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Optimizing Helmet Materials: A Comparative Analysis of Safety and Cost-Effectiveness

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Helmet materials, Safety optimization, Finite element analysis, Carbon fiber, ABS plastic

ABSTRACT:
This research focuses on identifying optimal materials for helmet production that not only prioritize safety but are also economically viable for a broad user demographic, particularly for those engaging in traffic activities. Employing finite element analysis as a crucial tool, we conduct simulations and tests on a helmet model using three distinct materials: carbon fiber, glass fiber crystal, and ABS plastic. The primary objective is to utilize ABAQUS to compare the performance of these materials when subjected to collision scenarios involving a human head and a rigid object. The simulation is executed in a dynamic environment (ABAQUS/Explicit), generating collision results to assess the impact and stress distribution across the helmet models made from different materials. Our findings indicate that, at the point of maximum stress, carbon fiber exhibits superior performance, showcasing the least damage to the head. Undoubtedly, carbon fiber emerges as one of the most exceptional materials available today, particularly in terms of its protective capabilities. However, it is noteworthy that ABS plastic demonstrates relative efficacy compared to carbon fiber in our experiments, offering a cost-effective alternative. Despite being considerably more affordable than carbon fiber, ABS plastic still maintains a satisfactory level of performance, meeting safety standards and ensuring user protection. The research highlights ABS plastic as a competitive option in the market, considering its cost-effectiveness in contrast to the superior performance of carbon fiber and glass fiber. This is especially significant in an era where carbon fiber remains a luxury material, making ABS plastic a viable and accessible choice for safety-conscious consumers.

1. Introduction

In contemporary society, the evolution of transportation methods has become integral to modern life, providing efficient solutions to commuting needs. As a result, the industry responsible for crafting these vehicles has concurrently given rise to the production of safety-oriented products. Notably, in Vietnam, where there are presently over 45 million motorcycles, representing one motorcycle for every two individuals, the significance of protective gear, particularly helmets, is underscored. Statistical data from Vietnam reveals that motorcyclists contribute to more than 70% of road traffic accidents, emphasizing the critical role helmets play in ensuring road user safety [1-2].
The development of helmets that adhere to stringent safety standards hinges on various factors, with the foremost being the selection of appropriate materials capable of mitigating risks during collisions while remaining cost-effective.
The Finite Element Method (FEM) [3], an approximate numerical technique for solving collision problems involving components with diverse materials, stands out as a pivotal tool. ABAQUS, the software employed in this study, has emerged as a primary computational resource globally, renowned for its high applicability in accurately forecasting dynamic, static, and combined kinematic/static phenomena. This makes it particularly well-suited for describing collision dynamics involving helmets constructed from distinct composite materials [4-5].
This research aims to scrutinize the collision impact experienced by an individual wearing a helmet fabricated from three different composite materials: carbon fiber, glass fiber, and ABS plastic. The study will systematically alter helmet parameters for each material

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during collisions with a flat surface, facilitating a comprehensive evaluation and comparison of the human head model's response to impact. Additionally, stress data will be analyzed to discern the most suitable materials for mass production, thus contributing to the ongoing discourse on helmet safety and manufacturing practices.

2. Materials and Simulation

2.1. Materials

2.1.1 Carbon Fiber Material

Over the past few decades, carbon fiber has gained widespread utilization owing to its exceptional properties. Characterized by fibers with diameters ranging from 5 to 10 microns, primarily composed of carbon atoms, carbon fiber boasts several advantages. These include high stiffness, superior tensile strength, low weight, elevated chemical resistance, high-temperature resilience, and minimal thermal expansion, especially when juxtaposed with steel. In fact, carbon fiber is twice as stiff as steel and can endure five times the load. Despite its remarkable qualities, it is essential to acknowledge its relatively higher cost [5].

The compressive stress-strain curve for a typical carbon fiber composite sample is illustrated in Figure 1. The chemical composition of carbon fiber materials is outlined in Table 1, while Table 2 provides an overview of their physical and mechanical properties.

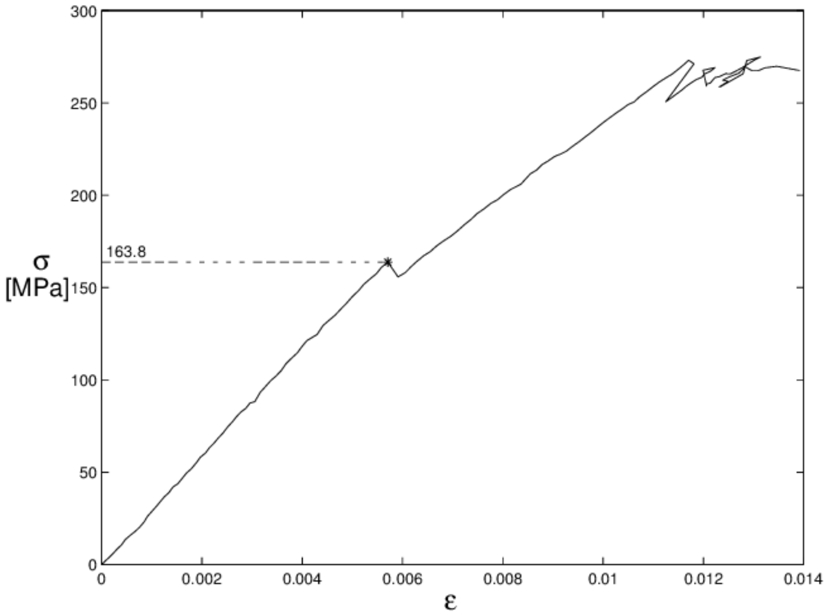

Figure 1. Stress-strain curve for a typical carbon fiber composite

Voce's chemical stability law is employed in this research to express stress and strain through the equation: $\overline{\sigma}$= 11,5+ 8,2*(1-exp(-0,003*ε))*10^6

Table 1. Carbon Fiber Chemical Composition

Element	%
Carbon(C)	90
Other (O,Ni,Si)	10

Table 2. Mechanical Properties of Carbon Fiber Materials

Density	1,8 g/cm^3
Elastic Modulus	228 GPA
Poisson Coefficient	0,26-0,28

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2.1.2 Fiberglass Material (Type E) (Fiber Glass)

Fiberglass is formed by pressing thin fibers, typically silica-based or other formulated glass, into fibers with small diameters suitable for textile processing. Noteworthy for its high durability, heat resistance, substantial bearing capacity, and silk-like softness, fiberglass surpasses stainless steel fibers of comparable size. For this study, Type E glass fiber, recognized for its widespread use and lower average price compared to carbon fiber, is chosen [5].

Figure 2 illustrates the compressive stress curve of a typical Type E glass strip studied by Anthony M Waas [1]. The chemical composition and physical-mechanical properties of glass fiber are detailed in Tables 3 and 4, respectively.

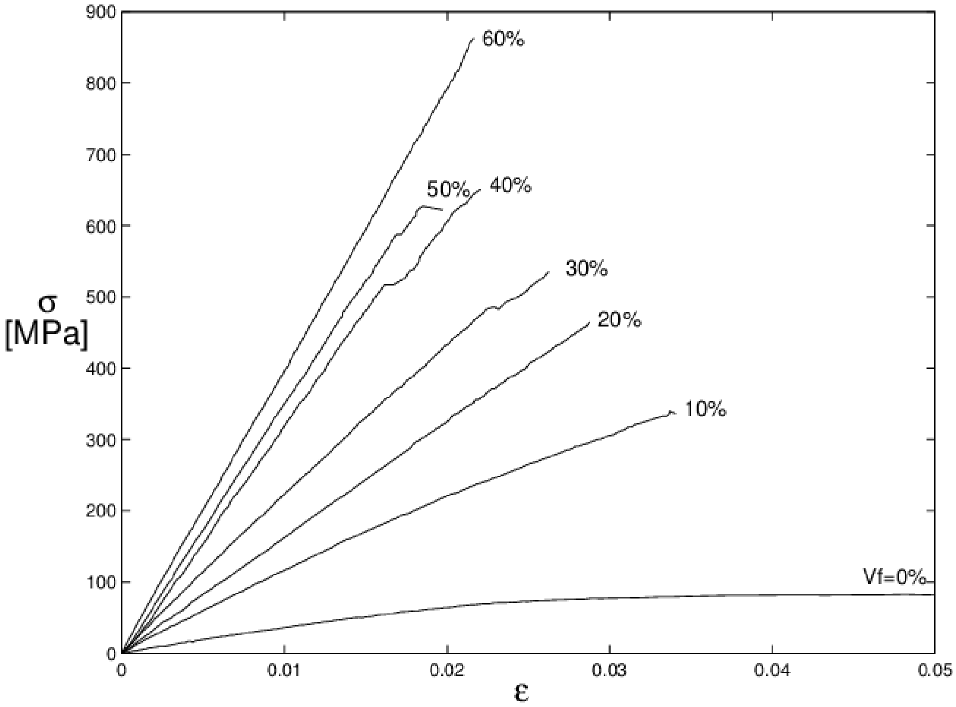

Figure 2. Stress curve of a typical Type E glass [1]

Table 3. Chemical Composition of Type E Glass Fibers

SiO_2	~50–60%
Remaining Composition (other oxides of Ca, Na, Al, Fe, etc)	~40–50%

Table 4. Mechanical Properties of Glass Fiber Materials

Density	2.56 g/cm^3
Elastic Modulus	72,4 MPA
Hệ số poission	0,21

Voce's chemical stability law for glass fiber stress and strain is expressed by the equation: $\overline{\sigma} = 9,9+ 5,1*(1-exp(-0,002*\varepsilon))*10^6$

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2.1.3 ABS Plastic Material

Acrylonitrile Butadiene Styrene (ABS) plastic, widely used across various fields, stands out for its affordability and high-quality attributes. Notable for its lightweight nature, robust impact resistance, high abrasion resistance, and flexibility, ABS plastic is an economical alternative to other materials [5].

Figure 3 demonstrates the stress-strain curve of ABS plastic studied by Anthony M Waas (1). The chemical composition and physical-mechanical properties are outlined in Tables 5 and 6, respectively.

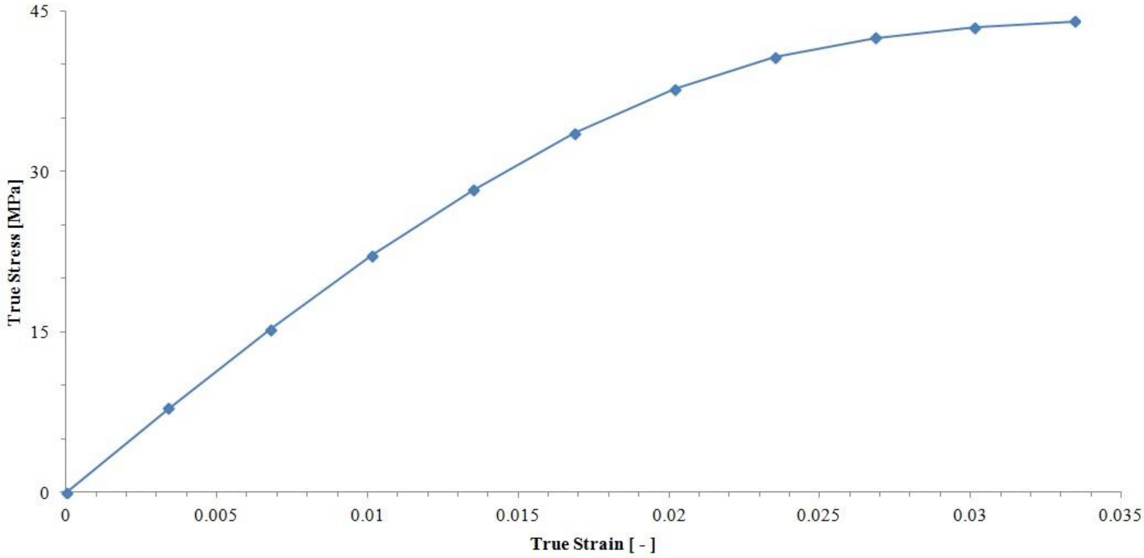

Figure 3. Stress-strain curve of ABS plastic

Voce's chemical stability law for ABS plastic stress and strain is represented by the equation: $\overline{\sigma}$= 5,1+ 8,3*(1-exp(-0,0002*ε))*10^6

Table 5. Chemical Composition of ABS Plastic

Carbon(C)	85%
Hidro(H)	8,5%
Nito(N)	6,5%

Table 6. Mechanical Properties of ABS Plastic

Density	1,05 g/cm^3
Elastic Modulus	2100MPA
Hệ số poission	0,35

2.2. Simulation Model

This comprehensive overview elucidates the distinctive attributes and characteristics of the chosen materials, setting the groundwork for their subsequent application and evaluation in collision simulations.

To rigorously assess the performance of each material—carbon fiber, glass fiber, and ABS plastic—in helmet production, three distinct crash test models are executed. In each case, a human head adorned with a helmet undergoes impact with a rigid surface, depicted comprehensively in Figure 5. The simulation design specifically focuses on vertical impacts, providing an in-depth analysis of the effects on the helmet. This deliberate approach allows for a meticulous comparison, with particular emphasis on evaluating the stress distribution during helmet-head collisions.

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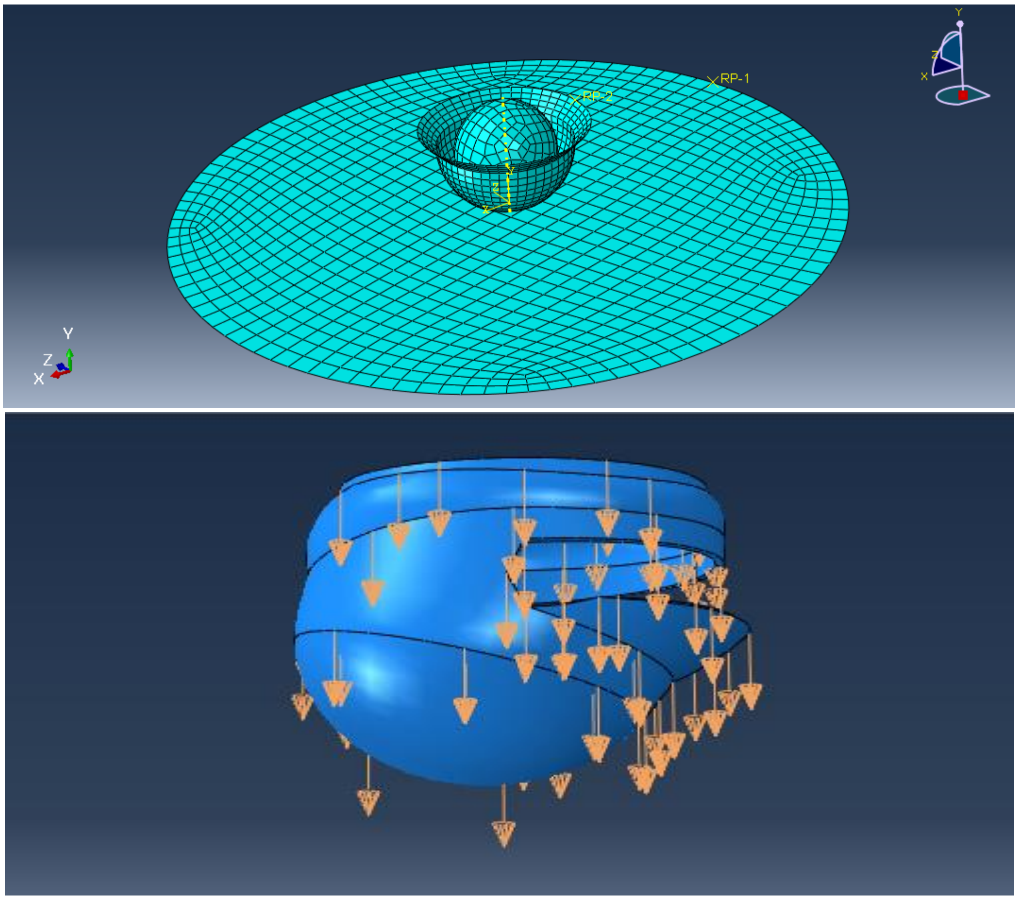

Figure 5. Sample Object Model in Simulation

The selected crash test scenarios serve to emulate real-world situations where vertical impacts are predominant, offering a targeted investigation into the protective capabilities of each material under specific conditions. This controlled experimental setup facilitates a nuanced understanding of the stress dynamics involved in helmeted head collisions, paving the way for a robust comparative analysis.

In order to make an informed selection for helmet production, this study employs a simulation model representing the general shape of different helmet types, with the head modeled akin to a sphere during collision scenarios. The helmet and human head model are equipped with deformable elements, while the ground is modeled as a discrete rigid surface. The simulation is conducted within the reference frame of the ground, where a force F is exerted upon impact, considering the collision friction coefficients between the helmet and ground (0.2) and helmet with the human head model (0.1).

The impact force (F) is calculated using the formula $F=V\cdot p\cdot a$, where V is the volume of the object, p is the density of the sample, and a is the object's acceleration. For freely falling objects, $a=g=9.8m/s^2$. The calculated impact forces for carbon fiber, glass fiber, and ABS plastic are 73.7, 104.86, and 44.24, respectively.

The mass of the object significantly influences collision dynamics. For the same model made from different materials, greater mass results in a stronger impact force. During the simulation process, three experiments are conducted to gather data on the stress of the human head model and observe deformation changes based on material parameters.

The finite element simulation diagram in ABAQUS, using isotropic mesh coverage mode, is illustrated in Figure 5. The output values include the maximum stress of an element through the three experiments.

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3. Results and Discussion

After conducting simulations for carbon fiber, glass fiber, and ABS plastic, the deformation of the cases is found to be equivalent. The stress calculation formula ($\sigma = F/A$) emphasizes the relationship between force and stress, where σ is stress, F is force, and A is the surface area (Fig. 6).

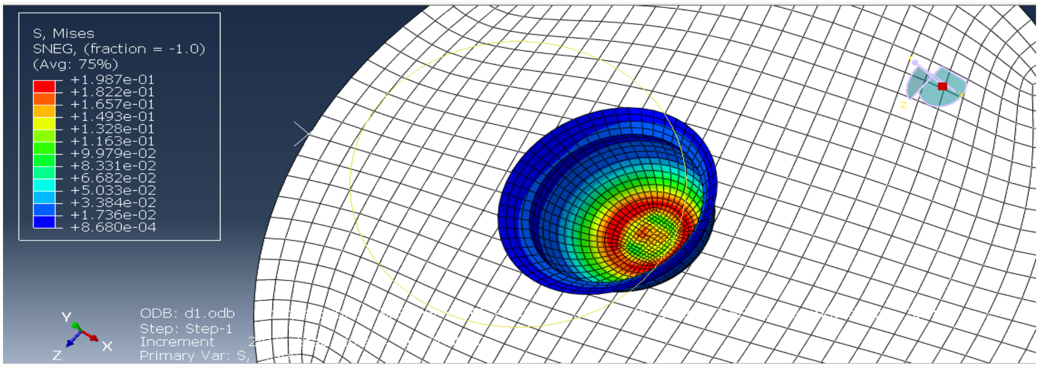
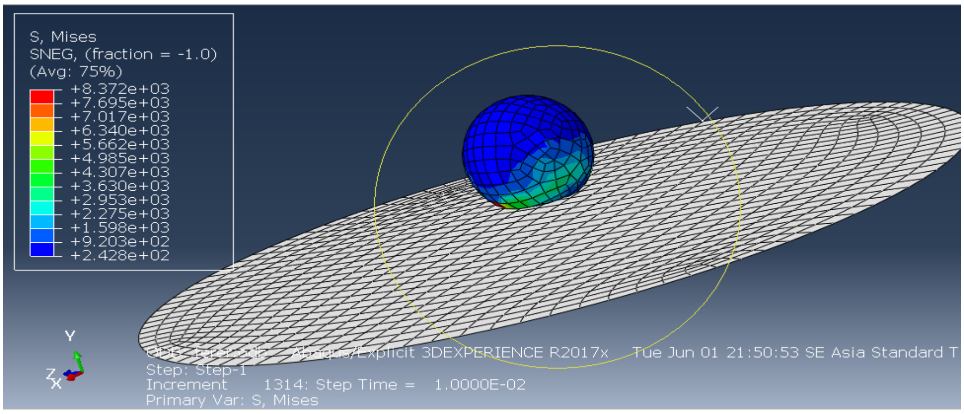


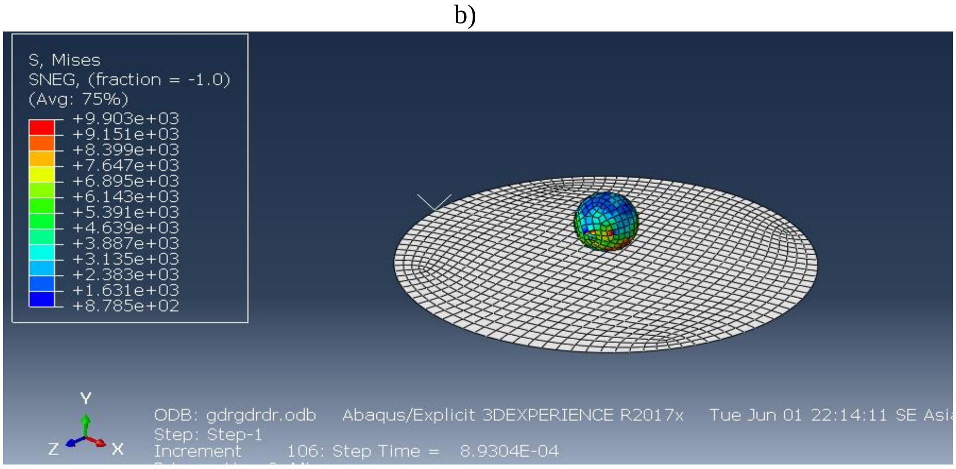
Figure 6. Results in ABAQUS

The stress values for carbon fiber, glass fiber, and ABS plastic are presented in Figures 7 a, b and c, respectively.



a) Stress Value of Carbon Fiber

b)



b) Stress Values of Glass Fibers

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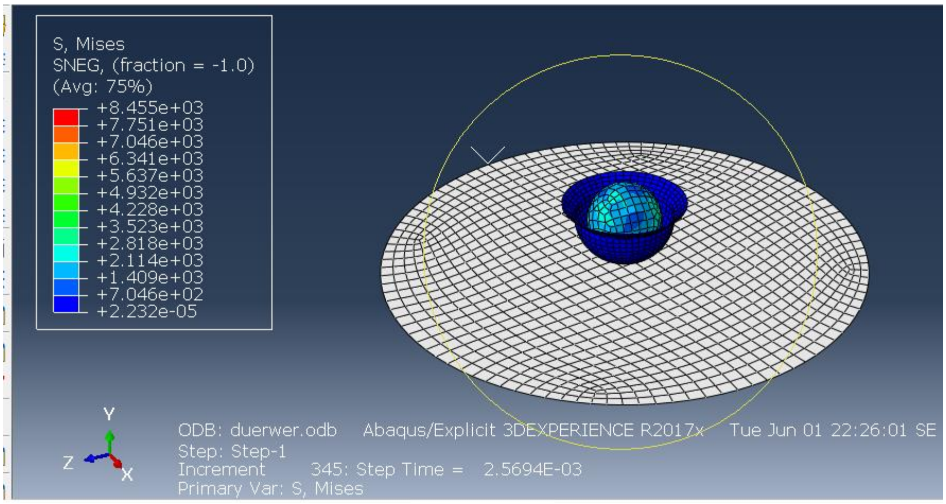

c) Stress Value of ABS Plastic

Figure 7. Stress values for carbon fiber, glass fiber, and ABS

The analysis reveals that all three materials meet the force resistance requirements as per European CEN standards for helmets. Considering the element with the highest stress, carbon fiber demonstrates the least impact force on the head, followed closely by ABS plastic, while glass fiber exerts the greatest force. Although carbon fiber exhibits superior protective capabilities, its high cost makes it impractical for mass-produced helmets. ABS plastic emerges as a suitable material for mass production due to its lightweight, good durability, and cost-effectiveness, providing a balanced choice for today's market demands.

4. Conclusion

In conclusion, this study meticulously navigates the labyrinth of material selection for helmet production, a critical pursuit in balancing safety and affordability for a diverse range of consumers engaged in traffic activities. Through a comprehensive model, integrating three materials – carbon fiber, glass fiber, and ABS plastic – the study not only addresses the reduction of vibrations experienced by helmet wearers but also orchestrates a multifaceted comparison encompassing several pivotal factors.

The research outcomes unequivocally advocate for ABS plastic as the material of choice for mass-produced helmets. This material exhibits an optimal blend of characteristics, including lightweight design, commendable impact resistance, and the capability to mitigate the forces transmitted to the wearer's head. Notably, ABS plastic's standout feature lies in its flexibility, enhancing comfort and adaptability to various head shapes. As such, the study unequivocally positions ABS plastic as the most viable and complete solution for helmet production, seamlessly marrying performance, practicality, and user comfort.

5. References

1. Waas, A. M. (Dec 1999). "Compressive response and failure of fiber reinforced unidirectional composites."
2. Marangoni, A. L., & Massaroppi Junior, E. (Year). "Estimation of Cowper-Symonds parameters for ABS materials using design of experiments with finite element simulation."
3. Duc-Toan, N., Young-Suk, K., Dong-Won, J. (2012). "Coupled Thermo-Mechanical FE Study to Improve Press Formability of a Camera Shape for Magnesium Alloy Sheet AZ31B." Metals and Materials International, 18(4), 583–595.
4. Huang, X. (2009). "Fabrication and properties of carbon fibers." Materials, 2, 2369-2403.
5. Goodhew, P. J., Clarke, A. J., & Bailey, J. E. (1975). "Review of the fabrication and properties of carbon fibers." Materials Science, 17, 3–30.