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Research Article

Strengthening of flexural behavior of reinforced concrete beams by using hybrid fibers: experimental and analytical study

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Abstract: The research investigates the flexural behavior of reinforced concrete (RC) beams by incorporating hybrid fibers (a combination of glass and steel fibers). Ten specimens measuring 150 mm x 200 mm x 1500 mm were cast and tested under two-point loading. The specimens were divided into three groups, each containing three specimens. Additionally, a control specimen was examined. Comparing the strength performance of each group to the control specimen revealed that the hybrid fiber-reinforced beams exhibited increased strength. The optimal hybrid fiber composition was 0.4% steel and 0.2% glass fiber. Similarly, the optimal steel and glass fiber percentages were both 0.4%. Experimental results showed that the load-carrying capacity improved significantly: 28.80% with glass fiber, 63.74% with steel fiber, and 79.23% with hybrid fiber compared to conventional RC beams. The study evaluated load-carrying capacity, load deflection, ductility, stiffness, and failure modes of RC beams. An analytical study using finite element modelling was conducted, and the analytical results were compared to experimental findings. Fundamental statistical values included mean, standard deviation, and coefficient of variation for load and deflection. Finite element analysis (FEA) was employed to predict experimental outcomes, and the analytical results closely correlated with experimental data. The load mean, standard deviation and coefficient of variation were 0.98, 0.01, and 0.56, respectively. The deflection exhibited corresponding values of 0.97, 0.01, and 1.41. The graphical abstract of the present study is displayed in Figure 1.

Keywords: Hybrid fibers, fiber-reinforced concrete beam, steel fiber, glass fiber, load-deflection, ductility.

1. Introduction

The flexural behavior of reinforced concrete beams can be enhanced by incorporating various fibers. These fibers are added to concrete to improve its tensile strength, ductility, and resistance to cracking. Steel and glass fibers are commonly used and extensively studied in research. Steel fibers are renowned for their high strength and durability, while glass fibers are known for their stiffness and lightweight properties. Numerous experimental studies have explored the use of steel fibers (Tran et al., 2019; Anvari et al., 2021; Fattouh et al., 2023; Ghalehnovi et al., 2021; Chen et al., 2021; Abbass et al., 2019; Xu et al., 2019; Cardoso et al., 2019; Raju et al., 2020; Fallah-Valukolaee et al., 2022) and hybrid fibers (Sathish Kumar et al., 2022). Researchers have investigated the flexural behavior of steel fiber-reinforced concrete beams using both high-strength concrete and high-performance concrete (Gümüş & Arslan, 2019; Sumathi & Mohan, 2019; Praveenkumar & Sankarasubramanian, 2019). Additionally, there have been experimental and analytical studies (Bywalski et al., 2021) and examinations of experimental and numerical analyses (Tahenni et al., 2021). Theoretical predictions have also been made (Zhao et al., 2021). Furthermore, the flexural behavior of concrete beams has been evaluated for strength properties using recycled aggregates rev(El-Sayed, 2019; Ghalehnovi et al., 2020; Anike et al., 2022).

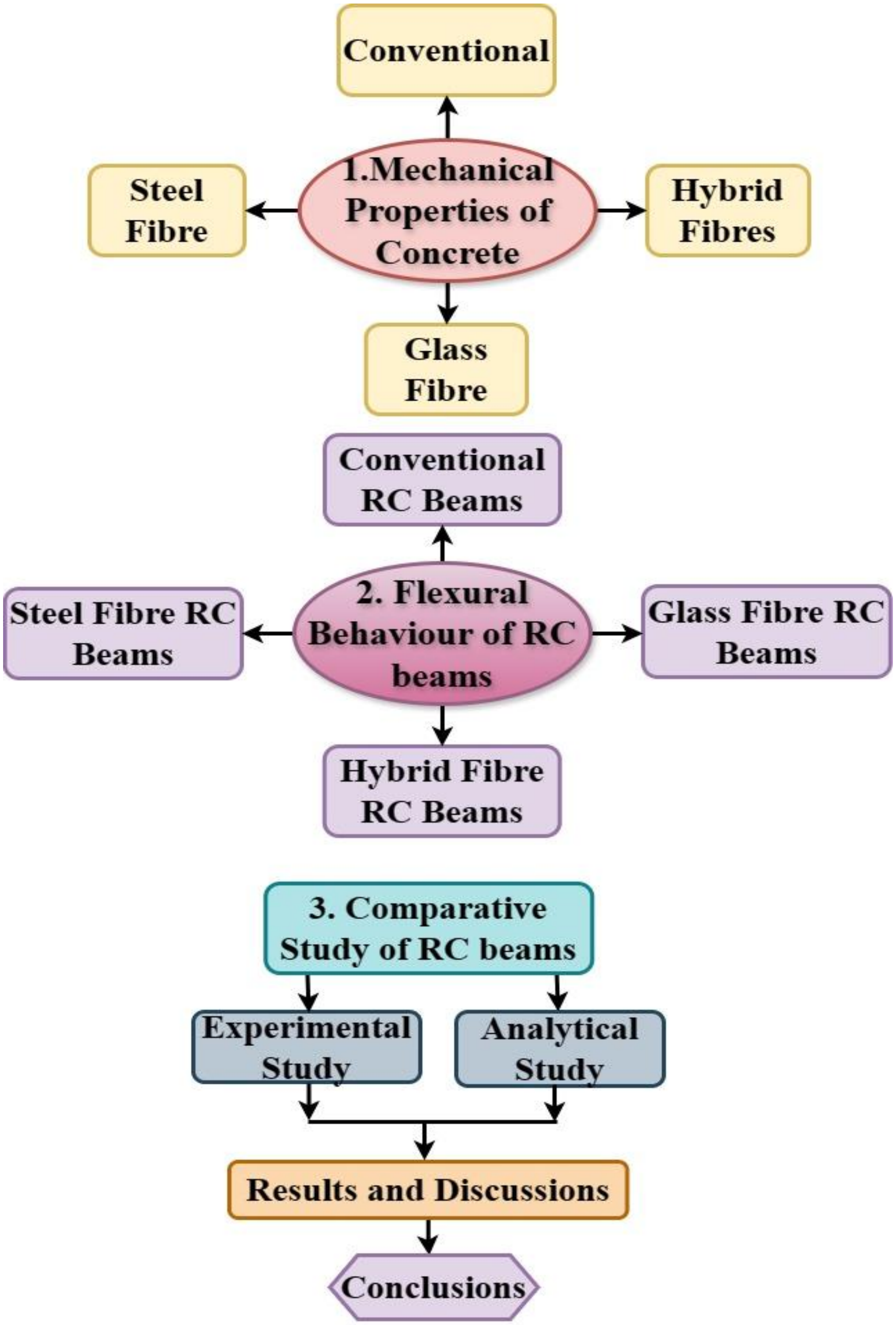


Figure 1. Graphical abstract for this research work.

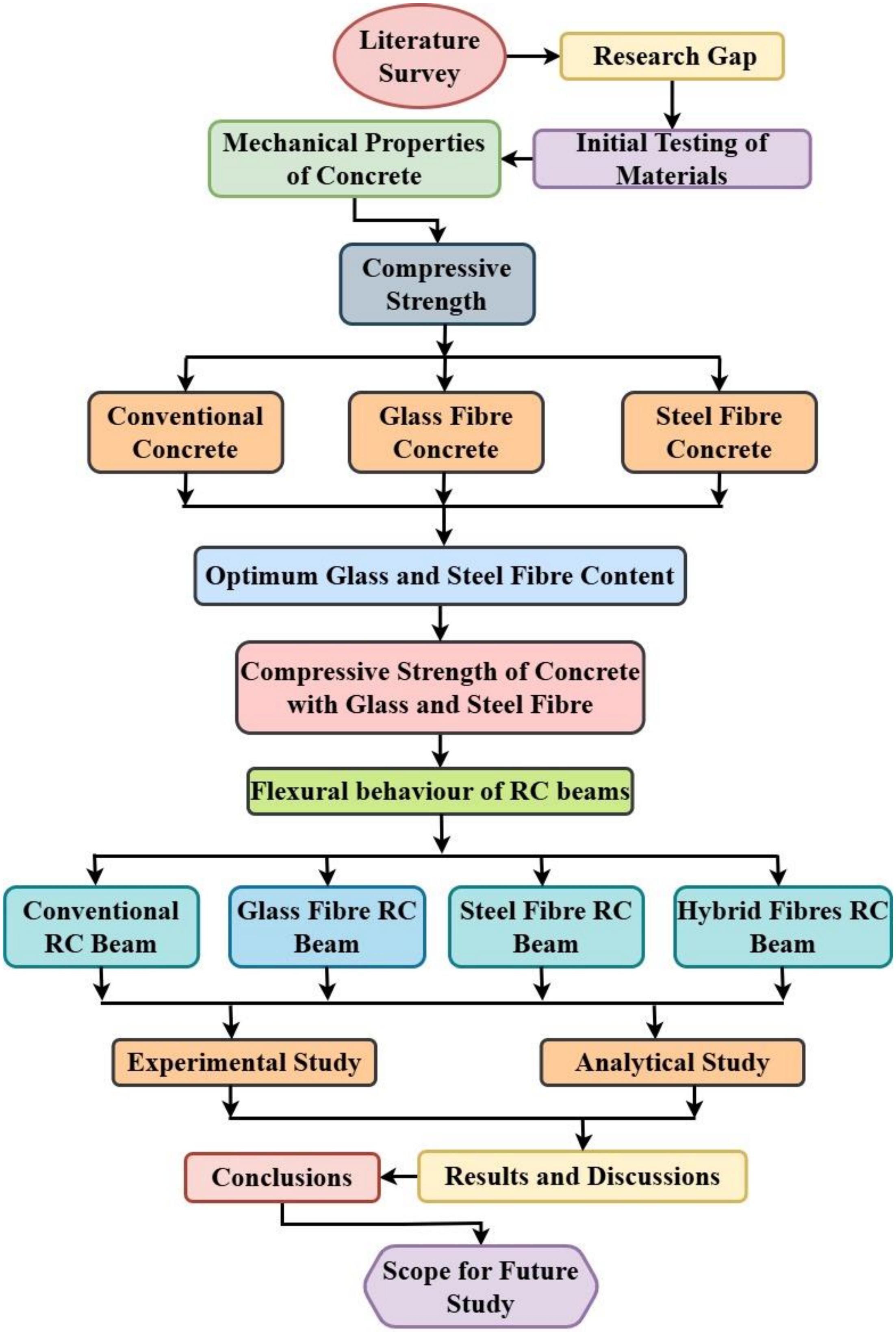


Figure 2. Flow chart for future research work.

(Tran et al., 2019) investigated the behavior of geopolymer concrete beams compared to ordinary Portland concrete (OPC) beams. They explored the impact of volume fraction and fiber length on the flexural behavior of geopolymer concrete. The experimental results revealed that geopolymer concrete beams reinforced with steel fibers significantly enhance cracking resistance, serviceability, and ductility compared to reference beams. Additionally, the load capacity of geopolymer concrete beams increases with a steel fiber volume fraction of up to 0.75%. (Anvari et al., 2021) Report the eight reinforced concrete beams with varying transverse reinforcement spacings. They analyzed both shear and flexural failures in a four-point bending test. The study demonstrated that concrete jacketing is an effective method for strengthening recycled aggregate concrete beams. Furthermore, the ductility ratio increased significantly when steel fibers were incorporated into recycled aggregate concrete, resulting in 160%, 24%, and 146% improvements for different scenarios. (Fattouh et al., 2023) Investigated the use of steel fibers and silica fume in concrete pavement slabs. Their findings indicated that incorporating these materials improves the flexural behavior of the slabs. Specifically, adding steel fibers and silica fume increased the ductility ratio by 50% and the flexural strength by 30%. Bywalski et al. (2020) reported that steel fibers and silica fume can enhance the mechanical properties of concrete pavement slabs, leading to increased service life. They also validated a numerical model using the finite element method, comparing the obtained FEM results with experimental data based on assumed criteria. (Raju et al., 2020) conducted experiments on 12 Steel fiber-reinforced self-compacting SFRSCC beams (size: 100 mm × 150 mm × 1200 mm) with a fiber volume fraction of 1.5%. These beams were tested under four-point bending conditions to evaluate their flexural behavior. The test specimens were cast at varying flow heights: 500 mm, 1000 mm, and 1500 mm. The subsequent test results were analyzed, considering load-deflection behavior, crack patterns, and the orientation and distribution of fibers.

The researchers conducted an experimental and numerical investigation to explore the impact of steel fibers on the deflection behaviors and stiffness contribution in tensioned concrete beams without stirrups. They fabricated 12 reinforced concrete beams measuring 1200 mm × 100 mm × 150 mm with a 1.5% fiber volume fraction. These beams were subjected to four-point bending tests using varying lengths of steel fibers (30 mm, 40 mm, and 50 mm). The study analyzed load-deflection behaviors, crack patterns, and failure modes. Adding steel fibers improved the deflection behaviors of reinforced concrete beams without stirrups, including steel fibers, reduced crack width, and enhanced ductility in the reinforced concrete beams (Tahenni et al., 2021). GFRP bars prevent corrosion and improve structural strength. Compared to traditional steel reinforcement, GFRP rebar is lighter (weighing only 1/4th) while maintaining twice the tensile strength. GFRP bars are non-conductive to electricity and heat, making them suitable for applications in power generation plants and scientific facilities. In summary, the research underscores the suitability of GFRP-reinforced concrete beams for durable and corrosion-resistant structures, with the proposed method aligning well with experimental outcomes, thus validating the effectiveness of GFRP bars in enhancing concrete performance (Sasikumar & Manju 2024).

The study's primary objective is to enhance the flexural behaviors of reinforced concrete beams by incorporating steel, glass, and hybrid fibers. Ten RC beams were cast and evaluated for their load-carrying capacity, load-deflection characteristics, stiffness, ductility, and failure modes. Additionally, the researchers developed a finite element model using ANSYS software. The analytical results were then compared to the experimental findings, revealing a strong correlation between the predicted and actual outcomes. The research process for the current study is represented in Figure 2.

2. Experimental program

2.1. *Materials*

In this study, ten concrete beams (B40-CS, B40-GF0.2, B40-GF0.4, B40-GF0.6, B40-SF0.2, B40-SF0.4, B40-SF0.6, B40-GF0.1-SF0.1, B40-GF0.2-SF0.1, and B40-GF0.3-SF0.1) were investigated. This study used OPC 53 grade cement, and its physical and chemical properties are reported in Tables 1 and 2. Cement, aggregates, superplasticizers, glass fiber, and steel fiber were added to the concrete mixtures, and the mix proportions are listed in Table 3. The target compressive strength of concrete was chosen as M40, and the characteristic compressive strength of concrete at 28 days is presented in Table 3. The strength properties of the concrete improved by adding the fiber up to the optimum fiber content. However, beyond this optimum content, the strength decreased due to improper bonding between the cement paste, aggregates, and fibers (Sasikumar et al., 2022). The deformed steel bars used and tested in the universal testing machine (400kN) are illustrated in Figure 3. The mechanical properties studied, including the ultimate stress, young's modulus, and strain, are shown in Table 4.

Table 1. Physical properties of the cement.

Properties of cement	Test values
Specific gravity	3.10
Consistency (%)	31.24
Initial setting time (minutes)	42
Final setting time (minutes)	286
Fineness modulus (%)	4.32

Table 2. Chemical properties of the cement.

Properties	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	LOI (%)
Cement	23.54	5.06	3.67	63.25	2.58	2.69	0.70	0.62

Table 3. Compressive strength and mix proportion of the concrete per $1m^3$ in kg/m^3.

Specimen ID	CS (MPa)	SF (%)	GF (%)	Cement	FA	CA	Water content	W/c	SP
B40-CS	43.26	-	-	412	642	1228	148	0.36	4.12
B40-GF0.2	45.18	-	0.2	412	642	1228	148	0.36	4.12
B40-GF0.4	48.62	-	0.4	412	642	1228	148	0.36	4.12
B40-GF0.6	47.54	-	0.6	412	642	1228	148	0.36	4.12
B40-SF0.2	47.25	0.2	-	412	642	1228	148	0.36	4.12
B40-SF0.4	52.67	0.4	-	412	642	1228	148	0.36	4.12
B40-SF0.6	51.74	0.6	-	412	642	1228	148	0.36	4.12
B40-GF0.1-SF0.4	46.17	0.1	0.1	412	642	1228	148	0.36	4.12
B40-GF0.2-SF0.4	49.68	0.1	0.2	412	642	1228	148	0.36	4.12
B40-GF0.3-SF0.4	49.24	0.1	0.3	412	642	1228	148	0.36	4.12

Note: CS, SF, GF, FA, CA and SP are called Compressive strength, steel fiber, glass fiber, fine aggregate, coarse aggregate, and superplasticizer.

Table 4. Mechanical properties of the steel bar.

Type	Diameter (mm)	Ultimate load (kN)	Ultimate stress (MPa)	Young's modulus (GPa)	Strain
Deformed Steel bar	10	44.16	562.26	200	0.0022
	8	27.45	546.10	210	0.0026
	6	15.20	537.59	206	0.0020

Figure 3. Tensile test on steel rebars.

The fine and coarse aggregates were sourced locally from the market. The grain distributions adhere to the specifications outlined in IS: 383 - 2016. Based on the experimental study, both the fine and coarse aggregates meet the grading limits for Zone I and II, as illustrated in Figures 4 and 5.

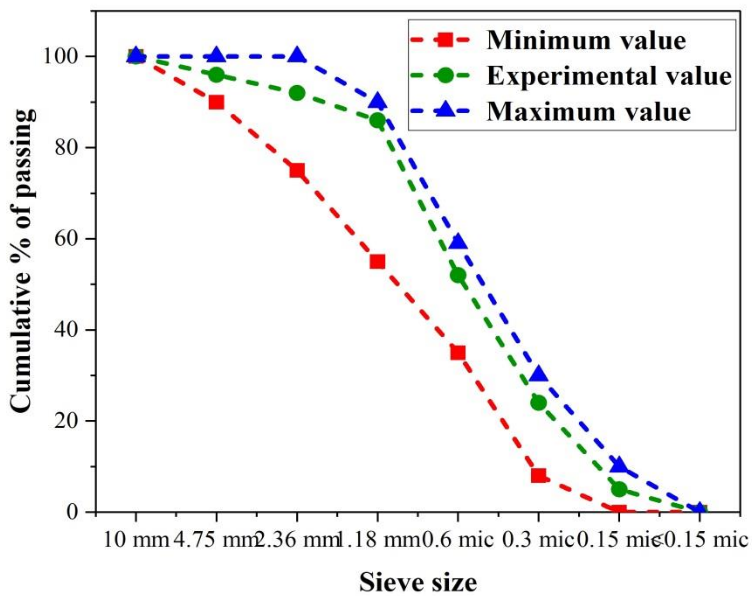


Figure 4. Grain distribution of fine aggregate.

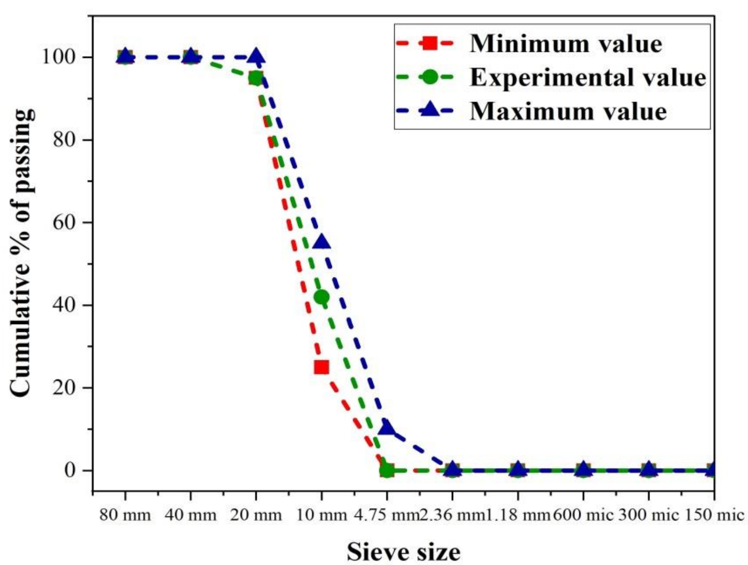


Figure 5. Grain distribution of coarse aggregate.

The glass fiber is a material composed of numerous excellent strands of glass. These fibers are lightweight, incredibly strong, and robust. In contrast, their strength properties are somewhat lower than those of carbon fiber. Similarly, steel fibers are another type of reinforcement used in concrete. They enhance the material's properties by reducing cracking, improving durability, and enhancing ductile behaviors before ultimate failure. While glass fibers contribute to tensile strength and fire resistance, steel fibers address shrinkage and enhance overall toughness in concrete. The physical properties of the glass and steel fibers are reported in Table 5. In Figure 6, the glass and steel fibers are depicted. These fibers are incorporated into the concrete based on the weight of the cement.

Table 5. Mechanical properties of the glass and steel fibers.

Properties	Steel fibre	Glass fibre
Specific gravity (g/cm^3)	7.73	2.62
Tensile strength (MPa)	1100-1500	1200-1800
Modulus of elasticity (GPa)	200	72
Length (mm)	50	35
Diameter (mm)	0.80	0.52
Aspect ratio (L/D)	62.50	67.30

a. Steel fibre **b. Glass fibre**

Figure 6. Steel and glass fibers.

2.2. Specimen details and preparation

The reinforced concrete beam was divided into three groups: the first was cast with glass fiber, the second with steel fiber, and the third with a combination of steel and glass fibers. These three groups of specimens are listed in Table 6. The geometric details of the specimens include dimensions of 150 mm x 200 mm x 1500 mm. In the tension zone, 2-#10 mm deformed steel bars were provided, while 2-#8 mm deformed steel bars were used in the compression zone. Additionally, two-legged #6 mm stirrups (shear reinforcement) were placed at 100 mm c/c, as depicted in Figure 7. The steel cage, composed of #10 mm and #8 mm steel deformed bars with a length of 1450 mm, was prepared.

Table 6. Geometric details of specimens.

Specimen ID	Specimen dimensions (mm)			Steel reinforcement		Shear reinforcement
	B	D	L	Bottom	Top	
B40-CS						
B40-GF0.2						
B40-GF0.4						
B40-GF0.6	150	200	1500	2 Nos #10 mm	2 Nos #8 mm	#6 mm @100 mm c/c
B40-SF0.2						
B40-SF0.4						
B40-SF0.6						
B40-GF0.1-SF0.4						
B40-GF0.2-SF0.4						
B40-GF0.3-SF0.4						

Furthermore, #6 mm shear reinforcement was provided at 100 mm c/c. The steel cage was positioned within a steel mold, and concrete was poured into the mold. Vibrations were applied to compact the concrete and prevent honeycomb structures. Afterwards, the concrete was levelled and left at room temperature for 24 hours. The following day, the specimen was carefully removed from the steel mold without any damage and underwent a 28-day curing process. Finally, the outer surfaces of the specimen were cleaned in preparation for testing.

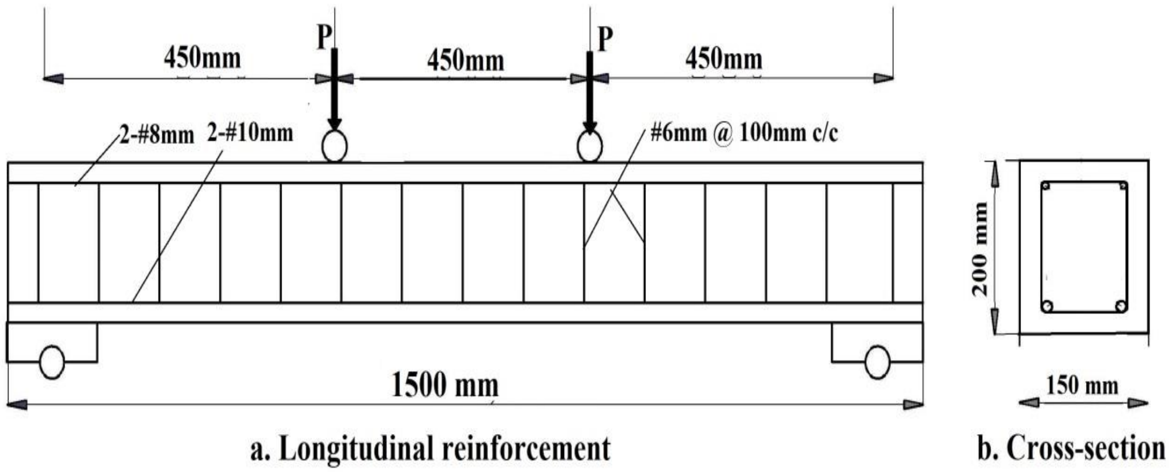


Figure 7. Details of the steel reinforcement.

2.3. Experimental setup and instrumentation

All the specimens underwent testing until failure using a 50 T capacity loading frame. These specimens were positioned at the center of the loading frame to apply the load. At the same time, a deflection meter was placed at the center of each specimen to measure the mid-deflection, as illustrated in Figure 8. The end condition of the specimen was a hinged support. For this study, a four-point loading configuration was applied. The total length of the specimen was 1500 mm, with an adequate size of 1400 mm. The load was applied 550 mm from the support at each end, and the distance between the two loadings was 300 mm. The displacement mode controlled the specimen, and the loading rate was maintained at 0.3 mm/minute.

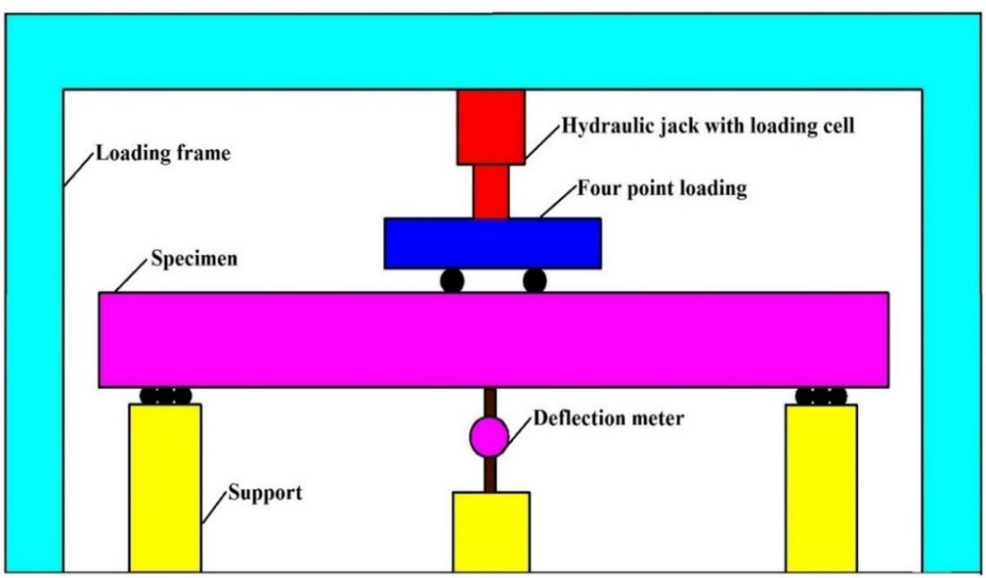


Figure 8. Experimental setup of the specimen.

3. Analytical study

3.1. Finite element model

The finite element model (FEM) was created using ANSYS software, as depicted in Figure 9. Finite element analysis (FEA) is a numerical technique for solving engineering and mathematical physics problems. FEA enables the prediction of structural behavior under various loading conditions. In this study, FEA was utilized to predict the ultimate load and deflection of the RC beams, focusing on their flexural behavior.

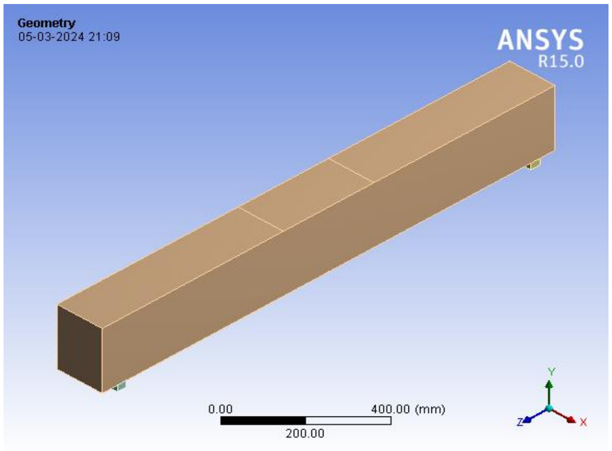
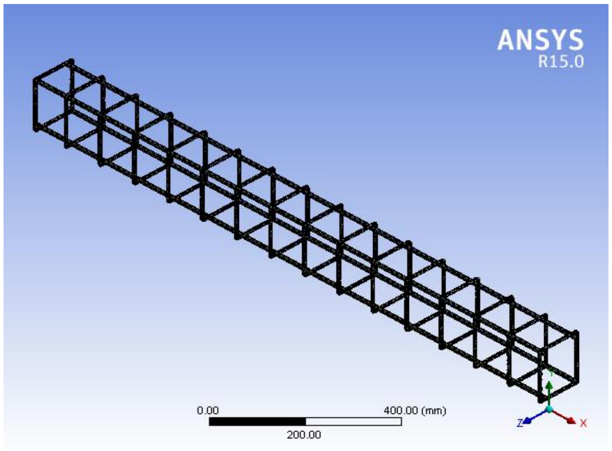


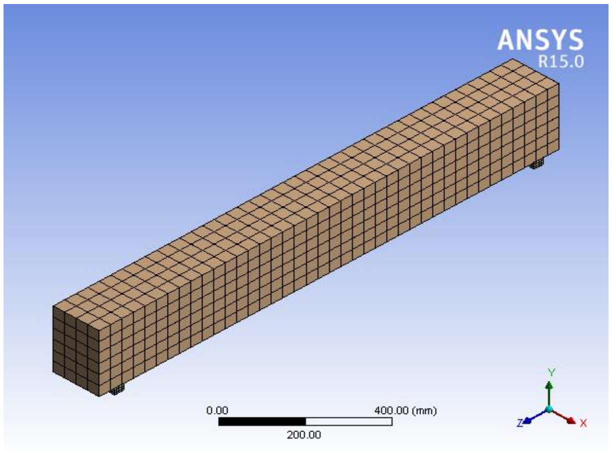
Figure 9. 3D modelling of the RC beams.

3.2. Mesh convergent study

In finite element analysis, a finer mesh generally provides more accurate results. However, finer meshes also increase computation time. A mesh convergence study aims to balance accuracy and computational efficiency by gradually refining the mesh until the results converge satisfactorily (Sasikumar & Manju 2022a). Figures 10 (a) & (b) show the small mesh size that was chosen for the examination of the beam's flexural behavior based on sensitivity assessments.



(a). Meshing for steel cage.



(b). Meshing for RC beam.

Figure 10. Finite element modelling of the RC beams.

3.3. Support condition

The analytical model of the RC beams incorporated a hinged support at one end and a roller support at the other. The loading on the RC beams was regulated by strain, and it was applied using a two-point loading configuration, as depicted in Figure 11.

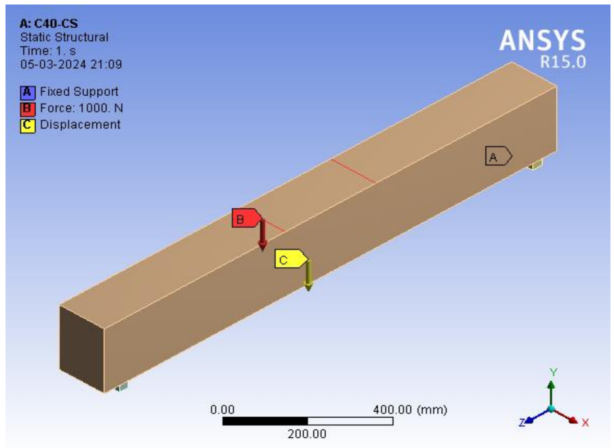
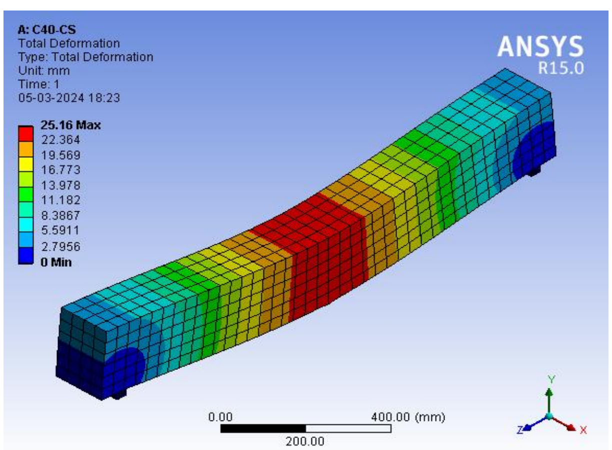


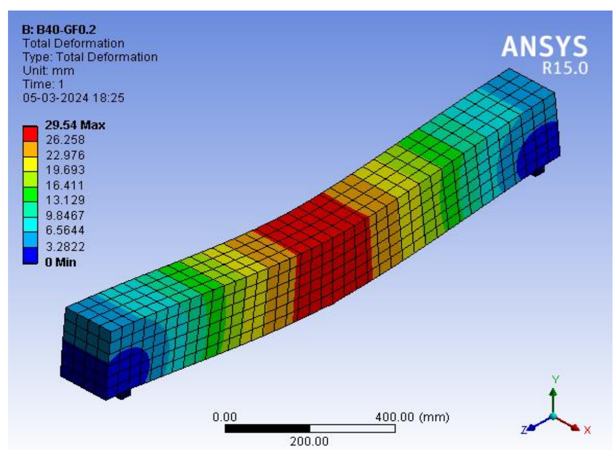
Figure 11. Loading setup of the RC beams.

3.4. Approach of the model

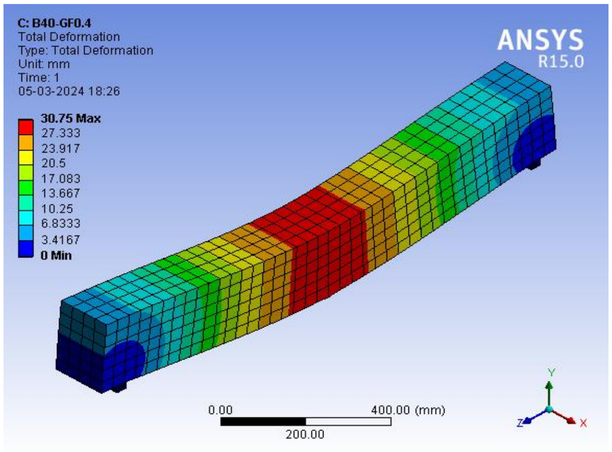
The reinforced concrete (RC) beams were divided into four components: plain cement concrete, compression reinforcement, tension reinforcement, and shear reinforcement. These beams underwent finite element modelling, and their elements were analyzed under non-linear conditions (Sasikumar & Manju, 2022a; Sasikumar & Manju, 2022b; Sasikumar & Manju, 2023). Experimental test results were compared to analytical results, revealing a strong correlation between the two, particularly in load and deflection. The analytical study assessed the material strength and flexural behavior of the RC beams. Figures 12 & 13 depict the total stress and strain in these beams.



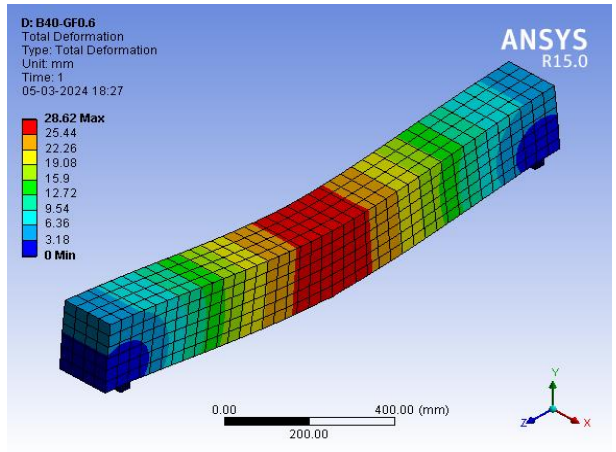
(a). B40-CS



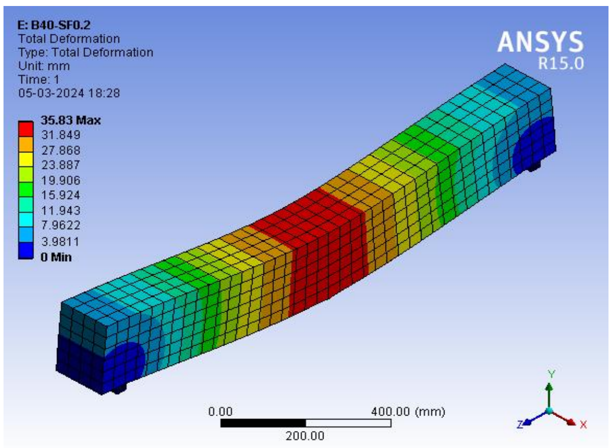
(b). B40-GF0.2



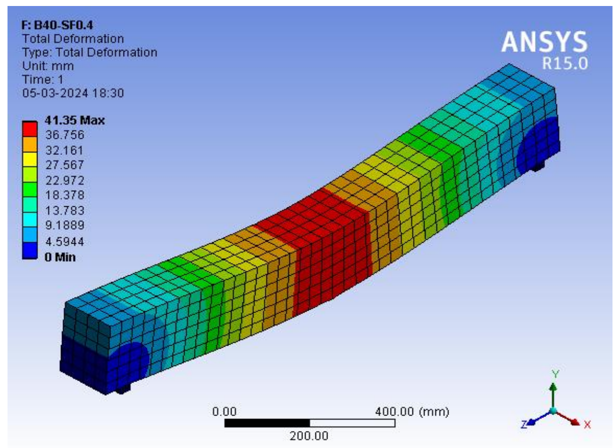
(c). B40-GF0.4



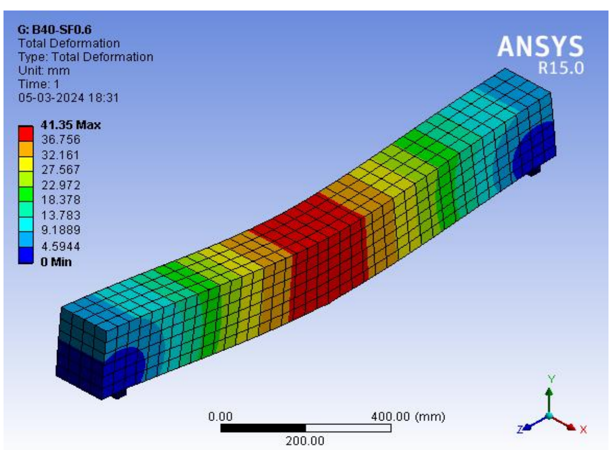
(d). B40-GF0.6



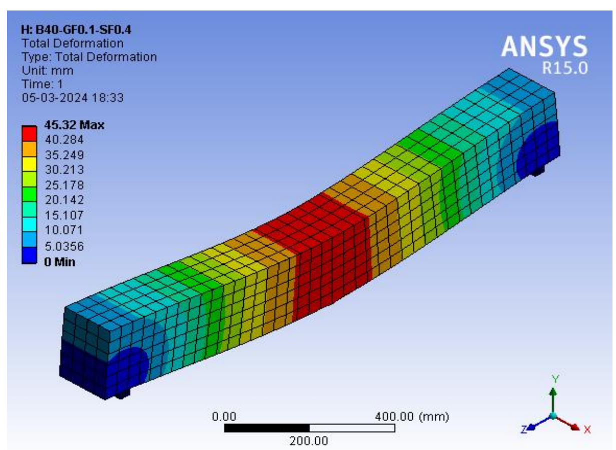
(e). B40-SF0.2



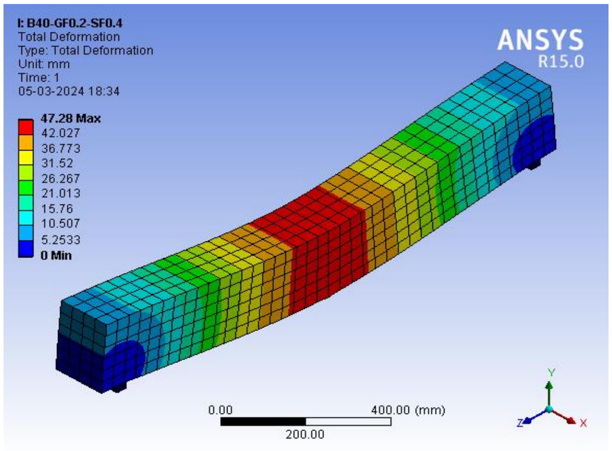
(f). B40-SF0.4



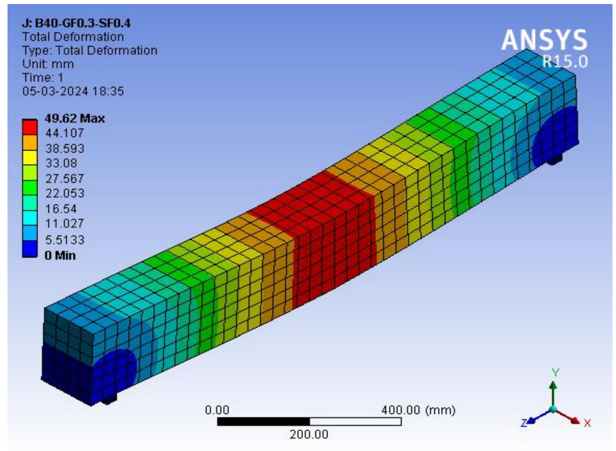
(g). B40-SF0.6



(h). B40-GF0.1-SF0.4

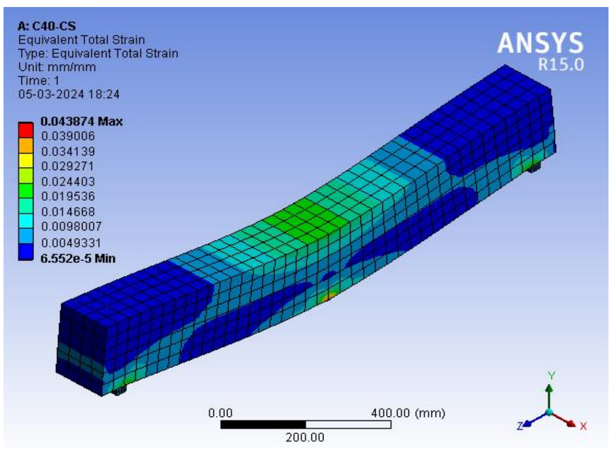


(e). B40- GF0.2-SF0.4

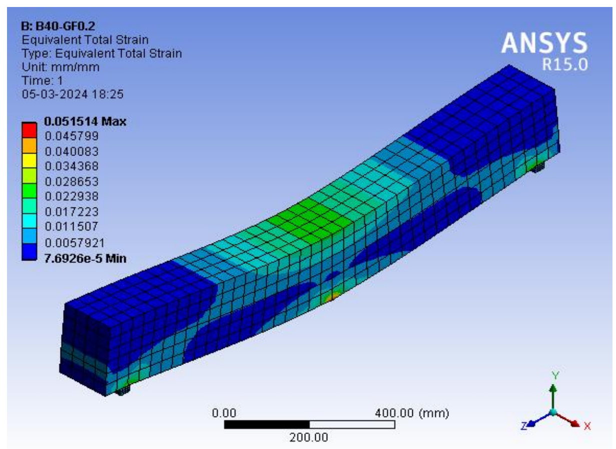


(f). B40- GF0.2-SF0.4

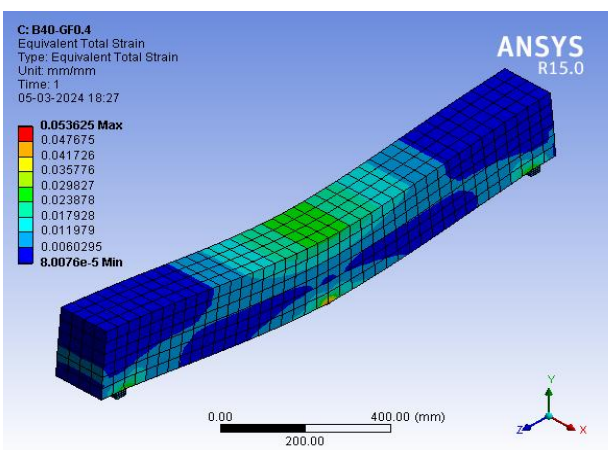
Figure 12. Maximum deflection of the RC beams.



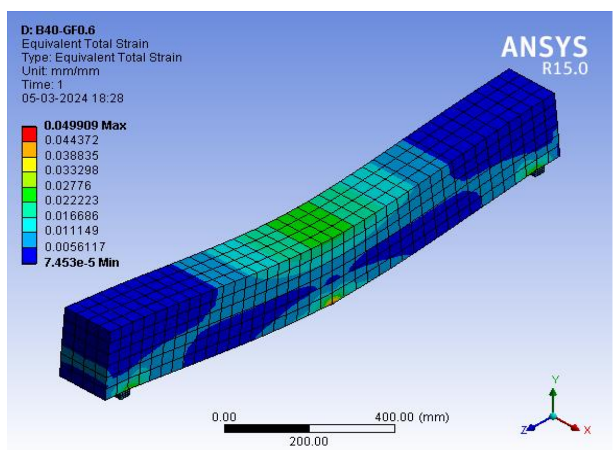
(a). B40-CS



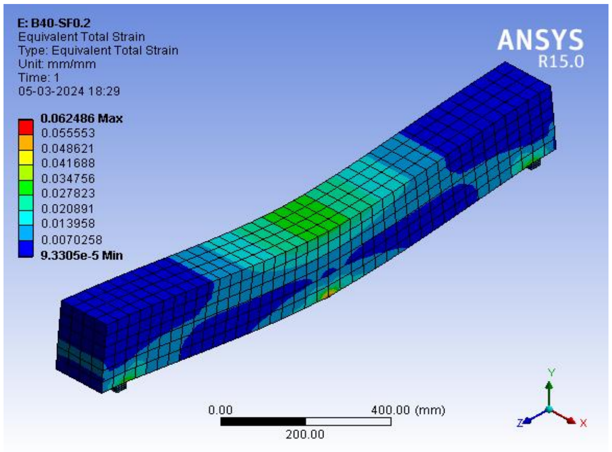
(b). B40-GF0.2



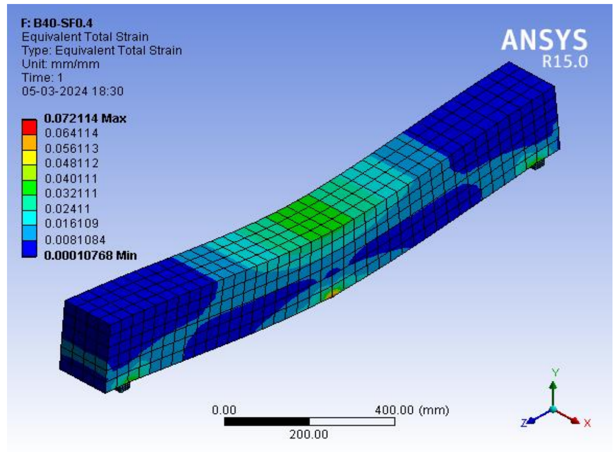
(c). B40-GF0.4



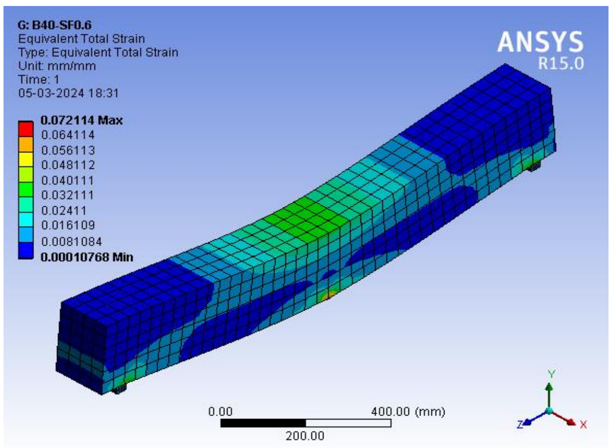
(d). B40-GF0.6



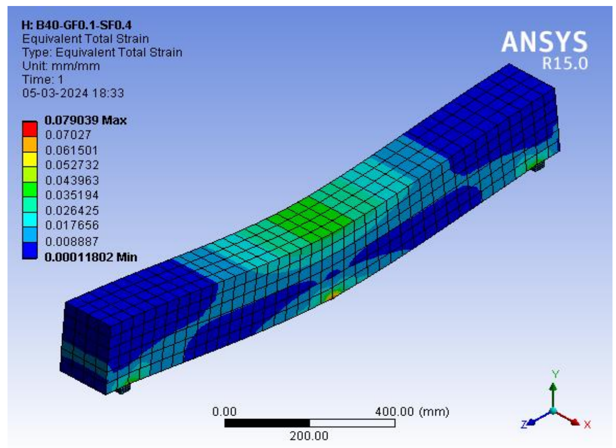
(e). B40-SF0.2



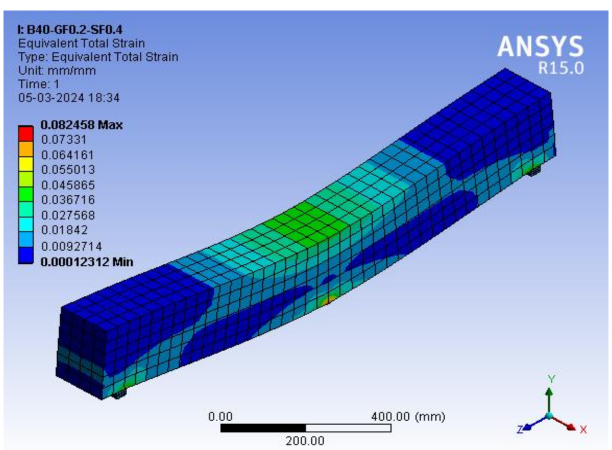
(f). B40-SF0.4



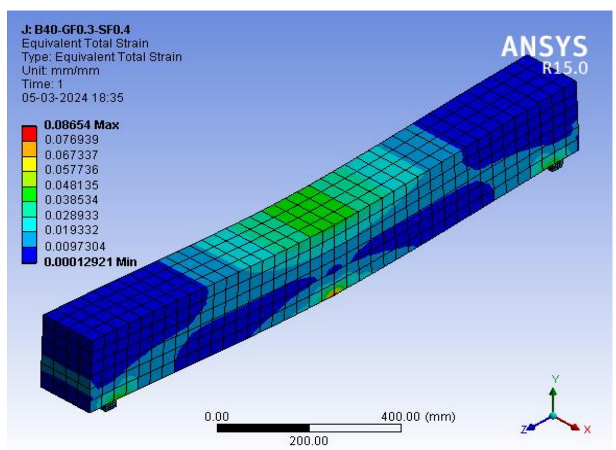
(g). B40-SF0.6



(h). B40-GF0.1-SF0.4



(e). B40- GF0.2-SF0.4



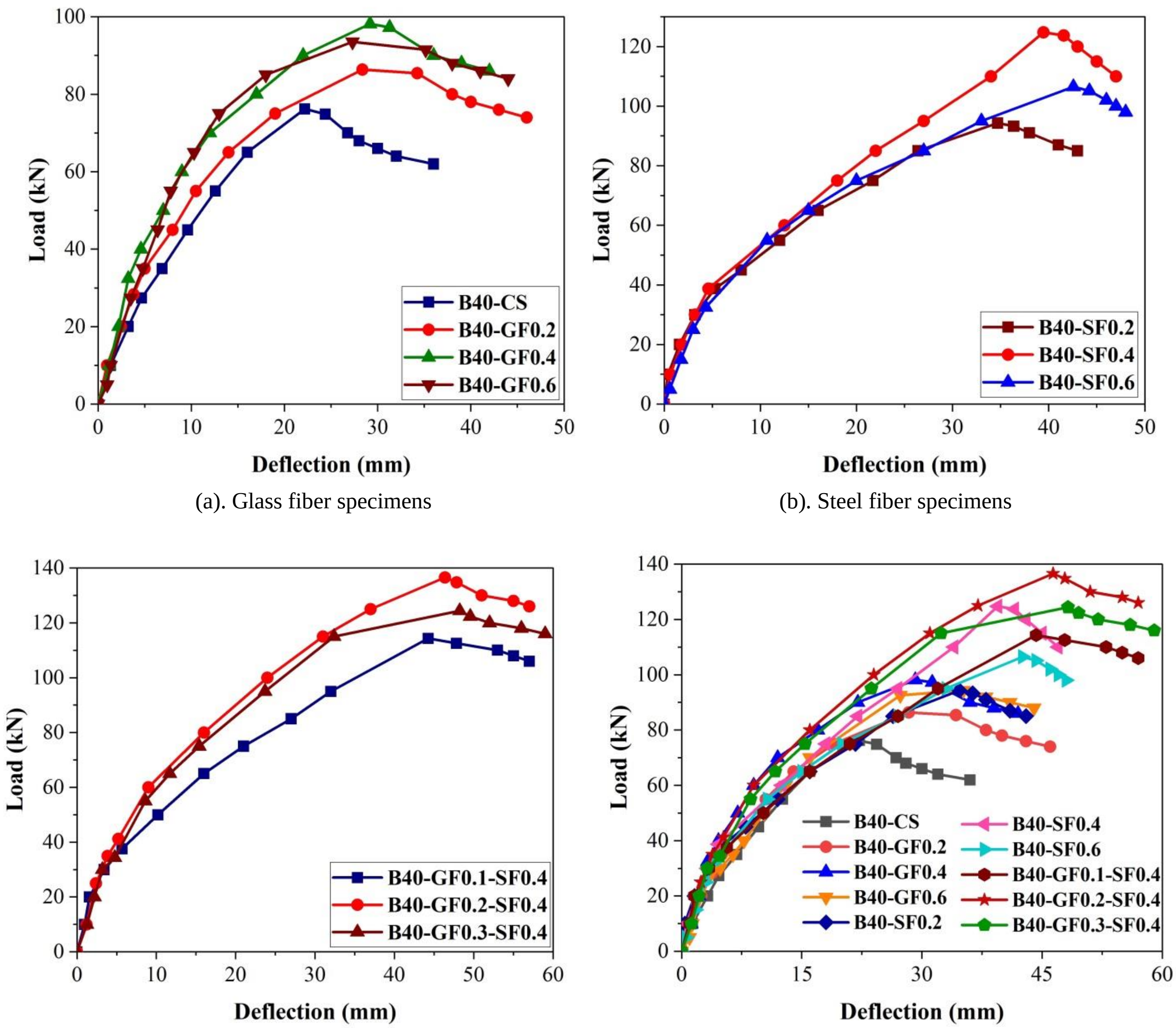
(f). B40- GF0.2-SF0.4

Figure 13. Strain distribution of the RC beams.

4. Results and discussions

4.1. Axial load-deflection response

All RC beam specimens were tested under two-point loading, and the experimental results were reported in Table 7. The load increased by 13.35% for B40-GF0.2, 28.80% for B40-GF0.4, 21.48% for B40-GF0.6, 23.78% for B40-SF0.2, 63.74% for B40-SF0.4, 39.74% for B40-SF0.6, 50.02% for B40-GF0.1-SF0.1, 79.24% for B40-GF0.2-SF0.1, and 63.27% for B40-GF0.3-SF0.1, respectively compared to the control specimen B40-CS. The flexural behavior of all RC beam specimens load-deflection curve groups is depicted in Figures 14 (a) – (d). The load-deflection curve exhibits linear behavior up to 70% of the load, after which the specimens transition from the elastic to the plastic region. The load is applied continuously until the specimens fail, but the specimens fail after reaching the ultimate load. Ductility is an important factor in reinforced concrete structures. It is calculated as the ratio between yield and the ultimate deflection of the specimen (Sasikumar & Manju 2022a; Sasikumar & Manju 2022b; Sasikumar & Manju 2023; Sasikumar 2023; Sasikumar & Manju 2024; Sasikumar 2024). Increasing the amount of glass, steel fiber, and hybrid fibers increased the ductility of the RC beam specimens compared to the control RC beam specimens.



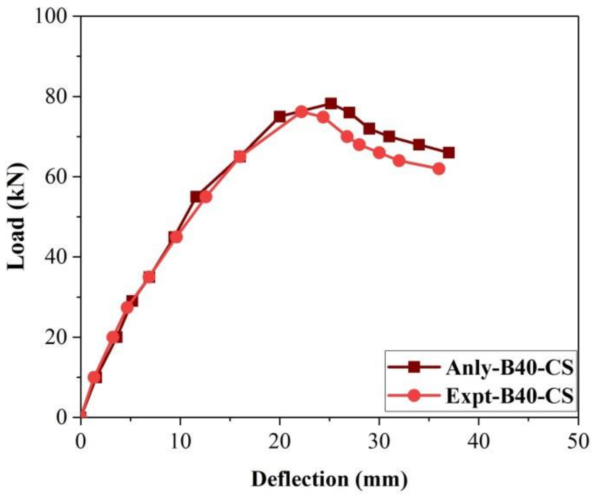
(a). Glass fiber specimens (b). Steel fiber specimens

(c). Glass and steel fiber specimens (d). All groups of specimens

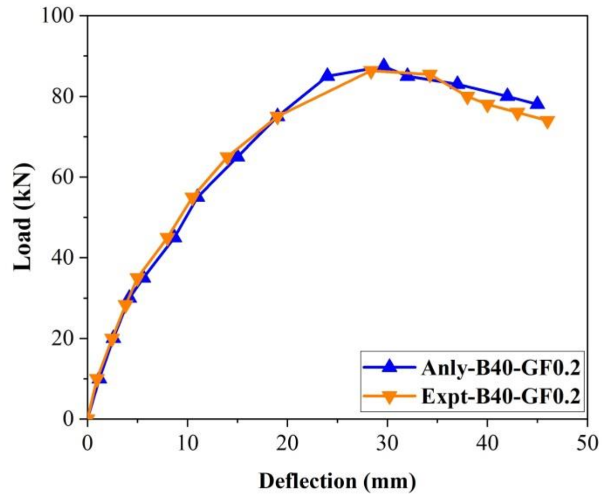
Figure 14. Load-deflection responses specimen.

4.2. *Comparison between experimental and analytical study*

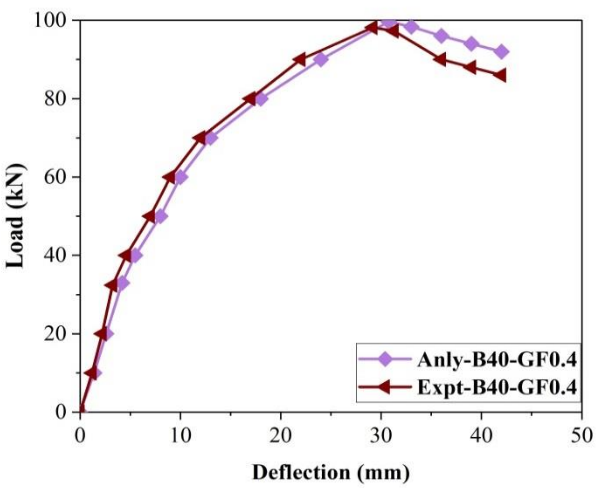
The flexural behavior of all specimens was evaluated using finite element analysis (FEA). The analytical study results were compared to the experimental test results reported in Table 7. Specifically, the experimental results were compared to the analytical study regarding load, deflection, and failure mode. Remarkably, the analytical results demonstrated strong agreement with the experimental findings. For the load, the mean, standard deviation, and coefficient of variation were 0.98, 0.01, and 0.56, respectively. Similarly, these values were 0.97, 0.01, and 1.41 for deflection. Figures 15 (a) – (j) visually compare the experimental and analytical load-deflection curves. Additionally, the failure modes observed in the analytical and experimental specimens (B40-CS) were similar, as illustrated in Figure 16.



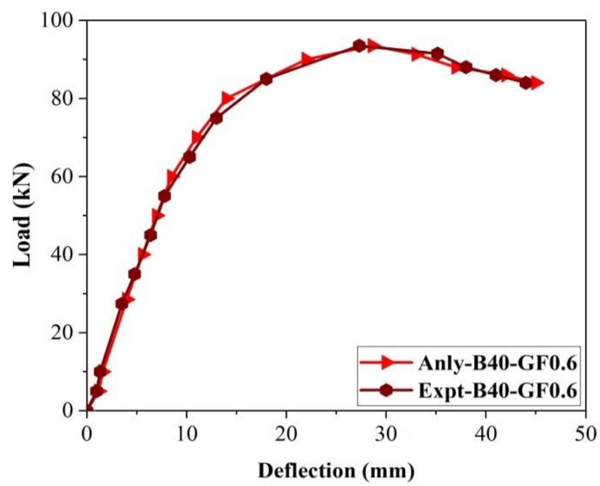
(a). B40-CS



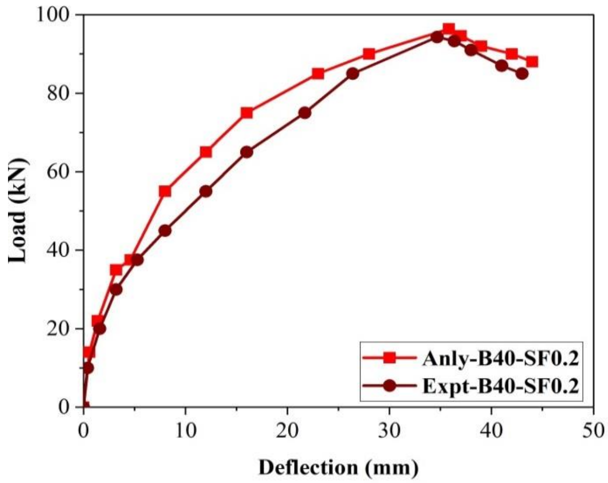
(b). B40-GF0.2



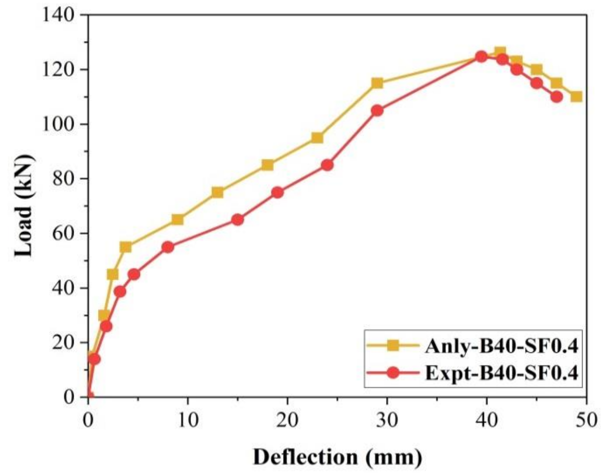
(c). B40-GF0.4



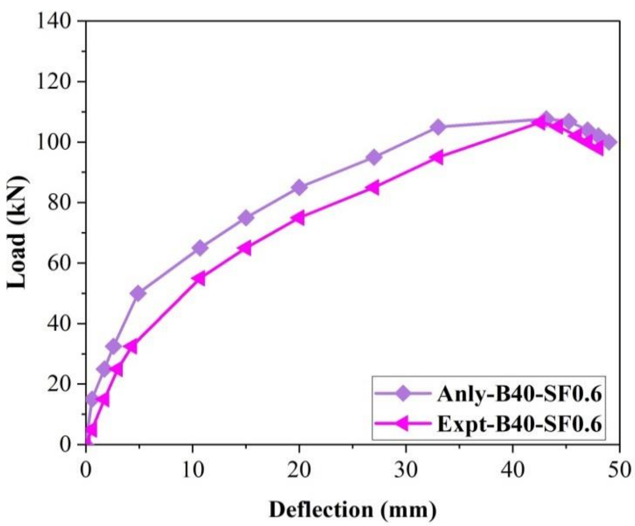
(d). B40-GF0.6



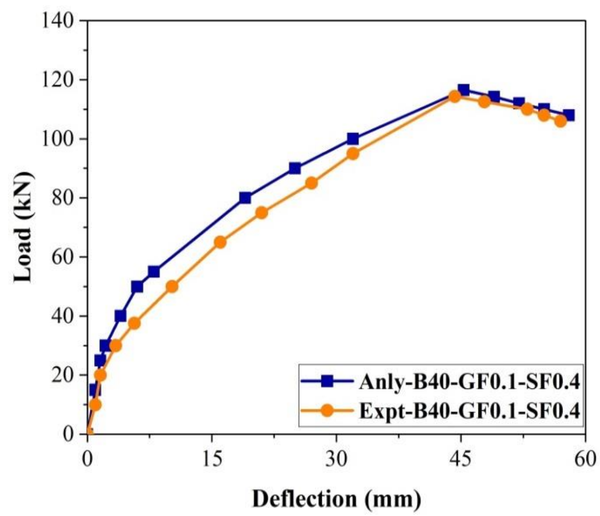
(e). B40-SF0.2



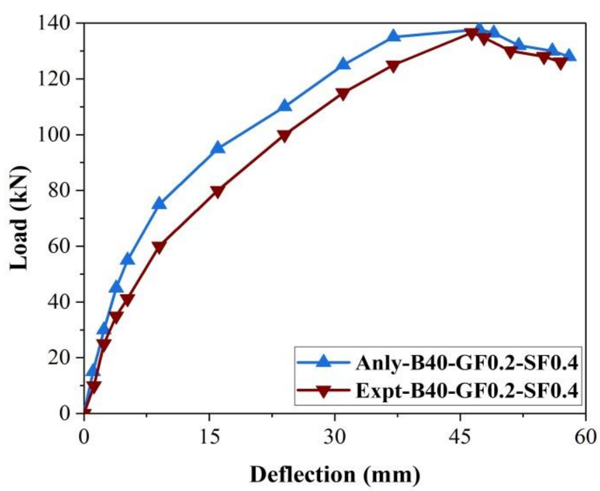
(f). B40-SF0.4



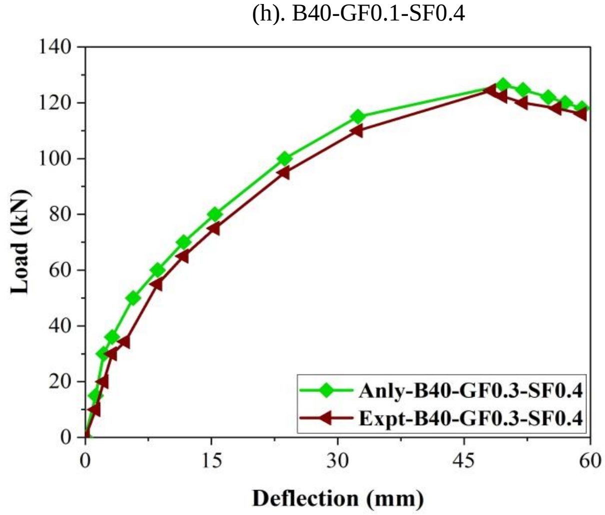
(g). B40-SF0.6



(h). B40-GF0.1-SF0.4



(i). B40-GF0.2-SF0.4



(j). B40-GF0.3-SF0.4

Figure 15. Comparison between experimental and analytical load-deflection responses.

Table 7. Comparative study between analytical and experimental.

Specimen ID	Experimental study		Analytical study		Ratio = Expt / Anly	
	Load (kN)	Deflection (mm)	Load (kN)	Deflection (mm)	Load	Deflection
B40-CS	76.2	24.37	78.24	25.16	0.97	0.97
B40-GF0.2	86.37	28.36	87.43	29.64	0.99	0.96
B40-GF0.4	98.15	29.18	99.64	30.75	0.99	0.95
B40-GF0.6	92.57	27.3	93.52	28.62	0.99	0.95
B40-SF0.2	94.32	34.68	96.38	35.83	0.98	0.97
B40-SF0.4	124.76	39.46	126.32	41.35	0.99	0.95
B40-SF0.6	106.48	42.57	107.68	43.14	0.99	0.99
B40-GF0.1-SF0.4	114.32	44.25	116.54	45.32	0.98	0.98
B40-GF0.2-SF0.4	136.57	46.38	137.76	47.28	0.99	0.98
B40-GF0.3-SF0.4	124.41	48.73	126.32	49.62	0.98	0.98
Mean	-	-	-	-	0.98	0.97
SD	-	-	-	-	0.01	0.01
CV(%)	-	-	-	-	0.56	1.41

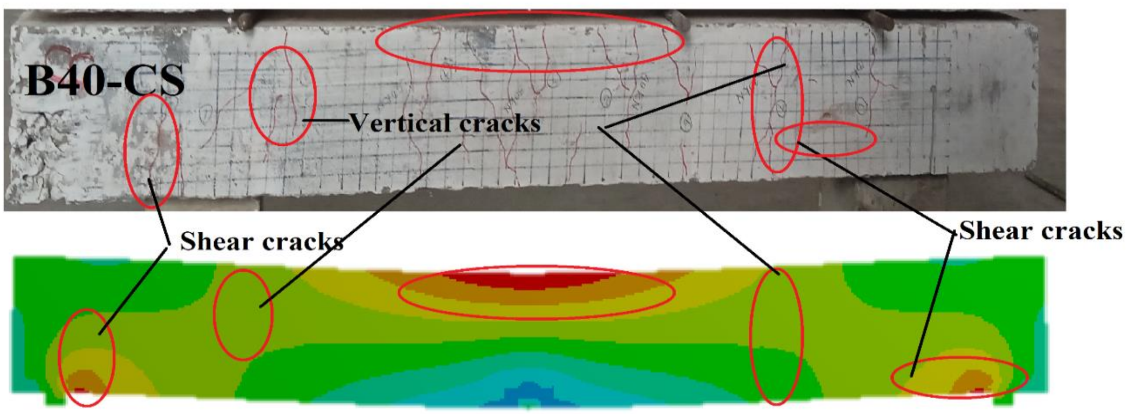


Figure 16. Comparison between experimental and analytical mode of failure of the specimen B40-CS.

4.3. Comparison between experimental and analytical study

All reinforced concrete (RC) beam specimens were subjected to a 50-ton capacity loading frame until failure occurred. The various failure modes are documented in Table 8. Flexural failure is a common observation across all RC beam specimens. Initially, a crack appears at 24.67 kN, and the load is continuously applied until the specimens fail. Simultaneously, multiple cracks develop throughout the B40-CS specimens. These cracks propagate vertically after reaching the ultimate load of 76.20 kN, and the specimens ultimately fail at 74.86 kN. Figure 17 visually illustrates the different failure modes in the RC beam specimens.

Table 8. Experimental results of all groups of specimens.

Specimen ID	Experiment load (kN)			Deflection (mm)			Ductility	Stiffness (kN/mm)	Mode of failure
	Initial	Ultimate	Failure	Initial	Ultimate	Failure			
B40-CS	24.67	76.20	74.86	4.67	24.37	26.78	5.22	3.13	CC+FF
B40-GF0.2	28.32	86.37	85.42	3.82	28.36	34.25	7.42	3.05	CC+FF
B40-GF0.4	32.40	98.15	97.25	3.24	29.18	31.28	9.01	3.36	FF
B40-GF0.6	27.38	92.57	90.47	3.52	27.3	35.16	7.76	3.39	FF
B40-SF0.2	34.87	94.32	93.28	5.28	34.68	36.35	6.57	2.72	FF
B40-SF0.4	38.72	124.76	123.42	4.65	39.46	41.56	8.49	3.16	FF
B40-SF0.6	32.47	106.48	105.14	4.32	42.57	44.23	9.85	2.50	CC+FF
B40-GF0.1-SF0.4	37.56	114.32	112.56	5.67	44.25	48.52	7.80	2.58	FF
B40-GF0.2-SF0.4	41.2	136.57	134.76	5.21	46.38	47.84	8.90	2.94	FF
B40-GF0.3-SF0.4	34.38	124.41	122.34	4.76	48.73	49.56	10.24	2.55	CC+FF

Note: CC and FF are called concrete crushing and flexural failure.

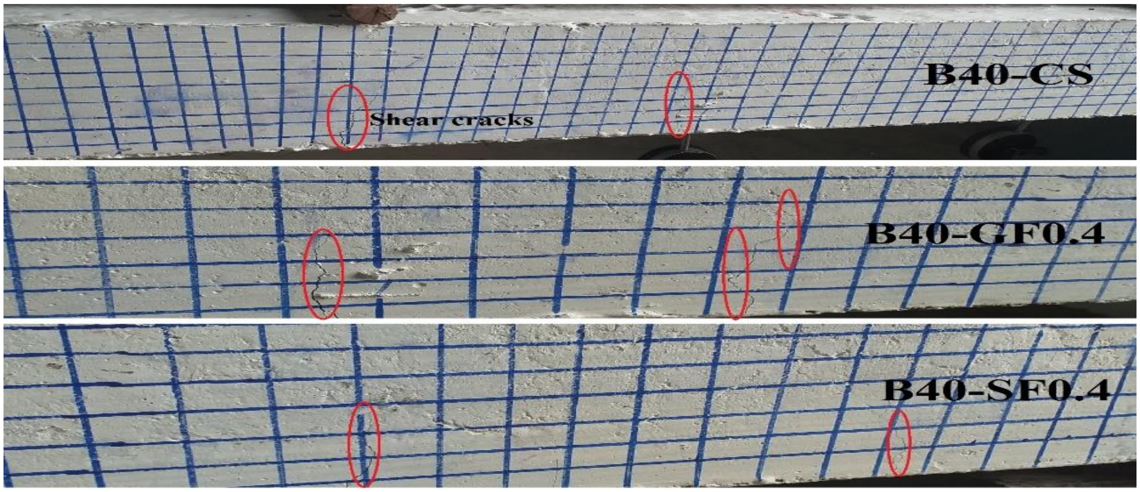


Figure 17. Tested specimens.

5. Conclusions and comments for future study

In addition to including glass, steel, and hybrid fibres, this study examined the experimental and analytical analysis, including the load, load deflection, mode of failure, and ductility. The experimental and analytical study's findings allow for the following conclusions to be made:

1. The flexural behaviour of the RC beams was evaluated with the addition of glass fibre, steel fibre, and combined glass & steel fibres. These fibre-reinforced concrete beam specimens were studied and compared to the control RC beam.
2. The load-carrying capacity of the reinforced concrete (RC) beams improved significantly by adding glass fibre, steel fibre, and combined glass & steel fibre content. The optimum fibre content has been identified as 0.4% for glass fibre, 0.4% for steel fibre, and a combination of 0.2% glass fibre and 0.4% steel fibre.
3. These optimum fibre content percentages contribute to enhancing the load-carrying capacity by 28.80% for B40-GF0.4, 63.74% for B40-GF0.4, 79.24% for B40-GF0.2-SF0.1 compared to the control specimens (M40-CS).
4. Additionally, finite element analysis was conducted on all RC beam specimens, and the analytical study exhibited a high correlation with the experimental test results. The finite element analysis helped predict all RC beam specimens' load-carrying capacity, deflection, and failure mode.
5. In particular, the load demonstrated a mean, standard deviation, and coefficient of variation of 0.98, 0.01, and 0.56, and the deflection exhibited these values of 0.97, 0.01, and 1.41.

The present research has focused on RC beams, utilizing steel fibre, glass fibre, and combined steel and glass fibres under static loading conditions. The same project may be extended for future research to explore various loading conditions. Furthermore, the findings from this research can be practically implemented.

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