International Journal of Current Engineering and Technology
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E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Design and Development of Sustainable Futuristic Helmet

Anup R Chavan[1*], Aditya Tembe[1], Shrinivas Kulkarni[1] and Dr. A S Reddy[2]

[1]Under Graduate Student, [2]Professor, Department of Mechanical Engineering, KLE Institute of Technology, Hubballi, Karnataka, India

Received 01 May 2025, Accepted 23 May 2025, Available online 24 May 2025, **Vol.15, No.3 (May/June 2025)**

Abstract

The rising fatalities from head injuries in road accidents highlight the need for effective and sustainable protective gear. Conventional helmets made from Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polystyrene, and ABS+PC plastics, while providing safety, are bulky, uncomfortable in hot climates, and harmful to the environment due to their non-biodegradability. To address these concerns, this study focuses on developing an eco-friendly helmet using bio-composite materials. A helmet was designed in SolidWorks with aerodynamic and aesthetic improvements and analyzed using ANSYS Workbench. Fabrication was done through a wet hand layup process using a white cement mould, with jute fiber as reinforcement and biodegradable Fevicol resin as the binder, forming an 8 mm thick laminate cured at room temperature. In static testing, the helmet withstood the BIS standard maximum impact force of 19.5 kN before showing cracks. Dynamic analysis using Explicit Dynamics in ANSYS recorded von-Mises stresses of 5.02 MPa at 50 km/h, 8.13 MPa at 60 km/h, and 9.11 MPa at 70 km/h. These results suggest that bio-composite helmets can be a sustainable and effective alternative to traditional helmets, offering strength and durability while reducing environmental impact.

Keywords: *Bio-composite helmet, Natural fiber reinforcement, Sustainable materials, Impact resistance, Compression strength, Eco-friendly fabrication*

1. Introduction

Helmets play a crucial role in rider safety, significantly reducing the risk of severe injuries, particularly head trauma, which accounts for 71–80% of all injuries sustained in road accidents (Pinnoji *et al.*, 2010). Research indicates that wearing a motorcycle helmet can decrease the likelihood of head injuries by approximately 29%, underscoring their importance in road safety regulations worldwide (Waghmare and Raj Kumar, 2016). A typical helmet consists of several key components, including the outer shell, liner, visor, retention system, and comfort padding. Among these, the outer shell and liner are the most critical in absorbing and dissipating impact energy. Traditionally, helmet manufacturers have relied on synthetic materials such as Acrylonitrile Butadiene Styrene (ABS), and polycarbonate for the outer shell and Expanded Polystyrene (EPS) for the liner. These materials offer high impact resistance and energy absorption capabilities but present significant environmental concerns due to their non-biodegradable nature. The increasing accumulation of plastic waste has raised concerns about the sustainability of synthetic materials, prompting the need for eco-friendly alternatives (Bharath *et al.*, 2021).

*Corresponding author's ORCID ID: 0000-000-0000-0000
DOI: https://doi.org/10.14741/ijcet/v.15.3.5

With growing environmental awareness, researchers and industries are exploring the use of natural fiber-reinforced composites as a sustainable alternative to conventional helmet materials. Natural fibers, such as jute, coir, flax, banana, and hemp, offer several advantages, including biodegradability, lightweight properties, cost-effectiveness, and ease of availability (Raji *et al.*, 2021). However, these fibers often exhibit lower mechanical properties compared to synthetic fibers like glass fiber, which limits their direct application in high-impact environments. To overcome these challenges, hybrid composites combining natural and synthetic fibers are being developed to enhance mechanical strength while maintaining environmental sustainability. The combination of different fibers allows for improved impact resistance, durability, and energy absorption, making them a potential candidate for helmet manufacturing (Agrawal., 2018).

In this study, Jute fiber (Fig. 4.2.2) known for its high tensile strength and low density, was selected as the reinforcement as shown in while biodegradable Fevicol synthetic resin served as the binder to evaluate their mechanical performance for helmet applications. A finite element analysis was conducted to simulate the impact resistance and energy absorption capabilities of these bio-composites under different accident scenarios, including Top-down, Side, and skidding impacts (Shanmugam *et al.*, 2021).

The main objectives of this research are to achieve mechanical properties superior to conventional helmets while making the product more affordable for users. The findings highlight the potential of natural fiber-reinforced composites as a viable alternative to traditional synthetic materials in helmet manufacturing. By integrating eco-friendly materials without compromising rider safety and performance, this study promotes sustainable and effective solutions for helmet design. Future research can explore optimizing fiber-matrix compositions and adopting advanced manufacturing techniques to further enhance helmet performance. Fig. 1 illustrates the various components of a conventional helmet, which include comfort padding, the shell, protective padding, edge trim, padding, the retention system (chin strap), and the neck curtain.

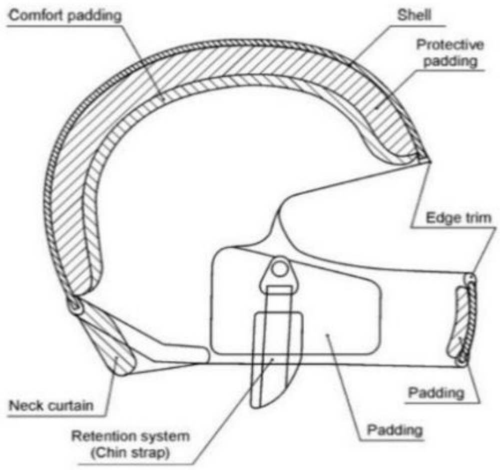

Fig. 1 Components of helmet

2. Design of Helmet

In the present study, a full-face helmet was designed with careful consideration of key factors such as safety, comfort, and aesthetics. The design process was conducted using SolidWorks, a widely adopted CAD software for 3D modeling and simulation of mechanical components. SolidWorks offered precise tools for developing the helmet geometry, ensuring dimensional accuracy and enabling effective visualization of the final design prior to manufacturing. In designing the helmet model, standard design parameters were followed, with reference to widely accepted British, American, and Indian Standards (IS) that are commonly applied in helmet manufacturing (Saroj Kumar Biswal *et al*., 2016). These standards guided the dimensions, safety features, and structural requirements of the helmet.

Figures 2.1 and 2.2 illustrate 2D and 3D helmet models. Figure 2.1 presents front, right-side, isometric, and bottom views, while Figure 2.2 shows top, front, and side views. The 3D model includes the protective shell and padding, providing a complete perspective of the helmet's features.

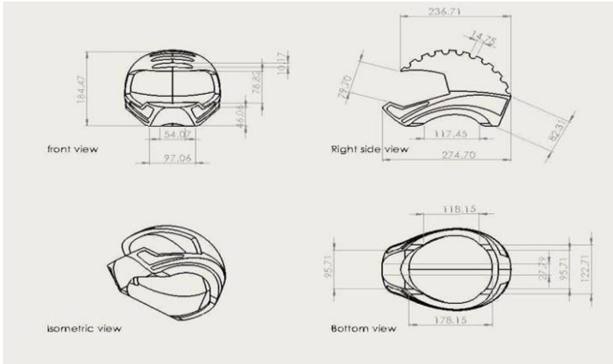

Fig. 2.1 Two-dimensional modeling of helmet

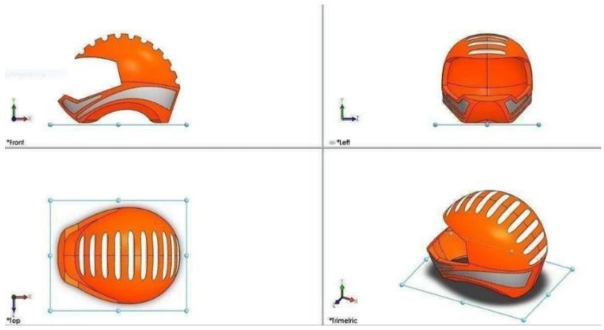

Fig. 2.2 Three-dimensional modeling of helmet

3. Finite Element Analysis

3.1 Static Structural Analysis

In the present work compressive impact analysis is performed on helmet by using ANSYS software. The model of helmet is prepared in SolidWorks software and it is imported in ANSYS software to perform analysis. Analysis is performed considering the mechanical properties of Jute fiber as shown in Table 3.1.1 (Subhankar Biswas *et al*., 2015). Fig 3.1.1 shows the meshed view of helmet and the Statistics of Mesh is shown in Table 3.1.2 The shell portion of the helmet is taken into consideration during analysis as it is the part exposed to the outer environment. The maximum permissible load of the maximum permissible limit of 19.5 kN (as per BIS standard) compressive impact is applied on the top surface of the helmet having thickness of 8mm as shown in Figure 3.1.2. this is because in practice helmet is fixed with our neck so it is considered as bottom fixed (V. C. Sathish Gandhi *et al*., 2014). If motorcyclist falls on the road, mainly load is performed on top and both right and left sides of the helmet. So far, the load has been applied on the top surface and various results of the stress in x, y and z direction as shown in Fig. 3.1.3, Fig. 3.1.4 and Fig. 3.1.5, total deformation Fig. 3.1.6 and, Equivalent (von-Mises) stress Fig. 3.1.7 has been taken for consideration. The compression stress is obtained in negative value due to downward force exerted. The Consolidated result of helmet is shown in Table 3.1.3 and Table 3.1.4 shows the Total Deformation of helmet.

Table 3.1.1 Mechanical properties of Jute fiber

Young's Modulus	31000 Mpa
Poisson's Ratio	0.35
Bulk Modulus	34444 Mpa
Shear Modulus	11481 Mpa

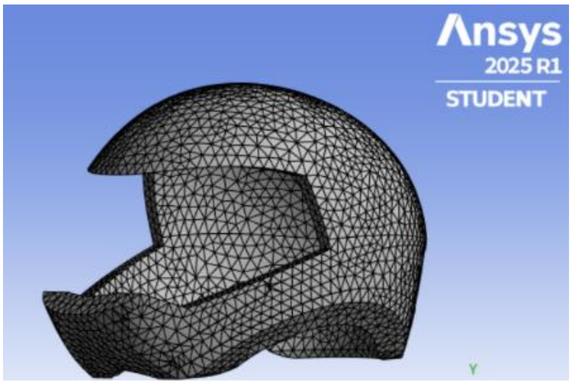

Fig. 3.1.1 Meshed view of helmet

Table 3.1.2 Statistics of Mesh

Nodes	Elements
38515	22623

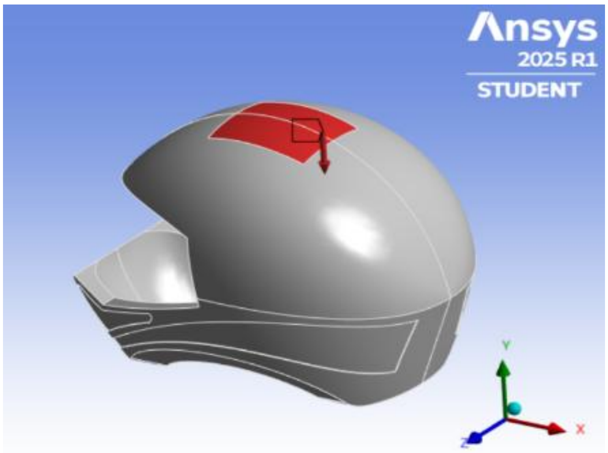

Fig. 3.1.2 Direction of Load Applied

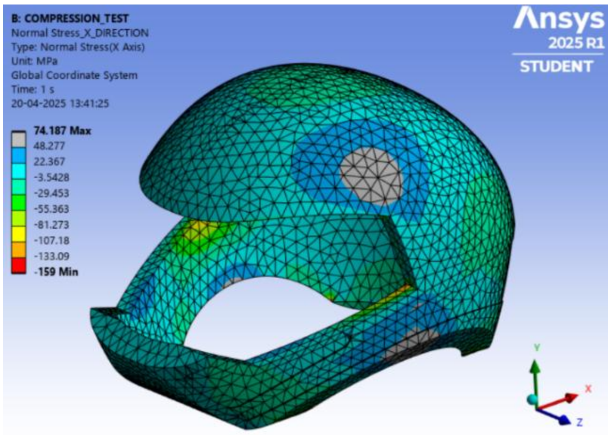

Fig. 3.1.3 Stress in X-direction

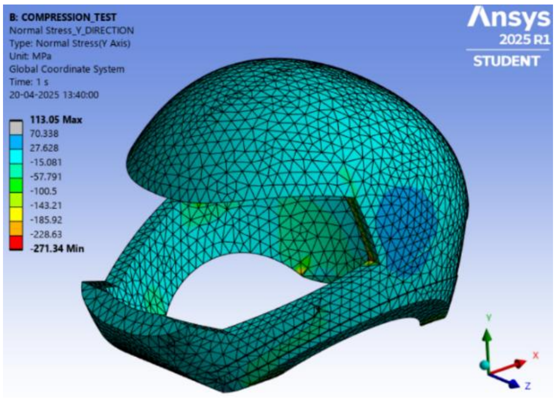

Fig. 3.1.4 Stress in Y-direction

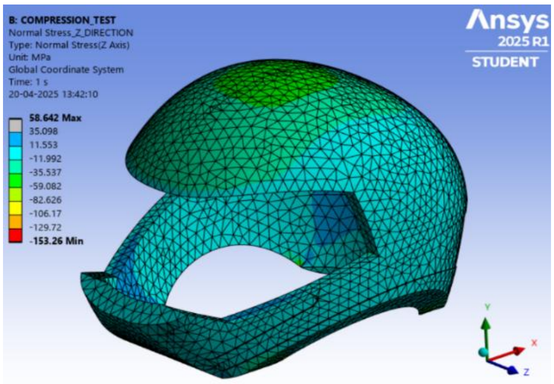

Fig. 3.1.5 Stress in Z-direction

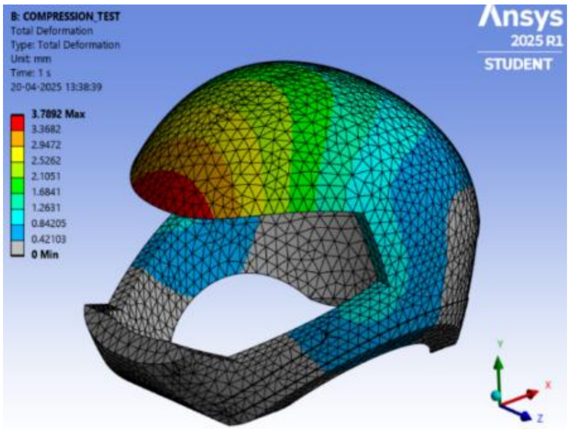

Fig. 3.1.6. Total deformation

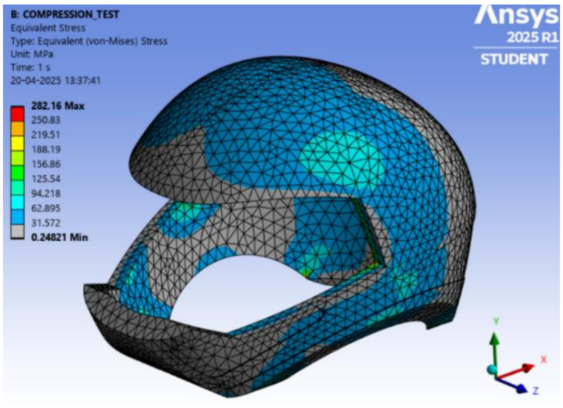

Fig. 3.1.7 Equivalent (von-Mises) stress

Table 3.1.3 The Consolidated result of helmet in 3-directions

Direction	Compression Stress in MPa	Tensile Stress in MPa
X	159	74.157
Y	271.34	113.05
Z	153.26	58.642

Table 3.1.4 Total Deformation of Helmet

Type	Load	Deformation in mm
Total Deformation	19.5 kN	3.789

3.2 Dynamic Analysis

For dynamic analysis, Explicit Dynamics in ANSYS was used. Sudden impact tests were performed at average motorcycle speeds of 50 km/h, 60 km/h, and 70 km/h to analyze impact energy absorption and structural response. To simulate real-world impacts, where an individual falling from a motorcycle may strike the ground or an object to the left or right, the helmet model was positioned against a perpendicular structural steel plane. The plane was meshed with an appropriate number of elements to ensure accurate results (S. Shankar *et al*., 2020). Equivalent (von-Mises) stresses were determined for each speed. Fig. 3.2.1 shows the helmet impact at 50 km/h, Fig. 3.2.2 at 60 km/h, and Fig. 3.2.3 at 70 km/h. Table 3.2.1 shows the (von-Mises) Stresses of Helmet for different speed.

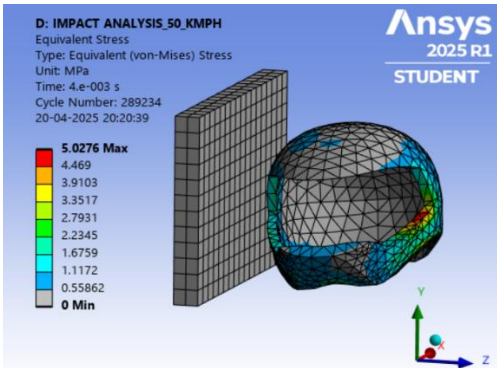

Fig. 3.2.1 Equivalent (von-Mises) stress at 50 km/h.

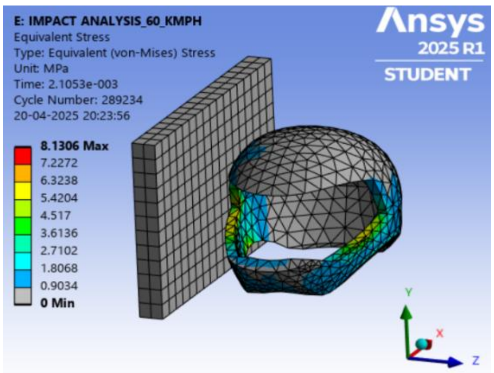

Fig. 3.2.2 Equivalent (von-Mises) stress at 60 km/h.

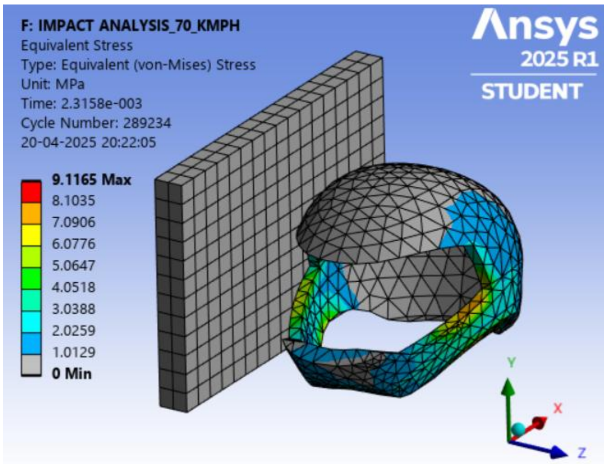

Fig. 3.2.3 Equivalent (von-Mises) stress at 70 km/h.

Table 3.2.1 (von-Mises) Stresses of Helmet for different speeds

Speed in km/h	von-Mises Stress in MPa
50	5.02
60	8.13
70	9.11

4. Fabrication

4.1 Moulding processes

The moulding process involves several steps, including mould creation, material preparation, and shaping using the mould. In this project, a mould was created using an old helmet made of ABS material, with standard dimensions matching our CAD design. Fig. 4.1.1 shows plastering of helmet for moulding process which was the initial step of fabrication part. A tape is wound around the helmet to withstand the flow of plaster of Paris. Fig. 4.1.2 shows Preparing plaster of Paris for the moulding process by mixing with sufficient quantity of water. Chemical formula is $CaSO_4{+}2H_2O$. Plaster of Paris mixed with water was poured into the helmet to form a precise mould. After setting for a week, the helmet was carefully broken to retrieve the desired mould (Raji *et al*., 2021). Fig. 4.1.3 shows the Final Mould.

Fig. 4.1.1 A tape is wound around the Mould

Fig. 4.1.2 Preparing plaster of Paris for the moulding process

Fig. 4.1.3 The Final Mould.

4.2 Lay-up process

The Lay-Up process, is a moulding technique for composite materials where the final product is created by layering multiple jute fiber sheets. It is categorized into Dry Lay-Up and Wet Lay-Up, depending on whether the layers are pre-impregnated. Dry Lay-Up is widely used in the aerospace industry due to its ability to form complex shapes with high mechanical strength. In contrast, Wet Lay-Up, which does not accommodate unidirectional fabrics with superior mechanical properties, is primarily employed in applications with lower performance demands.

In our work Fabrication was carried out using the wet hand layup process as shown in Fig. 4.2.1., with a white cement mould. Jute fiber (Fig. 4.2.2) known for its high tensile strength and low density, was selected as the reinforcement as shown in while biodegradable Fevicol synthetic resin served as the binder. The thickness of each Jute fiber sheet is 1mm, we have laminated 8 layers making it 8mm thick. In the Fig. 4.2.3. The lay-up is been carried out on the mould in which jute fiber sheet is laminated one upon the other. It is then allowed to cure for about 2 days and air dried. This process is in line with the works of other researchers (S. Shankar *et al.*, 2020, Emmanuel Adewumia *et al.*, 2019, M. Elkington *et al.*, 2015).

After the curing process of the composite, the internal mould was carefully broken to retrieve the final product. The helmet was then painted, and accessories such as the visor and internal components like comfort padding were assembled. As shown in Fig.4.2.4 (a), Fig 4.2.5 (b).

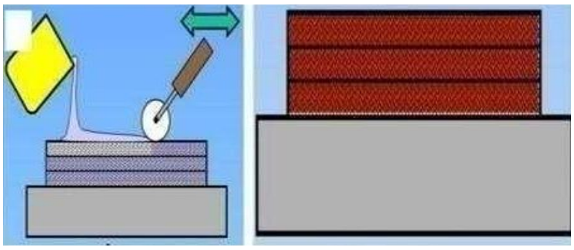

Fig. 4.2.1 Schematic representation of lay-up process

Fig. 4.2.2 Jute fiber sheet

Fig. 4.2.3 Jute fiber sheet

Fig. 4.2.4 (a) Final Product

Fig. 4.2.4 (b) Final Product

5. Compression Testing

During the physical testing conducted using a Universal Testing Machine (UTM), the helmet was positioned in a top-down manner and subjected to a gradually increasing load to evaluate its strength and structural integrity. The load was applied steadily until the helmet reached its maximum load-bearing capacity. It successfully withstood a load of up to 18.3 kN, demonstrating good resistance against deformation. However, beyond this point, visible cracks began to appear, indicating the onset of structural failure. Eventually, the helmet could no longer sustain the applied force and fractured, marking the completion of the test, as shown in Fig. 5.1. This result provided valuable insight into the helmet's load-bearing limit and failure behavior under compression. Table 5.1 represents the detailed specifications of the UTM used for this test.

Fig. 5 Compression Testing of Helmet using a Universal Testing Machine

Table 5 Specifications of Universal Testing Machine

Model	Capacity	Make
UTE-60	600 kN	Fuel Instruments and Engineers Pvt. Ltd.

6. Cost Comparison

Fabrication cost details of the composite Helmet is given in Table 5 Total cost incurred in the fabrication of the bio-composite Helmet is Rs.1055. Cost of conventional polycarbonate or ABS (Acrylonitrile Butadiene Styrene) Helmet as per market price is Rs.1500. This shows that the fabricated bio-composite full-face helmet is 29.7 % less costly than the conventional Helmet.

Table 5 Cost estimation of composite Helmet

Materials used	Quantity	Cost per unit (Rs.)	Tost Cost (Rs.)
Jute fiber	3 meters	150	450
Plaster of Paris	6 kg.	35	210
Fevicol	500 gms.	195	195
Other miscellaneous cost	----	-----	200
Total cost of bio-composite full-face Helmet (Rs.)			1055

7. Results and Discussions

The study focused on developing a bio-composite helmet as an eco-friendly alternative to conventional helmets, which are often bulky, costly, and made from non-biodegradable materials like Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polystyrene, and ABS+PC plastic blends all of which contribute to environmental pollution. Using SolidWorks software, an aerodynamically improved helmet was designed. Fabrication involved creating a plaster of Paris mould and applying a hand layup process with jute fiber and Fevicol as a binder, resulting in an 8 mm thick composite shell. For static analysis, the maximum permissible limit of 19.5 kN impact force, as per BIS standards, was considered. The bio-composite helmet successfully withstood this load, after which visible cracks began to form, indicating the onset of structural failure.

Additionally, experimental dynamic analysis was conducted using Explicit Dynamics in ANSYS. Sudden impact tests were performed at average motorcycle speeds of 50 km/h, 60 km/h, and 70 km/h. The corresponding von-Mises stresses recorded were 5.02 MPa at 50 km/h, 8.13 MPa at 60 km/h, and 9.11 MPa at 70 km/h. As this is an initial experimental analysis, more accurate results could be achieved by incorporating the precise stress-strain curve of jute fiber into the simulation. Furthermore, to enhance the helmet's compressive and impact resistance, increasing the shell thickness is recommended.

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