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Design and Structural Analysis of Glass Fiber Reinforced Composite for Two-Wheeler Mudguard

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Abstract: The increasing demand for sustainable and lightweight materials in the automotive industry has led to the exploration of reinforced composite materials. This study focuses on the design and structural analysis of a glass fiber reinforced composite mudguard for automotive applications. The mudguard was designed and simulated using ANSYS software to evaluate its performance under real-world conditions. A finite element model of the mudguard was created with a quadratic order element, and a mesh convergence study was conducted to ensure correct simulation results. The boundary conditions were applied, with fixed support at the fastener slots and a load of 1500N applied perpendicular to the surface of the mudguard. A comparative study was carried out by simulating the same model with different materials. The simulation results showed a maximum deformation and a significant maximum equivalent stress, showing that the glass fiber reinforced composite mudguard exhibits excellent mechanical strength and stiffness. This research highlights the potential of glass fiber composites in enhancing automotive safety and efficiency while contributing to weight reduction. A sustainability analysis of E-glass was conducted, and the results were summarized in a dedicated sustainability report. The findings provide a foundation for further research and sustainable practical implementation of glass fiber composites in automotive engineering.
Keywords: Glass Fiber Reinforced Composite, Mudguard, Finite Element Analysis, Lightweight Materials.

I. INTRODUCTION

The automotive sector is increasingly focused on reducing environmental impacts and developing sustainable, lightweight materials. Glass fiber-reinforced composites offer a promising alternative to traditional materials like metals and plastics. In 1200 AD, Composite materials were used by Mongolian empire to manufacture bows. Later, during the Second World War, the first fiber reinforced composites were made for various purposes[1]. Soon, polymer composites made their way into the aerospace and automotive industries, notably in fighter jets and 1953 Corvette[2]. Glass fibers enhance the mechanical properties of the composite, making it suitable for automotive components. Mudguards are crucial automotive parts that protect vehicles from debris and mud. They must offer both durability and impact resistance while being lightweight to help reduce the overall vehicle weight. In the case of internal combustion engine vehicles, the overall weight of the automotive is indirectly proportional to fuel efficiency. In electric vehicles, the motor power needed for the vehicle depends proportionally on the weight. Thus, decreasing weight whilst keeping the strength of materials will definitely help the design of the automotives. This study focuses on the design of a mudguard using glass fiber-reinforced composite and evaluates its impact resistance through simulation using ANSYS, a leading software for finite element analysis (FEA).

OEM	Model	Application	Material
BMW	i3	Passenger cell	CFRP
Alfa Romeo	4C	Chassis	Prepreg (CF, epoxy)
McLaren	MP4- 12C Spider	Passenger cell	CFRP
Chevrolet	Corvette	Body aerodynamics Kit	CFRP
Lexus	LFA	Passenger cell	CFRP
Lamborghini	Aventador	Bumpers	CFRP
Land Rover	Evoque	Instrumental panel	GFRP
Mercedes - Benz	Daimler	Fluid filter module	GFRP

Source: Adaptation of European Technology Platform for Sustainable Chemistry, Polymer composites for automotive sustainability, 2018.

Table 1 shows the main application of GFRP (Glass Fiber Composites) are Chassis, Passenger cell, Bumpers and instrument panel of an automobile[3].

II. LITERATURE REVIEW

Composite materials have four to six times the tensile strength of conventional automotive materials such as steel and aluminum. Less vibration transmission and low noise generation during operation are notable advantages of composite materials. In design considerations, composite materials allow versatile geometry requirements and still meet the performance demands[2].

With earlier studies and experiments, Reghunath et al., proved that volume percentage of the composite i.e., the weight percentage of the fiber in a unit volume of the composite plays a significant role in the impact strength of the material[4]. 43% is the preferred volume fraction for the fiber reinforced composite[4].

The glass fiber reinforced polymer (GRP) is comparatively cheaper than carbon fiber (CFRP) and pooper thermal insulator. Although, the Glass fiber has nearly the same strength as carbon fiber and polymers[5]. GFRP is increasingly used for impact-absorbing automotive parts due to its best impact resistance, cost-effectiveness, high thermo-formability, and recyclability. Additionally, glass-reinforced phenolic composites are replacing metals in critical automotive components such as engine manifolds, gas, and clutch pedals. The strategic orientation of fibers in these components enhances their strength and durability, improving long-term performance and safety[6]. The combination of n SiO_2, Al_2O_3, B_2O_3, CaO, or MgO powders gives us the composition of glass fiber with textile grade. [7]

III. METHODOLOGY

Polymer and Resin	Tensile strength (Gpa)	Young's modulus (Gpa)	Density (gm/cm^2)	Poisson Ratio (μ)
Glass Fiber	3.445	72.3	2.58	0.2
Epoxy Resin	0.014	5.5	1.2	N/A
Glass Fiber Reinforced Polymer	0.08	25	2.2	0.2

Table 2. mechanical and physical properties of glass fibers[11], [12], [13]

Figure 1. Glass fibre

Material Properties: The composite used in this study is made from glass fibers embedded in an epoxy resin matrix. The impact strength of random orientation GFRP is 143.5 (kN/m^2).[8]

Existing mudguards are made from ABS (Acrylonitrile Butadiene Styrene) and Polypropylene Copolymer whose density is significantly lower than GFRP. [9]

Experimental studies were conducted to measure the impact resistance of E-glass fiber reinforced polymer, since no data can be noted in literature reviews. The impact resistance of the GFRP specimen is evaluated using a Charpy Impact test setup. The test method is based on ASTM D6110 – Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastics. However, due to the structural and material characteristics of the GFRP specimens, the standard was adapted and not strictly followed.

The impact strength of ABS material is fo und to be 13.57 kJ/m^2. ABS is generally made as a composite consisting of Barite mineral (BRT) in various percentages ranging from 5%, 10%, 15 % and 20%. But the exact value of impact strength of ABS is found in previous research works in material sciences. [10]

A. *Specimen Dimensions*

Following the guidelines of ASTM D6110, with necessary modifications for Glass Fiber Reinforced Polymer (GFRP) specimens, the test specimens were prepared with a length of 68 mm and varying diameters of 6 mm, 8 mm, 10 mm, 12 mm, and 16 mm.

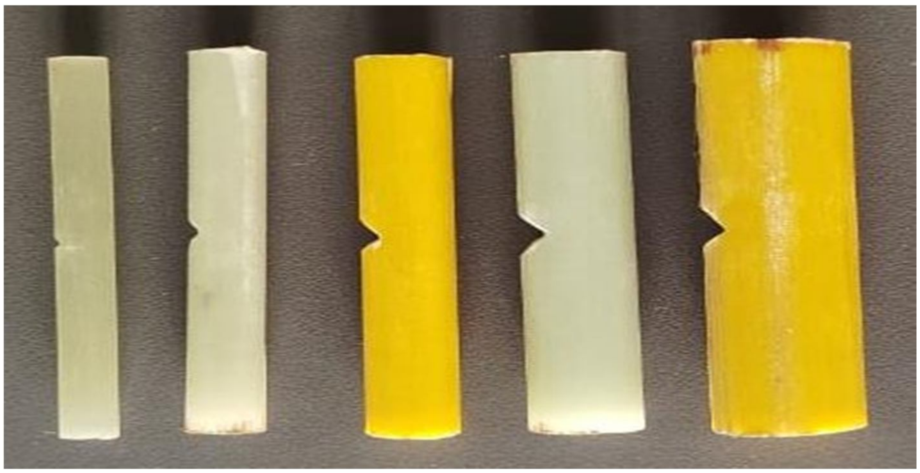

Figure 2. Specimens

A single V-notch with a depth of 2 mm and an included angle of 45° was machined at the center of each specimen. The notch was created carefully to prevent fiber damage or delamination.

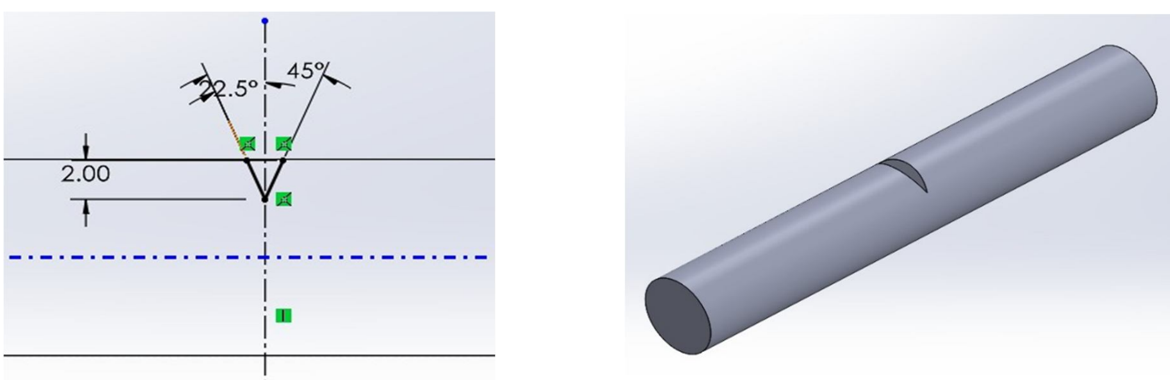

Figure 3. Specimen V-Notch profile

Figure 4: Charpy impact test apparatus

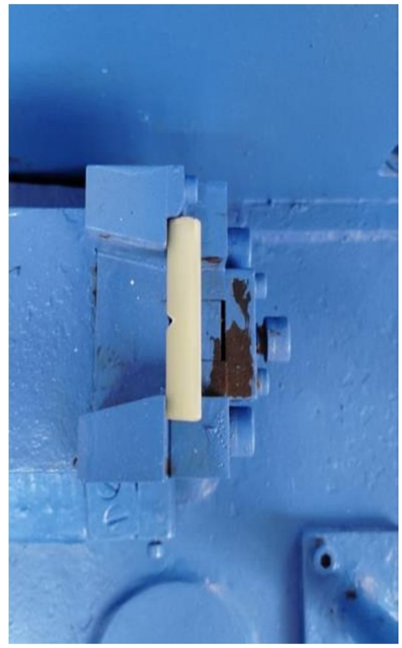

Figure 5: Specimen position

B. Experimental Setup

Testing Machine: A Charpy impact testing machine with a pendulum capacity of 300 J was used.
Support Configuration: The specimens were simply supported horizontally, with a span of 45 mm between supports.

C. Test Procedure

Each specimen was carefully positioned on the supports of the Charpy impact testing machine, ensuring that the notch was precisely centered and oriented to face away from the pendulum striker. The pendulum was then released to deliver a single, controlled blow at the notched region, causing the specimen to fracture. The energy absorbed by the specimen during impact was recorded directly from the machine’s digital display. A total of 5 specimens were evaluated to ensure repeatability and statistical significance of the results. After each test, the fracture mode and failure patterns were visually inspected and documented to aid in the analysis of material behavior under impact loading.

IV. CAD MODEL

A mudguard model is created using CAD software - SolidWorks which is then imported into Ansys Workbench for finite element analysis. Two sides of the mudguard have slots for temporary joints i.e., nut and bolt joint. The following CAD Model visualizes the detailed explanation of the project with the standard specification scale ratio of which is described below as follows.

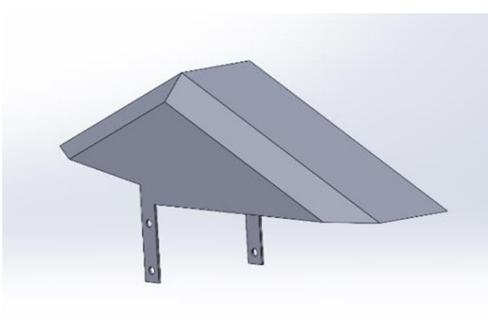

Figure 6: Isometric view

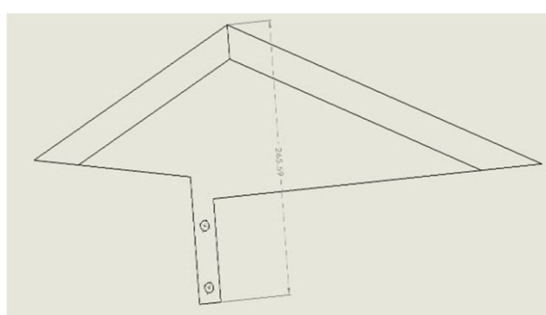

Figure 7: Side view

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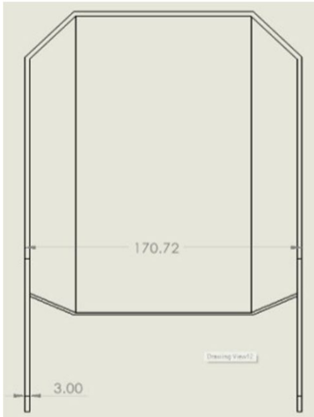


Figure 8: Front view

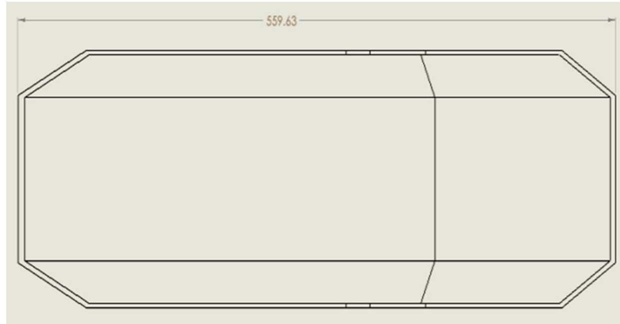


Figure 9: Top view

V. PROTOTYPE MODEL

A mudguard model is created using CAD software - SolidWorks which is then imported into Ansys Workbench for finite element analysis. Two sides of the mudguard have slots for temporary joints i.e., nut and bolt joint.

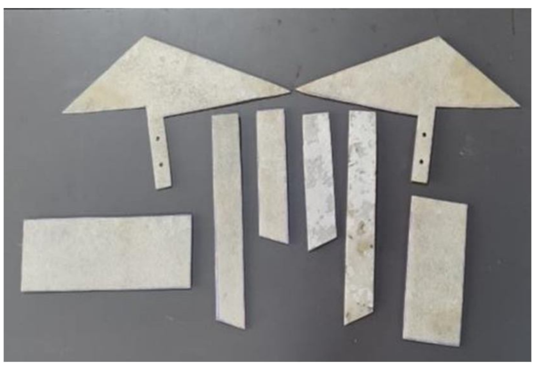


Figure 10: Mudguard parts

Figure 11: Side view

Figure 12: Isometric view

Figure 13: Front view

VI. RESULTS AND DISCUSSION

The glass fiber reinforced composite mudguard and ABS mudguard were simulated using ANSYS software to evaluate its deformation and equivalent stress under a load of 1500N. The results of the simulation are presented below:

A. *Element and Mesh*

The finite element model of the glass fiber reinforced composite mudguard was created using ANSYS software. The model was meshed with a quadratic order element, which provides a higher degree of accuracy and precision in the simulation results.

B. *Element Details*

- Element Order: Quadratic
- Number of Nodes: 996,229
- Number of Elements: 562,342

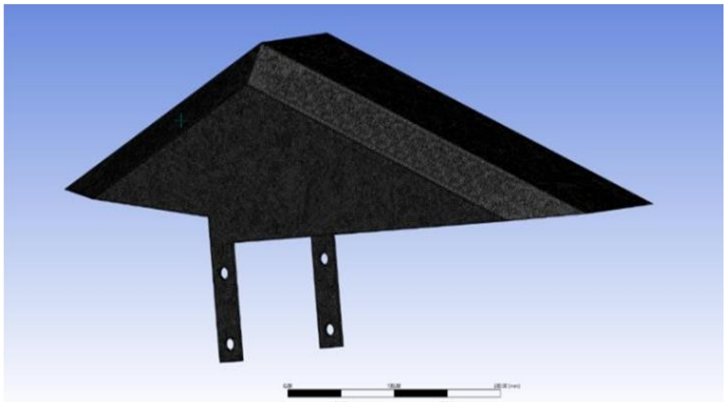


Figure 14: Meshed

C. *Boundary Conditions*

Simulate the real-world conditions of the glass fiber reinforced composite mudguard, the following boundary conditions were applied:

- Load Application: A load of 1500N was applied to the mudguard, simulating the external forces that the mudguard may experience during use. The load was applied in a direction perpendicular to the surface of the mudguard.
- Fixed Supports: The mudguard was fixed at the holes, which are typically used for mounting the mudguard to the vehicle. This constraint ensures that the mudguard is securely attached and cannot move freely.

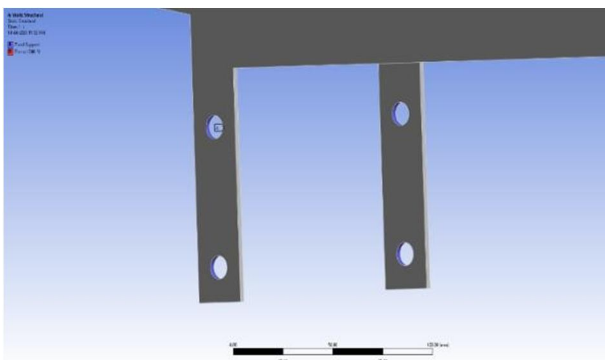


Figure 15: Fixed support – fastener slot

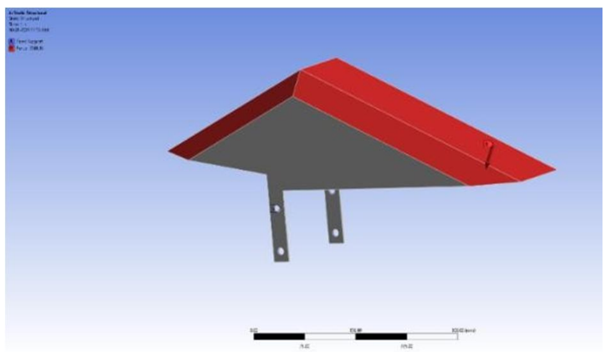


Figure 16: Force

D. Stress Analysis

GFRP: The ANSYS simulation results show that the glass fiber composite mudguard is capable of withstanding impacts from road debris, with relatively minimal deformation. The composite material showed excellent energy absorption and rigidity.

- Maximum Deformation: 7.99 mm
- Maximum Stress: 328.16 MPa

Figure 17: Stress distribution

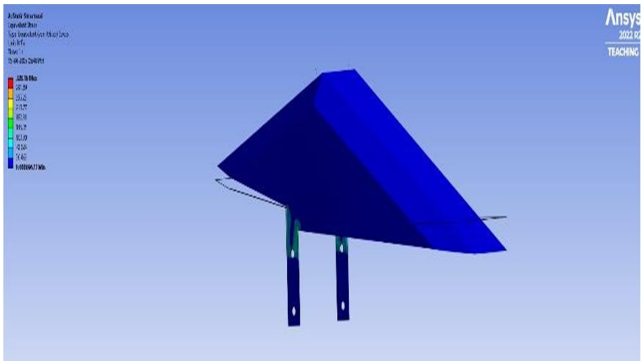
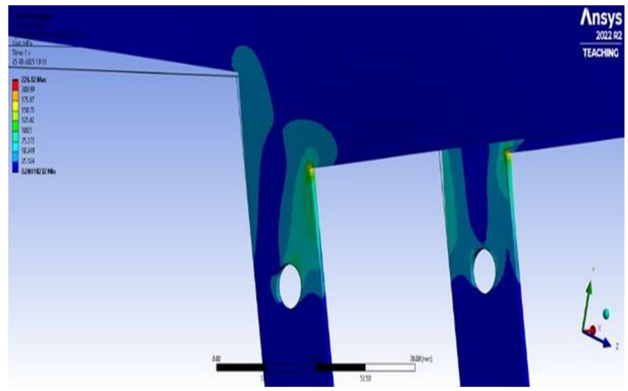


Figure 18: Stress induced - GFRP



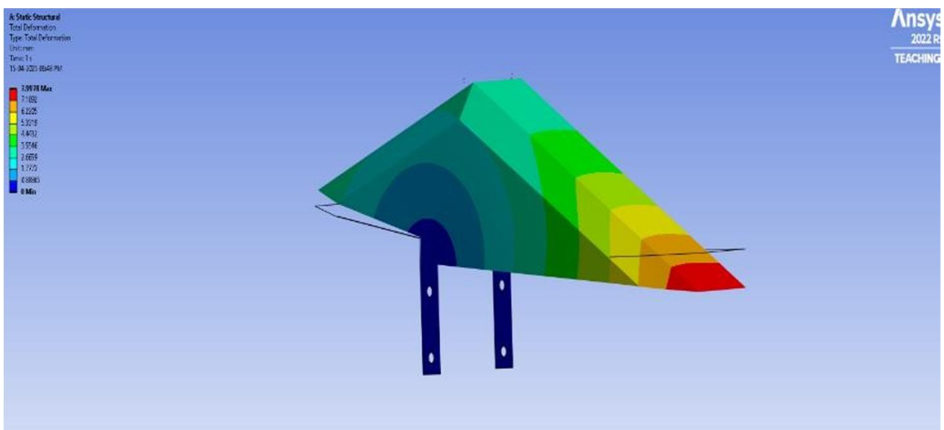


Figure 19: Deformation – GFRP

E. ABS (plastic)

The same force and boundary conditions were applied to another study with material assignment of ABS material which is the major conventional material for mudguards.

- Maximum deformation: 77.9 mm
- Maximum stress induced: 322.38 MPa

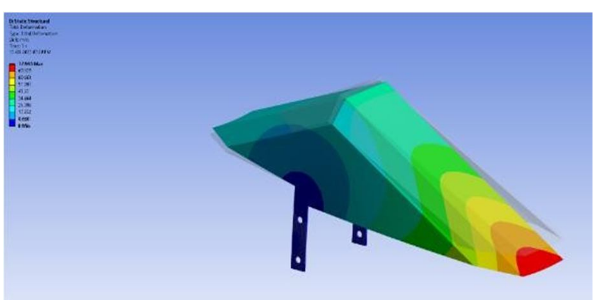


Figure 20: Deformation

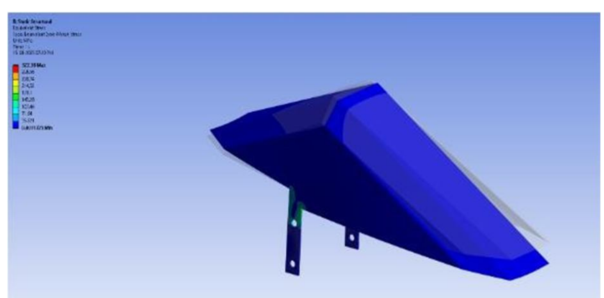


Figure 21: stress distribution

F. Data Analysis

(Calculation of Impact Strength for GFRP Specimens)

The impact strength (kJ/m²) of each specimen was calculated using the following formula:

$$\text{Impact Strength} = \text{energy absorbed} / \text{area}$$
$$= (4 * Ea * 1000) / (\pi D^2)$$

Where:

- Ea = Energy absorbed (in Joules)
- D = diameter of the specimen (mm)

The average impact strength, standard deviation, and coefficient of variation were determined for the tested batch. The ASTM D6110 standard is primarily intended for homogeneous plastic materials. As GFRP is an anisotropic and heterogeneous composite, the following adaptations were made:

- Specimen thickness was increased for better fracture clarity.
- Laminated structure was aligned to represent practical loading direction.
- Notch machining was done cautiously to prevent fibre bridging or delamination.

G. Impact Strength experimentation - Charpy test

Specimen No.	Diameter (D) (mm)	Energy Absorbed (Ea) (J)	Impact Strength (kJ/m²)	Fracture Mode
1	6	0.0092	457.03	Brittle
2	8	0.0180	437.63	Ductile
3	10	0.0310	447.58	Ductile
4	12	0.0480	459.15	Ductile
5	16	0.0860	437.59	Ductile

The mean impact strength derived from the readings table is 447.792 kJ/m².

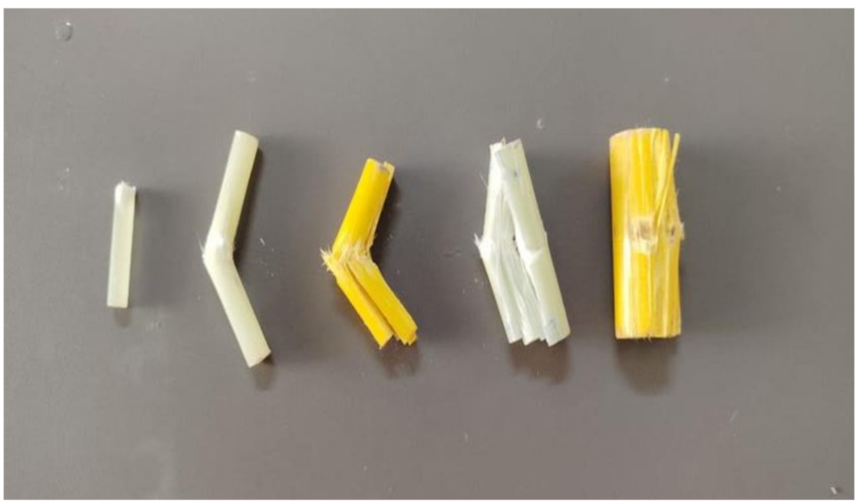


Figure 22: Tested specimen

H. Comparison with Conventional Materials

The performance of the glass fiber-reinforced polymer GFRP composite mudguard was analyzed in comparison with traditional material : ABS plastic, which is commonly used in automotive applications. The findings from the simulation study and experimental analysis highlighted the strengths and trade-offs of each material, showing the advantages of GFRP in achieving a balance between impact resistance, weight reduction, and durability.

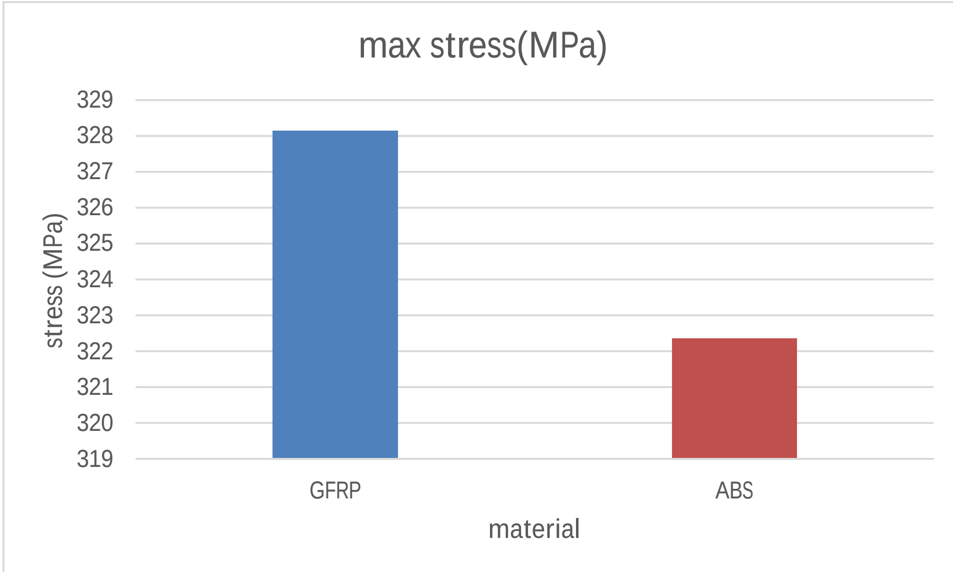


Figure 23. Stress induced (GFRP vs ABS)

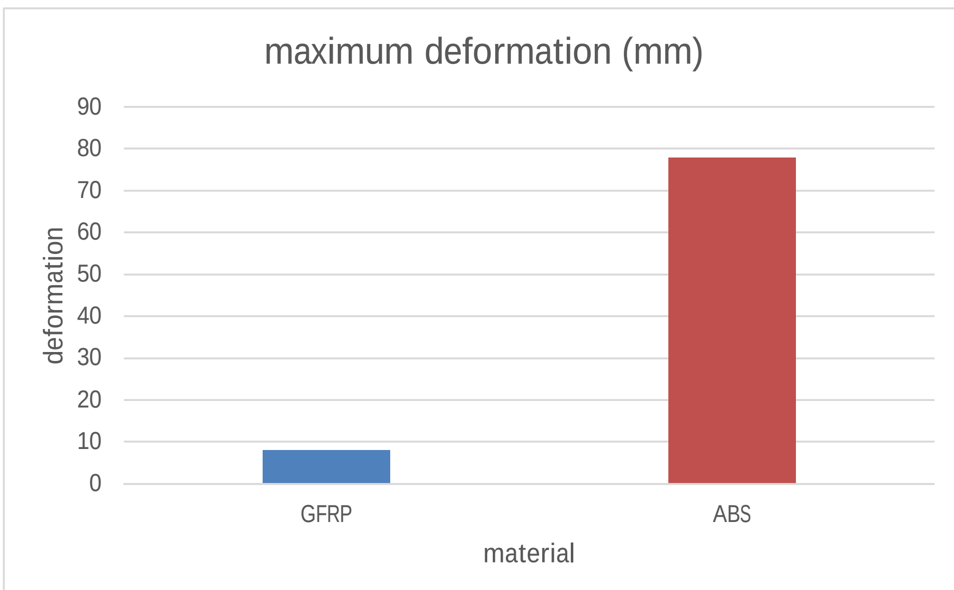


Figure 24. Deformation (GFRP vs ABS)

I. Sustainability report

Based on the resources available in SolidWorks 2022 (Student version), a sustainable report of the E-glass (the main composition of Glass fiber reinforced plastic) was generated with relevant details.

Model name	Mudguard
Material	E-glass fiber
Weight	1531.6 kg
Surface area	3.76E+5 mm^2
Duration of use(assumed)	7 years

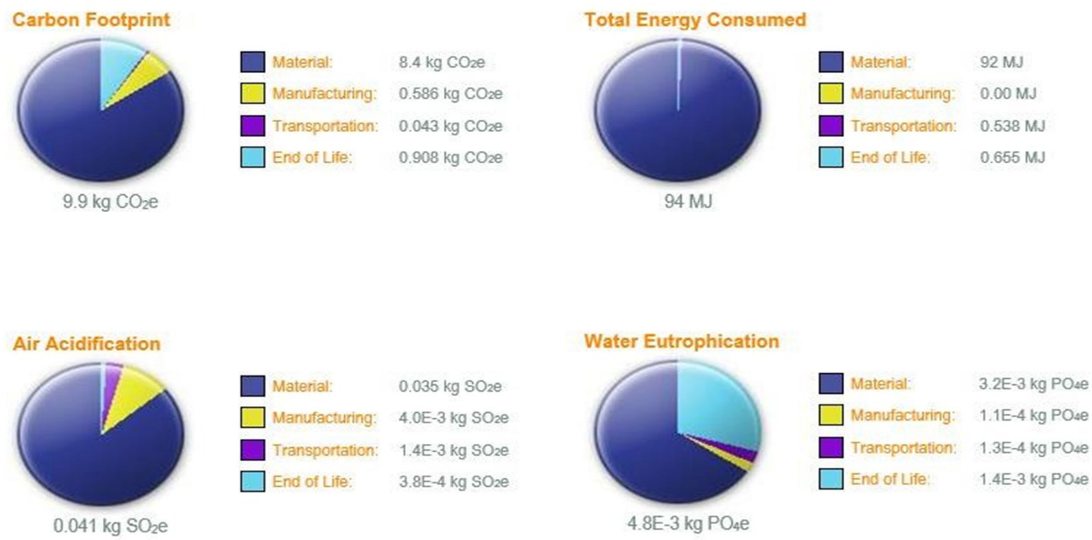


Figure 25: Sustainability report

This sustainability analysis, generated using SolidWorks, evaluates the environmental impact of a part made from E-glass fiber across its entire life cycle. The report focuses on four key metrics: Carbon Footprint, Total Energy Consumed, Air Acidification, and Water Eutrophication, broken down into the stages of Material, Manufacturing, Transportation, and End of Life.

Carbon Footprint (9.9 kg CO_2e)

- Major Contributor: Material stage (8.4 kg CO_2e, ~85%).
- Others: End of Life (0.908 kg), Manufacturing (0.586 kg), Transportation (0.043 kg).
- Inference: The high carbon footprint of E-glass fibre stems from its energy-intensive production, especially the melting and drawing of glass. Switching to natural fibres or optimizing composite layup could reduce emissions.

Total Energy Consumed (94 MJ)

- Major Contributor: Material stage (92 MJ, ~98%).
- Others: Transportation (0.538 MJ), End of Life (0.655 MJ), Manufacturing (0.00 MJ).
- Inference: E-glass fibre requires substantial energy during production due to high- temperature processing. Most of the product's energy consumption comes from this stage. Alternatives like basalt or flax fibres could lower this energy demand.

Air Acidification (0.041 kg SO_2e)

- Major Contributor: Material stage (0.035 kg SO_2e).
- Others: Manufacturing (4.0E-3 kg), Transportation (1.4E-3 kg), End of Life (3.8E-4 kg).
- Inference: The formation of acidic pollutants is attributed to the emissions during the production of E-glass, particularly from fossil fuel combustion. Cleaner production methods and emission control technologies may help reduce this.

Water Eutrophication (4.8E-3 kg PO_4e)

- Major Contributors: Material (3.2E-3 kg PO_4e), End of Life (1.4E-3 kg).
- Others: Manufacturing (1.1E-4 kg), Transportation (1.3E-4 kg).
- Inference: The leaching of nutrients during disposal and manufacturing contributes to water eutrophication. Using bio-resins or improving waste treatment at the end of life can reduce water-related impacts.

VII. CONCLUSION

The research scope and applications of composite materials are ever-expanding, and through this study and the simulation of working environment of the GFRP automotive part (i.e., a mudguard) using the Finite Element Method FEM was conducted. The impact analysis conducted in Charpy impact tester demonstrated that the glass fiber-reinforced polymer GFRP composite provides significant advantages in terms of impact resistance, structural integrity, and weight reduction compared to conventional materials like metals and plastics ABS.

The ANSYS simulation results demonstrate the glass fiber composite mudguard's excellent impact resistance, exhibiting minimal deformation of 7.99 mm and a maximum stress of 328.16 MPa, thereby showcasing its potential as a durable and reliable material for automotive applications.

Furthermore, the study highlights the potential of GFRP composites in automotive applications, particularly in lightweight structural components that require a balance between strength and flexibility. The reduced weight contributes to improved fuel efficiency and lower emissions, aligning with the automotive industry's sustainability goals.

VIII. FUTURE WORK

Future research can focus on optimizing fibre orientations, resin compositions, and hybrid reinforcements to further enhance the mechanical properties of GFRP composites. Additionally, experimental validation of the simulated results would provide deeper insights into real-world performance, ensuring the material’s viability for large-scale automotive manufacturing. With regards to sustainability, the E-glass composite does not fit into the sustainable material category. Using E-glass fibre results in significant environmental impacts, primarily during the material phase. This is due to high energy demand during production, Carbon-intensive processes, and non- biodegradable waste at the end of life.

To achieve the sustainable automotive material, much research works on Bio-composites and natural fibre composites are carried out all around the world. Other ways to boost sustainability with E-glass fibre products are reducing material usage with design optimisations and improve end of life recycling or reusing methods.

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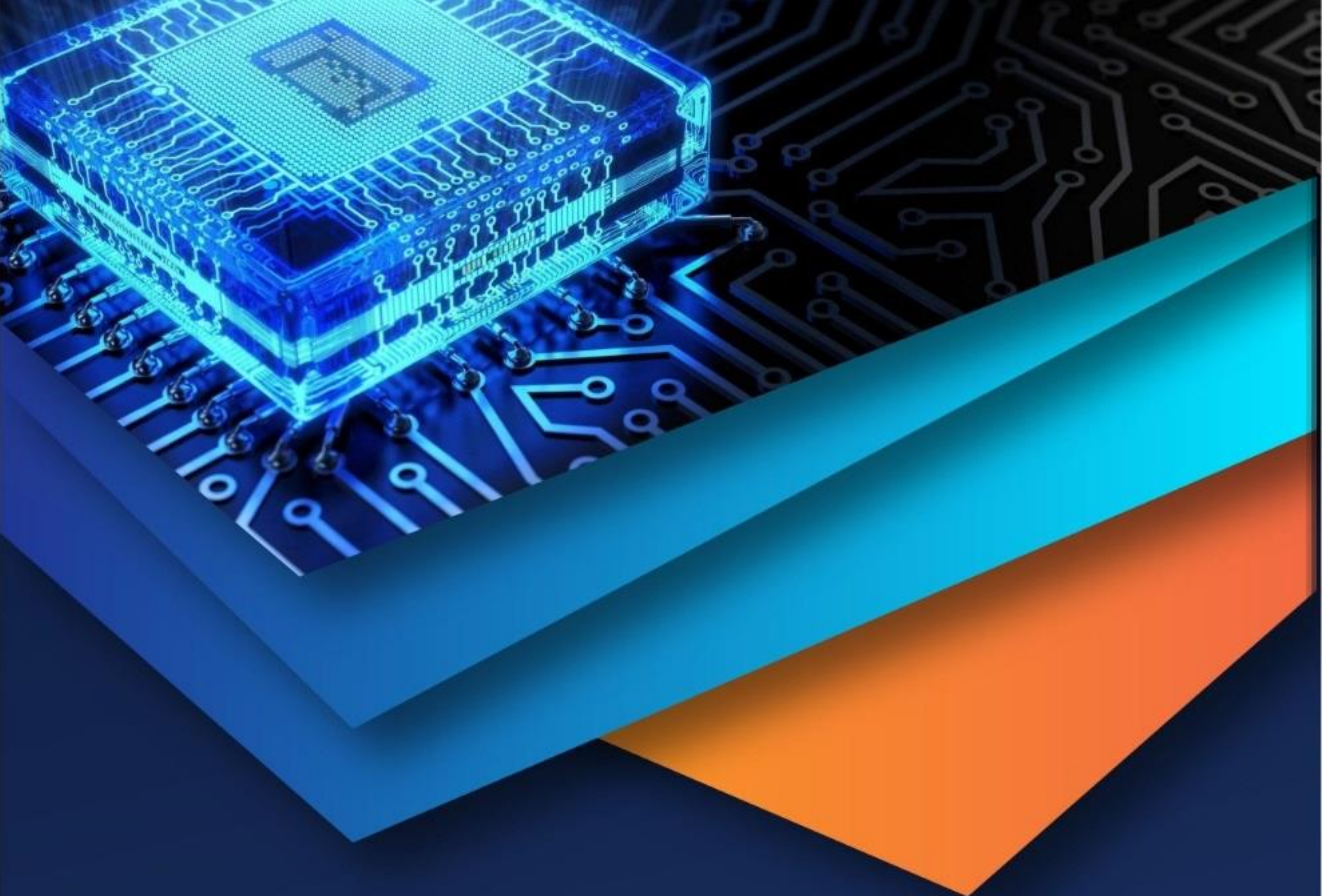

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