to the steel bars since the GFRP bar is a brittle material with low elastic modulus and high yield point before becoming the limit state [31]. Nevertheless, reinforced concrete structure using GFRP bars might have a large deflection and crack width comparing to that using steel bars. This is due to the low modulus of elasticity of the GFRP bars. As a result, this research aims to investigate the flexural of a reinforced concrete beams with GFRP bars in order to properly propose the design methods for practical engineers. This paper presents the flexural behavior of full-scale concrete beams reinforced with either steel reinforcements or GFRP bars. A total of six beams were carried out. The parameters include steel grade (SD30 and SD40) and GFRP bars. In this paper, the flexural behaviors such as the load-deflection relationship, the flexural capacity, the stiffness, and mode of failures is examined from the experiment test. The comparisons between the experimental results of six tested beams with the different tension reinforcement types (e.g., steel reinforcement grade [SD30 and SD40], GFRP bars) are carried out to portray the effects and performances of reinforcements in the paper.

2. Experimental program

2.1. Tested specimens

A total of six full-scale beams were carried out. The flexural behavior of concrete reinforced with GFRP bars was compared to the convention reinforced concrete beams. The dimension of all beams was 150 mm in width, 250 mm in height, and 2500 mm in length. The span length was 2400 mm. Two grades of steel reinforcements (Grades SD30 and SD 40) were chosen to investigate the effect of the strength of steel reinforcements. The nominal yield strength of steel reinforcements for Grades SD30 and SD 40 were 300 and 400 MPa, respectively. Two beams (B-30(A) and B-30(B)) were reinforced with two deformed bars (Grade SD30) with a diameter of 12 mm (DB12) as a longitudinal reinforcement. Similarly, two beams (i.e., B-40(A) and B-40(B)) were reinforced with two deformed bars (Grade SD40) with a diameter of 12 mm (DB12) as a longitudinal reinforcement. Another two beams (B-FRP(A) and B-FRP(B)) were reinforced with two GFRP bars with a diameter of 12 mm (DB12) as a longitudinal reinforcement. To prevent shear failure, a round bar with a diameter of

9 mm (RB9) with a spacing of 100 mm was used. Fig. 1 shows the details of the tested specimens.

2.2. Material properties

All specimens were cast in the same concrete batch. In this study, the average compressive strength of three standard cylinders at 28 days was 42 MPa. For steel reinforcements, the measured elastic modulus, yield strength, and ultimate strength of 12-mm diameter (deformed bar, DB12) from three samples (for Grades SD30 and SD40) were (195 and 196 GPa), (517 and 717 MPa), and (582 and 780 MPa), respectively. The measured elastic modulus, yield strength, and ultimate strength of 9-mm diameter (round bar, RB9) were 220 GPa, 285 MPa, and 480 MPa, respectively. For GFRP bars (9-mm diameter), the measured elastic modulus and ultimate strength from three samples was 34.2 and 664 MPa, respectively. Table 1 shows the mechanical properties of reinforcement materials.

2.3. Test setup and instrumentation

After air curing, all beams were tested at ambient temperature. A typical test setup of the tested beam was shown in Fig. 2. All beams were simply supported by two steel rollers. During the static test, the load cell was used to measure the load. And, three Linear Variable Differential Transformers (LVDTs) were used to measure the deflections at two loading points and mid-span location. The load and displacements were recorded until the beam failed. The crack patterns and failure mode were observed.

3. Experimental results and discussion

3.1. Load and displacement relationships

Fig. 3 shows the relationships of load and midspan deflection relationship for beams. It was observed that the first cracking load was similar for all beams. The cracking load was about 10.0 kN. The stiffness of concrete beam reinforced with steel bars Grade 30 and Grade 40 were similar due to the similar value of elastic modulus. Obviously, the stiffness of concrete reinforced with GFRP bars was less than the one reinforced with steel bars. The reason was the elastic modulus of GFRP bars was less than the one of steel bar (see Table 1). The maximum load and the corresponding deflection of all beams are summarized in Table 2.

Using steel Grade SD30, the maximum load of beams B-30(A) and B-30(B) were 35.8 and 35.3 kN (average of 35.6 kN), respectively. The deflections corresponding to the maximum load of beams B-30(A) and B-30(B) were 50.0 and 60.0 mm (average of 55.0 millimeters), respectively.

Using steel Grade SD40, the maximum load of beams B-40(A) and B-40(B) were 58.6 and 61.8 kN (average of 60.2 kN), respectively. The deflections corresponding to the maximum load of beams B-40(A) and B-40(B) were 45.0 and 57.0 mm (average of 51.0 millimeters), respectively.

Using GFRP bars, the maximum load of beams B-GFRP(A) and B-GFRP(B) were 69.0 and 72.0 kN (average of 70.5 kN), respectively. The deflections corresponding to the maximum load of beams B-GFRP(A) and B-GFRP(B) were 55.0 and 49.5 mm (average of 52.3 millimeters), respectively.

Based on the test results, the maximum load of concrete reinforced with steel bars tended to increase as the steel strength increased. The maximum load of beams reinforced with steel Grade 40 (B-40) higher than the one with steel Grade 30 (B-30) by 69%. The concrete reinforced with GFRP bars (B-GFRP) increased the maximum load by 98 and 17 percent when compared to the B-30 and B-40, respectively.

3.2. Failure mode

Fig. 4 shows the failure mode of all beams. It was found that the concrete reinforced with steel (beams B-30(A), B-30(B). B-40(A), and B-40(B)) failed by tensile steel yielded followed by concrete crushing. For concrete reinforced with GFRP bars (beams B-GFRP(A) and B-GFRP(B), the concrete crushing was observed.

4. Conclusions

In this paper, the flexural behavior of concrete beams reinforced with GFRP bars compared to concrete beams reinforced with conventional steel reinforcements is examined. There are six full-scale beams, including four beams reinforced with steel reinforcements and two beams reinforced with GFRP bars, are tested and compared in order to portray the influence of different tension reinforcement types such as steel reinforcement grades (SD30 and SD40) and GFRP material. The flexural behaviors including the load-deflection response, the flexural strength, and mode of failure, are emphasized. Based on the experimental results, the following conclusions can be drawn:

1. The maximum load of concrete reinforced with steel bars tended to increase as the steel strength increased. The maximum load of beams increased up to 69%.

2. The maximum load of the concrete beams reinforced with GFRP bars was greater than that of the beams reinforced with steel bars with Grade SD30 and Grade SD40 about 98% and 17%, respectively.

3. The stiffness of the concrete beams reinforced with GFRP bars was smaller than that one reinforced with steel bars.

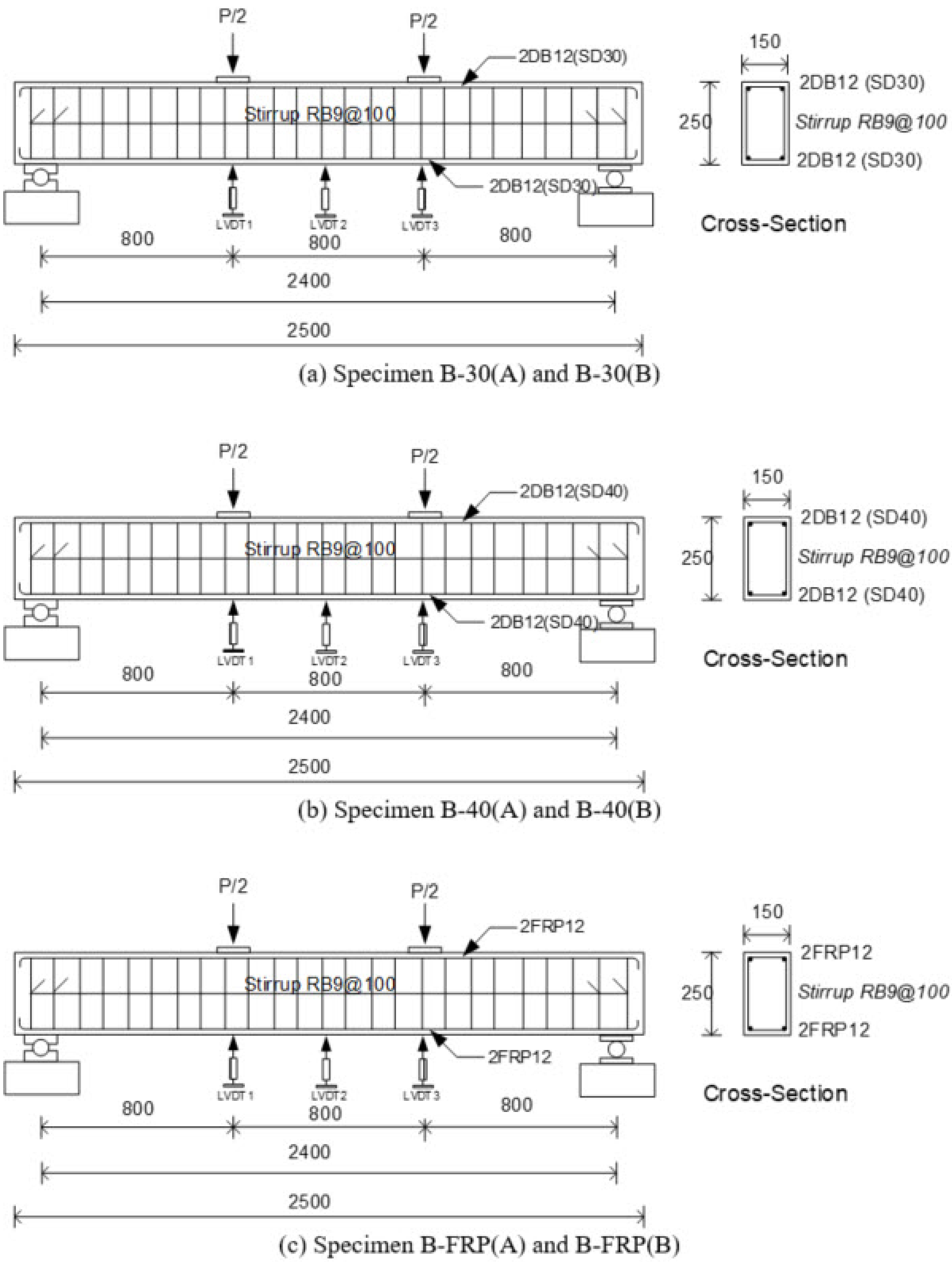

Fig. 1. Details of tested beams (dimensions in millimeter).

Table 1. Mechanical properties of reinforced materials.

Reinforcements	Elastic modulus (GPa)	Yield strength (MPa)	Ultimate strength (MPa)
Steel RB9 (Grade SR24)	220	285	480
Steel DB12 (Grade 30)	195	517	582
Steel DB12 (Grade 40)	196	717	780
GFRP bar	34.2	-	664

Table 2. Summary of the experimental results.

Beam no.	Tension reinforcement	Compression reinforcement	Maximum load (kN)	Maximum deflection* (mm)
B-30(A)	2-DB12 (SD30)	2-DB12 (SD30)	35.8	50.0
B-30(B)	2-DB12 (SD30)	2-DB12 (SD30)	35.3	60.0
B-40(A)	2-DB12 (SD40)	2-DB12 (SD40)	58.6	45.0
B-40(B)	2-DB12 (SD40)	2-DB12 (SD40)	61.8	57.0
B-GFRP(A)	2-GFRP12	2-GFRP12	69.0	55.0
B-GFRP(B)	2-GFRP12	2-GFRP12	72.0	45.9

*The deflection corresponding to the maximum load.

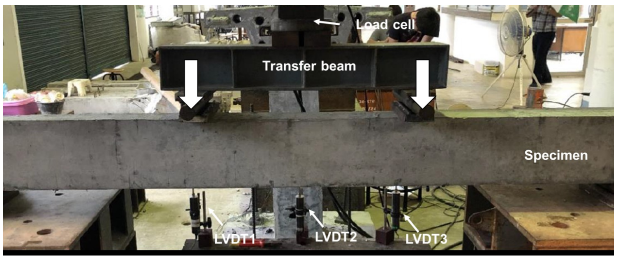

Fig. 2. Typical test setup.

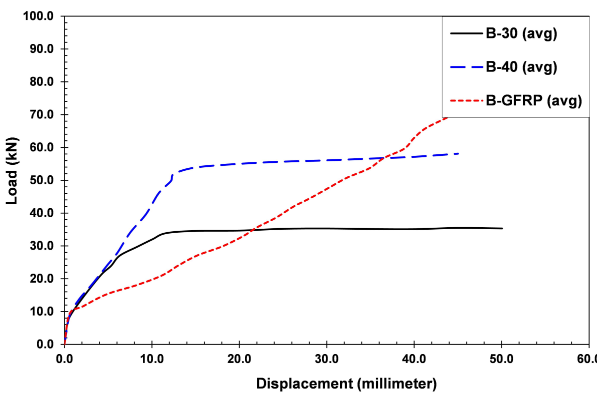

Fig. 3. Load and midspan deflection relationships of specimens.

4. The concrete crushing was observed in all beams.

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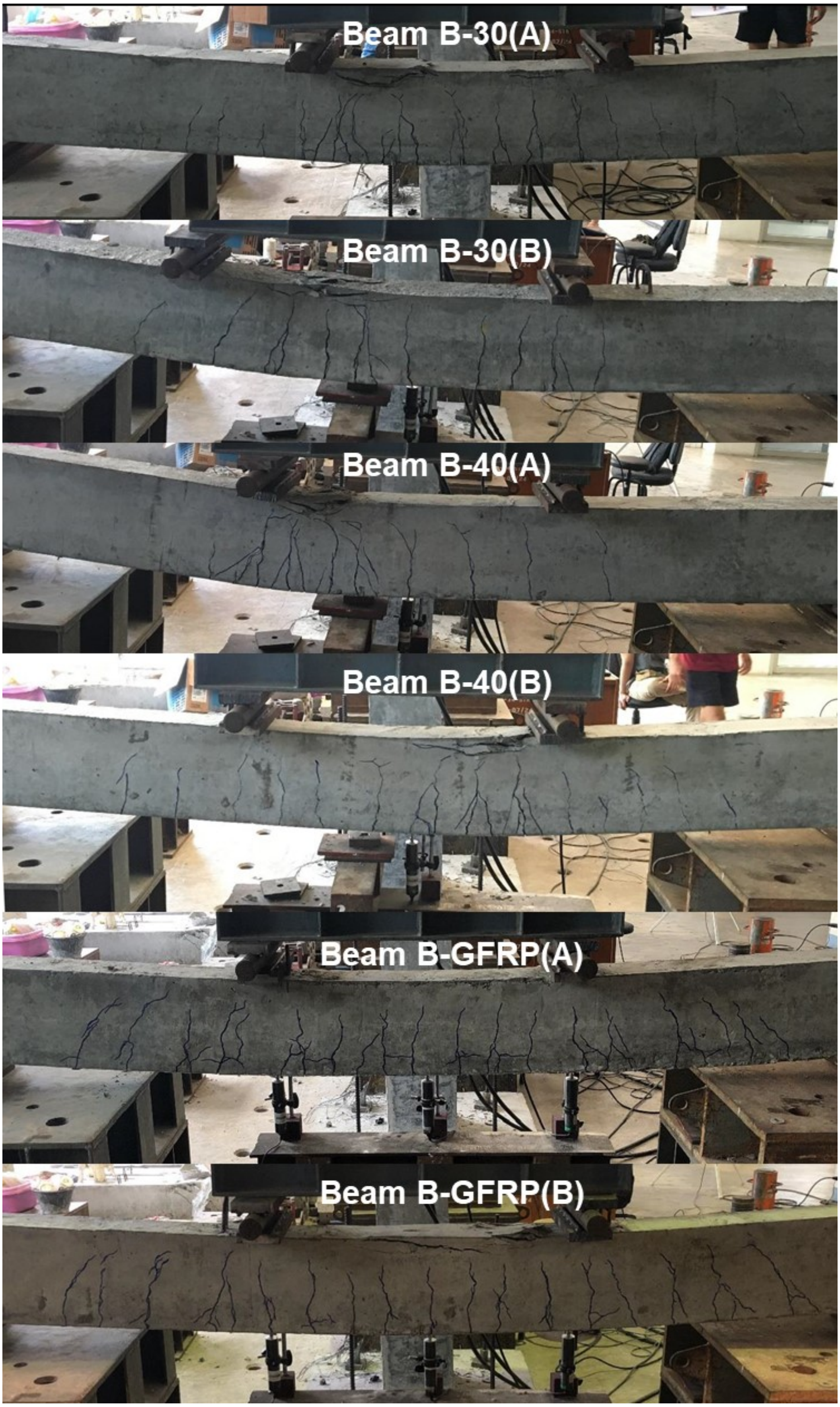

Fig. 4. Mode of failure.