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Design And Analysis of Four Wheeler's B-Pillar by Using Composite Material for Passenger Safety

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***Abstract*—The present study uses a combination of both experimental and FEA approaches for optimising the design of an automatic B-pillar outer panel used in vehicle side impact protection system. In case of accidents from the side, B-pillars are responsible for preventing any infiltration as well as taking care of the absorption of the shock energy in order to protect the passengers. The purpose of the research is to offer the design of an automatic B-pillar outer panel that would allow the vehicle to sustain more damage under collision conditions without weighing it down significantly, along with ensuring ease of manufacture in an automated environment. Development of comprehensive FE models for analysis of reactions forces, deformation and stress distribution when simulated under impact situations. Performance of controlled 3-point bending tests for improving FEA model design is most probable. Iterative optimization of geometric configuration, thickness, materials, and reinforcement of panels using FE data is expected.**

***Index Terms*—B-pillar, composite materials, UTM.**

I. INTRODUCTION

Modern composite materials have gained acceptance in automotive body parts due to their ability to make light but strong automobiles. In addition to the requirements of stiffness and load transmission, rigid B-pillars must be able to absorb energy during side-impact collisions on victims. While high-strength steels must endure extreme levels of deformation under stress and weigh down the vehicle, as environmental factors and safety performance are increasingly important, such materials may soon become insufficient.

Among other things, CFPRs and hybrid fibre composites offer high specific strength, flexibility in stiffness, corrosion resistance, and energy absorption capabilities. For that reason, it will be possible to replace traditional metallic impact zones in vehicles with composites or improve current designs.

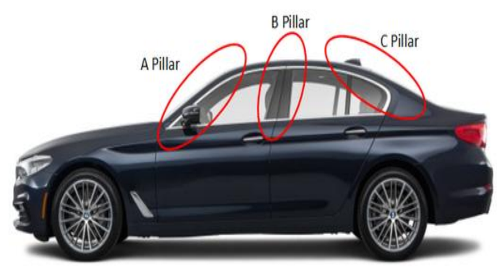


Fig No.1.1: A, B, C, and D-pillar locations

According to recent scientific research, composite structures of automobiles help to make vehicles lighter and increase their safety against impacts. Knowing about the materials' behaviour, the effect of the arrangement of plies, and manufacturability will be required to use composites as B-pillar materials. Aside from materials' properties, the design of the outer part of B-pillar should be optimized as well.

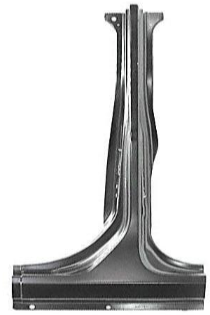


Fig No.1.2: Specimen of B-Pillar

Designing hybrid composite-metal interfaces that can avoid delamination's involves accurate predictions through modelling and designing robust structures. There is not much study on composite topology design, multi-material integration, and predicting the failure modes with complex side-impact loadings even though there have been some advancements. The current project attempts to design an outer B-pillar made of composite materials that is safe and lightweight compared to steel. Finite element analysis simulations along with composite material properties and fiber orientation impact have been utilized for designing this structure.

II. LITERATURE REVIEW

1. Guo et al. (2024)
Guo et al. (2024) investigated the crashworthiness of B-pillars during side-impact collisions using a detailed finite element model of a Toyota Yaris. Their simulations revealed that the upper region of the B-pillar experienced higher velocities and accelerations, indicating critical stress concentrations during impact. To tackle these challenges, the study suggested reinforcing the lower section and increasing the material thickness in order to improve structural integrity. The authors also explored alternative lightweight materials, such as PVC–nanomaterial blends, ABS resin, and SMC, as potential replacements for steel. These materials exhibited minimal deformation and significantly lower density, demonstrating considerable potential for lightweight automotive structures. The study underscores the cost-effectiveness of both design and material optimisation strategies that can enhance B-pillar crash performance while supporting manufacturing capability.

2. Yang et al. (2025)
Yang et al. (2025) investigated the application of CFRP composites for B-pillar reinforcement plates, aiming to enhance crashworthiness while simultaneously reducing weight. Employing a multi-scale design strategy, the authors conducted topology optimisation and assessed both bending stiffness and energy absorption. Their optimised CFRP design achieved a weight reduction of 23.5% while exhibiting greater stiffness than its steel equivalent. Full vehicle crash simulations indicated decreased intrusion velocities and displacements in the thorax, abdomen, and pelvis regions. These enhancements illustrate the effectiveness of the CFRP plate in improving side-impact performance. The study offers compelling evidence regarding the potential of composite reinforcement plates in the development of lightweight vehicle safety systems.

3. Wang et al. (2024)
Wang et al. (2024) concentrated on optimising the design of the B-pillar outer panel through the use of finite element crash simulations, along with an orthogonal experimental design. The study investigated how variations in material selection, geometric parameters, and thickness distribution affected side-impact performance. The results indicated that the optimised configuration led to a reduction in maximum intrusion by 14.7% and in intrusion velocity by 7.4%. The research demonstrates the importance of distinguishing material choices between the upper and lower regions to achieve a balance between stiffness and energy absorption. This study presents a systematic framework aimed at enhancing crashworthiness while managing weight. Its findings are highly relevant to the design of composite-based outer panels in contemporary vehicles, particularly in improving performance during collisions by optimising material properties for stiffness and energy absorption.

4. Du et al. (2024)
Du et al. (2024) investigated optimisation strategies for the B-pillar lower joint, recognising its vital role in absorbing side-impact forces. Through a sensitivity analysis of nine vehicle joints, they identified the B-pillar lower joint as a key contributor to structural deformation. Optimising this joint resulted in reductions in both the extent of intrusion and the intrusion velocity during simulated impact. Consequently, this enhancement led to improved occupant protection without the addition of unnecessary mass. The study highlights the significance of joint-level design in automotive crash-worthiness and provides practical guidance for enhancing safety while achieving light weighting objectives.

5. More et al. (2025)
More et al. (2025) used ANSYS ACP to look at composite B-pillars and see how different ply

orientations effect how well the structure works. The [0°/60°/90°] orientation gave the strongest response force and cut the weight of the steel by 50%. The simulation findings were quite close to the experimental data, with just a 7% difference, which shows that the model is reliable. These data show that employing composite layups makes things much stronger and better at crashing. The study shows that optimising ply is a good way to make lightweight B-pillars. It gives important information on how to use composites to make vehicle structures safer and more efficient.

6. Kang et al. (2021)
Kang et al. (2021) investigated a hybrid moulding technique that combines compression and injection moulding to create composite-reinforced central pillars. Their tests revealed that these hybrid pillars exhibited enhanced energy absorption and reduced intrusion during side impacts when compared to traditional steel pillars. The incorporation of composite reinforcements led to a significant reduction in weight while maintaining stability. The study also highlighted the importance of optimising lay-up design and moulding parameters to achieve optimal performance. These findings affirm the viability of employing integrated composite processes for components that are critical to safety. The research lays the groundwork for the development of lightweight, high-performance pillar structures.

7. Baskara et al. (2021)
Baskara et al. (2021) utilised SolidWorks and ANSYS to simulate side-impact loading on B-pillar designs with the purpose of evaluating crashworthiness. Their findings indicated that a conventional design underwent material rupture under high impact, surpassing the 1100 MPa tensile strength limit. In contrast, a B-pillar constructed from DP1000 dual-phase steel preserved its structural integrity under the same loading conditions. This illustrates the importance of material selection in ensuring occupant compartment safety. The study emphasises a simulation-based design approach as an effective method for optimising pillar structures. It further highlights the role of high-strength steels in achieving a balance between safety and weight considerations, particularly in automotive applications where reducing vehicle weight can enhance fuel efficiency without compromising structural integrity.

8. Capretti et al. (2024)
Capretti et al. (2024) conducted an evaluation of the utilisation of natural fibre composites and hybrid composites in narrow-walled vehicle crash constructions. The authors highlighted several advantages of natural fibres, such as their minimal density, sustainability, and effective absorbance of energy properties. They also discussed certain drawbacks, notably their lower mechanical strength in comparison to synthetic fibres, a limitation that hybridisation can help to overcome. The review underscored the significance of factors such as stacking sequences, shapes, and triggering mechanisms in relation to crash performance. Additionally, it explored the effect of loading rates on collapse behaviour. The study indicates that natural fibre hybrids could play a role in the development of sustainable lightweight structures; however, further advancements and the creation of standardised testing protocols are essential to ensure their effectiveness and reliability in practical applications.

9. Marszałek (2024)
Marszałek (2024) investigated a hybrid composite structure that combines DP780 steel with layers of aramid and carbon fibre and aims to enhance bending stiffness while reducing weight. Experimental tests revealed that this hybrid structure achieved up to 57% higher reaction force compared to bare steel. The reinforcement significantly improved bending resistance and facilitated substantial weight savings. Furthermore, simulation results were in close alignment with the experimental data, confirming the validity of the design approach. The findings suggest that hybrid composites can improve structural efficiency in crash-sensitive components, such as B-pillars. This study bolsters the case for incorporating fibre-reinforced hybrids in automobile safety structures.

10. Park et al. (2021)
Park et al. (2021) examined the delamination behaviour at the steel/CFRP interface in hybrid composite parts using a cohesive zone model. Experimental tests involving DCB (Double Cantilever Beam) and ENF (End Notched Flexure) provided the

necessary interfacial fracture parameters for accurate simulation. Finite element models that incorporated these parameters successfully predicted delamination during the forming process. Although some discrepancies were noted between the predicted and experimental delamination lengths, the model still exhibited strong predictive capability. The study demonstrates that cohesive zone modelling is effective for evaluating interfacial reliability in hybrid structures, thereby contributing to the enhancement of design and manufacturing processes for steel–CFRP automotive components.

Novelty of work: The novelty of this research lies in the systematic development of a lightweight yet structurally robust B-pillar outer panel through the strategic integration of composite materials, a direction that remains underexplored in current automotive crashworthiness studies. Unlike existing research that focuses primarily on B-pillar reinforcement plates, inner reinforcements, or steel–composite hybrid structures, this work concentrates on the outer panel, which has not been extensively optimized for composite-based design despite its direct influence on side-impact load transfer and intrusion management. The study incorporates a multi-parameter design framework that simultaneously considers ply orientation, laminate sequencing, geometric stiffness distribution, and manufacturability constraints—an approach that is rarely applied holistically to this specific component. Additionally, the research employs FEA-driven performance mapping to evaluate composite layups under realistic side-impact conditions, enabling targeted optimization beyond simple weight reduction. The use of sustainable or hybrid composite alternatives introduces further innovation by addressing both environmental and structural performance demands. Overall, the work provides a new pathway for replacing conventional steel B-pillar panels with high-performance composite structures, contributing a novel combination of material innovation, structural optimization, and crashworthiness enhancement not present in existing literature.

III. PROBLEM STATEMENT

- Conventional B-pillar trims made from polypropylene (PP) and other thermoplastics often lack sufficient load-bearing capacity and energy absorption during crash conditions.
- While the use of metallic reinforcement improves the strength, it contributes to the total weight of the vehicle, hence having a negative effect on the efficiency of fuel consumption.
- As more and more attention is being paid to lightweight and performance-oriented materials, it has become imperative to consider advanced approaches that can ensure safety without any additional burden of increased weight.
- While several studies have been conducted on the use of composite materials in automobile structures, there remains no research on the development of optimum designs of B-pillars trims using fiber-reinforced composite materials.
- This makes it essential to conduct an optimum design analysis for B-pillar trims using fiber-reinforced composite materials.

IV. OBJECTIVE

Purpose of research is to design and optimize the design of the automated B-pillar outer panel, which gives better performance in structural aspects in order to increase crashworthiness and occupant safety of the automobile in case of side impact collisions, especially considering the easiness of automation in the manufacturing process.

The primary objectives are as follows:

- To investigate existing designs and materials of B-pillar outer panels, assessing their performance characteristics under side impact conditions and identifying current limitations and areas for improvement.
- To conduct design and finite element analysis (FEA) simulations of the B-pillar outer panel using SolidWorks and ANSYS Workbench software, respectively.
- To identify suitable composite materials for strength optimisation and impact resistance in line with FEA boundary conditions.
- To manufacture a new composite B-pillar outer panel employing a cost-effective method.

- To validate the parameters derived from the FEA results through experimental testing under loading conditions.

V. RESEARCH METHODOLOGY

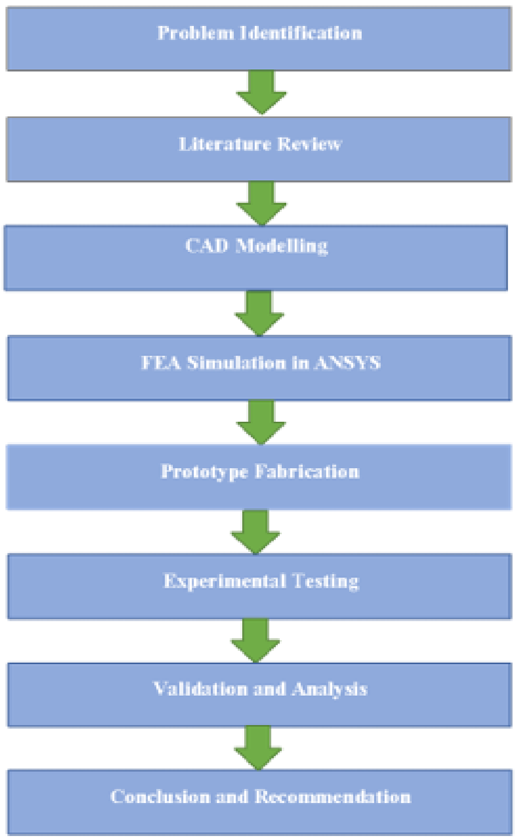


Fig No.5.1: Research Methodology

VI. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) uses numbers to predict how complex engineering structures would respond under varied loads. The method divides a continuous body into a finite number of connected components governed by mathematical equations based on elasticity, material science, and structural mechanics. By placing elements into a global system of equations, FEA enables engineers examine stress distribution, deformation patterns, strain fields, and failure tendencies that would be difficult to study analytically.

FEA checks structural integrity, crashworthiness, stiffness, and weight optimisation in real-world service scenarios, making it important in the automotive sector.

A popular commercial FEA software platform is ANSYS. It includes structural, thermal, dynamic, and Multiphysics simulation tools. Engineers can create exact CAD models, use nonlinear, anisotropic, and composite materials, and apply complex boundary conditions like real-world working conditions.

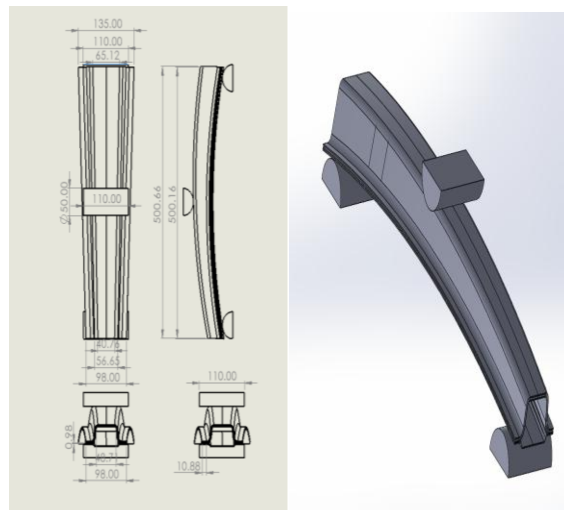


Fig No.6.1: Details of the B-pillar in 2-D & 3-D dimensions

Since it can model contact, detailed dynamics, and composite layup definitions, ANSYS Mechanical is ideal for crash-sensitive elements like the B-pillar outer panel.

The software uses strong solvers for composite analysis that can handle linear and nonlinear behaviour, huge deformations, and failure criteria like Tsai–Wu or Hashin.

6.1 Fea of Existing B-Pillar

1. Geometry:

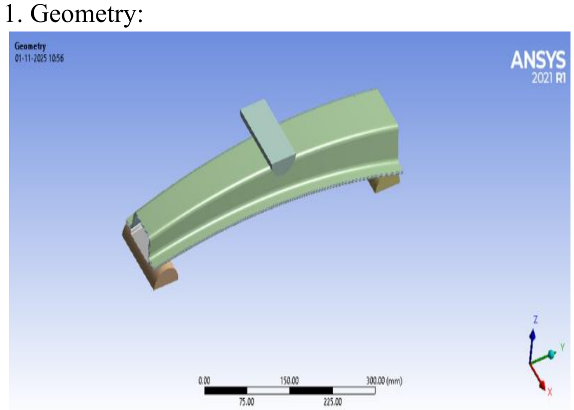


Fig No.6.2: Geometry of existing B-Pillar.

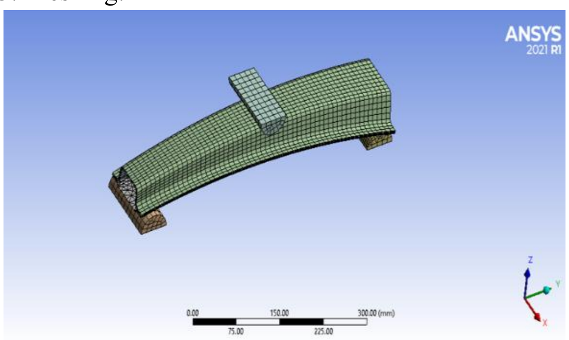
2. Material Properties:

Properties of Outline Row 3: Structural Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	Isotropic Elasticity		
7	Derive from	Young's Modulus a...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa

Fig No.6.3: Material properties of structural steel.

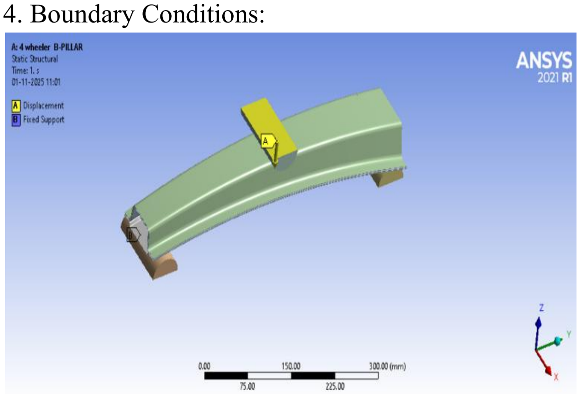
3. Meshing:



Statistics	
Nodes	38250
Elements	9631

Fig No.6.4: Meshing details of existing B-Pillar.

4. Boundary Conditions:



Tabular Data

	Steps	Time [s]	Z [mm]
1	1	0.	= 0.
2	1	1.	-1.
*			

Fig No.6.5: Boundary conditions for existing B-Pillar outer panel.

5. Results:

a) Total Deformation:

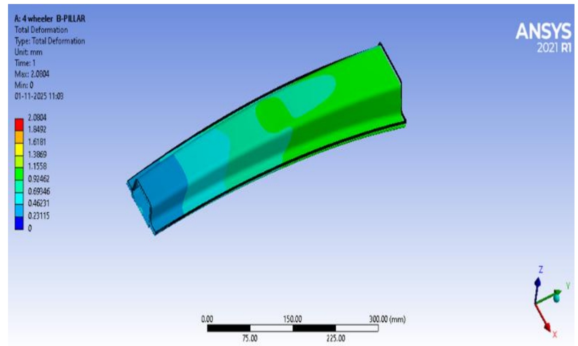


Fig No.6.6: Total deformation of existing B-Pillar outer panel.

b) Equivalent Stress:

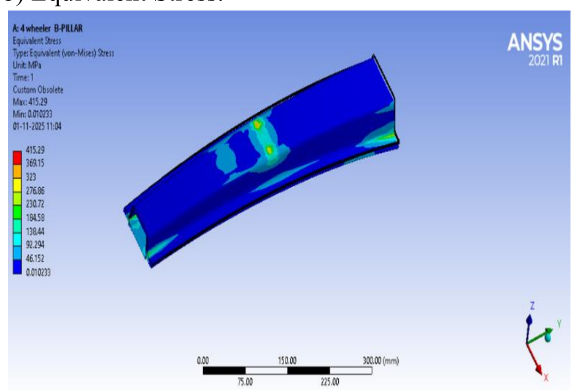
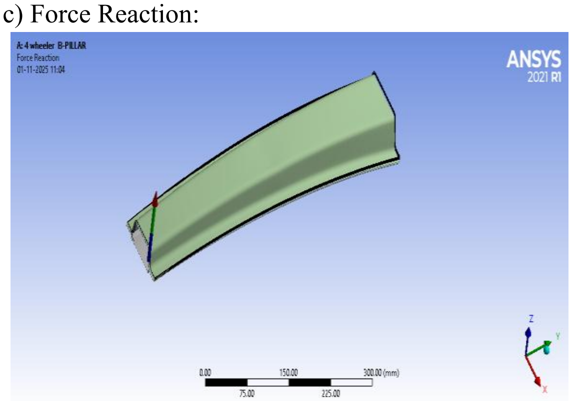


Fig No.6.7: Equivalent Stress of existing B-Pillar outer panel.

c) Force Reaction:



Maximum Value Over Time	
X Axis	-1.1762e-003 N
Y Axis	-7.2768e-003 N
Z Axis	2964.2 N
Total	2964.2 N

Fig No.6.8: Force reaction of existing B-Pillar outer panel.

6.2 Fea of Glass Epoxy Reinforced B-Pillar Outer Panel

1. Geometry:

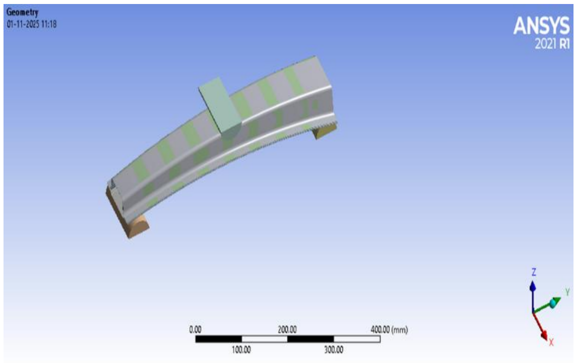


Fig No.6.9: Geometry of Glass Epoxy reinforced B-Pillar outer panel.

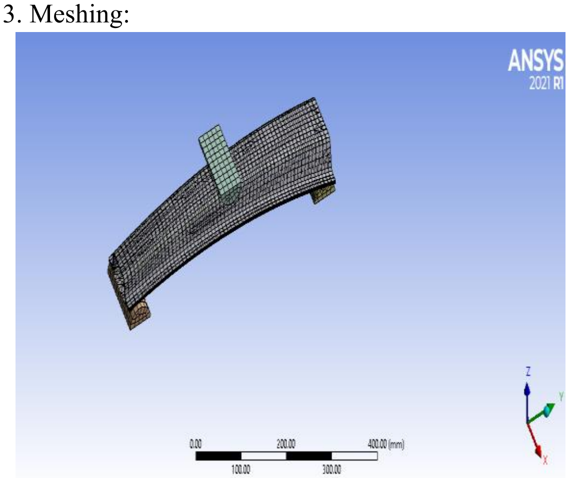
2. Material Properties:

Properties of Outline Row 4: Epoxy E-Glass UD

	A	B	C
1	Property	Value	Unit
2	Density	2000	kg m^-3
3	Orthotropic Elasticity		
4	Young's Modulus X direction	4.5E+10	Pa
5	Young's Modulus Y direction	1E+10	Pa
6	Young's Modulus Z direction	1E+10	Pa
7	Poisson's Ratio XY	0.3	
8	Poisson's Ratio YZ	0.4	
9	Poisson's Ratio XZ	0.3	
10	Shear Modulus XY	5E+09	Pa
11	Shear Modulus YZ	3.8462E+09	Pa
12	Shear Modulus XZ	5E+09	Pa
13	Orthotropic Stress Limits		
14	Tensile X direction	1.1E+09	Pa
15	Tensile Y direction	3.5E+07	Pa
16	Tensile Z direction	3.5E+07	Pa

Fig No.6.10: Material Properties of Glass Epoxy.

3. Meshing:



Type	Element Size
Element Size	10.0 mm

Statistics	
Nodes	39518
Elements	10852

Fig No.6.11: Meshing details of Glass Epoxy reinforced B-Pillar outer panel.

4. Boundary Conditions:

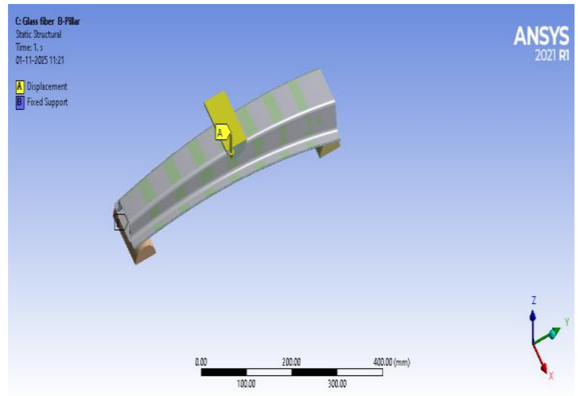


Fig No.6.12: Boundary conditions for Glass Epoxy reinforced b-pillar outer panel.

5. Results:

a) Total Deformation:

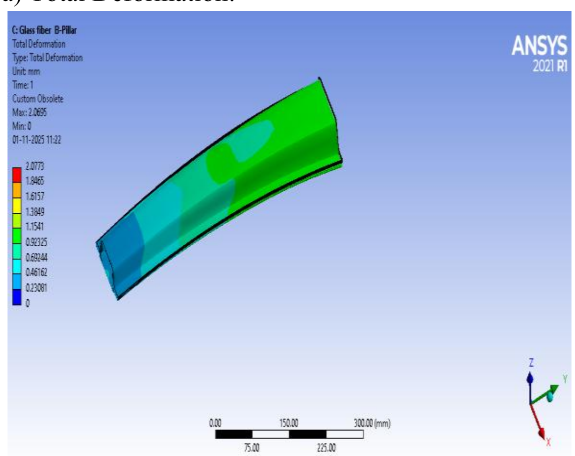


Fig No.6.13: Total Deformation of Glass Epoxy reinforced B-Pillar outer panel

b) Equivalent Stress:

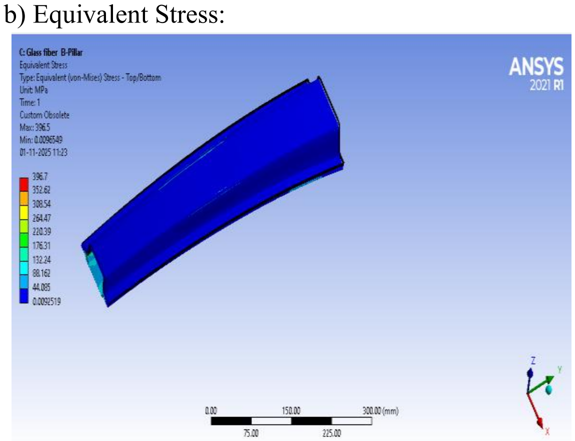
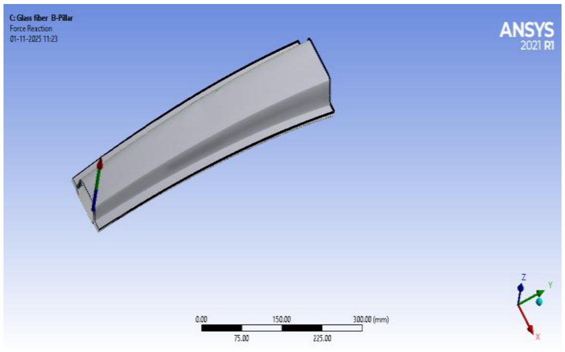


Fig No.6.14: Equivalent Stress of Glass Epoxy reinforced B-Pillar outer panel.

c) Force Reaction:



	Results	
	Maximum Value Over Time	
	X Axis	-1.0897e-003 N
	Y Axis	-7.8782e-003 N
	Z Axis	3045.8 N
	Total	3045.8 N

Fig No.6.15. Force reaction of Glass Epoxy reinforced B-Pillar outer panel.

6.3 Fea of Carbon Epoxy Reinforced B-Pillar Outer Panel

1. Geometry:

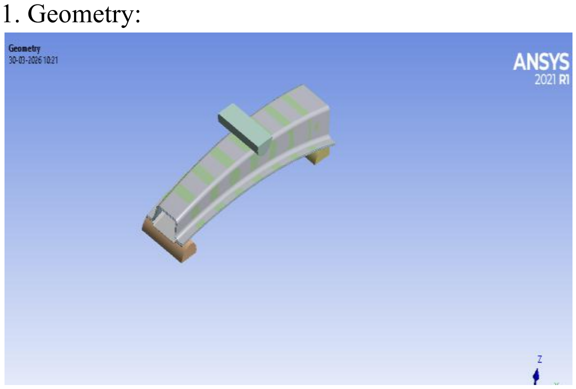


Fig No.6.16: Geometry of Carbon Epoxy reinforced B-Pillar outer panel.

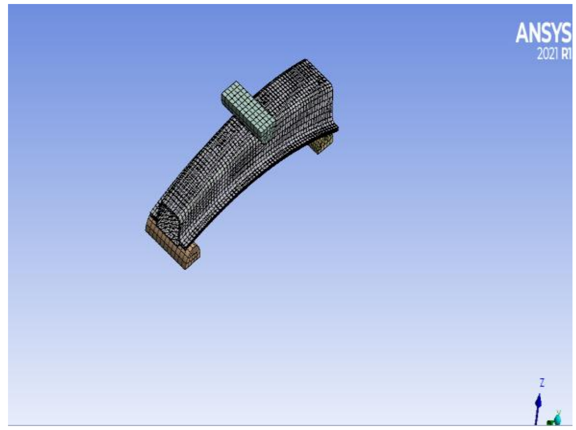
2. Material Properties:

Properties of Outline Row 3: Epoxy Carbon Woven (230 GPa) Wet

	A	B	C
1	Property	Value	Unit
2	Density	1451	kg m^-3
3	Orthotropic Secant Coefficient of Thermal Expansion		
8	Orthotropic Elasticity		
9	Young's Modulus X direction	5.916E+10	Pa
10	Young's Modulus Y direction	5.916E+10	Pa
11	Young's Modulus Z direction	7.5E+09	Pa
12	Poisson's Ratio XY	0.04	
13	Poisson's Ratio YZ	0.3	
14	Poisson's Ratio XZ	0.3	
15	Shear Modulus XY	3.3E+09	Pa
16	Shear Modulus YZ	2.7E+09	Pa
17	Shear Modulus XZ	2.7E+09	Pa
18	Orthotropic Stress Limits		
19	Tensile X direction	5.13E+08	Pa
20	Tensile Y direction	5.13E+08	Pa
21	Tensile Z direction	5E+07	Pa

Fig No.6.17: Material Properties of Carbon Epoxy.

3. Meshing:



Type	Element Size	Statistics	
Element Size	10.0 mm	Nodes	39518
		Elements	10852

Fig No.6.18: Meshing details of Carbon Epoxy reinforced B-Pillar outer panel.

4. Boundary Condition:

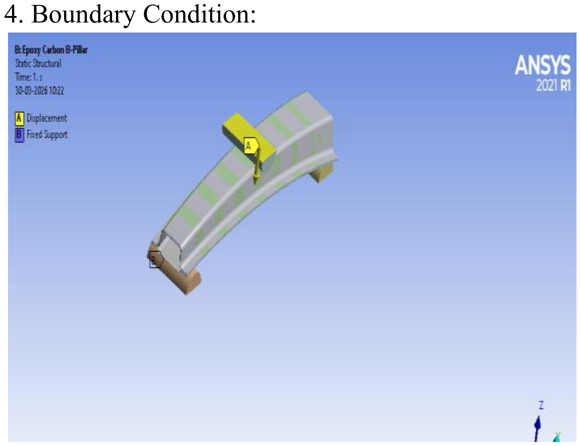


Fig No.6.19: Boundary conditions for Carbon Epoxy reinforced b-pillar outer panel.

5. Results:

a) Total Deformation:

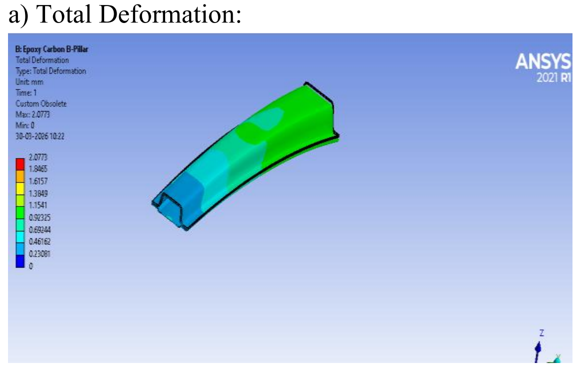


Fig No.6.20: Total Deformation of Carbon Epoxy reinforced B-Pillar outer panel.

b) Equivalent Stress:

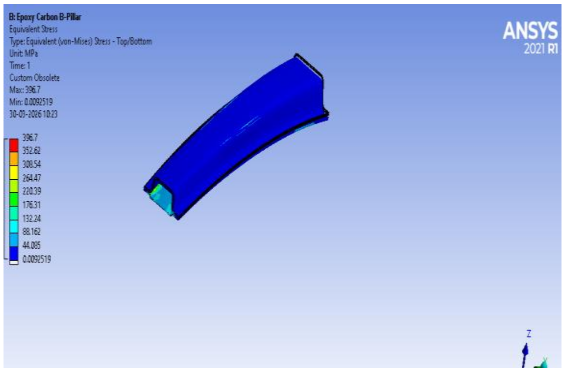


Fig No.6.21: Equivalent Stress of Carbon Epoxy reinforced B-Pillar outer panel.

C) Force Reaction:

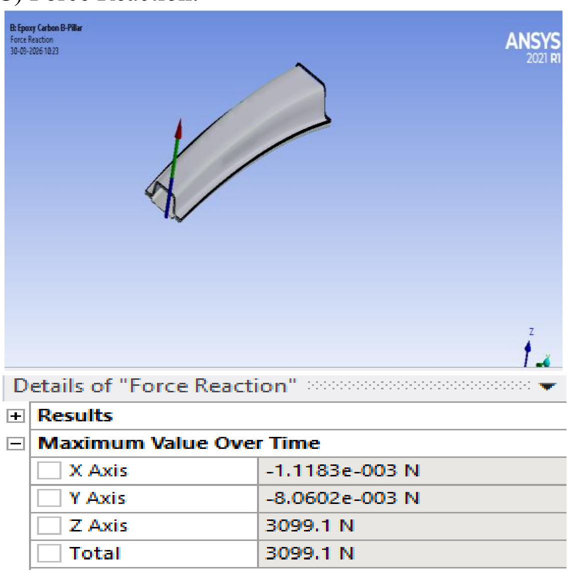


Fig No.6.22: Force reaction of Carbon Epoxy reinforced B-Pillar outer panel.

6.4 Fea Results

Material Configuration	Observed Deformation (mm)
Structural Steel (baseline)	2.0804 mm
GFRP (0°-0°-0°)	2.0695 mm
CFRP (0°-0°-0°)	2.0773 mm

Table No.6.1: Total Deformation

Material Configuration	Equivalent Stress Results (MPa)
Structural Steel (baseline)	415.29 MPa
GFRP (0°-0°-0°)	396.5 MPa
CFRP (0°-0°-0°)	396.7 MPa

Table No.6.2: Equivalent Von Mises Stress

Material Configuration	Reaction Force (N)	% Improvement from steel
Structural Steel (baseline)	2964.2 N	-
GFRP (0°-0°-0°)	3045.8 N	+3%
CFRP (0°-0°-0°)	3099.1 N	+4.55%

Table No.6.3: Reaction Force Comparison of Different Material

VII. EXPERIMENTAL ANALYSIS

7.1 The Process of Manufacturing

- To strengthen a pillar with glass fibre and epoxy resin, first clean the surface well to get rid of dust and oil.
- Then, use sandpaper to roughen up smooth regions to improve mechanical bonding.
- After cutting the glass fibre mats to fit the pillar, mix the resin and hardener together in the exact ratio that the manufacturer says to do so to make sure the structure stays strong.
- When hand-laying up the pillar, first put down a coating of resin, then the glass fibre sheets.
- Keep putting down layers of resin and fibre, using a brush or roller to make sure the layers are completely saturated and there are no air pockets, until the right thickness is obtained.
- Finally, let the laminate dry for the necessary amount of time without being disturbed to have the best strength and performance.

7.2 Testing Specimen Of B-Pillar

Experimental Procedure:

- Measure the specimen's width and thickness.
- Commence marking and verifying the locations where the three-point bending will apply the strain.
- Determine the distance within all supports.
- Gently place the sample on the 3-point bendable attachment of the universal measuring machine.

- Verify that the loading point is located in the appropriate location.
- Conduct the bend test.

Fig. No.7.1: B-Pillar with Glass Epoxy Reinforcement for Testing

Fig. No.7.2: Testing Specimen of B-Pillar

7.3 Experimental Testing

Test Setup:

- B-pillar prototype made with GFRP using hand lay-up technique.
- Tested under three-point bending to simulate flexural strength

Results:

Property	Value	Observation
Maximum Load Taken	3189.9	Close to FEA GFRP result
Deformation Mode	Central Deflection	As expected in simply supported beam
Flexural Performance	Consistent with Simulation	Validates FEA Model

Table No.6.1: Experimental Testing

7.4 Experimental Setup

Fig. No.7.2: Experimental Setup View-1

Fig. No.7.3: Experimental Setup View-2

UTM Graph:

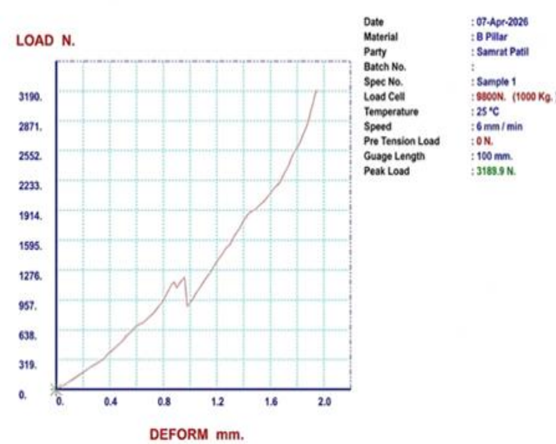


Fig. No.7.3: UTM Test Graph

VIII. CONCLUSION

Under 3-point bending, the structural performance of normal steel design was compared to that of glass fibre and carbon fibre composite B-pillar outer panels. Even though they are stiff, both composite parts reduce stress and support loads better. The stress levels in the glass fibre and carbon fibre composite B-pillars were 396.5 and 396.7 MPa, while the stress levels in the steel B-pillars were 415.29 MPa. The part's structural strength and durability get better when stress is lower because of load dispersion and localised failure. Measurements of response force and stress effectiveness show that composites work. The reaction forces for glass and carbon fibre composite B-pillars were 3045.8 N and 3099.1 N, while the response force for steel was 2964.2 N. More reaction forces while under load mean that the structure is stronger and can hold more weight. Composite B-pillars work better than steel ones. Carbon and fibreglass composites increase load and stress resistance without losing rigidity. Carbon fibre composite B-pillars are stronger, crash worthier, and more durable. Composite B-pillars improve safety and efficiency in high-performance, lightweight cars, according to studies.

IX. FUTURE SCOPE

Future study will focus on automated production techniques such as RTM and compression moulding to assure scalability and precision. Advanced dynamic simulations with LS-DYNA will assess crashworthiness against FMVSS and NCAP requirements. AI-driven multi-objective optimisation will strike a compromise between weight reduction and maximum energy absorption, while the integration of smart sensors will allow for real-time structural health monitoring. Finally, full-scale vehicle testing and detailed lifespan assessments will guarantee that these composite A-pillars exceed worldwide safety and sustainability standards, easing their acceptance by mainstream automotive OEMs.

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