Parametric Study on Fatigue Behaviour of Beam - Column Joint Retrofitted with Various Patterns of Fibre Reinforced Polymer Sheets

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Abstract - Shear failure of B-C joints is recognized as the primary cause of collapse of various moment-resisting frame buildings during recent earthquakes. When B-C joint subjected to huge forces during severe ground shaking and its behaviour has a very much influencing on the structure, sometimes it may Leeds to collapse of entire structure. To study the energy dissipation of B-C joint with different types and combinations of FRP sheets used to retrofit the BC joint in this study. Fiber reinforced polymer is composite material made up of polymer matrix reinforced with fibres. It is alternative method for retrofitting of structures. In this project work, a RC beam-column joint model was developed and externally wrapped with FRP sheets using ABAQUS-CAE. Then parametric study was carried out for beam-column joint retrofitted with various pattern of FRP sheets like different orientation, layers and material of fibres. Various materials of the fibres used carbon, glass and basalt. Orientation of fibres were used like 0^o,-45^o,45^o,90^o and combinations of CFRP&GFRP, CFRP&BFRP and GFRP&BFRP were used in this parametric study. Finally FEA analysis was compared and discussed with respect to layers and materials of fibres. Specimens with B-C joint are retrofitted with FRP and their performances are compared with corresponding un-retrofitted specimens under cyclic loading. It has been found that after retrofitted with CFRP, GFRP and BFRP the energy dissipation capacity had increases to 44.56, 46.3 and 60.58% and stiffness, ductility also increased.

***Key Words*:** Finite Element Method (FEM); Beam-column joints; Carbon fibre reinforced polymer (CFRP); Glass fibre reinforced polymer (GFRP); Basalt fibre reinforced polymer (BFRP); Strengthening.

1. INTRODUCTION

In RC construction, the Beam-Column Joint (BCJ) is regarded as the crucial zone since it is the important component that experiences strong forces during intense ground shaking. Its behaviour has a big effect on how the structure reacts, especially in terms of its ductility and energy dissipating capability.

The FRP materials are composites made of strong fibres woven into a resin matrix. The fibres in the composite's provide it rigidity and strength and they generally withstand the bulk of applied loads. The fibres are bound and protected by the matrix, which also enables the shear stresses that transmit stress from one fibre to another. Glass, carbon, and basalt fibres are the most common types.

FRP composites offer numerous solutions for the needs of the civil engineer and owner. The service life of the structure may be extended since FRP products are more resistant to corrosion than reinforcing steel in civil infrastructure and construction applications. FRP products feature strength capabilities that are superior to steel and high strength-to-weight ratios. The materials' light weight and ease of use during repair and rehabilitation may provide for labour cost savings. The materials' primary flaw is their comparatively high material cost. Many FRP products are being offered for the construction or repair of civil engineering projects.

These products have been used and demonstrated several times internationally. FRP composite products include, as examples,

- FRP composite solutions for walls, slabs, columns, and beams for seismic retrofit, repair, and strengthening.
- Grids, tendons, and bars made of FRP are used for concrete reinforcement. pedestrian bridge systems and bridge deck panels. new forms of structure. For marine waterfront construction, piling systems and supplies are available.
- FRP dowel bars for lifelong, dependable use in concrete roadway paving.

Objectives

Following are the objectives defined based on the literature review

1. To develop a Numerical model of Beam-column joint using finite element method.
2. To study the performance of Beam-column joint retrofitted with different patterns of Fiber Reinforced Polymer sheets.

2. MODELLING AND ANALYSIS

Table -1: Material properties of structure

SL. NO	MATERIALS	PARAMETER	PROPERTIES
1		Concrete strength	40Mpa
2		Yield strength of steel	420Mpa
3		Type of FRP	Unidirectional CFRP sheet
4		Elastic modulus in primary	61.5e3 MPa
5		Elastic modulus of CFRP 90o	34.5 MPa
6		Fracture strain	1.2%
7		Thickness	1.8mm
8		Shear modulus	2.51e3 MPa
9		Poisson's ratio	0.25

Table -2: Details of the structure chosen (saleh H Alsayed et.al, 2018)

SL.NO	STRUCTURE	COMPONENT	DETAILS
		Width	250mm
		Depth	400mm
		Span	1750mm
		Top steel	4M20
		Bottom steel	4M20
		Transverse steel diameter	M10
		Transverse steel spacing	200mm
		Width	400mm
		Depth	400mm
		Span	3000
		Longitudinal steel	6M20
		Longitudinal centre steel	2M15
		Transverse steel spacing	200mm
		Concrete cover	25mm

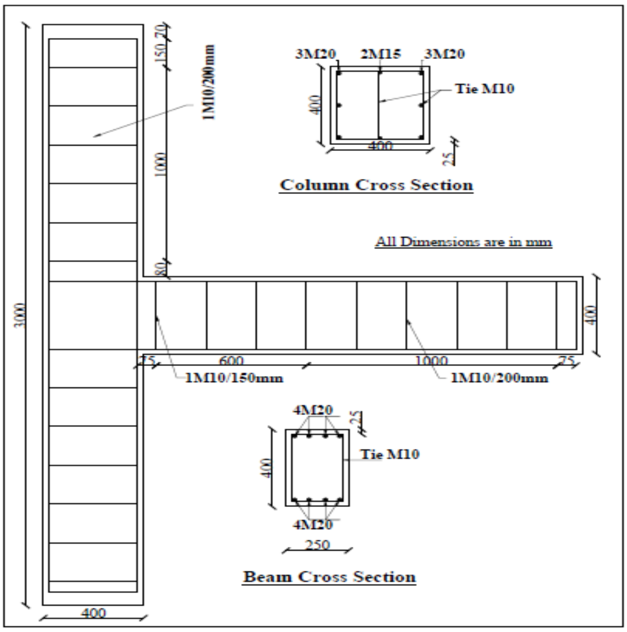

Fig -1: Details of the specimen (Yazan B. Abu et.al, 2018)

The simulation took advantage of the FE software's dynamic explicit analysis. The element utilised in each component of the model and its description are shown in the table.

Table -3: Element properties

Part	Element description
Concrete	8 Node linear-brick
Steel bar	2 Node truss-element
FRP	4 Node thin-shell

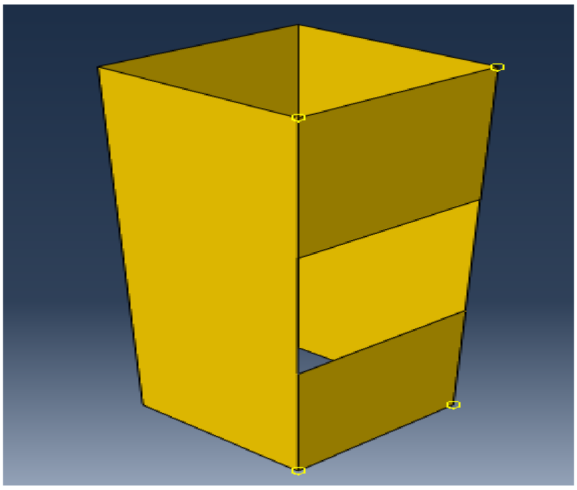
Fig -1: FRP lamina sketch

The aspects of repair and retrofitting techniques used for the RC B-C joint model under cyclic loading are determined using nonlinear FE analysis, where the time period is set to 100 and the amplitude values are produced in load details. The bottom and top faces of the column model are confined in the x, y, and z directions in the current study's boundary condition for the B-C joint. U1, U2, U3, and UR1, UR2, and UR3 to fully constrain

Solution

The following are the results obtained from the FEM software.

- Deformation
- Energy dissipation

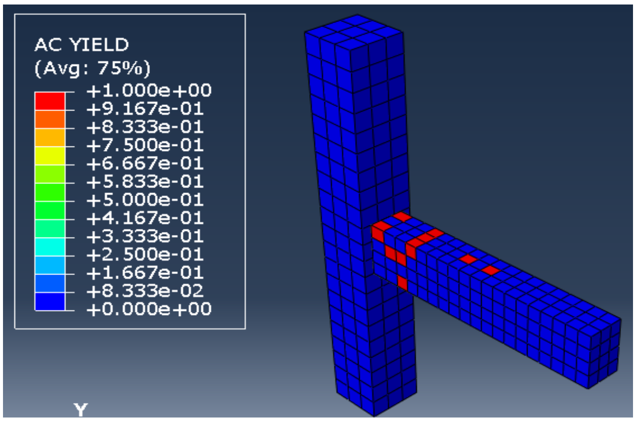

Fig -2: Yielding of reinforcement

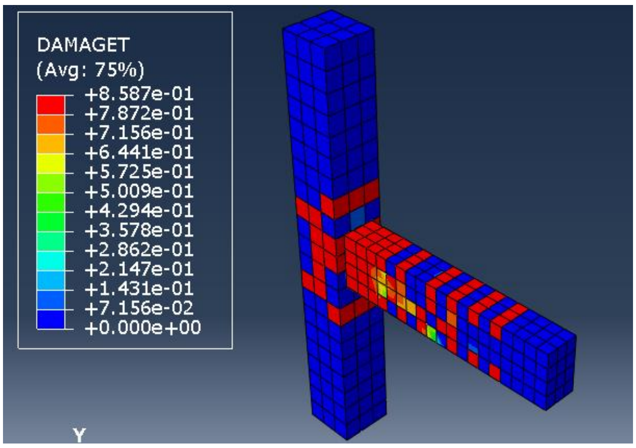

Fig -3: Cracks in the model

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FRP Composites

The RC B-C junction is strengthened with FRP sheets. The fibre exhibits linear elastic behaviour up until rupture failure.

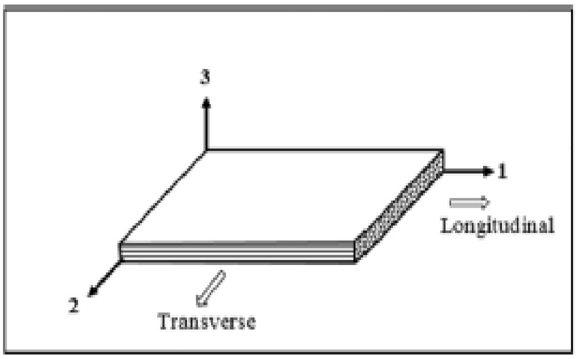


Fig -4: FRP sheet (Yazan 2018)

Input values data required for the FRP lamina in the FE analysis for the parametric study as follows.

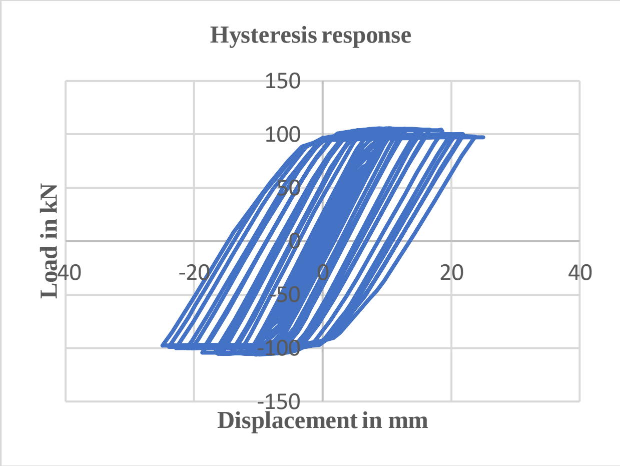
- Material of the fibres = CFRP, GFRP and BFRP.
- Number of layers = 4
- Thickness of each layer = 1.5

Table -4: Element properties

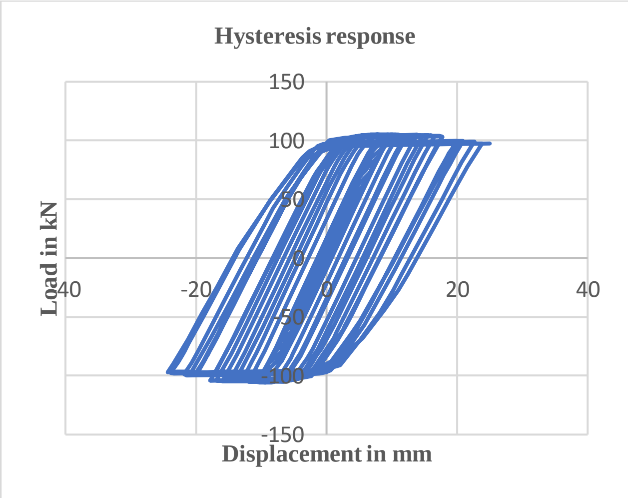
Material	Elastic modulus (MPa)	Poisson's ratio	Shear modulus (MPa)
CFRP	E1 = 106509 E2 = 33970	μ12 = 0.31	G12 = 12400 G13 = 12400 G23 = 13065
GFRP	E1 = 12531 E2 = 4955	μ12 = 0.31	G12 = 1800 G13 = 1800 G23 = 1800
BFRP	E1 = 134500 E2 = 9400	μ12 = 0.39	G12 = 4800 G13 = 4800 G23 = 1450

RESULTS AND DISCUSSION

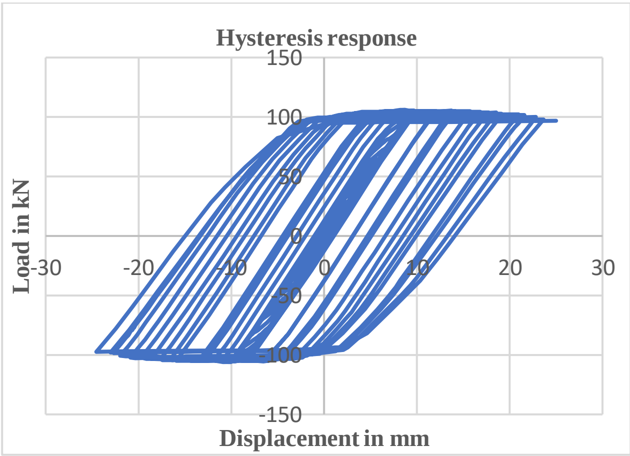
Results and discussions on the parameter study of the retrofitted B-C joint are presented. In this work, three distinct FRP types CFRP, GFRP and BFRP are employed for retrofitting B-C joints under cyclic loads. These FRPs have orientations of 0/0/0/0, 45/45/45/45, -45/-45/-45/-45, 90/90/90/90, 0/45/0/45 and 0/90/0/90.



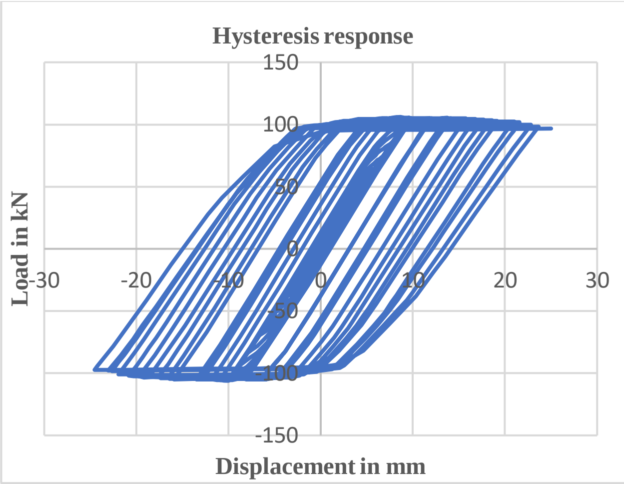
The B-C joint's hysteresis response is simulated without retrofitting. Based on the area of the hysteresis curve, the total energy dissipation is 56678.95kN/mm.



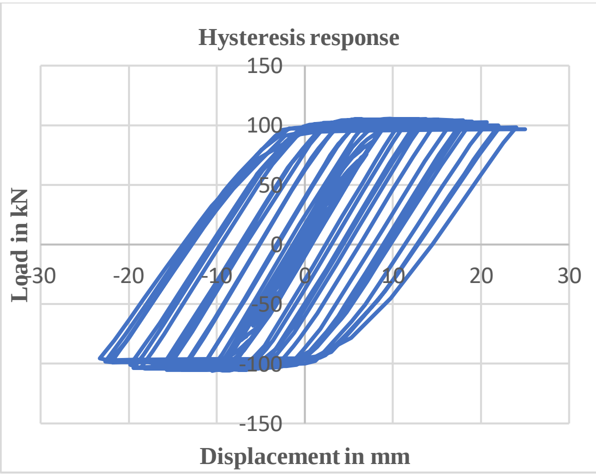
The hysteresis response of the B-C junction for the retrofitted modelled CFRP sheets with 0/0/0/0 fibre orientations. The total energy dissipation is 89868.04kN/mm, which is 36.9% greater than the control specimen, according to the area of the hysteresis curve.



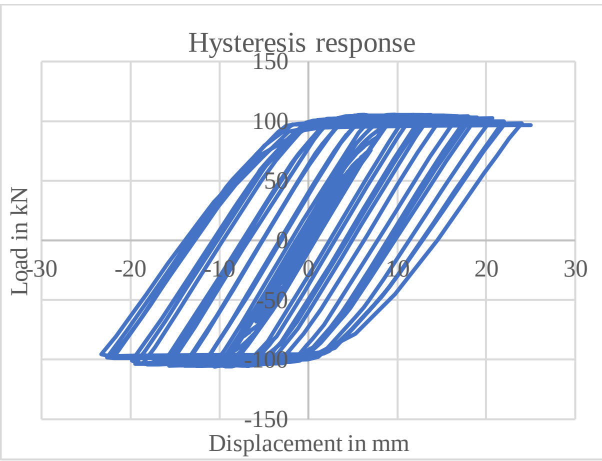
The B-C joint's hysteresis response for the simulated CFRP sheets with fibre orientations of 45/45/45/45. According to the area of the hysteresis curve, the energy dissipation is 102242.2 kN/mm, which is 44.56% more than the control specimen.



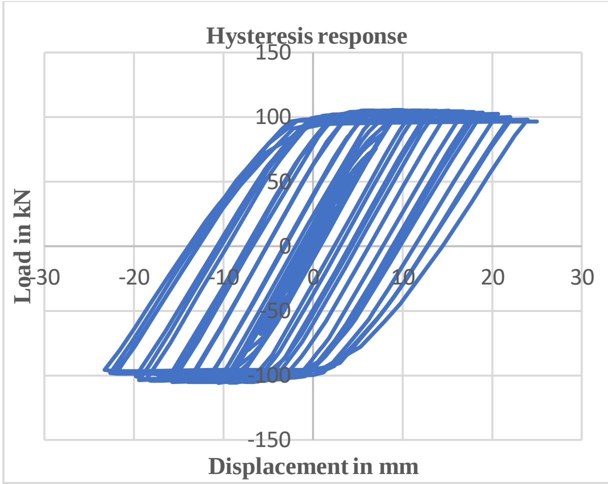
The B-C joint's hysteresis response for the retrofitted modelled CFRP sheets with -45/-45/-45/-45 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 102207.22kN/mm, which is 44.54% greater than the energy dissipation of the control specimen.



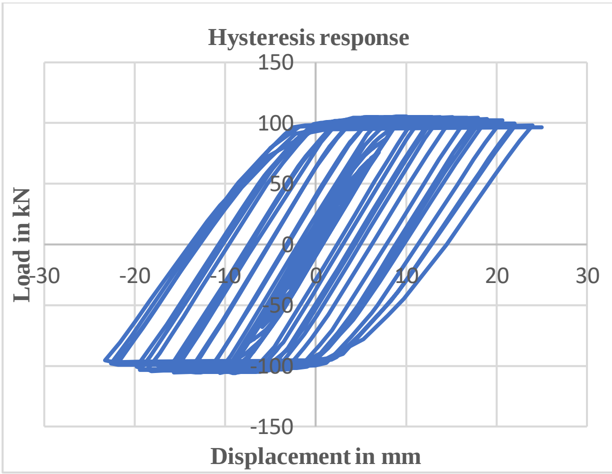
The hysteresis response of the B-C junction for the retrofitted modelled CFRP sheets with 90/90/90/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 98776.6 kN/mm, which is 42.62% greater than the control specimen.



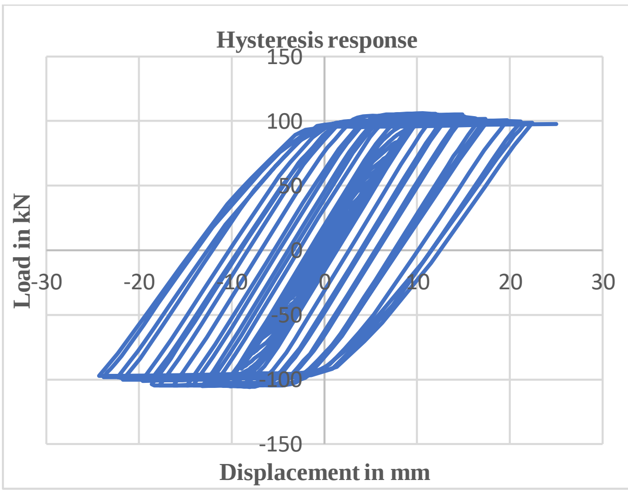
The B-C joint's hysteresis response for the retrofitted modelled CFRP sheets with 0/45/0/45 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 98778.67 kN/mm, which is 42.62% greater than the control specimen.



The B-C joint's hysteresis response for the retrofitted modelled CFRP sheets with 0/-45/0/-45 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 98715.0 kN/mm, which is 42.58% greater than the control specimen.



The B-C joint's hysteresis response for the simulated CFRP sheets with 0/90/0/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 98478.63 kN/mm, which is 42.44% greater than the control specimen.



The B-C joint's hysteresis response for retrofitted model GFRP sheets with 0/0/0/0 fibre orientations. The total energy dissipation is 100602 kN/mm, based on the area of the hysteresis curve, which is 43.66% greater than the control specimen.

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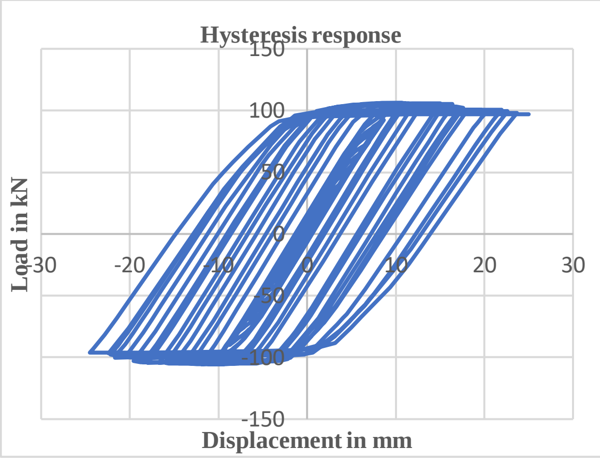
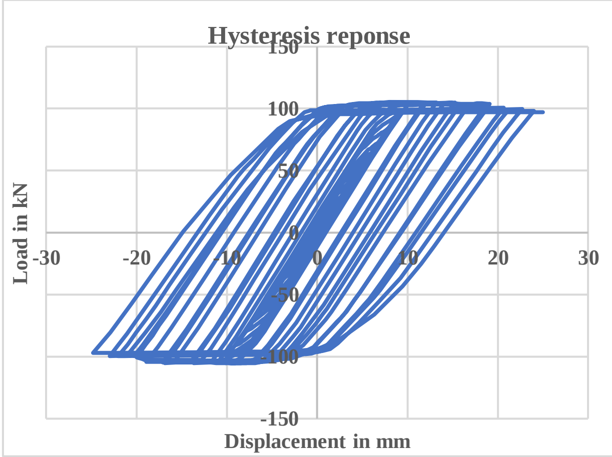
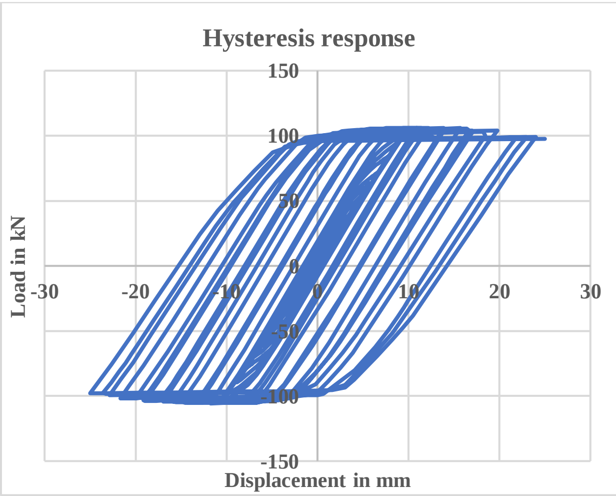


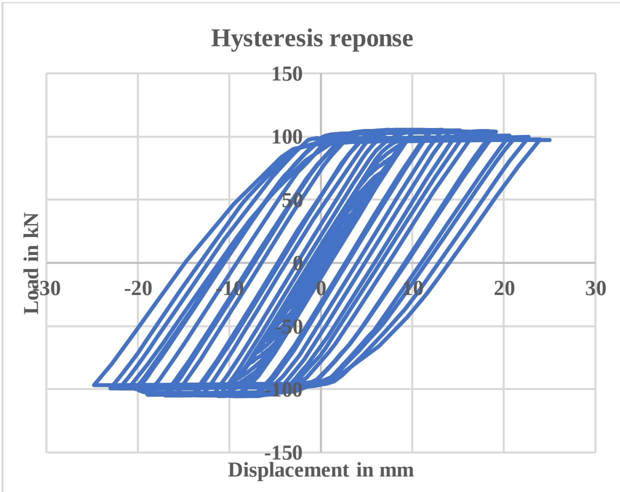
The B-C joint's hysteresis response for the retrofitted modelled GFRP sheets with 45/45/45/45 fibre orientations. The total energy dissipation is 105561.7 kN/mm, calculated from the area of the hysteresis curve, which is 46.30% greater than the control specimen.



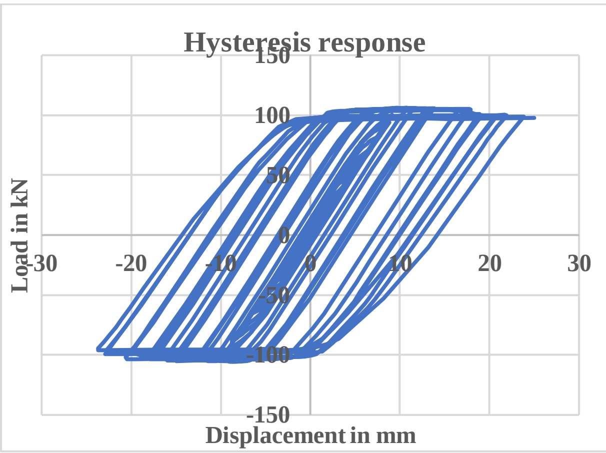
The B-C joint's hysteresis response for the retrofitted modelled GFRP sheets with 0/45/0/45 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 102813.33kN/mm, which is 44.87% greater than the control specimen.



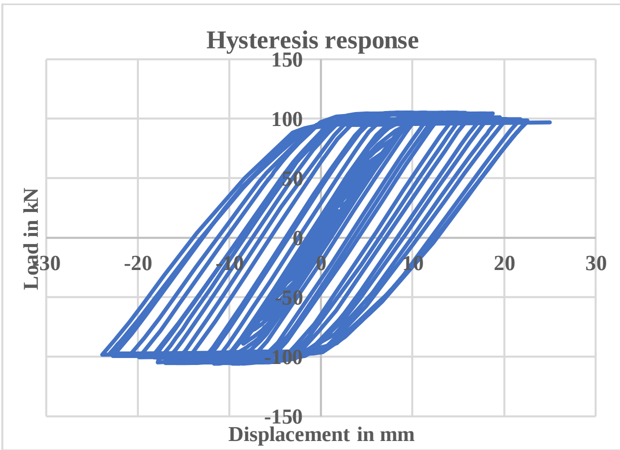
The hysteresis response of the B-C joint for the retrofitted modelled GFRP sheets with -45/-45/-45/-45 fibre orientations. The total energy dissipation is 101771.83 kN/mm, according to a calculation using the area under the hysteresis curve, which is 44.30% greater than the control specimen.



The B-C joint's hysteresis response for the retrofitted modelled GFRP sheets with 0/-45/0/-45 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 102484.99 kN/mm, which is 44.69% more than the control specimen.



The hysteresis response of the B-C joint for the retrofitted modelled GFRP sheets with 90/90/90/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 68119.48 kN/mm, which is 16.79% higher than the control specimen.



The B-C joint's hysteresis response for the retrofitted simulated GFRP sheets with 0/90/0/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 46685.99 kN/mm, which is 21.95% more than in the control specimen.

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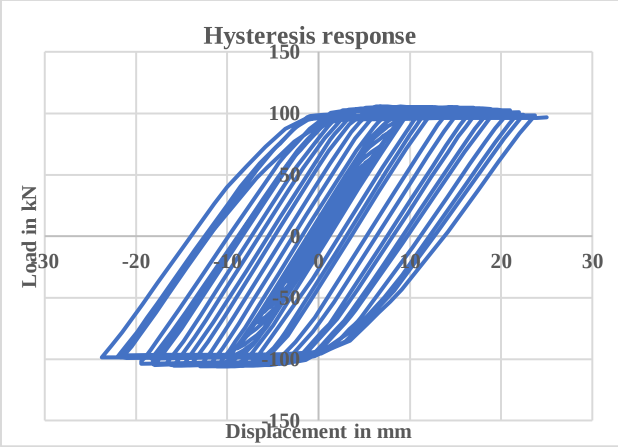
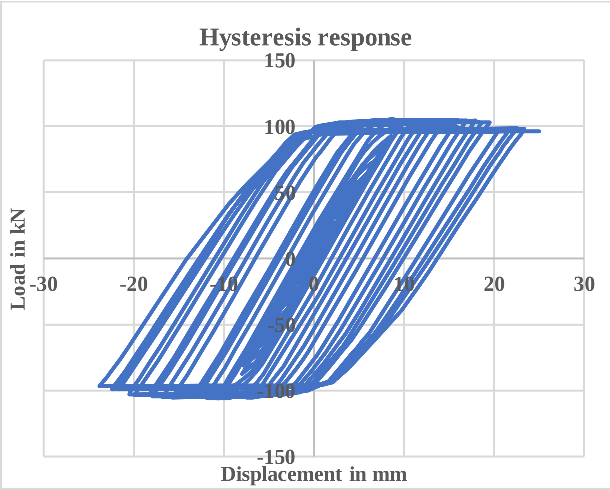
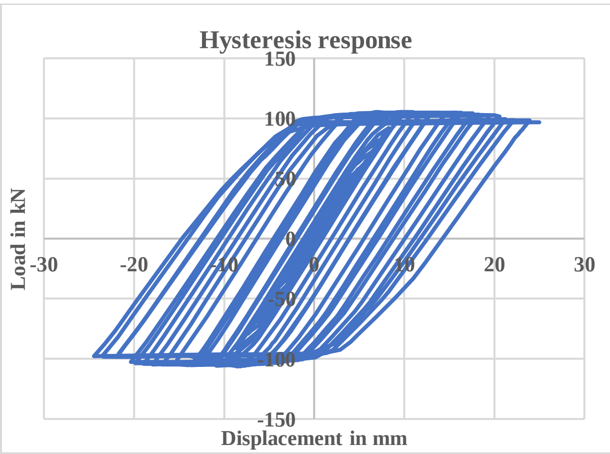


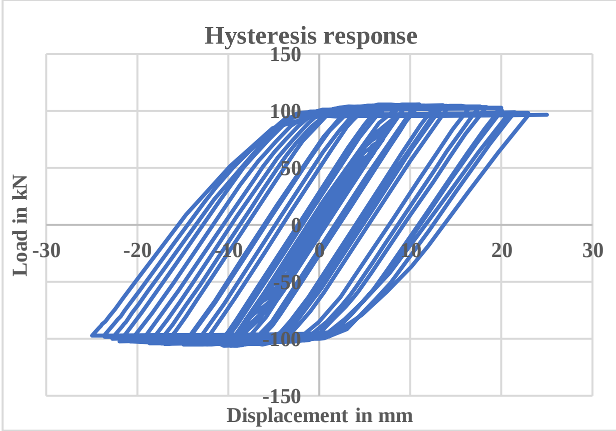
The hysteresis response of the B-C junction for the retrofitted simulated BFRP sheets with 0/0/0/0 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 97269.74kN/mm, which is 41.73% greater than the control specimen.



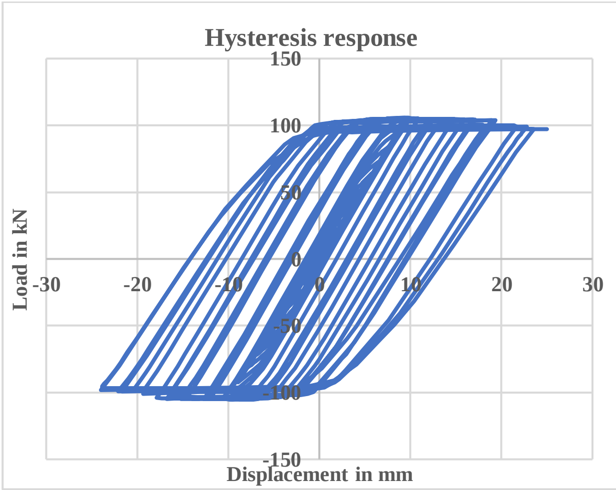
The B-C joint's hysteresis response for the retrofitted simulated BFRP sheets with fibre orientations of 45/45/45/45. According to the area of the hysteresis curve, the total energy dissipation is 106719.36kN/mm, which is 46.89% larger than the energy dissipation of the control specimen.



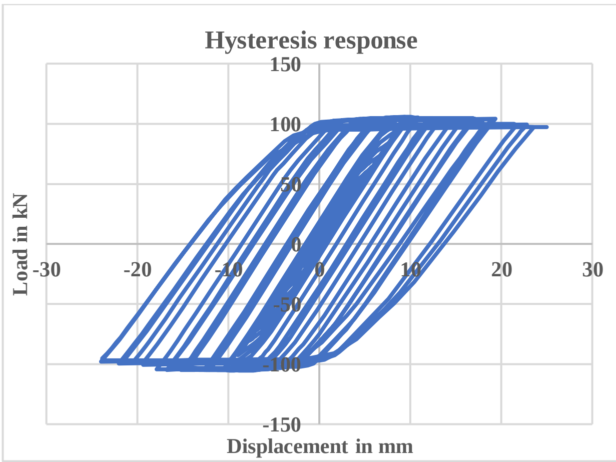
The B-C joint's hysteresis response for the retrofitted simulated BFRP sheets with -45/-45/-45/-45 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 109669.57 kN/mm, which is 48.32% greater than the control specimen.



The B-C joint's hysteresis response for retrofitted model BFRP sheets with 90/90/90/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 100131.35 kN/mm, which is 43.39% greater than the energy dissipation of the control specimen.



The B-C joint's hysteresis response for the retrofitted simulated BFRP sheets with 0/45/0/45 fibre orientations is shown in Fig.36. According to the area of the hysteresis curve, the total energy dissipation is 143789.41kN/mm, which is 60.58% greater than the energy dissipation of the control specimen.



The B-C joint's hysteresis response for the retrofitted simulated BFRP sheets with 0/-45/0/-45 fibre orientations. The total energy dissipation is 143789.40kN/mm, which is 60.58% greater than the control specimen and the specimen with the highest energy dissipation in comparison to other specimens, according to the area of the hysteresis curve.

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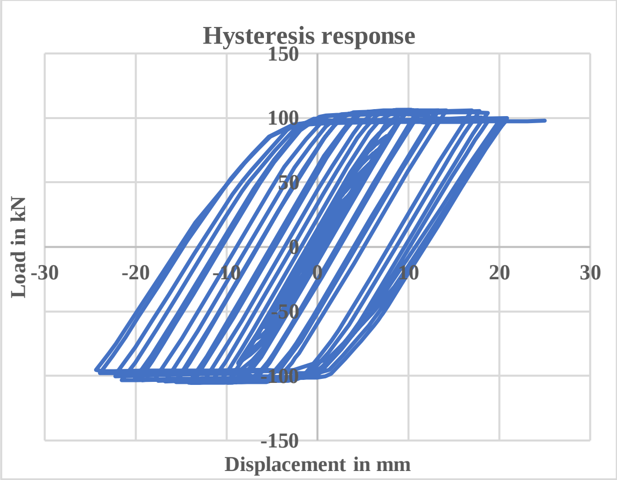
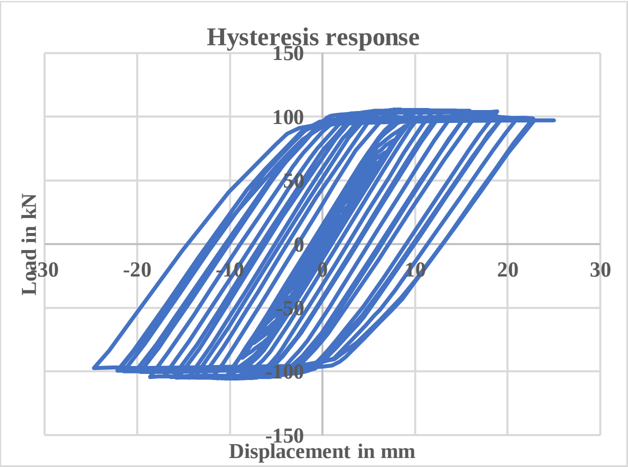
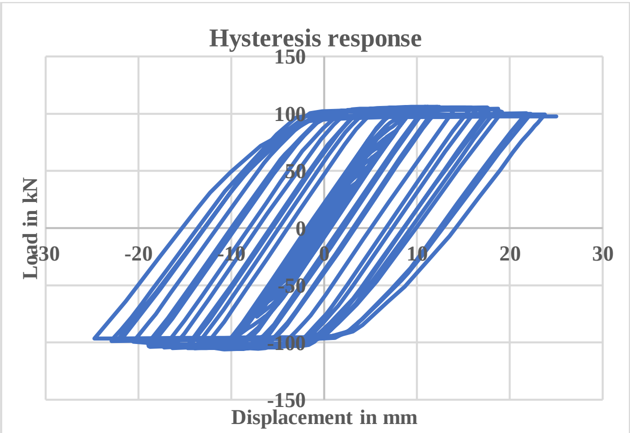


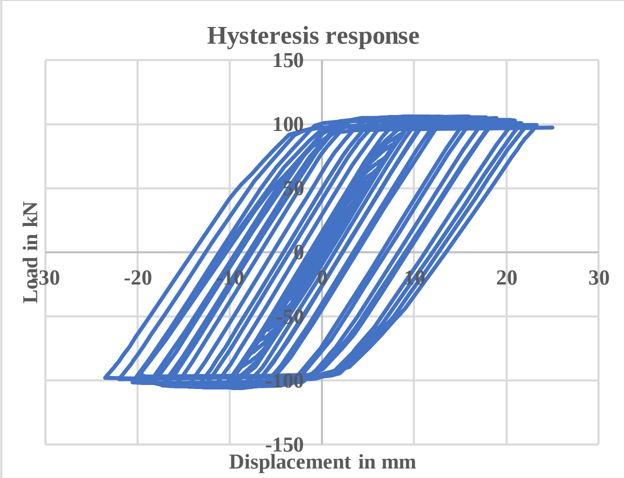
The B-C joint's hysteresis response for the retrofitted simulated BFRP sheets with 0/90/0/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 104990.17kN/mm, which is 46.01% more than in the control specimen.



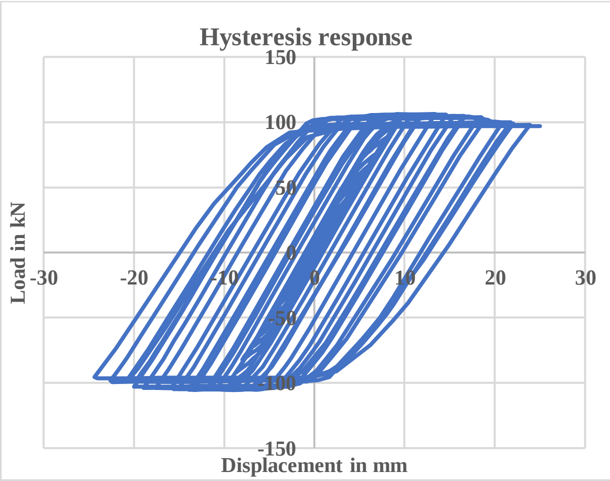
The B-C joint's hysteresis response for the retrofitted modelled composite material comprising CFRP and GFRP sheets with 0/0/0/0 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 94674.99 kN/mm, which is 40.13% more than in the control specimen.



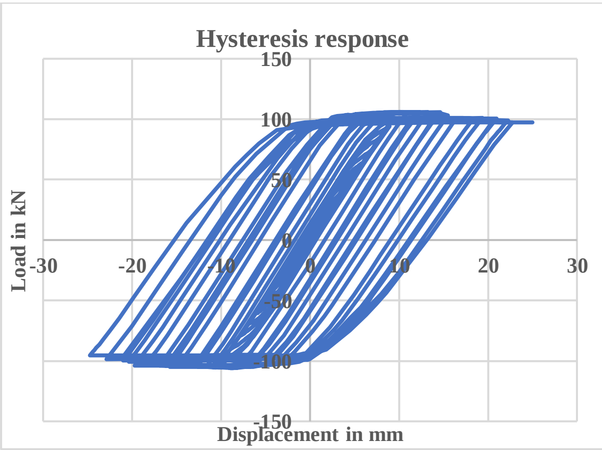
The B-C joint's hysteresis response for the retrofitted modelled composite material comprising CFRP and GFRP sheets with 90/90/90/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 64880.28 kN/mm, which is 12.64% greater than the control specimen.



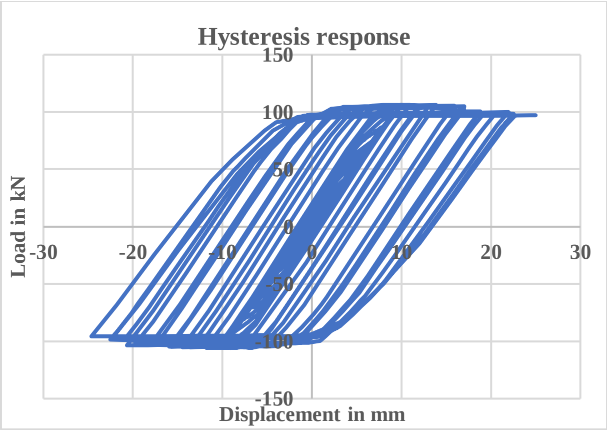
The Hysteresis response of the B-C junction for the retrofitted modelled composite material comprising CFRP and BFRP sheets with fibre orientations of 0/0/0/0. The total energy dissipation is 68093.33kN/mm, which is 16.76% more than the control specimen.



The B-C joint's hysteresis response for the retrofitted modelled composite material comprising CFRP and BFRP sheets with 90/90/90/90 fibre orientations. The total energy dissipation is 80475.56kN/mm, which is 29.57% greater than the control specimen.



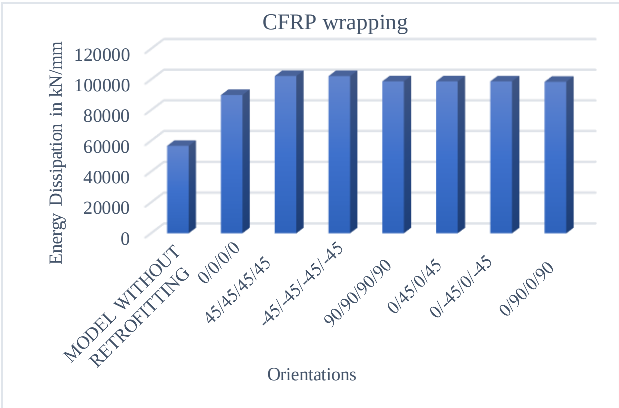
The B-C joint's hysteresis response for the retrofitted modelled composite material comprising GFRP and BFRP sheets with 0/0/0/0 fibre orientations. The total energy dissipation is 59487.41 kN/mm, which is 4.72% greater than the control specimen and much less than the other specimens.



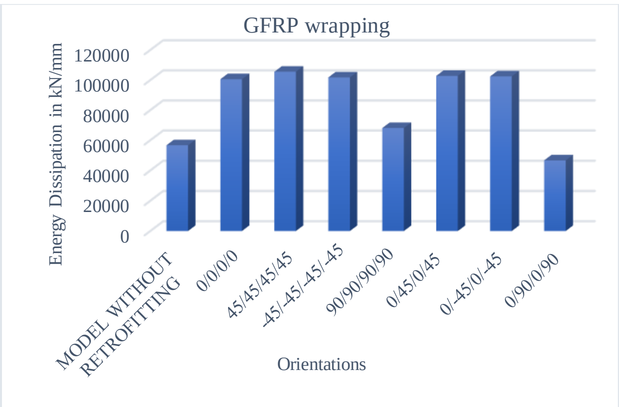
The B-C joint's hysteresis response for the retrofitted modelled composite material comprising GFRP and BFRP sheets with 90/90/90/90 fibre orientations. According to the area of the hysteresis curve, the total energy dissipation is 81793.80kN/mm, which is 30.70% more than in the control specimen.

It can be seen that while the response for each hysteresis loop is identical, the energy dissipation capacity which is determined by the hysteresis loop's area varies. It has been shown that models without retrofits have a higher energy dissipation capacity than those with retrofits. The energy lost by retrofitted models is rising in comparison to un-retrofitted ones.

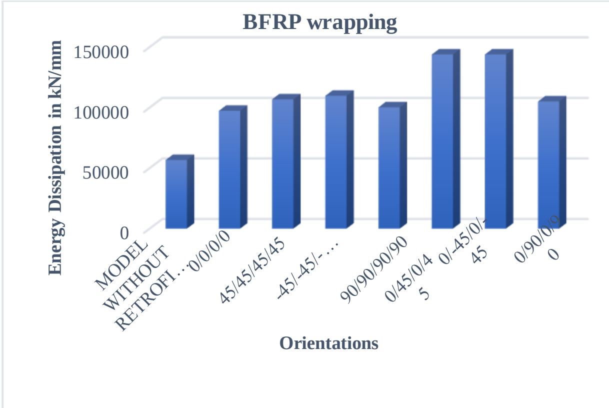
Energy Dissipation Variation Versus Orientations of Fibres



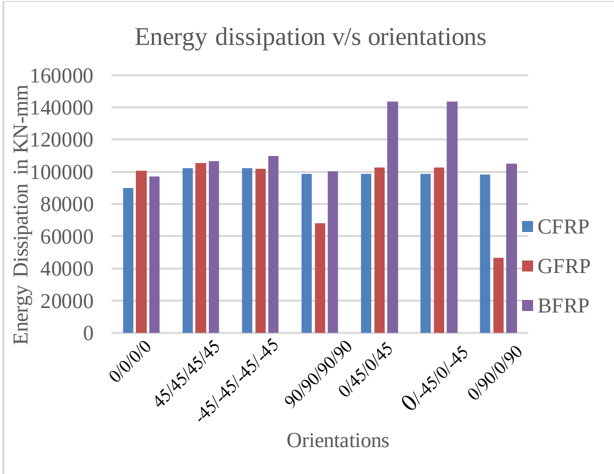
The orientation 45/45/45/45 of CFRP has a higher energy dissipation capability than the other orientations.



It can be demonstrated that the 45/45/45/45 orientation of GFRP has a superior energy dissipation capability than the other orientations.

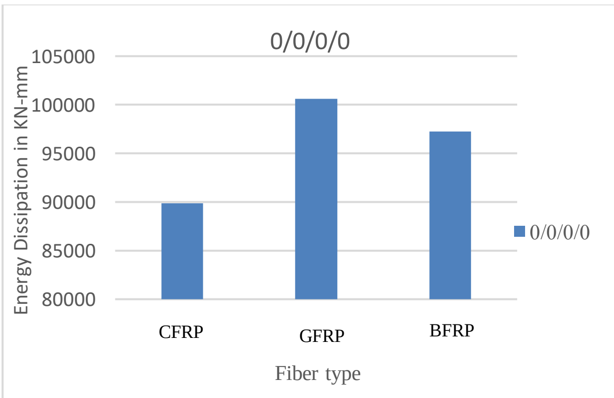


The energy dissipation capacity of orientation 0/-45/0/-45 is increased compared to the other orientations of BFRP.



Compared to un-retrofitted models, the energy dissipation capability of retrofitted CFRP, GFRP and BFRP has risen by 12.2, 11.08, 11.13, and 14.23 percent, respectively.

Energy Dissipation Variation Versus Fibers



The contrast between energy dissipation and fibre orientations of 0/0/0/0. In this instance, GFRP exhibits superior performance in terms of energy dissipation capability.

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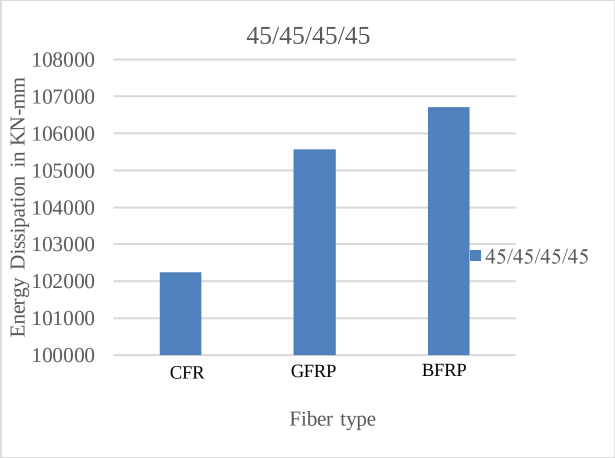
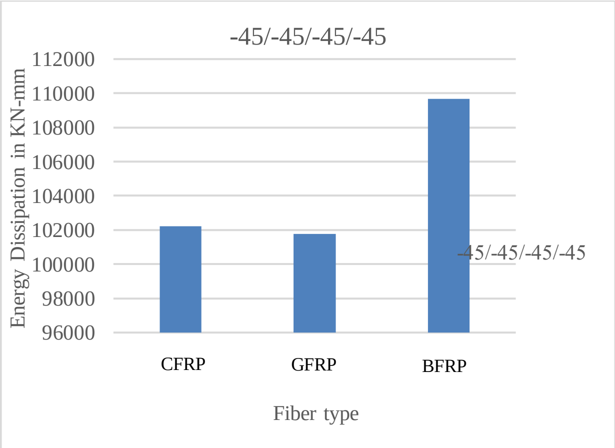
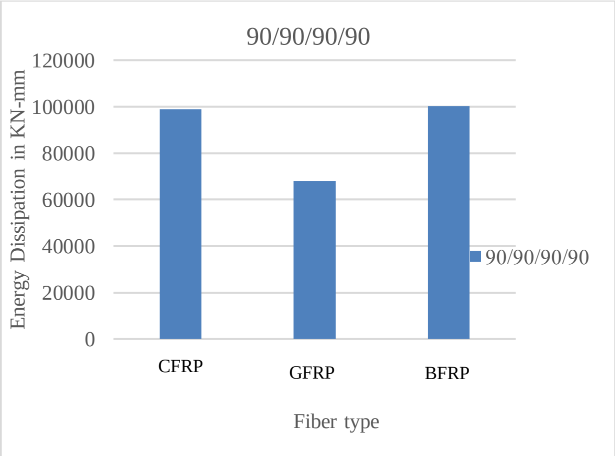


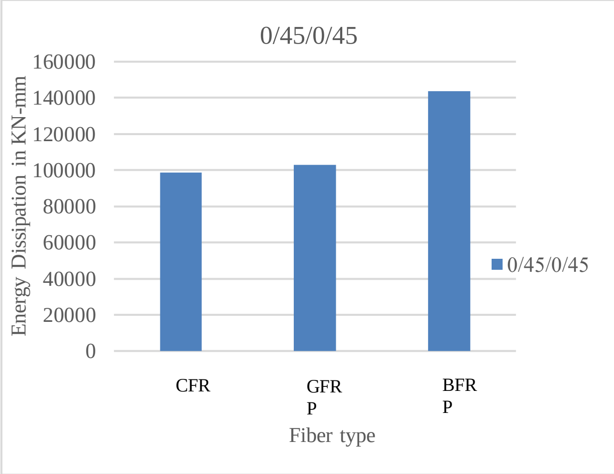
The comparison between energy dissipation and fibre orientations of 45/45/45/45. In this instance, BFRP exhibits superior performance in terms of energy dissipation capability.



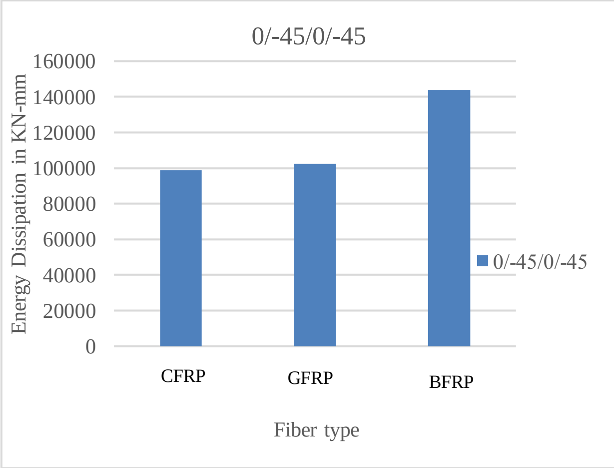
The comparison between energy dissipation and the fibre orientations of -45/-45/-45/-45. In this instance, BFRP exhibits superior performance in terms of energy dissipation capability.



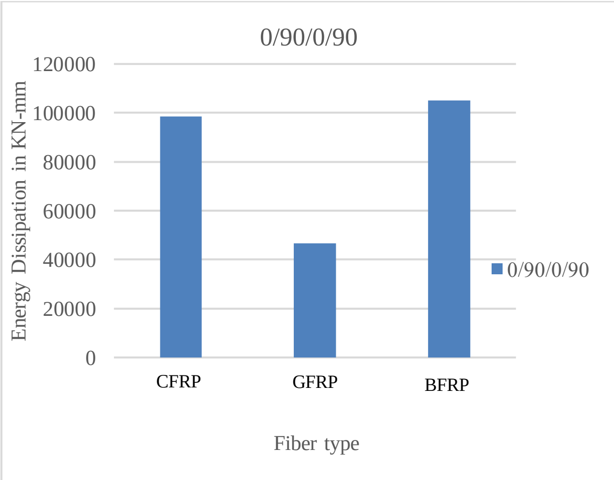
The comparison between energy dissipation and fibre orientations of 90/90/90/90. In this instance, BFRP exhibits superior performance in terms of energy dissipation capability.



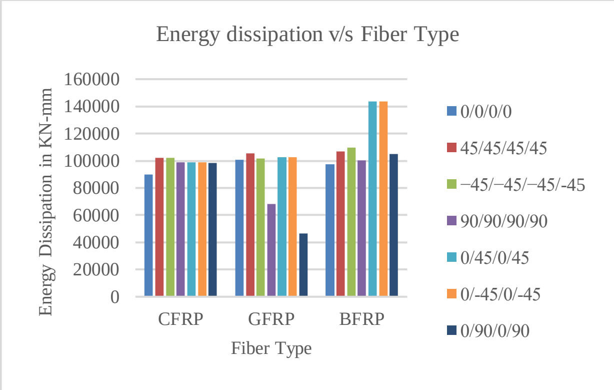
The comparison between energy dissipation and fibre orientations of 0/45/0/45. In this instance, BFRP exhibits superior performance in terms of energy dissipation capability.



The comparison between energy dissipation and fibre orientations of 0/-45/0/-45. In this instance, BFRP exhibits superior performance in terms of energy dissipation capability.

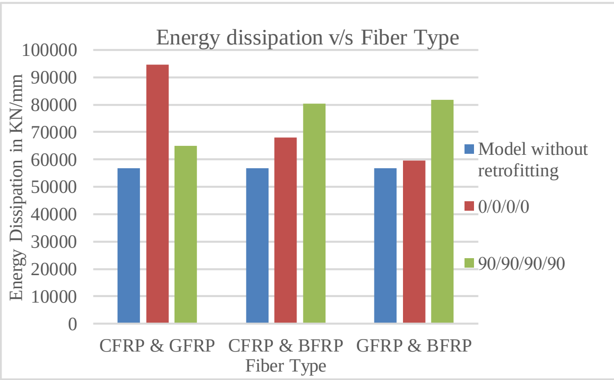


The comparison between energy dissipation and fibre orientations of 0/90/0/90. In this instance, BFRP exhibits superior performance in terms of energy dissipation capability.



The orientation of the fibres and the kinds of fibres affect the load bearing capacity and energy dissipation capacity of CFRP, GFRP and BFRP retrofitted with the BFRP, which produced good results in comparison to the other fibre types. due to the importance of BFRP's characteristics as a strengthening material for concrete construction. In terms of load bearing capability and energy dissipation, basalt fibre reinforced polymers perform better.

Energy Dissipation Variation Versus Multi-Material Wrapping



- When two distinct fibres are retrofitted together, the dissipation capacity is increased by 5 to 15% compared to retrofitting the fibres separately.
- When compared to other combinations, the AFRP and BFRP combination increased energy dissipation capability by up to 15%.

3. CONCLUSION

- The energy dissipation capacity and efficiency of reinforced B-C joints in seismic zones were both boosted by the use of FRP sheets during retrofitting.
- The energy dissipation capacity of CFRP, GFRP, and BFRP sheet models increased by 44.56, 46.3, and 60.58%, respectively, when compared to un-retrofitted models.
- When compared to the control specimen, BFRP sheet retrofitting with the orientation 0/45/0/45 increased energy dissipation capacity by 60.58%.
- It has been noted that using CFRP and BFRP sheets has more energy dissipation.
- When compared to other combinations, the CFRP/GFRP sheet combinations produced better results.
- When employing external FRP reinforcement to strengthen reinforced concrete beams, BFRP sheets have been shown to be a practical substitute.

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