Published by :
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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 05, May-2025

# Analysis of CFRP & GFRP Sheets for Enhancing Shear Strength in RC Beams

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***ABSTRACT***
**Reinforced concrete (RC) structures are necessary for modern construction, and they are constantly subjected to shear loads that could weaken and shorten their lifespan. These structures must be strengthened for long-term safety. Fiber-reinforced polymer (FRP) sheets—specifically, carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP)—are widely used to strengthen reinforced concrete (RC) beams due to their exceptional strength and resistance to corrosion. FRP materials are frequently chosen for retrofitting because they offer improved tensile strength and flexibility in usage without appreciably increasing the structure's weight. Their adaptability to different orientations and configurations enables customized strengthening solutions to solve particular structural problems, such as shear failure.**
**The purpose of this study is to compare the shear strengthening of RC beams using sheets made of glass fiber-reinforced polymer (GFRP) and carbon fiber fiber-reinforced polymer (CFRP). The study focuses on assessing the characteristics of CFRP and GFRP materials at various wrapping angles with respect to the beam's longitudinal axis and its three phases. Utilizing finite element modeling, the shear capacity augmentation offered by CFRP and GFRP sheets will be examined. This configuration will be further investigated to evaluate possible debonding behavior and test the impact of altering the wrapping distance from the beam's end support on overall shear performance after the best material and orientation for maximum strength have been determined. It is expected that the study's findings will enhance structural engineering research and practical applications by offering insightful information about the effective usage of FRP materials for RC beam strengthening.**

***Keywords:-*** **Reinforced Concrete (RC), Shear Strength, Carbon Fibre Reinforced Polymer (CFRP), ANSYS Finite Element Analysis (FEA), Debonding Behavior, U-Wrapping Distance.**

## 1. INTRODUCTION

### 1.1 General

Reinforced concrete structures are extensively utilized in the field of civil engineering due to their adaptability, longevity, and cost efficiency. Nevertheless, a prevalent issue encountered in such structures pertains to shear failure, particularly in beams. The occurrence of shear failure arises when the shear stress surpasses the concrete's shear capacity, ultimately resulting in an abrupt and disastrous structural collapse. It is imperative to enhance the shear strength of reinforced concrete beams to guarantee the safety and steadfastness of structures, especially in precarious settings like bridges, parking facilities, and tall buildings.
Traditional techniques of shear enhancement, such as increasing beam cross-sectional dimensions or integrating steel shear reinforcement, are limited due to practicality, cost, and structural interference. In recent years, novel materials such as Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) have emerged as promising solutions for improving the shear resistance of RC structures.
CFRP and GFRP materials have numerous advantages over previous strengthening approaches. They are lightweight, corrosion resistant, and have strong tensile and stiffness qualities. Furthermore, its versatility enables for simple application and customization to a variety of structural geometries. Externally connecting CFRP or GFRP sheets to the tension face of RC beams can greatly increase shear capacity, reducing the danger of shear failure.
The use of numerical analytical tools, such as finite element analysis (FEA) software like ANSYS, is critical in designing and evaluating shear strengthening procedures. Engineers may use ANSYS software to simulate complicated structural behaviors under varying stress situations, precisely forecast failure mechanisms, and optimize

design parameters. Numerical simulations can be used to systematically examine and validate the effectiveness of CFRP and GFRP sheets in increasing the shear strength of RC beams.

### 1.2 Need for the Study

Shear failure in reinforced concrete (RC) structures poses serious safety risks and structural vulnerabilities, especially in aging infrastructure not originally designed to withstand high shear forces. Traditional strengthening methods are often costly, disruptive, and limited by space and architectural constraints. In contrast, CFRP and GFRP sheets offer a high strength-to-weight ratio, corrosion resistance, and ease of application, making them ideal for efficient and durable shear strengthening. Numerical tools like ANSYS enable engineers to predict performance, optimize designs, and reduce costs by identifying failure mechanisms early. This study aims to analyze and compare the effectiveness of CFRP and GFRP sheets in enhancing the shear capacity of RC beams using ANSYS, by exploring different wrapping orientations, investigating debonding behavior with increased sheet thickness, and assessing the impact of varying wrapping distances from the support.

## 2. LITERATURE REVIEW

### 2.1 Studies on Strenghthening Techniques for RC Beams

C.T.N. Tran et al (2022): Numerous studies have focused on FRP reinforcement in RC beams, but this study specifically examines the deformation capacity of shear-strengthened beams using CFRP laminates and GFRP bars. A variable angle truss model was developed to predict load-displacement behavior under service loads. Experimental results showed the model accurately predicted deformations, with analytical-to-experimental ratios ranging from 1.061 to 1.075, providing valuable insights for designing FRP-reinforced concrete structures.

Aref A. Abadel (2021): This study experimentally investigated various shear strengthening techniques for reinforced SCC beams, comparing traditional RC jacketing with advanced materials like FRPs, TRM, and UHPFRC. Seven beams were tested under four-point bending—one control with sufficient shear reinforcement and six with different strengthening methods. Analytical predictions closely matched experimental results. Strengthening with NSM-CFRP, NSM-TREM, NSM-WWM, and UHPFRC significantly improved shear strength by 47–56% over steel web reinforcement. The strengthened beams shifted from brittle shear to ductile flexural failure, highlighting the effectiveness of these methods and the potential of innovative materials like UHPFRC in enhancing structural performance.

A.M.R. Moubarak et al (2023): This study examined the shear performance of reinforced beams using GFRP trusses instead of steel stirrups. Nine beams were tested under various loading conditions, supported by ANSYS simulations for numerical analysis. Results showed a significant shear capacity increase of 56–80% compared to beams without stirrups and 29–50% over those with only vertical stirrups. GFRP trusses improved concrete confinement and delayed severe cracking, while their use did not noticeably affect ductility. The findings were validated through both experimental and numerical data.

Haya H. Mhanna et al (2022): This study explored the flexural performance of RC beams strengthened with CFRP, PET-FRP, and their hybrid combination using externally bonded reinforcement. Aimed at enhancing strength and ductility, the hybrid system leverages PET-FRP's deformability and CFRP's high strength. Beams were tested under four-point bending with strain gauges and LVDTs to monitor behavior. Results showed a 46–48% increase in strength and improved stiffness with the hybrid system, though limited by CFRP's strain capacity. Anchoring was found essential for optimal performance under various loading conditions.

Ayesha Siddika, Krishno Saha, Md. Sumodro Mahmud, Sumon Chandra Roy, Md. Abdullah Al Mamun2, Rayed Alyousef (2019): This study analyzes the performance and failure of CFRP-strengthened RC beams, focusing on load-bearing improvements and the interaction between internal stirrups and external CFRP strips using methods like U-wrapping and strip wrapping. Compared to control beams, CFRP-strengthened beams showed enhanced ductility, load-deflection behavior, and resistance to failure modes like crushing, rupture, and debonding. Surface preparation, especially CA treatment, improved bond strength and load capacity more than SA treatment. The findings highlight CFRP's effectiveness in retrofitting and upgrading existing structures.

Cai, L., Liu, Q., & Guo, R. (2021): This study investigates the shear performance of RC beams reinforced with CFRP grids embedded in epoxy mortar. Six beams with varying properties—such as concrete strength, shear span ratio, and CFRP grid ratio—were tested using four-point bending. Results showed that CFRP grids significantly enhanced shear capacity and improved crack behavior. The findings provide valuable insights into strengthening RC structures with CFRP grid reinforcement.

Haya H. Mhanna et al (2022): Strengthening RC beams with FRP for shear is complex due to interactions among concrete, steel, and FRP. Unlike flexural strengthening, shear research is less advanced, and factors like wrapping methods, crack orientation, and FRP type affect design accuracy. This study compares key standards—ACI 440.2R-17, CSA-S806.12, fib bulletin 90, and TR55—revealing that most overestimate fully wrapped configurations. While fib bulletin 90 offers the best accuracy, TR55 is the most conservative. The findings highlight the need to refine strain limits and improve design models, aiding more informed structural engineering decisions.

Abdelmohaymen and Salem's (2022): This study explores enhancing shear capacity in RC beams using Near Surface Mounted (NSM) technology with manually made CFRP (MMFRP) sheets. Experimental results showed that MMFRP effectively resisted shear forces, with consistent materials, geometry, and loading conditions. Increasing the number of CFRP strips (double to quadruple layers) improved shear strength, while closer strip spacing further increased the beam's ultimate load capacity, indicating an inverse relationship between spacing and strength.

Haya H. Mhanna et al (2019): This study evaluated the shear enhancement of RC beams using CFRP wraps in different configurations through three-point bending tests. It compared U-wrapped and fully wrapped beams, highlighting CFRP's high strength-to-weight ratio and durability. Fully wrapped beams showed greater ductility, while U-wrapped beams failed more brittlely due to debonding. The findings underscore the importance of proper anchoring and offer insights into improving shear performance.

Huang et al (2020): This study used structural stressing state theory and the numerical shape function (NSF) approach to analyze the behavior of CFRP-reinforced RC beams. Given the challenges of corrosion and damage in RC structures, CFRP has proven effective in improving mechanical properties, though experimental data on CFRP-reinforced beams remains limited. The M-K method was applied to estimate failure loads, and five CFRP-reinforced RC beams with varying concrete strengths and reinforcement ratios were tested. The beam with higher concrete strength and balanced reinforcement showed the best performance. The findings provide valuable insights into the behavior of CFRP-strengthened RC beams and their failure load estimation.

### 2.2 Gaps in Literature

Literature shows that CFRP and GFRP materials are effective for shear strengthening of RC beams, but research gaps remain, such as limited comparative studies and a lack of exploration into material configurations, orientations, and wrapping angles. This study aims to fill these gaps by comparing CFRP and GFRP sheets at various wrapping angles to assess their effectiveness in enhancing shear strength. The optimal material and orientation will be identified, followed by an investigation into debonding behavior and the effect of wrapping distance on shear performance, ensuring both structural integrity and cost-effectiveness.

## 3. METHODOLOGY

The methodology of this study follows a systematic approach to evaluate the effectiveness of CFRP and GFRP sheets for shear strengthening of RC beams. It begins with a literature survey to identify research gaps, followed by material selection, finite element modeling in ANSYS, and analysis of different wrapping orientations. The stronger sheet and its optimal orientation, determined through these analyses, are then used to study the debonding behavior and the impact of varying wrapping distances from the end support to enhance shear strength.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 05, May-2025

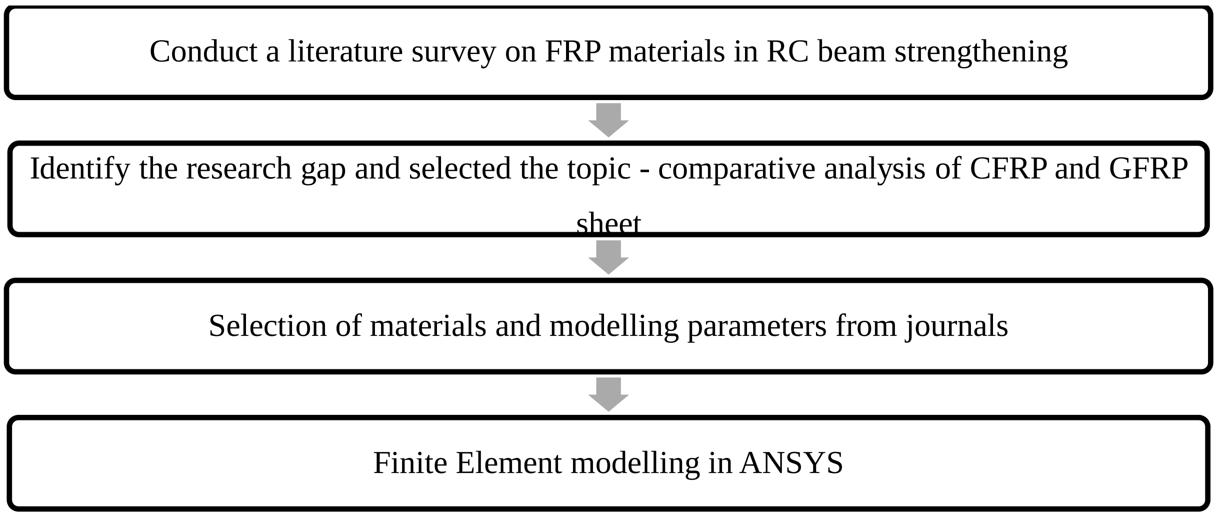


Fig: 3.1. Overall methodology flowchart

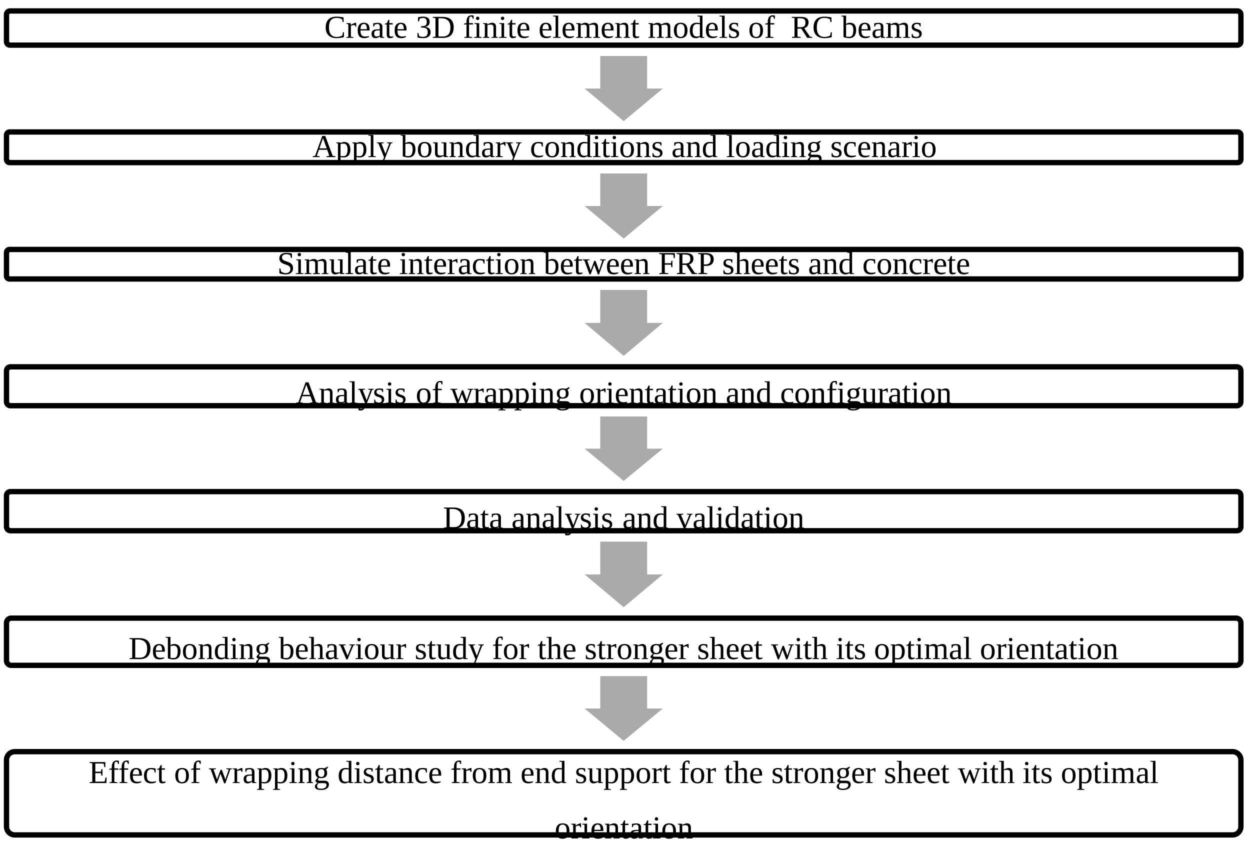


Fig: 3.2. Finite Element Modeling flow chart

International Journal of Engineering Research & Technology (IJERT)
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## 4. COMPARATIVE ANALYSIS OF CFRP AND GFRP SHEET-REINFORCED RC BEAM

This chapter provides a thorough comparison of reinforced concrete (RC) beams reinforced with glass fiber-reinforced polymer (GFRP) sheets and carbon fiber-reinforced polymer (CFRP) sheets. The shear performance of the beams at different wrapping angles and configurations is assessed in this study. To guarantee consistent findings, a journal-sourced beam geometry is used constantly throughout the finite element analysis. In order to determine the amount of shear resistance achieved by the reinforced beam in comparison to a standard RC beam, a specific boundary condition is imposed by applying a force of 5000N per second on the beam, with a maximum load of 48000N on the structure.

### 4.1 Materials Used for the Study

• The beam geometry, steel grade, and concrete grade are from the journal "Govind Reddy and Dr. T. Muralidhara Rao (2017) Flexural Behavior of Reinforced Concrete Beams using ANSYS. CVR Journal of Science and Technology, Vol.12." It is described in Table 4.1: beam geometry.

• The properties of CFRP, GFRP, and epoxy resins are based on a review in the journal "I. Shakir Abbood et al (2021) Properties evaluation of fiber reinforced polymers and their constituent materials used in structures. Materials Today: Proceedings 43, 1003-1008". Its specifications are listed in tables 4.2: CFRP and GFRP properties and 4.3: Epoxy resin properties.

Table 4.1: Beam geometry

| | |
|---|---|
| Width of beam (mm) | 266 |
| Depth of beam (mm) | 532 |
| Length of beam (mm) | 1500 |
| Main reinforcement diameter (mm) | 25 |
| Stirrups diameter (mm) | 8 |
| Characteristics strength of concrete (MPa) | 20 |
| Grade of steel | Fe 250 |

Table 4.2: Properties of CFRP and GFRP

| Property | Material Type | |
|---|---|---|
| | CFRP | GFRP |
| Density (gm/cm³) | 2.1 | 2.5 |
| Tensile strength (MPa) | 3920 | 4580 |
| Young's Modulus (GPa) | 784 | 86 |
| Elongation (%) | 1.8 | 5.0 |

Table 4.3: Properties of epoxy resin

| Property | Resin |
|---|---|
| | Epoxy |
| Density (gm/cm³) | 1.4 |
| Tensile strength (MPa) | 130 |
| Young's Modulus (GPa) | 4.1 |
| Poisson's ratio | 0.4 |

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http://www.ijert.org
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4.2 Modelling of a Normal RC Beam

Finite Element Modeling was done using ANSYS R18.1. The dimensions and properties of the model are given in the table 4.1.

Where, Length of the beam =1500mm
Width of the beam =266mm
Depth of the beam =532mm

Four point bending test was carried out to find shear stress. Fixed support condition was provided.

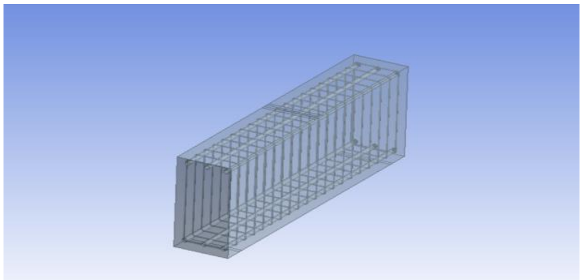

Fig:4.1Modelling of a normal RC beam

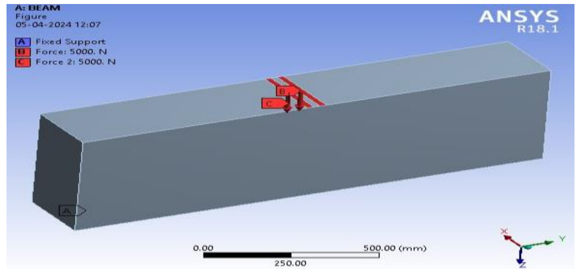


Fig: 4.2. Loading on RC beam

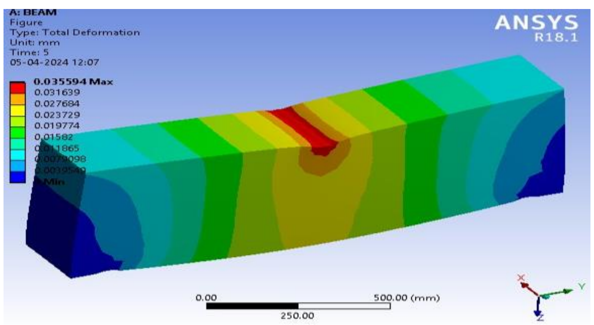


Fig: 4.3. Deflection of normal RC beam

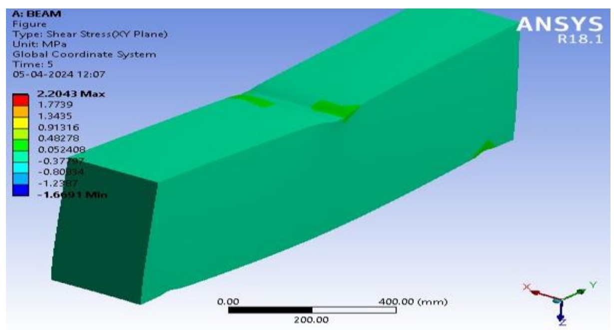


Fig: 4.4. Shear stress of normal RC beam

International Journal of Engineering Research & Technology (IJERT)
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4.3 Modelling of RC Beam with CFRP & GFRP At $0^0$ Side Wrap

Finite Element Modeling was done using ANSYS R18.1. The dimensions and properties of the model are given in the table 4.1.

Where, Length of the beam =1500mm

Width of the beam =266mm

Depth of the beam =532mm

CFRP properties and epoxy resin properties are given in table 4.2 and table 4.3 Let as assume a 2mm CFRP sheet for the design. Four point bending test was carried out to find shear stress. Fixed support condition was provided.

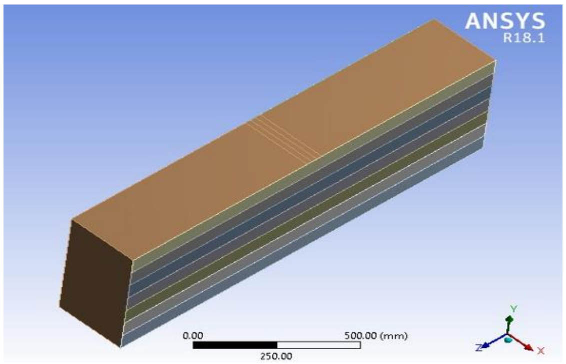


Fig: 4.5. Modelling of beam with $0^0$ side wrap

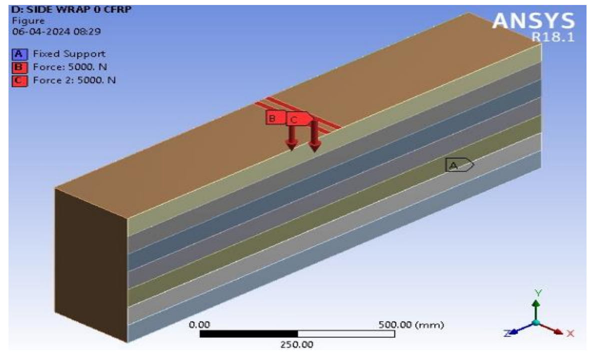


Fig: 4.6. Loading on beam with $0^0$ side wrap

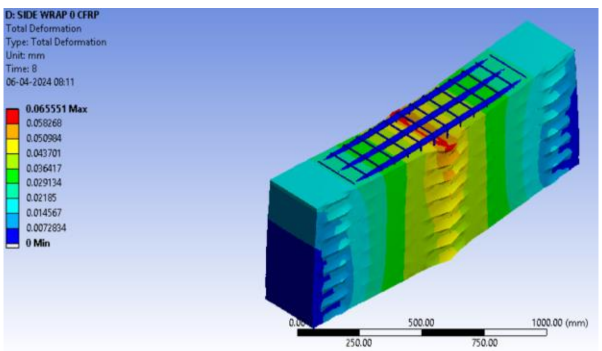


Fig: 4.7. Deflection on beam with $0^0$ CFRP side wrap

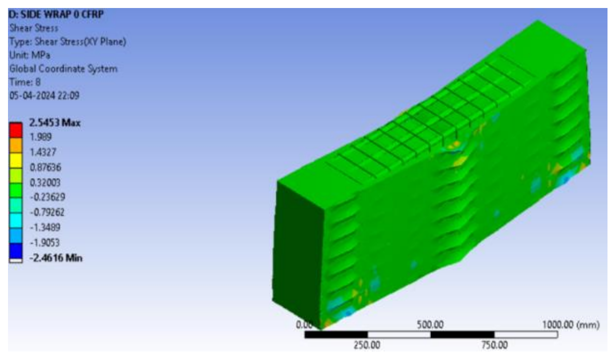


Fig: 4.8. Shear stress on beam with $0^0$ CFRP side wrap

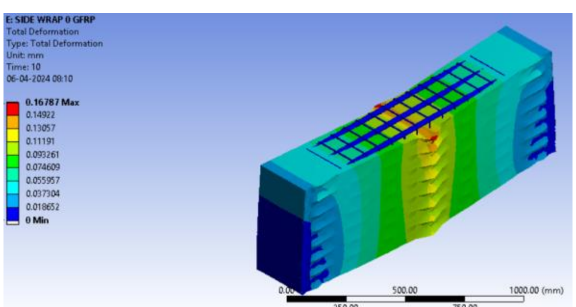


Fig: 4.9. Deflection on beam with $0^0$ GFRP side wrap

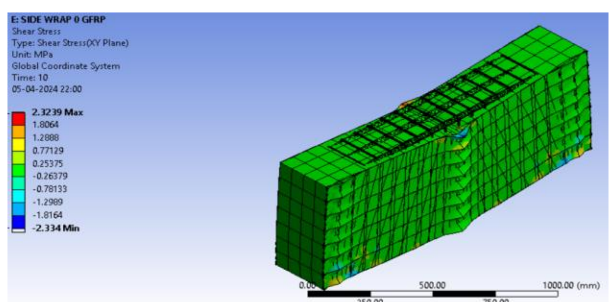


Fig: 4.10. Shear stress on beam with $0^0$ GFRP side wrap

4.4 Modelling of RC Beam with CFRP & GFRP At $90^0$ Side Wrap

Finite Element Modeling was done using ANSYS R18.1. The dimensions and properties of the model are given in the table 4.1.

Where, Length of the beam =1500mm
Width of the beam =266mm
Depth of the beam =532mm

CFRP properties and epoxy resin properties are given in table 4.2 and table 4.3 Let as assume a 2mm CFRP sheet for the design. Four point bending test was carried out to find shear stress. Fixed support condition was provided.

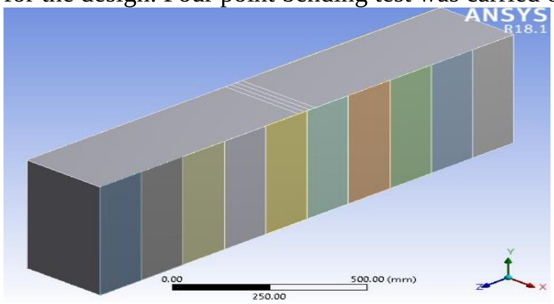


Fig: 4.11. Modelling of beam with $90^0$ side wrap

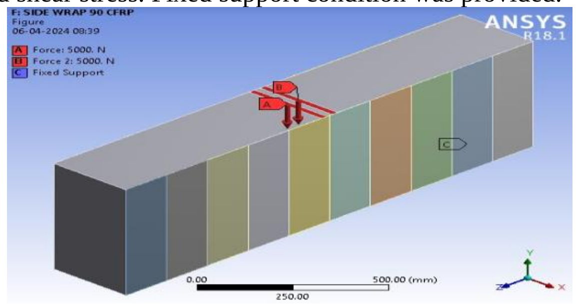


Fig: 4.12. Loading on beam with $90^0$ side wrap

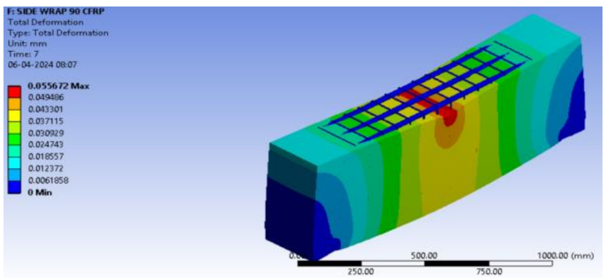


Fig: 4.13. Deflection on beam with $90^0$ CFRP Side wrap

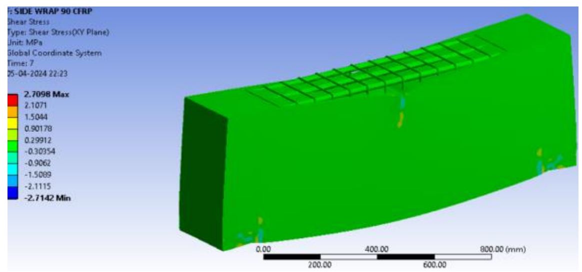


Fig: 4.14. Shear stress on beam with $90^0$ CFRP side wrap

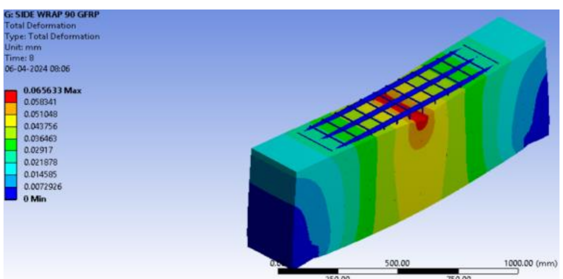


Fig: 4.15. Deflection of beam with $90^0$ GFRP side wrap

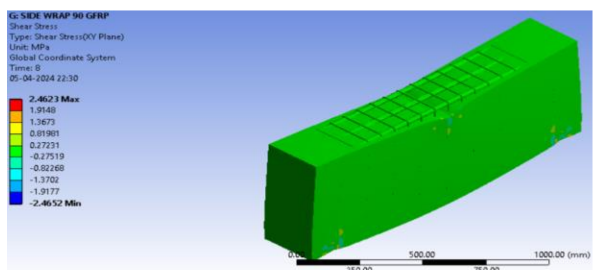


Fig: 4.16. Shear stress of beam with $90^0$ GFRP side wrap

4.5 Modelling of RC Beam with CFRP & GFRP At $45^0$ Side Wrap

Finite Element Modeling was done using ANSYS R18.1. The dimensions and properties of the model are given in the table 4.1.

Where, Length of the beam =1500mm
Width of the beam =266mm
Depth of the beam =532mm

CFRP properties and epoxy resin properties are given in table 4.2 and table 4.3 Let as assume a 2mm CFRP sheet for the design. Four point bending test was carried out to find shear stress. Fixed support condition was provided.

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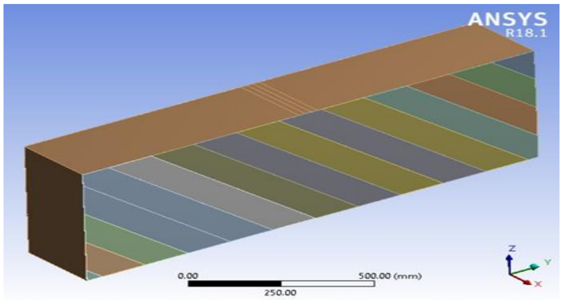


Fig: 4.17. Modelling of beam with 45$^0$ side wrap

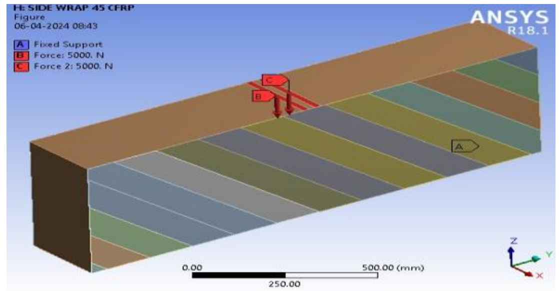


Fig: 4.18. Loading on beam with 45$^0$ side wrap

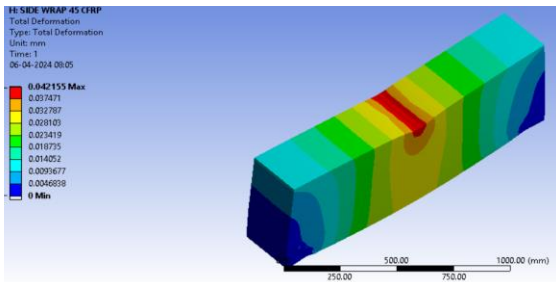


Fig: 4.19. Deflection of beam with 45$^0$ CFRP side wrap

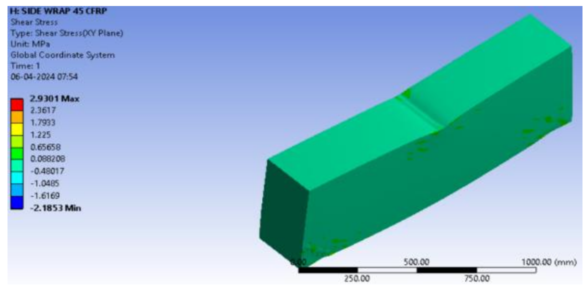


Fig: 4.20. Shear stress of beam with 45$^0$ CFRP side wrap

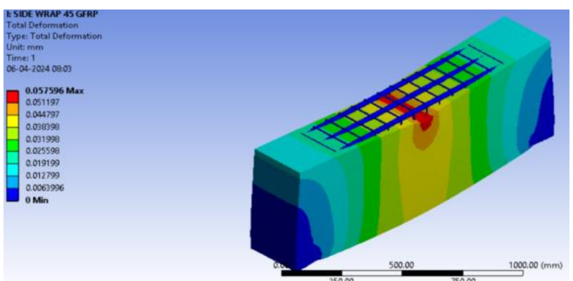


Fig: 4.21. Deflection of beam with 45$^0$ GFRP side wrap

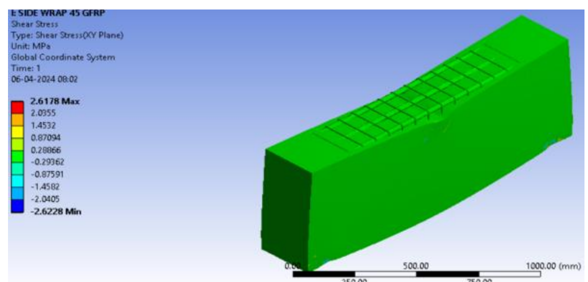


Fig: 4.22. Shear stress of beam with 45$^0$GFRP side wrap

4.6 Modelling of RC Beam with CFRP & GFRP U-Wrap

Finite Element Modeling was done using ANSYS R18.1. The dimensions and properties of the model are given in the table 4.1.

Where, Length of the beam =1500mm
Width of the beam =266mm
Depth of the beam =532mm

CFRP properties and epoxy resin properties are given in table 4.2 and table 4.3. Let as assume a 2mm CFRP sheet for the design. Four point bending test was carried out to find shear stress. Fixed support condition was provided.

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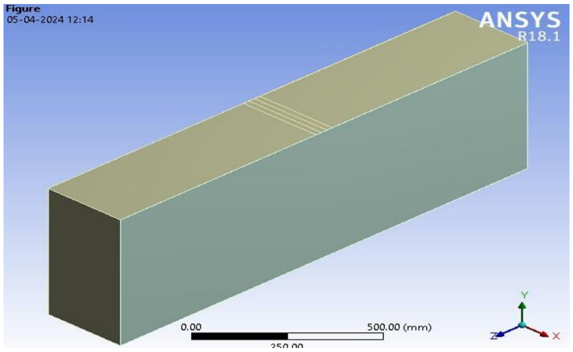


Fig: 4.23. Modelling of Beam with U-wrap

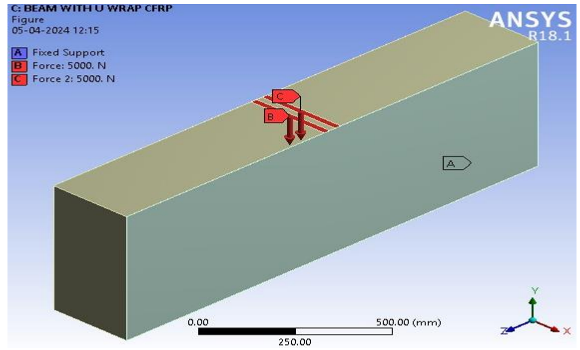


Fig: 4.24 Loading on Beam with U-wrap

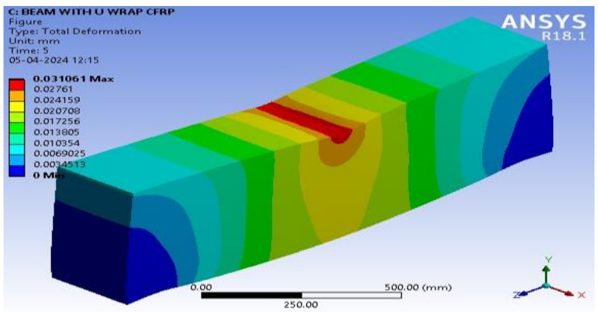


Fig: 4.25 Deflection of beam with CFRP U-wrap

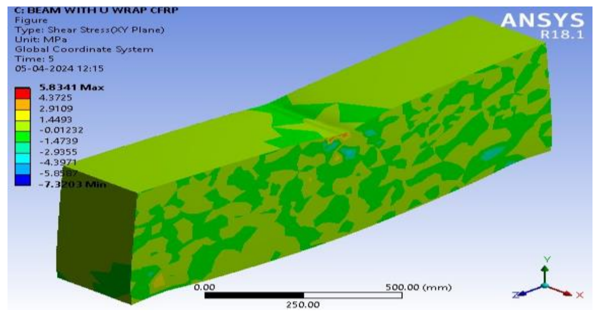


Fig: 4.26 Shear stress of beam with CFRP U-wrap

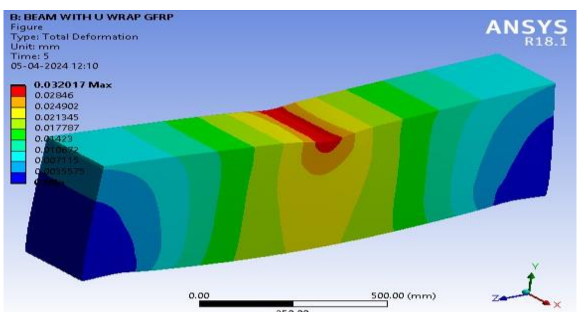


Fig: 4.27. Deflection of beam with GFRP U-wrap

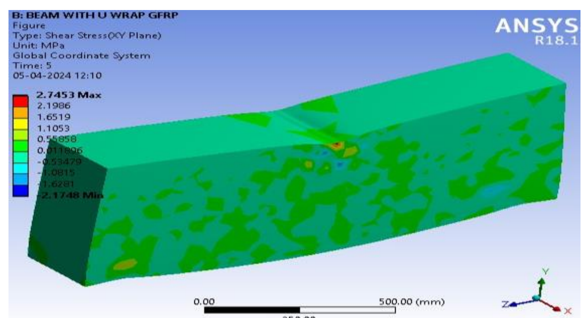


Fig: 4.28. Shear stress of beam with GFRP U-wrap

## 5 VALIDATION

Finite element analysis (FEA) requires validation to make sure the numerical model faithfully captures behavior in the actual world.

### 5.1 Experimental Study Overview

To validate the numerical model, an experimental study from the literature is considered. This study, presented in the journal article "Jassim, M. F., Lafta, Y. J., & Malik, H. S. (2023). Shear behavior of reinforced concrete beams with different arrangements of externally bonded carbon fiber-reinforced polymer. Journal of Engineering, 12(3), 1465410", examines an RC beam strengthened with CFRP sheets using a U-wrap configuration.

International Journal of Engineering Research & Technology (IJERT)
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5.1.1 Boundary Conditions and Experimental Results

In the validation procedure, the beam was evaluated using a four-point bending arrangement with two concentrated loads applied by a measurement apparatus having a maximum load capacity of 500 kN. According to the experimental investigation, the CFRP-woven wrap-strengthened beam failed in shear at a maximum deflection of

5.9 mm and an ultimate stress of 190 kN on three sides parallel to the longitudinal axis. The ANSYS numerical model was created in light of these experimental results in order to reproduce the test circumstances and confirm that it accurately predicts shear capacity and displacement behavior.

5.2 Numerical Model Setup in Ansys

Finite Element Modeling was done using ANSYS 2024.R2. The dimensions and properties for the model is taken from the journal.

Where, Length of the beam =1700mm

Width of the beam =200mm

Depth of the beam =250mm

Four point bending test was carried out to find shear stress. Fixed support condition was provided.

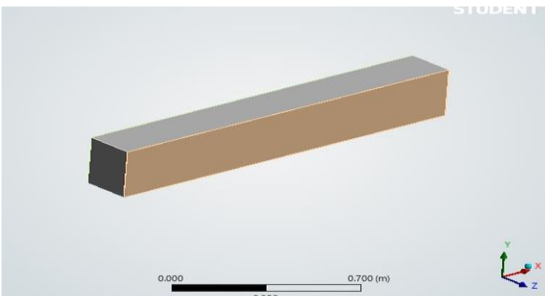


Fig: 5.1. Modeling of beam with CFRP U-wrap

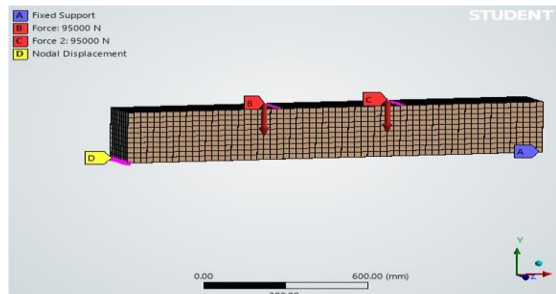


Fig: 5.2. Loading on beam with CFRP U-wrap

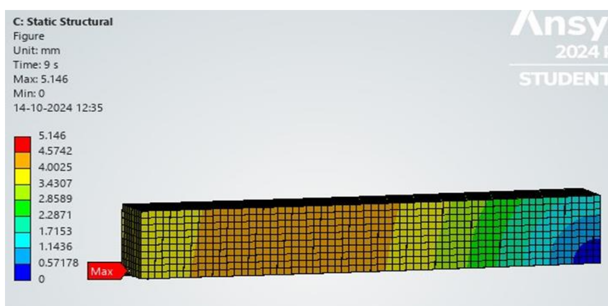


Fig: 5.3. Deformation of beam with CFRP U-wrap

The numerical model predicts a maximum displacement of 5.146 mm, closely aligning with the experimental result of 5.9 mm.

## 6. DEBONDING BEHAVIOR

Debonding is a critical failure mechanism in fiber-reinforced polymer (FRP)-strengthened reinforced concrete (RC) beams, particularly in shear strengthening applications. Hence, for this advanced analysis, CFRP U-wrap configuration was selected as the optimal solution for studying debonding behavior. This study investigates the debonding behavior of CFRP U-wrap strengthening with varying thicknesses to assess its influence on shear strength and deflection. The same beam model validated in the previous chapter is used here to ensure consistency in analysis and comparison.

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To evaluate the effect of CFRP thickness on debonding behavior, three different thicknesses of CFRP sheets were considered: 0.5 mm, 1.0 mm, 1.5 mm. The loading condition for all three cases ranges from 5 kN to 125 kN, applied gradually.

6.1 Modelling of RC Beam to Evaluate Debonding Behavior

Finite Element Modeling was done using ANSYS 2024.R2. The dimensions and properties for the model is taken from the validation beam.

Where, Length of the beam =1700mm

Width of the beam =200mm

Depth of the beam =250mm

Four point bending test was carried out to find shear stress. Fixed support condition was provided.

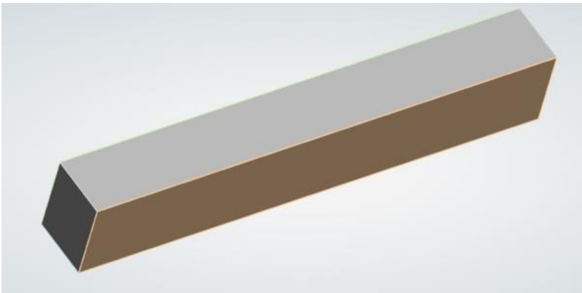


Fig: 6.1. Modelling of beam with CFRP U-wrap

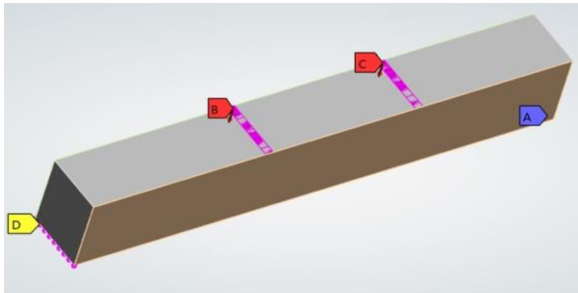



Fig: 6.2. Loading on beam with CFRP U-wrap

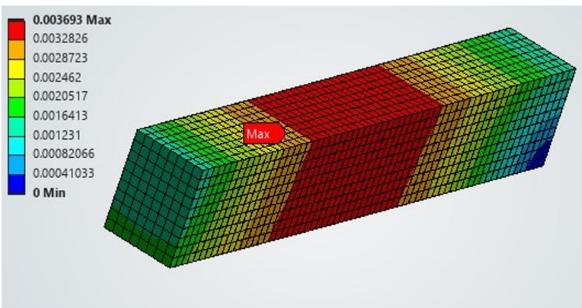



Fig: 6.3. Deflection of beam with 0.5mm CFRP U-wrap

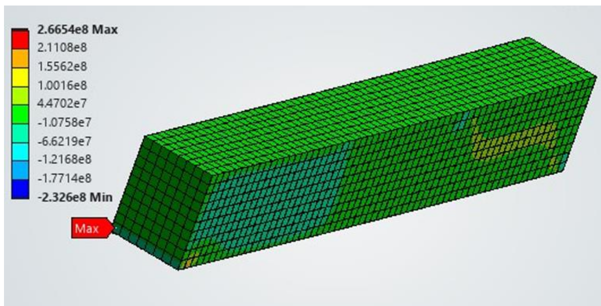
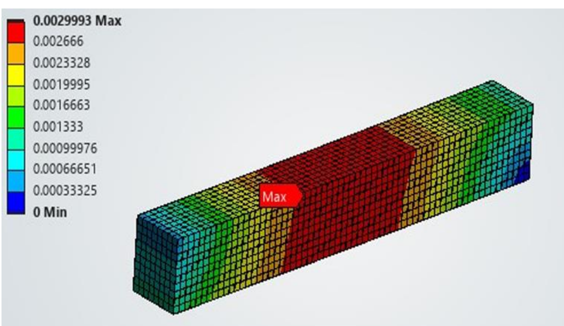



Fig: 6.4. Shear stress of beam with 0.5mm CFRP U-wrap



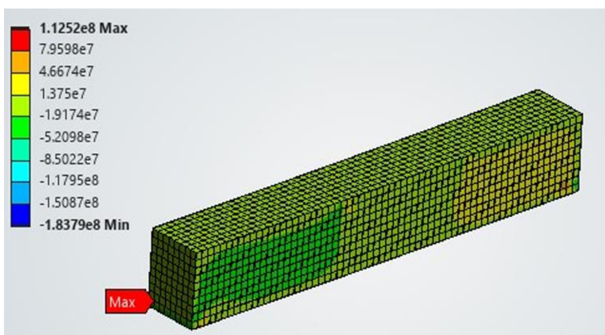



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Fig: 6.5. Deflection of beam with 1mm CFRP U-wrap

Fig: 6.6. Shear stress of beam with 1mm CFRP U-wrap

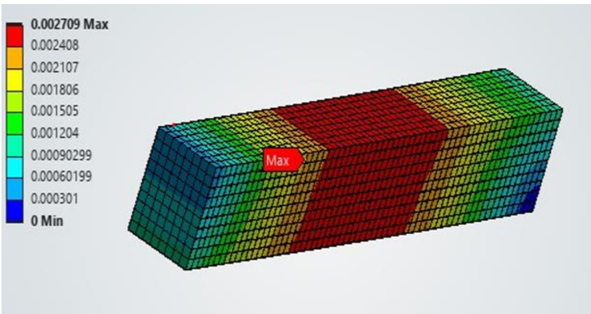



Fig: 6.7. Deflection of beam with 1.5mm CFRP U-wrap

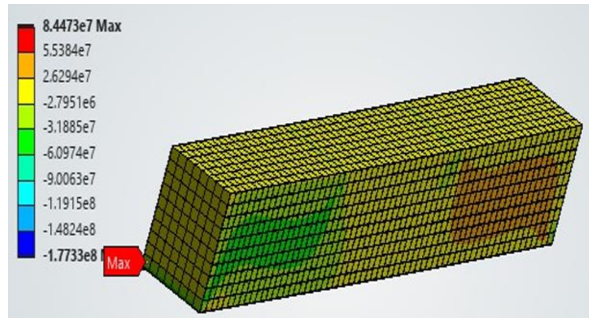



Fig: 6.8. Shear stress of beam with 1.5mm CFRP U-wrap

## 7. EFFECT OF WRAPPING DISTANCE FROM END SUPPORT

This chapter investigates the influence of the wrapping distance of CFRP sheets from the end support on the shear strengthening performance of reinforced concrete (RC) beams. Following the validation of the CFRP U-wrap model, further parametric analysis was conducted by varying the distance of the CFRP U-wrap from the support. In this study, a CFRP sheet of 1 mm thickness—the most commonly available commercial thickness—was used. The same RC beam configuration from the validation chapter was employed, ensuring consistency in geometry, material properties, and boundary conditions.

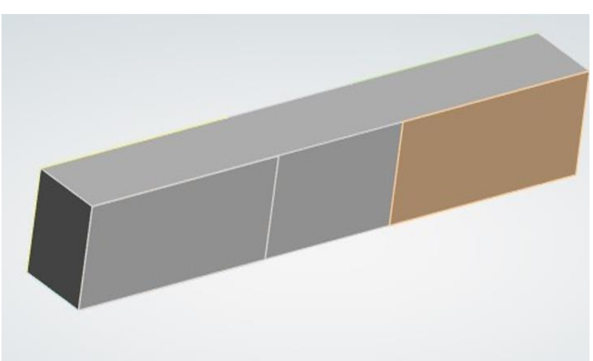
Three wrapping distances from end support were considered: 600 mm, 400 mm, and 200 mm. These distances were chosen to evaluate the influence of decreasing the wrapping length on the beam's shear stress distribution and overall deflection.A peak load of 190 kN, derived from the validated beam, was applied to all three models to simulate realistic shear demands. The load was applied in a four-point bending configuration consistent with the validation model.

### 7.1 Modelling of RC Beam with Varying CFRP U Wrap

Finite Element Modeling was done using ANSYS 2024.R2. The dimensions and properties for the model is taken from the validation beam.

Where, Length of the beam = 1700mm
Width of the beam = 200mm
Depth of the beam = 250mm

Four point bending test was carried out to find shear stress. Fixed support condition was provided.



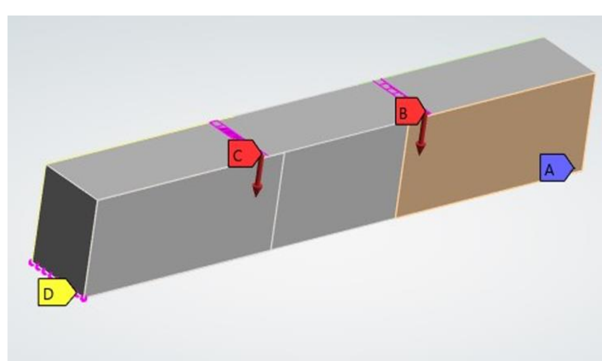


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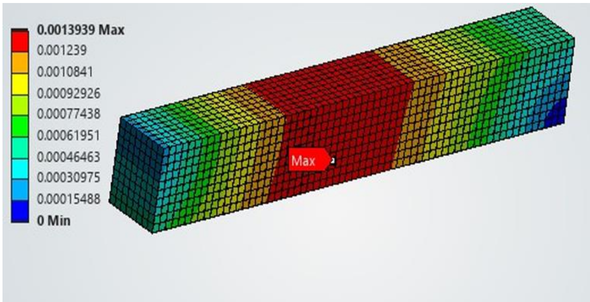
Fig: 7.1. Modeling of beam with 600mm CFRP U-wrap

Fig: 7.2. Loading on beam with 600mm CFRP U-wrap



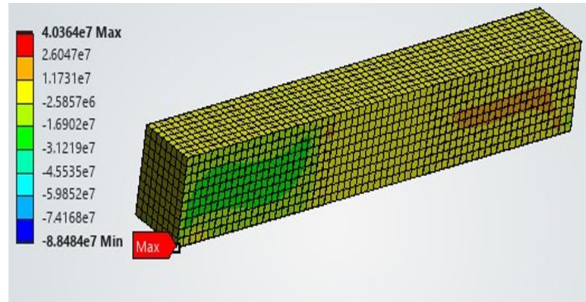
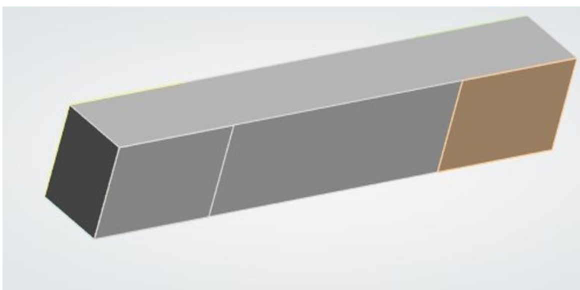




Fig: 7.3. Deflection of beam with 600mm CFRP U-wrap

Fig: 7.4. Shear stress of beam with 600mm CFRP U-wrap



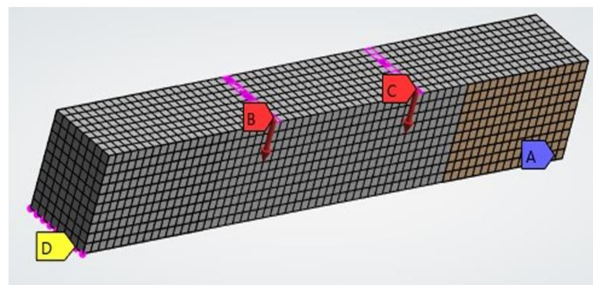
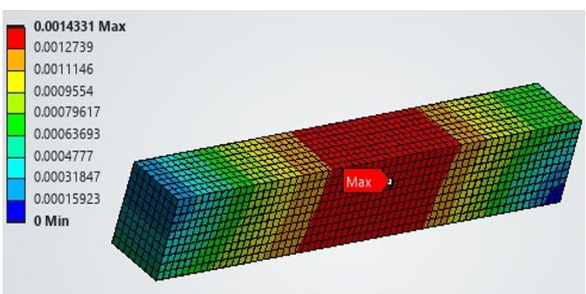



Fig: 7.5. Modeling of beam with 400mm CFRP U-wrap

Fig: 7.6. Loading on beam with 400mm CFRP U-wrap



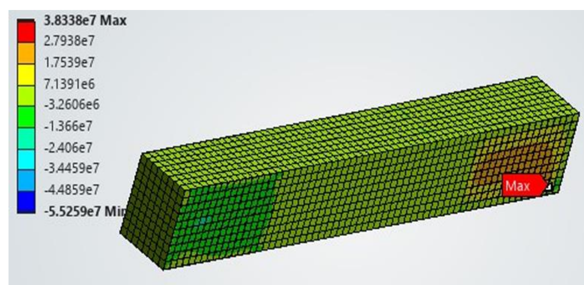
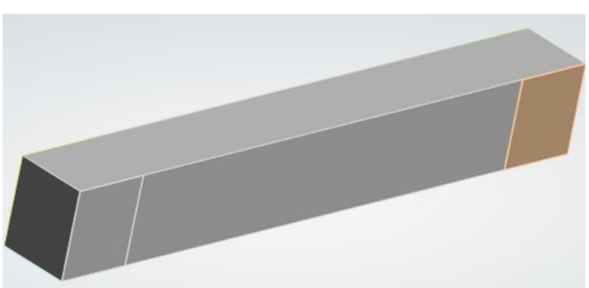




Fig: 7.7. Deflection of beam with 400mm CFRP U-wrap

Fig: 7.8. Shear stress of beam with 400mm CFRP U-wrap



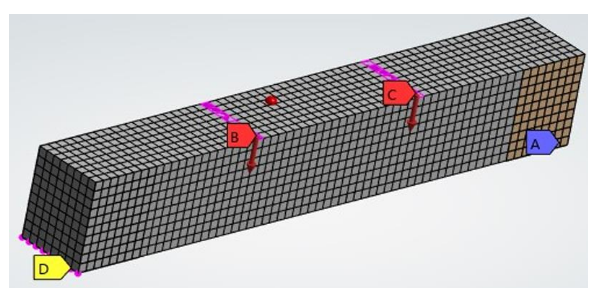


Fig: 7.9. Modeling of beam with 200mm CFRP U-wrap

Fig: 7.10. Loading on beam with 200mm CFRP U-wrap

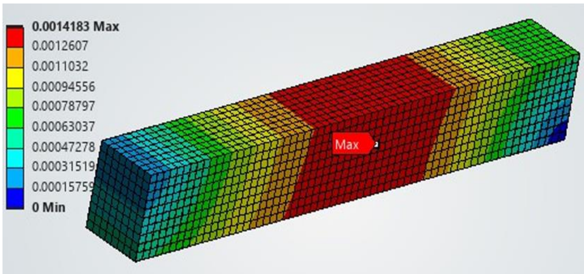



Fig: 7.11. Deflection of beam with 200mm CFRP U-wrap

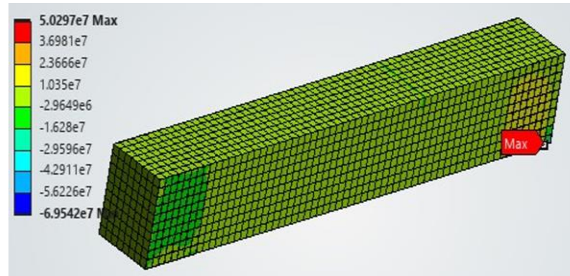



Fig: 7.12. Shear stress of beam with 200mm CFRP U-wrap

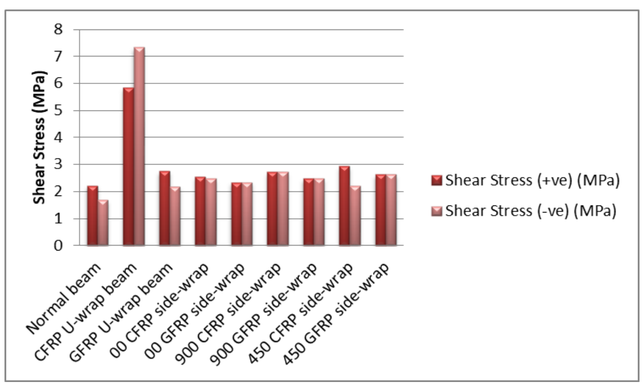
## 8. RESULTS AND DISCUSSION

FRP is defined as a composite system consisting of a polymer matrix that is strengthened with fibers. The utilization of CFRP and GFRP sheets in FRP is a common practice to enhance the strength of RC beams. Various parameters were studied, including sheet material, wrapping orientation, debonding behavior with varying CFRP thicknesses, and the effect of wrap distance from the beam end support. The results are discussed in detail to identify the optimal configurations for enhanced structural performance.

### 8.1 Comparison of Shear Stress of GFRP and CFRP Strengthened Beam

A comparative study was performed on RC beams strengthened with CFRP and GFRP sheets at different orientations—0°, 45°, and 90°, as well as U-wrapping. The aim was to evaluate how the material type and orientation affect shear stress and deflection.

Fig.8.1. Comparative analysis diagram showing the shear resistance of models




- In the context of CFRP U-wrap beams, the compressive shear stress measures 7.32MPa and the tensile shear stress is recorded at 5.834MPa, indicating a significant rise in shear capacity when contrasted with the shear strength of conventional beams and GFRP U-wrap beams.
- The deflection figures of the U-wrap beams, specifically 0.031mm for CFRP and 0.032mm for GFRP, demonstrate a slight decrease in comparison to the standard beam at 0.0356mm, implying an enhancement in rigidity and overall structural robustness.
- CFRP side-wrap beams typically showcase elevated shear stress levels in relation to GFRP side-wrap beams, with the 45° side wrap exhibiting superior shear resistance compared to the 0° and 90° orientations, thus establishing it as the more pertinent configuration for achieving optimal shear strength.
- The deflection values observed in side-wrap beams generally surpass those of U-wrap beams, suggesting a potentially lower level of stiffness while still offering improved shear resistance in contrast to standard beams.
- U-wrapping with CFRP provided the maximum shear stress resistance and the lowest deflection, indicating its superior structural efficiency.

8.2 Model Validation with Experimental Data

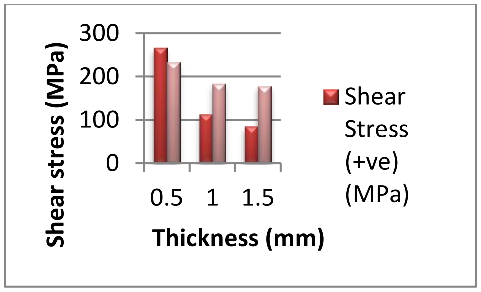
To confirm the accuracy of the ANSYS finite element model, it was validated against available experimental results.

- The numerical model is successfully validated against experimental data
- ANSYS prediction (5.146 mm) falls within the acceptable range.
- The model confirms that the numerical study is valid and reliable for extended parametric studies (e.g., debonding and wrapping distance effects).

8.3 Debonding Behavior Based on CFRP Thickness

The effect of CFRP sheet thickness on debonding and structural performance was studied.

Fig.8.2. Debonding behavior of CFRP U-wrap

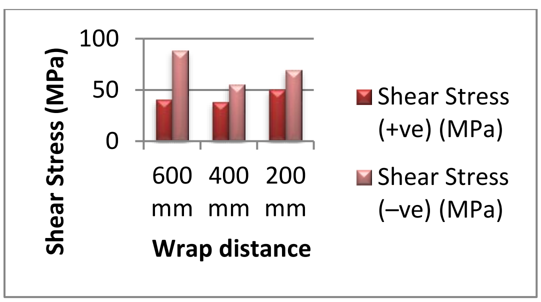



- Increasing the CFRP thickness reduces deflection, indicating increased stiffness.
- The 0.5 mm sheet showed the highest deflection, while the 1.5 mm sheet demonstrated the most controlled deflection under loading.
- However, positive shear stress decreases, likely due to early debonding or ineffective stress transfer at higher thicknesses.
- Increasing CFRP thickness improves stiffness but may reduce strengthening due to debonding.

8.4 Influence of U-Wrap Distance from Beam Support

An additional parametric study examined how the distance of the CFRP U-wrap from the beam support affects performance.

Fig.8.3. Influence of CFRP U-wrap




- 200 mm wrap distance produced the highest positive shear stress, indicating better crack confinement when wrapping is placed closer to the support.
- While negative shear stress is highest at 600 mm, the overall performance favors closer wrap distances for shear enhancement.
- Deflection varied only slightly, showing minimal influence of wrap position on global stiffness but a clear impact on stress transfer.

## 9. CONCLUSION

Studying the improvement in shear resistance of reinforced concrete (RC) beams with the incorporation of Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) sheets has provided meaningful insights into the impact of different strengthening materials, orientations, and configurations. This research contributes both practical recommendations and theoretical understanding, especially regarding shear enhancement using fiber-reinforced polymers.

- Optimized Material Selection and Configuration:
  According to the comparison investigation, CFRP sheets routinely perform better than GFRP in terms of shear strengthening, particularly when used in U-wrap and at 45° orientations. U-wrapped CFRP demonstrated the maximum shear capacity of every design, suggesting that it is the most efficient strengthening solution.
- Validation of Numerical Modeling:
  Reliability for sophisticated parametric investigations was confirmed by the validated ANSYS model's precise prediction of the experimental beam's peak load and deflection. This validation increases the model's suitability for use in next studies and real-world simulations.
- Understanding Debonding Behavior with Thickness Variation:
  The examination of various CFRP thicknesses showed that while thinner sheets (such as 0.5 mm) can accomplish more stress transmission, they may also raise the possibility of debonding. While marginally lowering stress values, thicker sheets increase stiffness and decrease deflection, preserving structural integrity. This emphasizes how thickness and bond dependability must be balanced.
- Efficient Wrapping Distance from Supports:
  When CFRP wrapping distance from the beam support was varied, it was found that greater shear performance was obtained when wrapping closer to the support (e.g., 200 mm). This discovery gives engineers the ability to maximize material use without sacrificing safety, providing a more cost-effective method of retrofitting.
- Practical Applications and Design Guidance:
  The findings provide structural engineers with useful information for creating FRP retrofitting solutions. Through comprehension of the impact of material type, orientation, sheet thickness, and application distance, designers may produce shear strengthening solutions for RC beams that are more robust and efficient.

In conclusion, the use of CFRP and GFRP sheets to strengthen RC beams shearly demonstrates the usefulness of fiber-reinforced polymer applications in civil engineering. The results cover important topics such bonding dependability and economical use in addition to recommending the best material and design selections. The wider application of FRP technologies in reinforced concrete design and rehabilitation can be facilitated by these insights, which can direct safer and more resilient structural upgrades

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