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Performance of Laced Reinforced Concrete Beams with Different Ratios of Glass Fiber

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Keywords:
Glass fiber; Laced reinforced concrete; Load deflection; Crack width.

Highlights:

- Innovative longitudinal bending reinforcement with shear stirrups welded at 45° strengthened the beams.
- The impact of various glass fiber ratios on the properties of concrete.
- The maximum load displayed by the LRC beam was approximately twice that of a plain concrete beam.

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Abstract: This research experimentally studied the performance of laced reinforced concrete (LRC) beams with different ratios of glass fiber subjected to bending loads. These beams were reinforced by innovatively welding longitudinal bending reinforcement with shear stirrups at an angle of 45°. First, the effect of different glass fiber ratios on concrete properties, such as compressive and tensile strength, was studied. Then, four beams, a plain concrete beam, an LRC beam, and two LRC beams with 0.5% and 1% glass fiber were tested under bending. All beams had cross sections of 150×150 mm and a length of 1050 mm. The load deflection, stiffness, ductility, and crack width between these beams were compared. The experimental results showed good performance in terms of load and deflection curves for all LRC beams. The maximum load of the LRC beam was 34 kN with ductile behavior. LRC beams with glass fiber ratios had a maximum load of 35 kN; however, they were stiffer than LRC beams without fiber. Also, the LRC beam, compared to the plain concrete beam, showed an increase in strength about two times while the ductility improved about 1.6 to 2 times. Meanwhile, adding glass fiber to LRC beams had approximately the same strength and ductility as the LRC beams; however, it reduced the crack width from 2.63 mm to 0.92 mm.

الأداء الإنشائي للعتبات الخرسانية المسلحة LRC ذات النسب المختلفة للألياف الزجاجية

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الخلاصة

في هذا البحث تم إجراء دراسة تجريبية على أداء العتبات الخرسانية المسلحة ذات النسب المختلفة من ألياف الزجاجية المعرضة لأحمال الانحناء. لذلك، تم تسليح هذه العتبات بطريقة مبتكرة عن طريق لحام تقوية الانحناء الطولي بركاب القص بزاوية ٤٥ درجة. أولاً، تمت دراسة تأثير نسب ألياف الزجاجية المختلفة على خواص الخرسانة مثل مقاومة الضغط والشد. بعد ذلك، تم اختبار أربع العتبات الخرسانية كعتبة خرسانية عادية، وعتبة LRC، واثنين من العتبات LRC ذات ٠,٥٪ و١٪ ألياف الزجاجية تحت الانحناء حيث كانت جميع العتبات ذات مقطع عرضي ١٥٠ × ١٥٠ مم وطول ١٠٥٠ مم. بعد ذلك تم مقارنة انحراف الحمل والصلابة والمطيلية وعرض التشقق بين هذه العتبات. أظهرت النتائج التجريبية أداء جيد من حيث منحنيات الحمل والانحراف لجميع العتبات LRC. كان الحد الأقصى للحمل لعتبة LRC هو القوة القصوى البالغة ٣٤ كيلو نيوتن مع سلوك مطاوع. حيث أن العتبات LRC ذات نسب ألياف الزجاجية كان حملها الأقصى ٣٥ كيلو نيوتن ولكنها كانت أكثر صلابة من العتبات LRC بدون ألياف. كما أن العتبات LRC مقارنة مع العتبات الخرسانية العادية، فقد أظهرت زيادة في القوة حوالي مرتين بينما تحسنت الليونة حوالي ١,٦ إلى ٢ مرة. وفي الوقت نفسه، فإن إضافة ألياف الزجاجية إلى عتبات LRC لها نفس القوة والليونة تقريبًا لعتبات LRC ولكنها خفضت عرض الشق من ٢,٦٣ ملم إلى ٠,٩٢ ملم.

الكلمات الدالة: الياف الزجاجية، عتبات خرسانية LRC، منحنى الحمل -الانحراف، عرض الشق.

1.INTRODUCTION

Structural concrete beams require large quantities of reinforcement steel, so the reinforcement work must be conducted correctly, in economical quantities, and without errors. Therefore, implementing the concrete beam reinforcement must be considered of great importance. The literature has introduced many investigations to enhance the overall structural response of laced reinforcement concrete beams (LRC). In their 2023 study, Allawi et al. studied inclined LRC beams at 45° and 60° under a bending load test, obtaining better-bending resistance and durability than conventionally reinforced beams [1]. Sai Venkata Ramanjaneyulu and Papa Rao [2] examined the performance of reinforced concrete (RC) elements with Laced Reinforced Concrete (LRC). Four beam specimens were tested for their shear reinforcement arrangement. The results showed that the LRC arrangements adapted to the specimens achieved greater ultimate loads, decreased elements' resistance to sudden impact and blast loads, and reduced concrete spalling. The structural integrity and ductility of the elements improved more in LRC elements. The study compared the performance of the specimens with conventional and laced reinforcement under monotonic loading. Sudharsan et al. [3] compared the performance of Laced Reinforced Concrete (LRC) beams with conventional Reinforced Concrete (RC) beams in defense environments. The LRC beam performed better than the RC beam in terms of deformation, with support rotations of 4.7 and 2.43, respectively. The LRC beam is more ductile. Therefore, many researchers showed that the LRC beams had a better structural response under the influence of different loads and conditions [4, 5]. At the same time, another research study on combining two or more components to create a composite is familiar to the construction sector [6]. Natural fibers, such as straw, have been used for a long time to produce bricks to alter and enhance the brittle matrix characteristics [7]. The idea behind fiber-reinforced concrete is that when a matrix is stressed, it deforms and passes the load to the fibers [8]. However, the additional fibers must be robust and have strong bonding qualities to achieve significant gains in the composites' static, dynamic, and impact strength properties [9]. Steel, charcoal, glass, polypropylene, nylon, rayon, polyethylene, asbestos, cotton, coir, sisal, and other natural fibers have been used to create fibers in various forms and sizes [10]. From the above, it is necessary to study the behavior of laced reinforced concrete beams with added glass fiber. Therefore, the main objective of this research is to study the effect of bending on LRC beams containing different proportions of glass fibers reinforced innovatively by welding shear stirrups with longitudinal reinforcement.

2.EXPERIMENTAL PROGRAM

2.1.Materials

More rigorous guidelines for material selection, control, and component proportion are necessary to produce plain concrete efficiently. The mix design techniques must choose the best ratios, considering the properties of all utilized ingredients. The present investigation utilized the following materials:

1- Ordinary Portland: Its chemical composition and physical characteristics meet the requirements of the Iraqi standard specification (I.O.S.) (No. 5/2019) [11], as shown in Tables 1 and 2.
2- The gravel was cleaned and washed multiple times using municipal water and then left to dry in the open air. The coarse aggregate used in the experiment had a dry density of (1650) kg/m^3, which grades it

according to the Iraqi standard specification (I.Q.S.) No. 45/ 1984 [12] requirements. Figure 1 shows the grading of fine and coarse aggregate.

3- The Natural sand used in this study is from Al-Ukhaidher in Iraq. The fine aggregate's grading meets the Iraqi standard specifications (I.O.S.) No. 45 [12] requirements with a 1770 kg/m^3 dry density.

4- Ukrainian deformed bars with diameters of about 8 mm for longitudinal reinforcement and 6 mm for transverse reinforcement (stirrups). The properties of steel bars are shown in Table 3.

5- In the present study, glass fiber was added to the concrete mix to get less plastic shrinkage cracking, resulting in slower drying and bleeding rates as shown in Fig.2.

6- Tap water, also used for curing.

Table 1 Chemical Composition of the Cement.

Chemical composition	Percentage by weight
CaO	62.44
SiO_2	21.28
$Fe2O_3$	3.19
$Al2O_3$	5.32
MgO	1.61
SO_3	2.0
L.O.I	0.27

Table 2 Ordinary Portland Cement's Physical Properties.

Chemical Composition	Test Results	limit of I.Q.S (No.5 (2019)
Initial settling time (minutes)	194	minimum of 45 minutes
Final settling time (minutes)	247	maximum of 10 hours
Fineness (cm^2/gm) by Blaine method	2650	minimum of 2500
Compressive Strength at 3 days MPa	17	minimum of 15 (MPa)
Compressive Strength at 7 days MPa	30	minimum of 23 (MPa)
Compressive Strength at 7 days MPa	30	minimum of 23 (MPa)

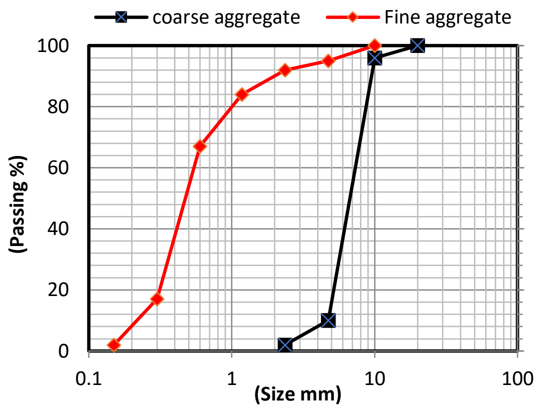


Fig. 1 Grading of Sand and Gravel.

Table 3 Properties of Steel Bars (*).

Size (mm)	Yield stress (MPa)	Ultimate stress (MPa)
Bar 8	410	540
Bar 6	340	520

*All data collected from the fourth dimension of contracting engineering procurement in Najaf.

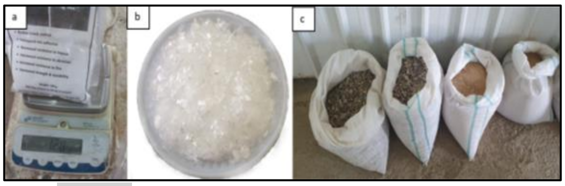


Fig. 2 (a) Weight of Fiber, (b) and (c) Preparing Materials.

2.2.The Beams Molds

The wood mold was used in building beams, as shown in Fig. 3, to get the required dimensions after casting concrete with accurate dimensions measurements to the design. The beams were cast with dimensions of 150 mm by 150 mm and a length of 1050 mm. The LRC beams were reinforced longitudinal steel and fixed stirrups by welding with precision in measurements and fixation after the LRC beams were cast in a laboratory at about 25°. Then, the samples were taken from the molds. The LRC beams were treated in a water tank for 28 days. Finally, the LRC beams as a plain concrete beam, an LRC beam, and two LRC beams with 0.5% and 1% glass fiber in weight per volume (kg per 1 m^3) were tested after 28 days (see Fig. 3).

Fig. 3 Preparing the Beam Molds.

2.3.Reinforcement Steel

Longitudinal reinforcement and stirrups were fabricated in the laboratory, as shown in Fig. 4, and were brought from the fourth dimension of contracting engineering procurement in Najaf. The specimens had an overall length of 1050 mm and an across-section of 150 mm in width by 150 mm in depth. These measurements were relatively close to the diameters of several beams [13, 14]. Additionally, the percentage of fiber used in the current investigation was consonant with several earlier investigations [15]. A machine shown in Fig. 5 was used for steel reinforcement works and produced longitudinal steel and fixed stirrups welded integrally with longitudinal steel with precision in measurements and fixation.

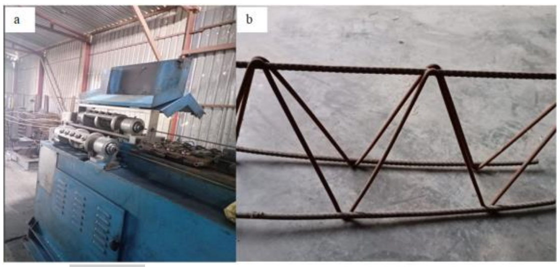


Fig. 4 (a) Machines for Reinforcing Longitudinal and Stirrups, (b) Output Reinforcement of Steel.

Fig. 5 Reinforcement of Steel.

2.4.Concrete Mix

For one cubic meter of concrete with a nominal maximum aggregate size of 10 mm and good workability, the concrete mix proportions and the amount of ingredients utilized were as follows: The mix proportions for cement, sand, and coarse aggregates per 50 kg of cement were 1: 1.70: 2.6, respectively, according to the standard mix for common structural concrete. The mix design for the experimental work was prepared according to the proportion of glass fibers in weight per volume (1 kg per 1 m^3), as tabulated in Table 4.

Table 4 Quantity of Concrete Per 1 m^3 of Concrete Mix.

Item	Value
Cement content	400 kg
Fine aggregate	680 kg
Coarse aggregate	1040 kg
Water/cement ratio	0.5
Glass fiber	0.5%, 0.75 and 1.0%

2.5.Test Specimens

The testing program collected data on slump, the compressive strength of hardened concrete (measured using 150×150×150 mm cubes), splitting-tensile strength (measured on three-cylinder specimens of 100×200 mm) at 28 days of age, and load curves with deformation for beams (measured using 1050×150×150 mm). Figure 6 shows the details of casting concrete.

Fig. 6 Cast of Specimens.

3.RESULTS AND DISCUSSION

3.1.Slump Test

According to ASTM C143 [16], the slump test evaluated each fresh concrete mixture's workability. The slump test showed that the fibers significantly impacted the consistency and workability of concrete. The results showed that the workability of concrete deteriorated and grew stiffer at the most outstanding fiber content, as illustrated in Fig. 7 when the fiber percent was increased. At the same time, the value of the (w/c) ratio remained constant. The decrease in workability was linked to the fibers and prevented items from moving about in the mixture since they were longer than the aggregate.

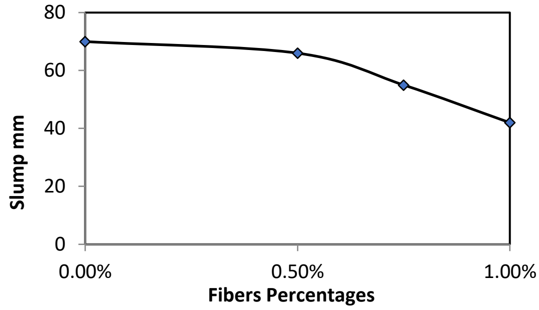


Fig. 7 Fibers' Impact on the Workability.

3.2.Compressive Strength

Concrete Cube Sample Compressive Strength Tests (N/mm2) results illustrated in Fig. 8, which was 28-day compressive strength. It can be noticed that the fiber inclusion increased compressive strength.

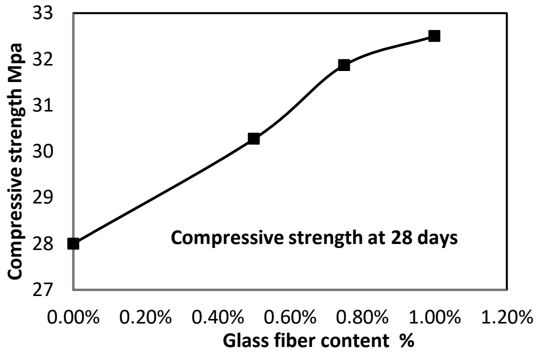


Fig. 8 Fibers' Impact on 28-day Compressive Strength of Cubes.

3.3.Splitting Tensile Strength

As illustrated in Fig. 9, the splitting tensile strength of a typical cylinder (150×300 mm) was computed at 28 days for all fiber percentages following ASTM C496 [17]. The splitting test results of concrete were used to evaluate its tensile strength. Unlike the control sample, splitting strength often improved. According to the splitting strength test results, adding glass fiber enhanced splitting strength compared to the control sample, which is consistent with Ahmad et al. [18].

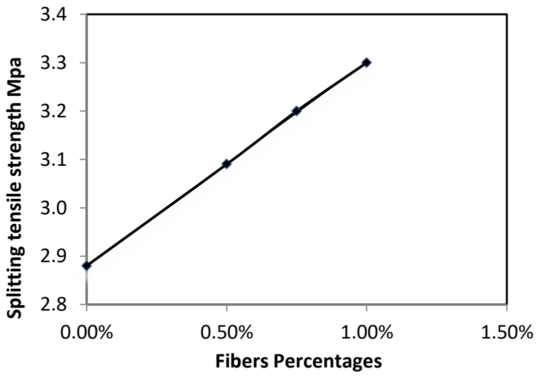


Fig. 9 28 Days Splitting Test Results.

3.4.Behavior of Laced Reinforced Concrete Beams

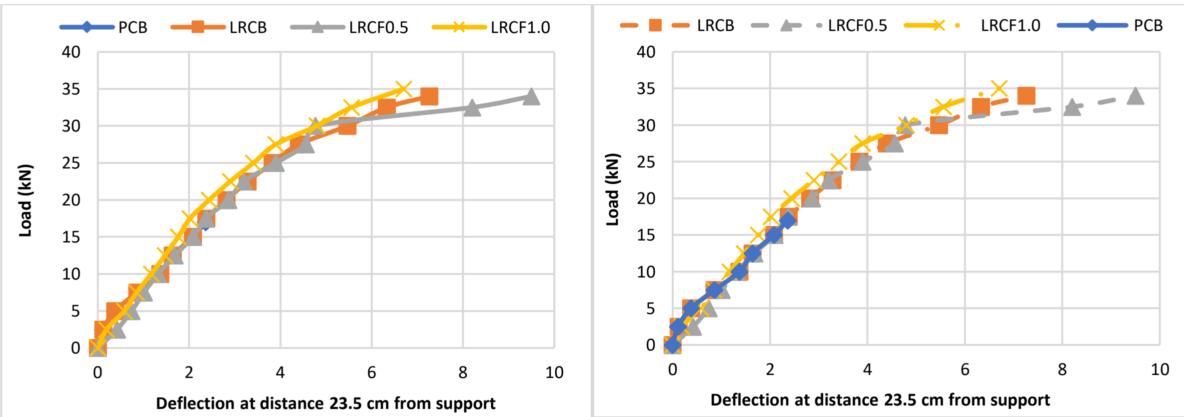
This paper presents the bending occurring at different beam locations with increasing loads, clearly affected by the innovative steel reinforcement. Therefore, two longitudinal steel reinforcements with a diameter of 8 mm were in the tension zone, and one bar was in the compression zone. Meanwhile, the shear reinforcements were inclined at an angle of 45° from the plane of the longitudinal reinforcement, and it was fixed by welding using a special machine.

3.4.1.Load Deflection Curve of Laced Reinforced Concrete Beams

Through experimental investigation, the performance of laced reinforced concrete beams containing different ratios of glass fibers (LRCF0.5 and LRCF1.0) was compared with laced reinforced concrete (LRCB) and plain concrete beams (PCB) without fibers subjected to flexural loads. The experimental results for all LRC beams showed good performance in load curves with deformation, as shown in Fig.10. The LRC beams behaved better and were more ductile than the plain concrete beams. However, the LRC beams containing fiber ratios had slightly better strength and more stiffness than the LRC beams without fiber. Therefore, the stiffness was the force of a beam against deformation, while the ductility defines $\Delta u/\Delta y$ as the Δu ultimate displacement to Δy yield displacement. As for the maximum load, 17, 34, 34, and 35 kN for PCB, LRCB, LRCF0.5, and LRCF1.0 beams, respectively, are present in Tables 5 and 6. The LRC beam has good strength and ductility about two times compared to a plain concrete beam. The LRC beams with glass fiber had more stiffness glass fiber. Thus, a clear improvement has been found in the behavior of laced reinforcement concrete beams with glass fiber.

3.4.2.Load Crack Relation of Laced Reinforced Concrete Beams

The present research studied the width of the crack occurring in the beam due to the loads. Figure 11 shows the important effect of the innovative reinforcement on giving ductile behavior to the LRC beams. It was found that any glass fiber added to the concrete mixtures in different proportions effectively reduced the width of the cracks in those beams. The importance of laced reinforcement was also noted by reducing the crack width with increasing loads and limiting the crack width using fiber in the laced reinforcement concrete beams, reducing the crack width from 2.63 mm to 0.92 mm, as presented in Table 7. Thus, the behavior of laced reinforcement concrete beams with glass fiber clearly improved. Initially, the micro-cracks appeared in the tension area of the middle part of the bending load zone. With increasing loading, these cracks became more expansive and expanded to the compressive area. Some shear cracks between the loading point and the support were also noticed. Thus, laced reinforcement is important because it reduces the crack width by increasing loads and limits the crack width using fiber in the laced reinforcement concrete beams. Thus, a clear improvement has been found in the behavior of laced reinforcement concrete beams with glass fiber. The LRC beams' failure modes were almost similar and had the same type of shear-flexural failure. The cracking stages were tracked with the loads gradually increasing, as shown in Fig. 12.



(a) (b)

Fig. 10 (a) Load-Deflection at a Distance of 23.5 cm from Support, (b) Load-Deflection at a Distance of 47 cm from Support.

Table 5 Effect Load on Deflection at a Distance of 23.5 cm of Laced Reinforced Concrete Beams.

Beam code	Pcr (kN)	Deflection mm	Pu kN	Deflection mm	Stiffness N/mm	Ductility mm/mm
PCB	7.5	0.86	17	2.36	7203.38	2.744
LRCB	12.5	1.64	34	7.26	4683.19	4.426
LRCF0.5	15..0	2.09	34	9.5	3578.94	4.545
LRCF1.0	15.0	1.76	35	6.7	5223.88	3.806

Table 6 Effect Load on Deflection at a Distance of 47 cm of Laced Reinforced Concrete Beams.

Beam code	Pcr (kN)	Deflection mm	Pu kN	Deflection mm	Stiffness N/mm	Ductility mm/mm
PCB	7.5	1.11	17	2.88	5902.7	2.594
LRCB	12.5	2.13	34	11.3	3008.84	5.305
LRCF0.5	15..0	3.11	34	15.4	2207.79	4.951
LRCF1.0	15.0	2.33	35	10.3	3398.05	4.478

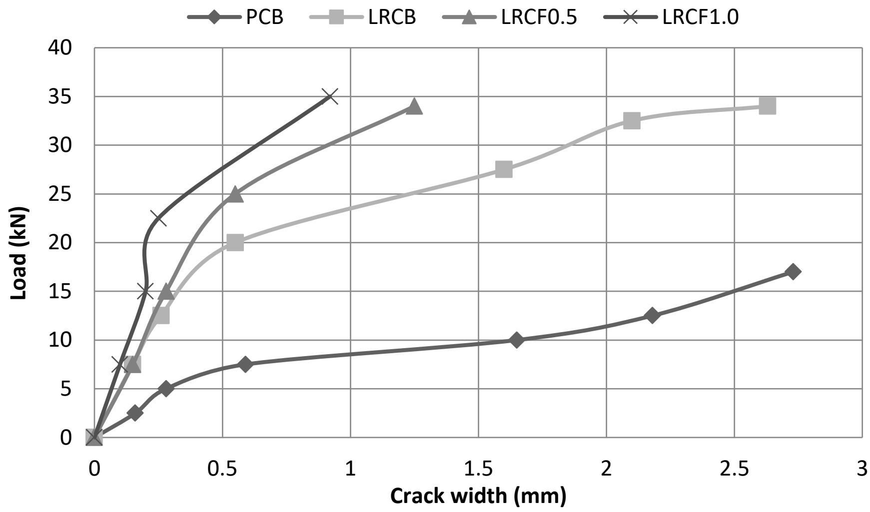


Fig. 11 Load-Crack Width Curve.

Table 7 Effect of Load on Crack Width of Laced Reinforced Concrete Beams.

Beam code	Pcr kN	Crack Width mm	Pu kN	Crack Width mm
PCB	7.5	0.59	17	2.73
LRCB	12.5	0.26	34	2.63
LRCF0.5	15..0	0.28	34	1.25
LRCF1.0	15.0	0.2	35	0.92

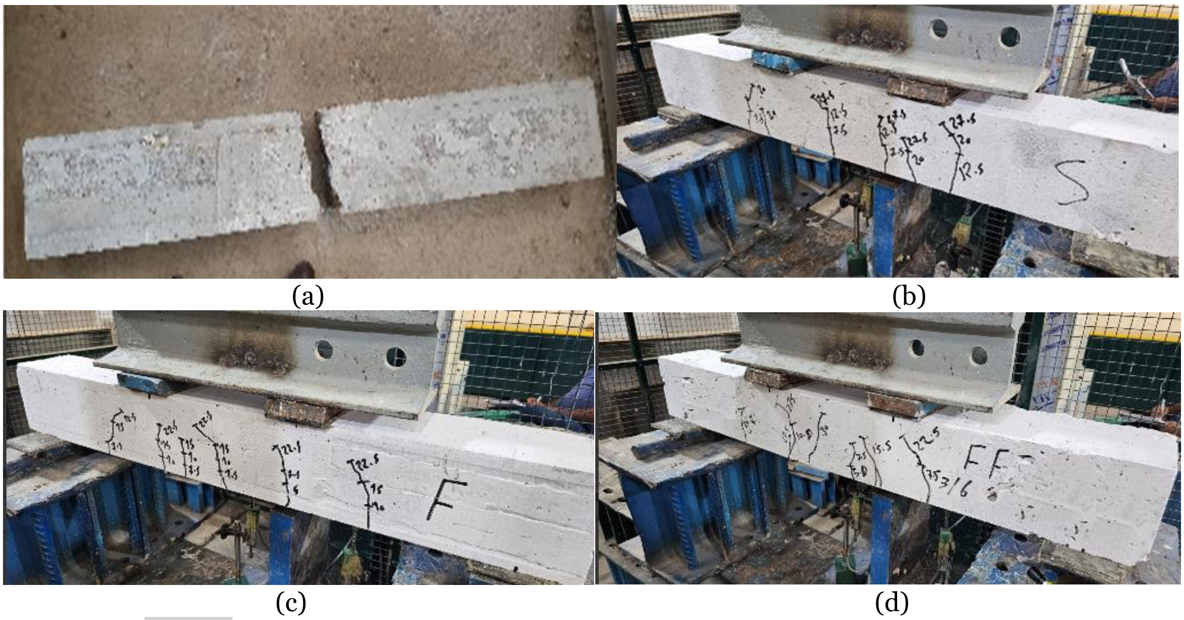


Fig. 12 (a) Plain Concrete Beam (PCB), (b) Laced Reinforced Concrete Beam (LRCB), (c) Laced Reinforced Concrete Beam with Fiber 0.5 % Fiber (LRCF0.5), (d) Laced Reinforced Concrete Beam with Fiber 1 % Fiber (LRCF1.0).

4.CONCLUSIONS

From the preceding, the following can be concluded:

- The LRC beam showed a maximum load of about 2 times that of a plain concrete beam.
- The LRC beam showed about 1.6 to 2 times the ductility of a plain concrete beam.
- LRC beams with 1% glass fiber presented more bearing and stiffness than LRC beams.
- A good improvement has been found in the beams' behavior by adding glass fiber to laced reinforcement concrete beams, which reduced the crack width from 2.63 mm to 0.92 mm.

- According to the results above, produced longitudinal steel and fixed stirrups by welding, the amount of the steel reinforcement could be reduced with speed in implementation, dependable. It might be used as reinforced in structural members as an alternative to current methods.

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