ENSET FIBER REINFORCED COMPOSITE VEHICLE BODY CRASH ANALYSIS USING ANSYS

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ABSTRACT

The impact of a frontal car collision whose body is made from the new Enset fiber-reinforced composite material and the existing glass fiber-reinforced composite material has been investigated and compared using an explicit dynamics setup on the ANSYS Workbench. Using a car body composed of Enset fiber-reinforced composite material and the current glass fiber-reinforced composite material, which are modeled on ANSYS Composite Prepost, the equivalent stress and deformation on impact with a static steel wall and a moving car with speeds of 120 m/s and 200 m/s are investigated. For both materials, the deformation and stress produced as a result of the crash analysis are displayed and elaborated. For 120 m/s of car speed, the maximum deformation and stress that can result from a collision are 94.5 mm and 6.707 GPa for Enset fiber-reinforced composite material and 84 mm and 19.866 GPa for glass-reinforced composite material, respectively. Enset fiber-reinforced composite material has an outstanding energy absorption characteristic; the vibration of the vehicle body built from this material is reduced. Generally, the most suitable alternative material for a vehicle's body will typically turn out to be the Enset fiber-reinforced composite material.

Keywords: Crash Analysis, Enset Fiber Reinforced, Vehicle Body, ANSYS Composite Prepost , Glass Fiber

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1. Introduction

Ethiopian native Enset ventricosum, sometimes known as the "false banana," is grown mainly for its starchy pseudo-stem, which is a staple food in the area [1,2]. The pseudo-stem of the plant yields Enset fibers, which are lightweight, eco-friendly, and have great tensile strength and excellent energy absorption [2-4]. Because of these characteristics, Enset fiber reinforced composites are especially well-suited for use in automotive applications, where they improve crashworthiness by offering superior impact resistance and facilitating in weight reduction, which raises fuel economy and lowers emissions [5]. Because of their excellent strength-to-weight ratio and environmental advantages, composite materials are becoming more and more significant in sectors like aerospace and automotive[5,6]. Because of their sustainability, natural fiber composites stand out among the others. Particularly, Enset fibers have demonstrated remarkable potential for impact energy absorption [7,8]. On the other hand, there isn't any in-depth research on Enset fibers' energy absorption properties during impact events.

Automobile manufacturers began implementing crash testing in the 1970s, which entailed physically destroying an automobile to determine its crashworthiness [9]. However, as technology advanced, computer simulations took the place of physically destroying the car. Consequently, in order to examine the essential parameters prior to actual testing and lower test costs, the vehicle crash test utilizing Finite Element (FE) simulation like ANSYS is a useful method [10,11]. In recent years, automakers have used more lightweight materials; such as composites, polymers, aluminum, magnesium, and novel forms of high-strength steels to minimize weight. The composites industry has been moving forward in recent times to produce green composites since sustainability is fast becoming a global priority for many different businesses. Composites made of natural fibers have gained attention from significant industries like building, automotive manufacturing, and packaging. Research on false banana (Enset) fiber-reinforced composites is promising because of their significant mechanical qualities, affordability, ease of supply, and partial or complete biodegradability [12].

Because of their superior qualities, including high specific strength, low weight, low cost, good mechanical properties, non-abrasiveness, eco-friendliness, and biodegradability, natural fibers are preferred over synthetic fibers by engineers, researchers, professionals, and scientists worldwide as an alternative reinforcement [11-13]. Furthermore, because they are inherently renewable and require less energy to manufacture and process.

1.1 Availability and Mechanical properties of Enset fiber

The Enset (Enset ventricosum) crop plant shown in Figure 1, was selected as the natural fiber plant for this study. Ethiopia and all of East Africa have a plenty of surplus Enset fiber, which is agricultural waste. The purpose of the crop, which is extensively cultivated on thousands of hectares of land, particularly in southern Ethiopia, is to generate starchy food from its robust pseudostem, corm, and inflorescence stem [14 ,15]. Over 20% of Ethiopians consume it as their primary diet, and it is extremely important to the nation's food security [16 ,17]. This coverage of the Enset plant yields surplus resources of agricultural wastes, or byproducts, known as Enset fiber, which were not widely or effectively utilized [18]. Currently, the primary byproduct obtained by converting the pulp from the leaf sheaths of the Enset plant's pseudostem is Enset fiber. As a result, it can be obtained only for manufacturing needs without taking into account the additional cost for input. However, Ethiopian expertise in exploiting Enset fiber is still in its infancy, making it unsuitable as a substitute for synthetic and other natural fibers. This could be because the majority of earlier studies on Enset focused on the chemical and physical characteristics of food [19]. Enset fiber, however, has been the subject of some encouraging limited research that suggests it may be utilized as a substitute for synthetic and other natural fibers [20].

Ten distinct breeds of Enset fiber were examined by Balcha D. et al., who also conducted a tensile test on the material. Furthermore, the impacts of the fibers' location along and across the plant pseudostem as well as the duration of the 5% Na-OH surface treatment were investigated. The test findings show that the fibers from ten different Enset breeds do not significantly differ in rupture stress. However, there is a significant variation in strain among the ten Enset breeds' fibers, with Dego fiber displaying the highest strain before failure. Surface-treated fibers showed improved elastic modulus and rupture strength following a full day of treatment. The elastic modulus varied very little both along and across the stem. Rupture stress, elastic modulus, and strain are, respectively, 360.11 ± 181.86 MPa, 12.80 ± 6.85 GPa, and 0.04 ± 0.02 mm/mm for Enset fiber.

The elastic modulus varied very little both along and across the stem. Rupture stress, elastic modulus, and strain are, respectively, 360.11 ± 181.86 MPa, 12.80 ± 6.85 GPa, and 0.04 ± 0.02 mm/mm for Enset fiber. These results show that Enset fiber is comparable to fibers from abaca, bananas, and sisals and can be used in composite applications as an alternative to other natural fibers (14). The impact of Poisson ratio on the mechanical behavior of the composites was investigated by Temesgen B et al. [22] using a range of Poisson ratios. They concluded that modifications in the fibers' Poisson's ratio had no effect on the FEA results. Thus, when the micromechanics model was used, it was discovered that the poison's ratio value had no appreciable effect on the computed results.

For artificial banana fibers, epoxy resin, and glass fibers, the Poisson ratios v = 0.175, 0.35, and 0.22 were utilized in this investigation.

1.2 Composites materials for Automobiles

Composites with various forms of reinforcement can reduce weight by 15% to 40% in addition to providing other desirable properties for the automotive sector, such as good corrosion resistance, low thermal conductivity, high specific strength, and design flexibility [23,24]. In recent decades, there has been an increasing need for the global automakers have sparked a weight-saving revolution because to increased fuel economy and decreased environmental effect [25 ,26]. In the meantime, the cost goal control and simple recovery elevate the standard even higher for automobile choice of materials and structural layout. As a result, the replacement of traditional automobile materials like cast iron and it is shown that steel combined with cutting-edge lightweight materials is a successful tactic producing a significant decrease in the just created automobiles [27]. Three key areas of vehicle lightweight technology can be distinguished: innovative production techniques, lightweight material applications, and structural optimization design [28].

All of the major markets have seen a consistent increase in the production of light vehicles in recent years. Lightweight materials for cars can be broadly categorized into four groups as potential replacements for traditional engineering materials (steel and cast iron): light alloys (aluminum, magnesium, and titanium alloys); HSS family (e.g., conventional HSSs and AHSSs); composites (carbon fiber reinforced plastics, or CFRP); and advanced materials (e.g., mechanical meta materials) [29]. These lightweight materials have been widely used in automobiles since the turn of the 20th century for a variety of parts, including the dashboard, bumper, engine, body shell, wheel, suspension system, brake, steering system, battery, seat, and gearbox [26].

Previous study has examined the mechanical characteristics of a variety of natural fibers, including flax and jute, emphasizing both their advantages and disadvantages [30]. For example, Meredith et al. discovered that jute fibers can absorb an enormous amount of energy [31], but there aren't any comparable studies for Enset fibers. This gap in the literature emphasizes how important it is to do a thorough investigation on Enset fiber composites. This work aims to examine the energy absorption performance of Enset fiber composites and simulate their impact behavior. It is essential to understand Enset fiber-reinforced composites' energy absorption capabilities for possible use in the automobile sector. This work intends to close the gap in the literature by offering a thorough simulation analysis and insights on the viability of employing Enset fibers to improve vehicle crashworthiness. The results of this study may influence the development of lighter, more environmentally friendly, and more effective car body designs, which would improve both vehicle safety and environmental sustainability.

2. Mathematical modeling of car crash

Mathematical approach: The fundamental laws of physics, such as Newton's Laws or the conservation principle, are the source of a phenomenon or system's dynamics. The details presented in this section are taken from previously published articles [32].

2.1 Overview of the Kelvin model

An automobile collision or crash analysis involves the transformation of energy since it is a dynamic occurrence [33]. Consequently, it is justified to conceptualize an automobile as a viscoelastic element in order to model its behavior (combination of masses, springs and dampers). The basic Kelvin model serves as the foundation for the considerations in this study. A spring and damper coupled in parallel to a mass is known as the Kelvin model [34-36] which is shown in **Error! Reference source not found.**.

Where; k – spring stiffness, c – damping coefficient, m – mass of the vehicle and v0– initial impact velocity, x- displacement of the mass [m] ξ- damping factor ω_e-circular natural frequency [rad/s]. The Kelvin model's equation of motion (EOM) is as follows:

$$s^2 + 2\zeta\omega_e s + \omega_e^2 = 0$$

$$Where, \zeta = \frac{c}{2m\omega_e} \, and \, \omega_e = \sqrt{\frac{k}{m}}; \, c_1 \, and \, c_2 \, are \, \mathrm{int} \, egration \, cons \, \tan ts$$

For the automobile collision analysis using the Kelvin model, the natural frequency (ω_e) and damping coefficient (ζ) values are determined based on the material properties and system parameters. The characteristic equation is given by:

$$\mathrm{s}^2 + 2\zeta\omega_\mathrm{e}\mathrm{s} + \omega_\mathrm{e}^2 = 0$$

$$s1 = a + ibs_2 = a - iba = -\zeta\omega_e; b = \beta\omega_e\beta = \sqrt{1-\zeta^2}$$

$$\alpha = e^{at}[c_1 \sin(bt) + c_2 \cos(bt)]$$

Transient responses of the underdamped system are:

$$\alpha(t) = \frac{v_o e^{-\zeta\omega_e t}}{\sqrt{1-\zeta^2\omega_e}} \sin(\sqrt{1-\zeta^2\omega_e t}) \ldots \text{displacement (dynamic crush)}$$

$$\dot{\alpha}(t) = v_o e^{-\zeta\omega_e t}[\cos(\sqrt{1-\zeta^2\omega_e t}) - \frac{\zeta}{1-\zeta^2} \sin(\sqrt{1-\zeta^2\omega_e t}) \ldots \text{velocity}$$

$$\ddot{\alpha}(t) = v_o \omega_e e^{-\zeta\omega_e t}[-2\zeta \cos(\sqrt{1-\zeta^2\omega_e t}) + \frac{2\zeta^2 - 1}{1-\zeta^2} \sin(\sqrt{1-\zeta^2\omega_e t}) \ldots \text{deceleration}$$

This study compares an automobile body constructed of recently developed Enset fiber reinforced composite material to that of glass fiber reinforced composite material using

3. Finite element analysis (FEA) of a car body

3.1 Material setup

Mechanical properties of the Enset fiber is previously studied by researchers which are mentioned under Table 1 and their research output is used for the analysis purpose in this paper.

3.2 Geometric Modeling

A car body is created using 3D CAD and ANSYS design modeler software, taking into account all of the forms and characteristics of an actual car. To make the composite setup on ACP simply, the 3D model is converted to 2D shell elements, as seen in Figure 3. In front of the car body, a rectangular steel barrier is also modelled for crash testing purposes.

3.3 Meshing of the car model

Meshing is the process of breaking down a complicated geometry into smaller, more manageable components, like triangles or quadrilaterals in 2D model or tetrahedral or hexahedral in 3D model. These components discretize the domain for numerical analysis by forming a mesh that represents the geometry. Meshing is an essential phase in the finite element analysis (FEA) process, and simulation quality and efficiency are heavily affected by it.

As presented in Figure 4 mesh convergence analysis in ANSYS examined the relationship between von Mises stress and mesh size. Initially, larger mesh sizes showed significant variations in stress values, indicating insufficient detail. As the mesh was refined, these variations decreased. At a mesh size of 0.4 mm, the graph of von Mises stress versus mesh size flattened, showing that the solution had converged. The von Mises stress at this mesh size was 19866 MPa, indicating that further mesh refinement would not significantly alter the results. This demonstrates that a 0.4 mm mesh size provides an accurate and efficient representation of the stress distribution in the model.

ANSYS offers numerous ways to measure mesh quality. In this work, the fine or higher quality mesh is used for the analysis through the application of the Skewness approach [37]. Skewness is a measure of how far an element deviates from an equiangular form. It is an arbitrary number that depends on the angles inside the element. Superior mesh quality is indicated by lower levels of equiangular skewness. As depicted in Figure 5 almost all elements are close to 0 element metrics which implies that the applied mesh size for the current analysis is very strong and the result gives very approximate with the reality. Based on the Skewness value, 34362 nodes and 32491 elements are used in this analysis (Figure 6).

3.4 Composite modeling on ACP

The ACP model was done by considering the arrangement of the fiber is considered to be 0-90 degree woven fabric [38] for both Enset and existing glass fiber composite material (Figure 7).
After ACP model for the finite element analysis of the overall thickness of the car body to be considered as 8mm, and there was four layers with thickness of 2mm, that means 1 mm fiber ply and 1 mm thickness of epoxy risen ply was modeled (Figure 8). Procedures that are applied in ACP are: Creating fabrics for both the fiber and the epoxy, Creating Rosettes, Creating oriented selection sets, Creating ply layers in modelling groups finally Converting into solid model.

4. Result and discussion

For an objective of contrasting the two Enset and glass fiber reinforced composite materials that can be utilized for the construction of an automobile bodies and to validate the consequences of the automobile's starting velocity on the result, a crash analysis is conducted for two distinct initial car velocities: 120 m/s and 200 m/s. For the two materials, all loading and boundary conditions are the same during analysis. Plotting and discussion of the results are done in terms of the vehicle body's deformation, stress, and acceleration during the collision with the wall.

Figure 9 and Figure 10 (a) up to (c) are depicted that the total deformation and equivalent stress results of the two materials at v_0=120m/s. Total deformation and equivalent stress are critically important output results in vehicle crash analysis utilizing ANSYS that provide information on how a car body will respond in an impact or collision.

The total deformation of the Enset fiber reinforced composite and glass fiber reinforced composite material are almost the same except for the last few seconds. As depicted in Figure 9 (a), (b) and (c), the maximum deformation for Enset fiber reinforced composite at initial velocity (v_0) = 120m/s is 94.99 mm, somewhat greater than that of the glass fiber reinforced composite material, which is 83.73 mm. This maximum deformation value is due to the ductile nature of Enset fiber reinforced composite. Extreme structural distortion is indicated by high total deformation values, and examining these data enables engineers to determine how much the applied forces have altered or affected the structure.

As depicted in Figure 10 (a), (b) and (c), the equivalent stress for Enset fiber reinforced composite is 6.708GPa, which is much lower than that of the glass fiber reinforced composite material, which is 19.866GPa. Minimum values are usually of importance when discussing total deformation and equivalent stress since they can be used to determine which parts of the structure are least deformed or stressed. Low values may indicate parts of the structure that are less impacted by the loading circumstances, whilst high values indicate possible failure [39].

As shown in **Error! Reference source not found.**, comparing two materials for a car crash analysis based on how they respond to acceleration, the material that reduces the acceleration that the occupants experience during a collision is usually preferred. The vehicle's structural integrity is impacted by acceleration as well. Numerous sections of the vehicle may experience stress and deformation as a result of the forces produced during a collision. Understanding how the car's structure reacts to impact and using that knowledge to develop cars that can more effectively absorb and disperse collision energy can be achieved through the analysis of acceleration patterns. Understanding acceleration is crucial for assessing the effectiveness of the materials utilized in the vehicle's construction. The way that various materials behave during acceleration can have an impact on the vehicle's overall safety since they differ in their capacity to withstand and disperse forces. Therefore, Based on the simulation result shown in **Error! Reference source not found.**

and 14 Enset fiber composite material is the preferable material than the glass fiber composite material.

To control the analysis result, the simulation is repeated for the second input velocity of 200m/s and the results are displayed under Figure 12 and

Figure 13 below. Figure 12 and

Figure 13 (a) up to (c) shows the two materials' total deformation and equivalent stress values at v_0=200 m/s. The nature of the output is unaffected, with the exception of the output values increasing at the second input velocity (200 m/s). This suggests that the behavior of the two materials in a collision with a barrier with different velocity of the car will be the same regardless of the car's initial input velocity, which is 120 m/s.

As shown on Figure 14 the acceleration value during car crash for Enset fiber composite material is lower than that of the glass fiber composite material. This is due to the high energy absorption nature of the newly developed Enset fiber composite material. Understanding acceleration is necessary when evaluating the effectiveness of the materials applied in the vehicle's construction. The way that various materials behave during acceleration can have a direct effect on the vehicle's overall safety since they differ in their capacity to withstand and redistribute forces. Acceleration-related requirements are frequently included in vehicle safety regulations, particularly with regard to the amount of acceleration an occupant should feel in the event of a collision.

As given in Figure 15 the Enset fiber reinforced composite exhibited significantly higher internal energy absorption compared to the glass fiber composite. This superior energy absorption performance is attributed to the enhanced deformation and damage dissipation mechanisms inherent in the Enset fibers. Consequently, the Enset fiber composite demonstrates better crashworthiness and damage tolerance, highlighting its potential as a promising material for improving the impact resistance and safety of vehicle bodies. This enhanced energy absorption is likely due to the higher toughness and better damage dissipation mechanisms [40] of the Enset fibers. Consequently, the Enset fiber composite would provide better impact resistance and improved safety in vehicle body applications, making it a promising material for such uses.

5. Conclusion

This study presents a comparative analysis of crash performance between glass fiber reinforced composite material and the newly developed Enset fiber reinforced composite material. The results highlight the advantages of Enset fiber composites in terms of energy absorption, structural strength, and safety. Key findings include:

- The crash analysis results for both materials at two distinct vehicle speeds are presented.
- Glass fiber reinforced composite material exhibits the highest equivalent stress value, while the newly developed Enset fiber composite material has the lowest stress value for both input velocities.
- Both materials show nearly equal deformation, with the total acceleration value during impact also discussed.
- The lower acceleration value for Enset fiber composites indicates superior energy absorption compared to Glass fiber composites.
- Enset fiber composites offer greater safety compared to glass fiber composites.
- The findings highlight the potential of Enset fiber reinforced composites as a competitive or alternative material for low weight and high strength applications.
- Figures 9 through 15 illustrate that Enset fiber reinforced composites outperform glass fiber composites in structural strength and deformation resistance.
- Enset fiber reinforced composite material enhances vehicle safety in collisions, making it a promising choice for automobile body construction.

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Biographies

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Figures

a. b. c.

Figure 1 a). Enset plant b). Manual extraction method c). Extracted false banana fiber [21]

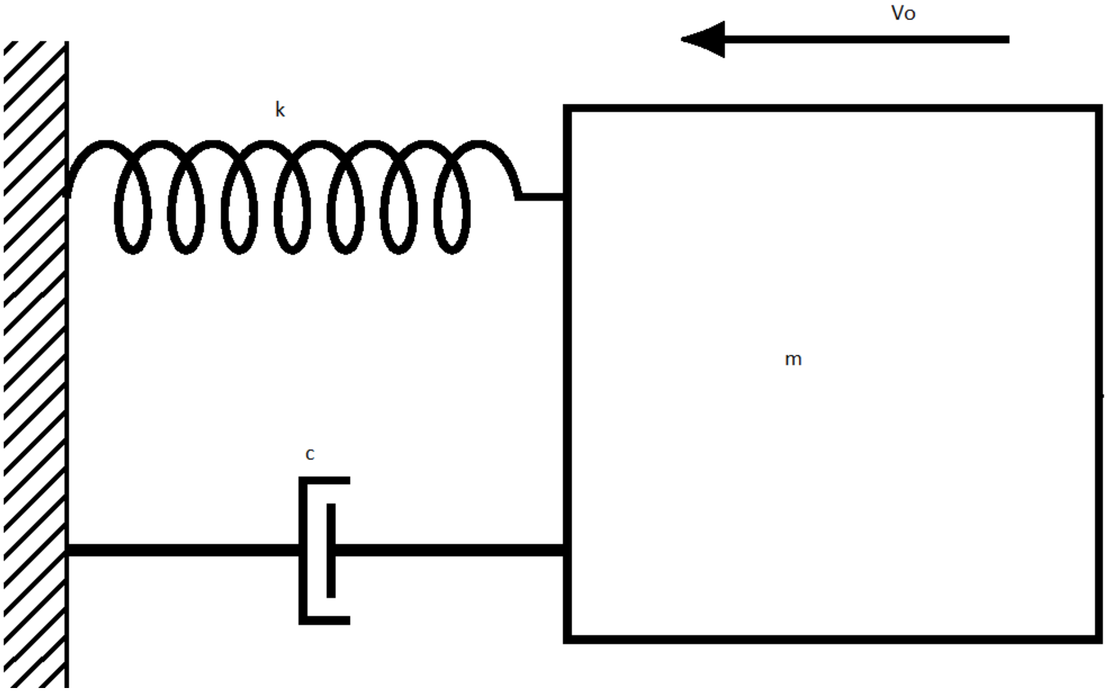

Figure 2 Kelvin model [36]

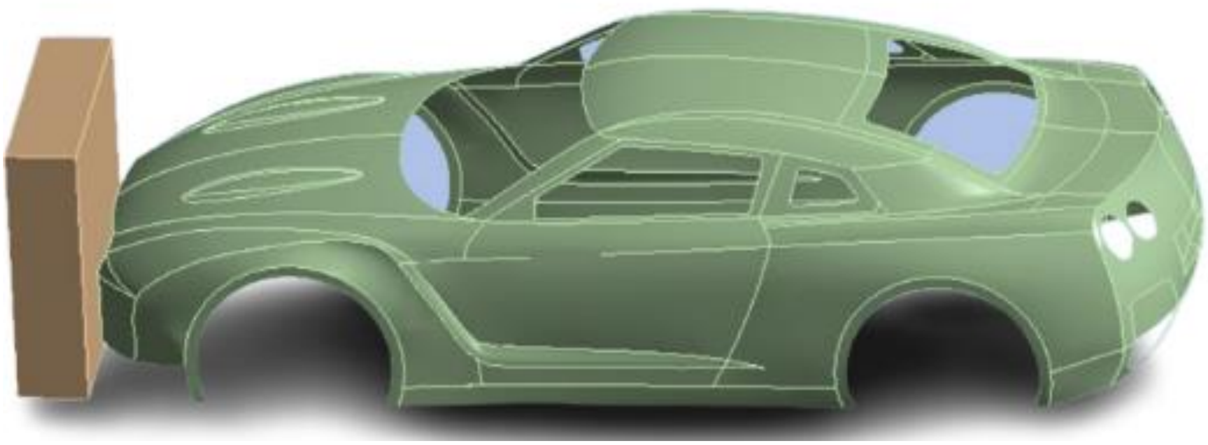

Figure 3 3D surface modeling of a car body

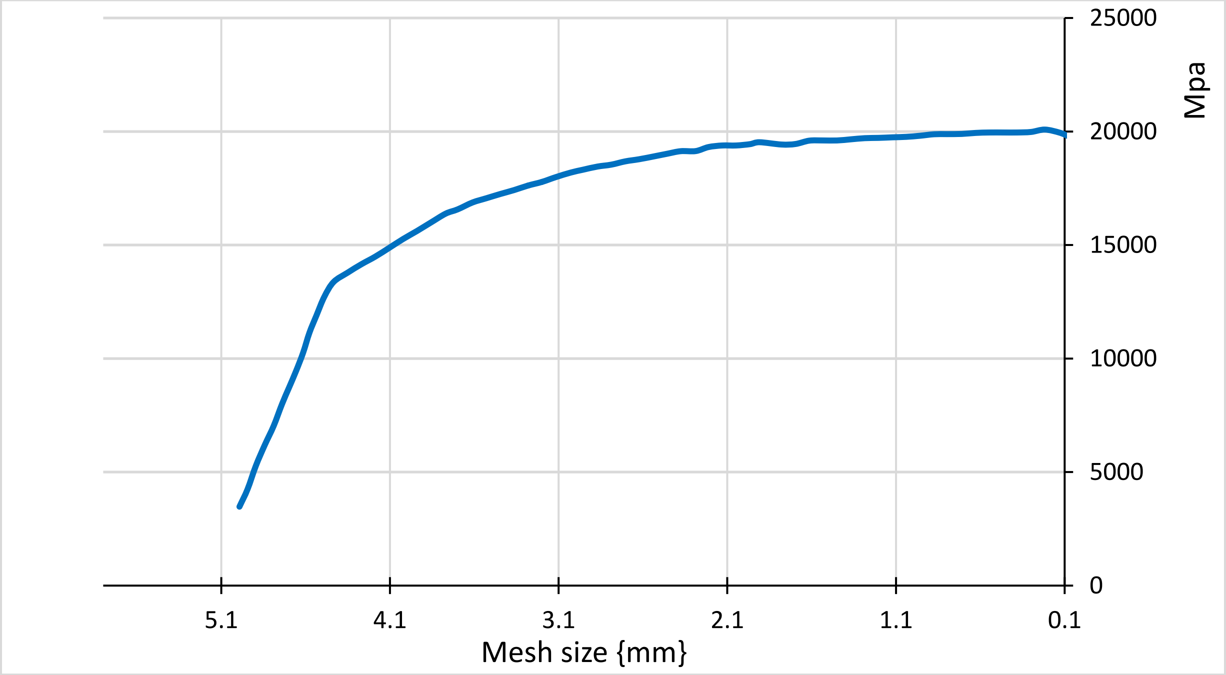

Figure 4 Mesh convergence

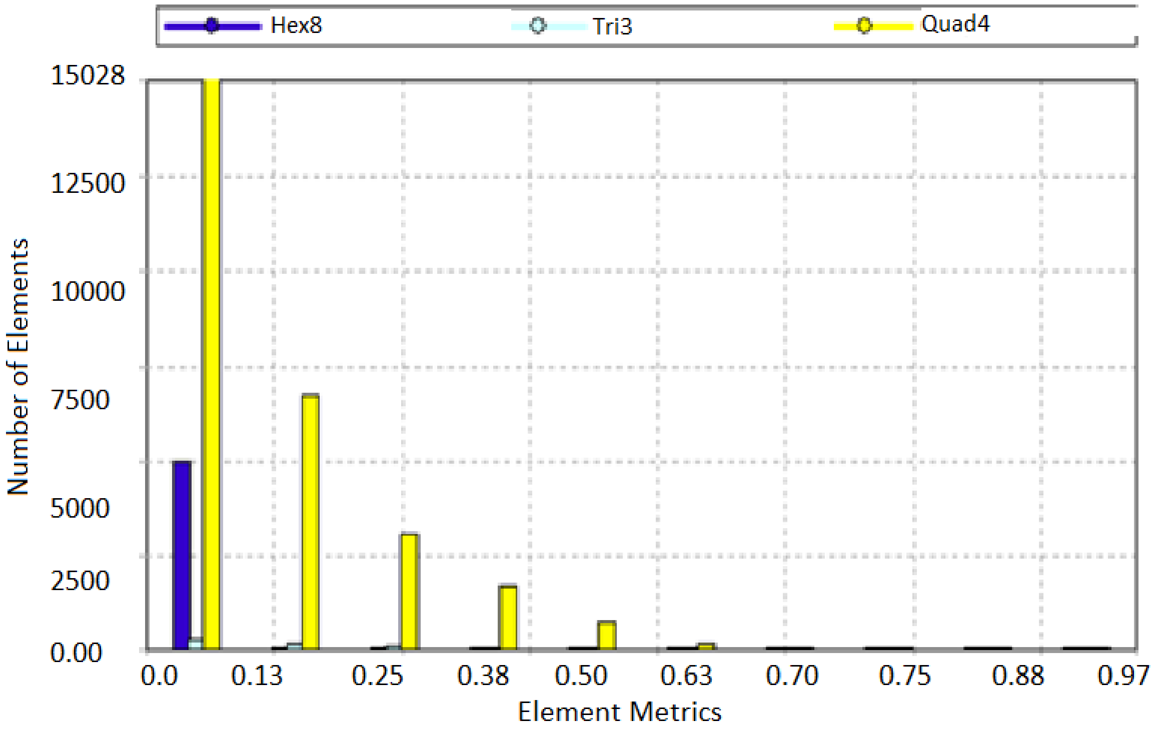

Figure 5 Skewness mesh metrics

Figure 6 Meshing

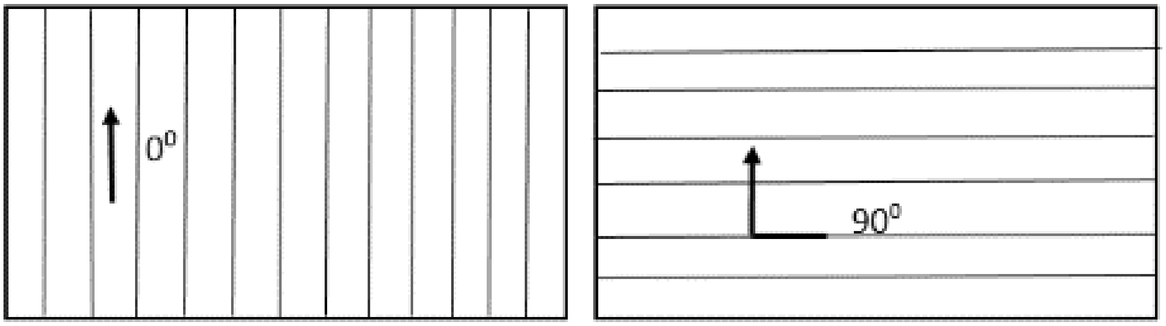

Figure 7 the orientation of the fiber

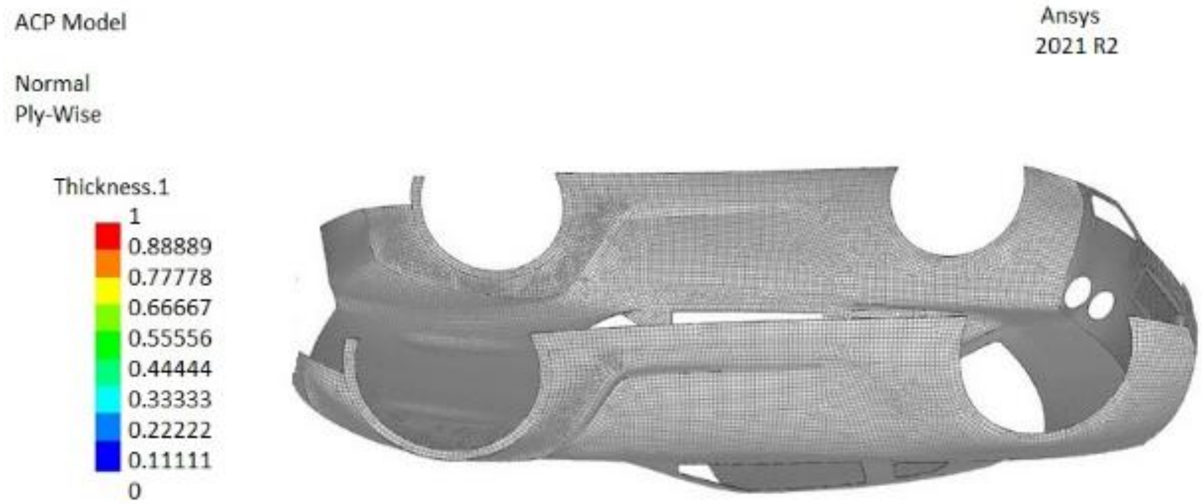

Figure 8 Composite layers orientation and stack up position

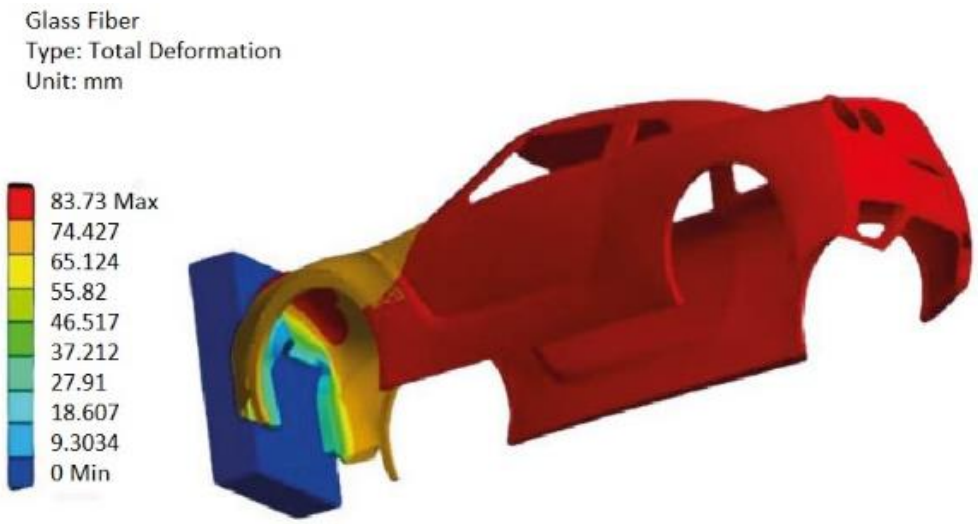

Figure 9a. Total deformation for glass fiber at V_0=120m/s

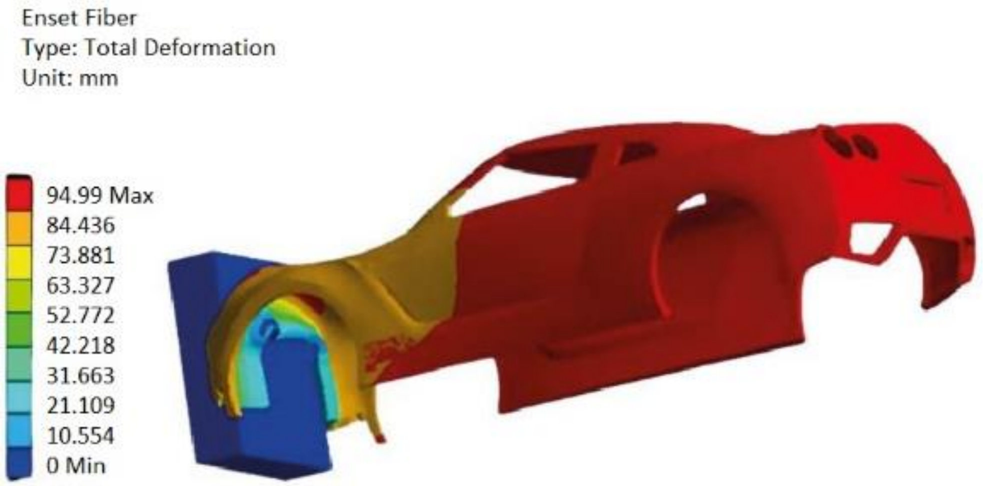

Figure 9b. Total deformation for Enset fiber at V_0=120m/s

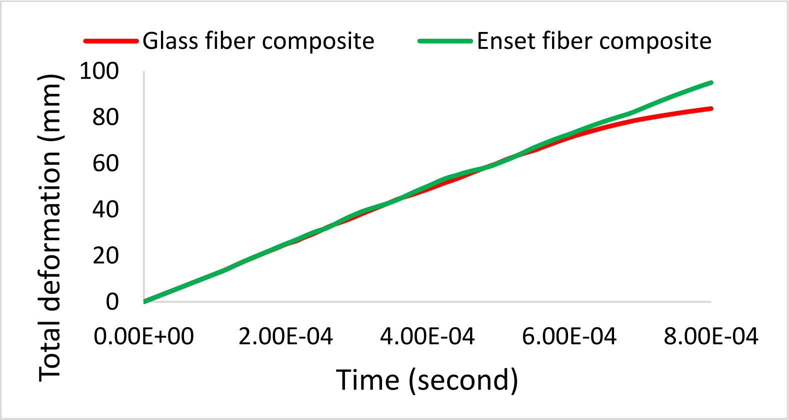

Figure 9c. Total deformation for glass and Enset fiber composite material at V_0=120m/s

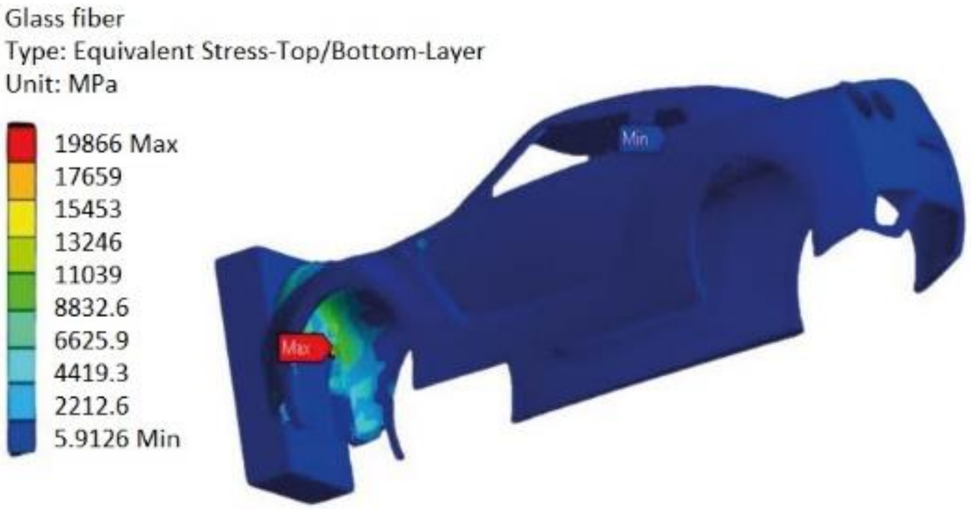

Figure 10a. Equivalent stress for glass fiber at V_0=120*m/s*

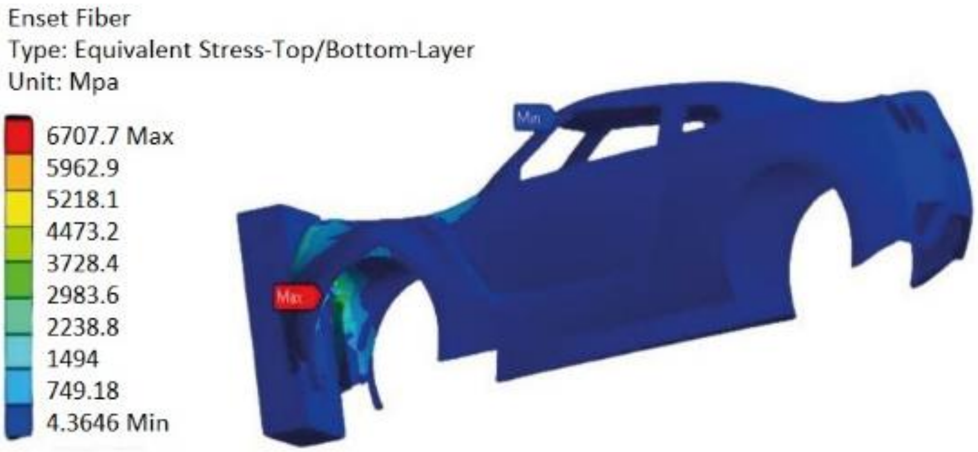

Figure 10a. Equivalent stress for Enset fiber at V_0=120m/s

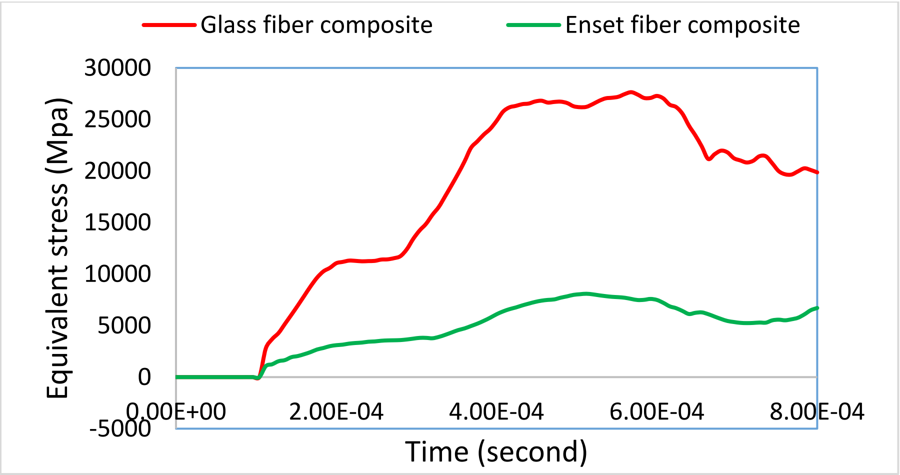

*Figure 10*c. *Equivalent stress for glass and Enset fiber composite material at* V_0=*120*

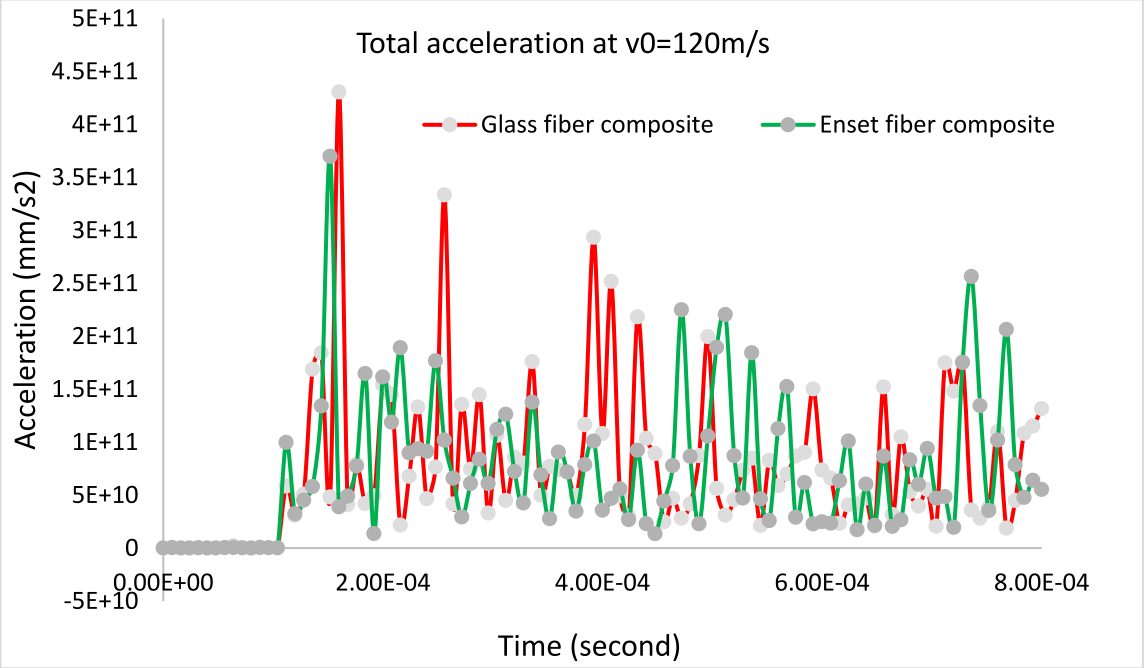

Figure 11. Total acceleration of the vehicle body during crash at v_0=120m/s

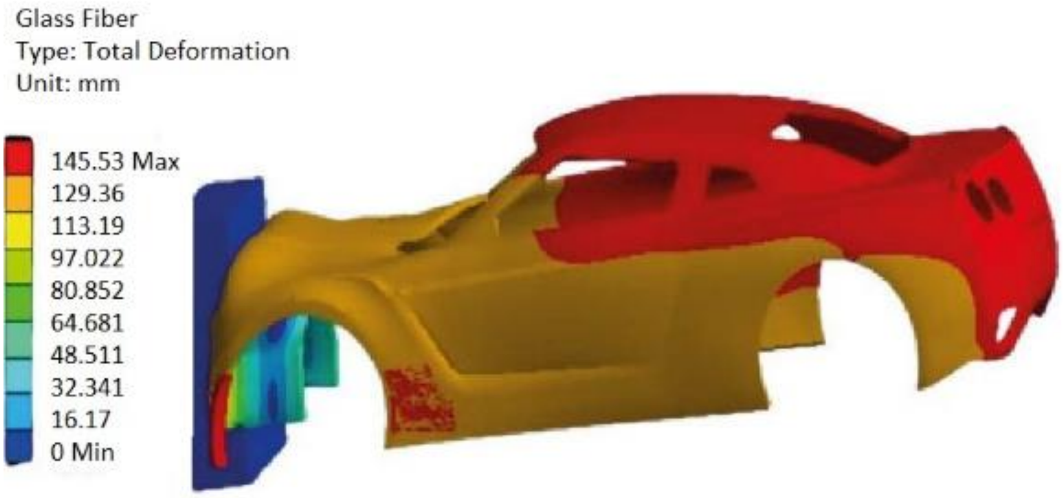

Figure 12a. Total deformation for glass fiber at V_0*=200m/s*

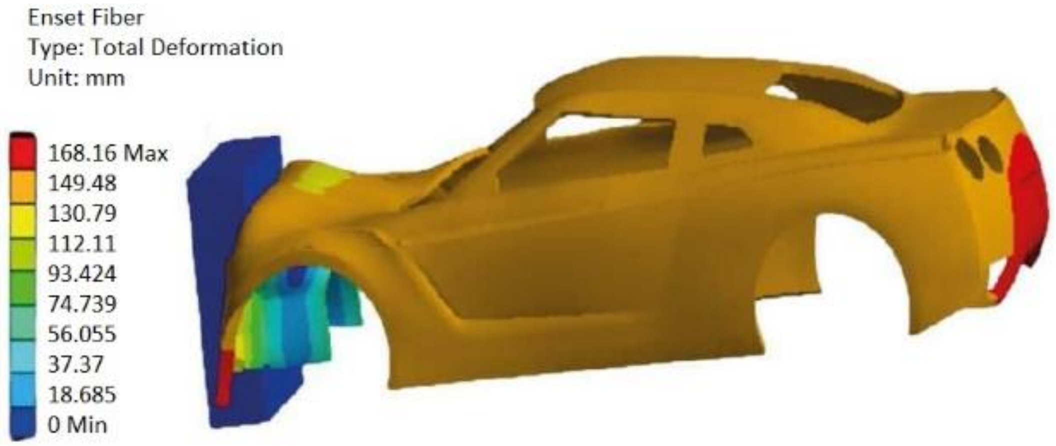

Figure 12b. Total deformation for Enset fiber at V_0=200m/s

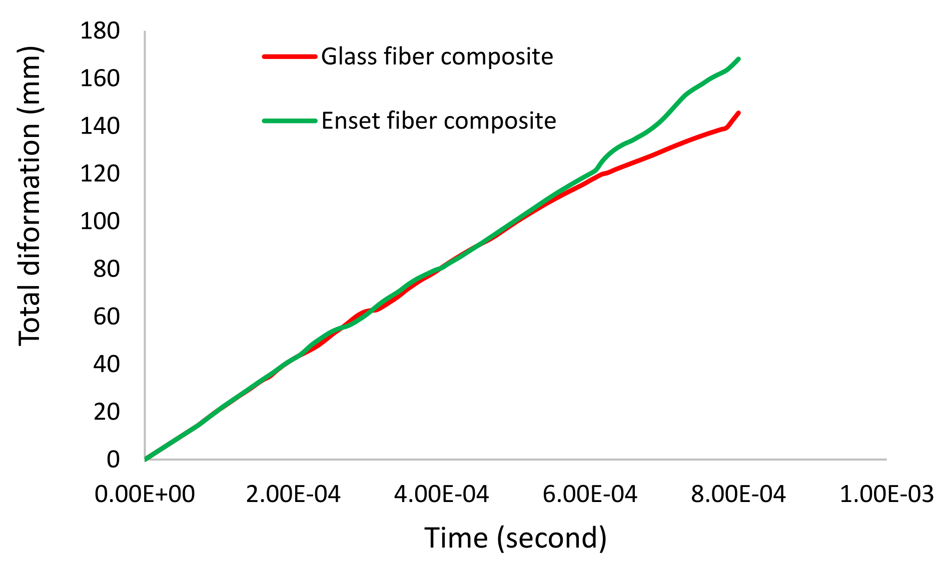

Figure 12c. Total deformation for glass and Enset fiber composite material at V_0=200m/s

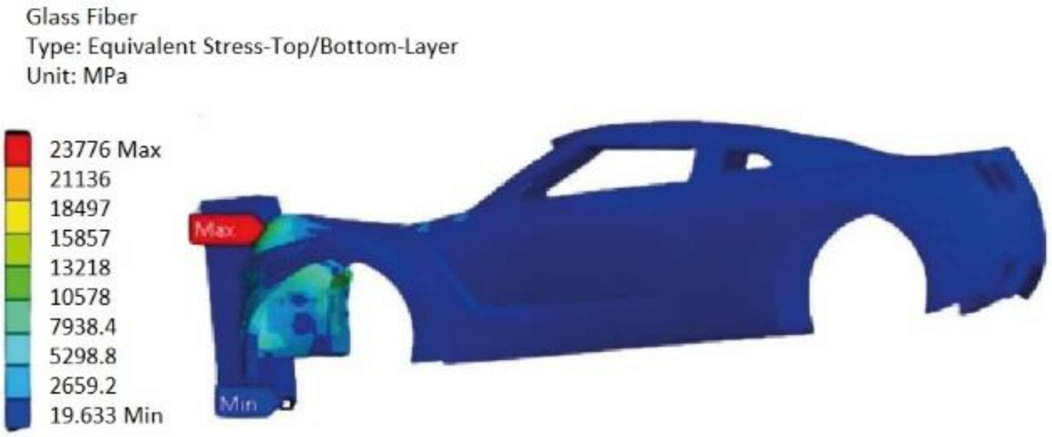

Figure 13a. Equivalent stress for glass fiber at V_0=200m/s

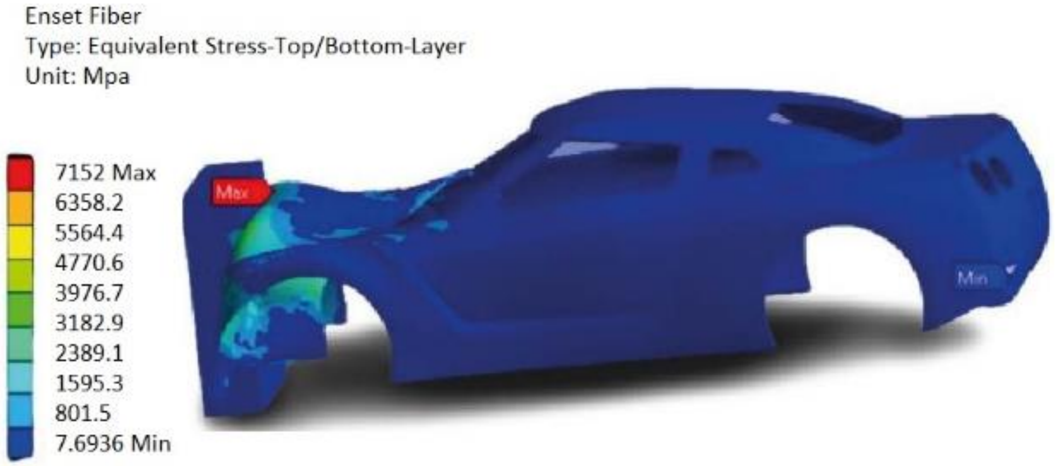

Figure 13b. Equivalent stress for Enset fiber at V_0=200m/s

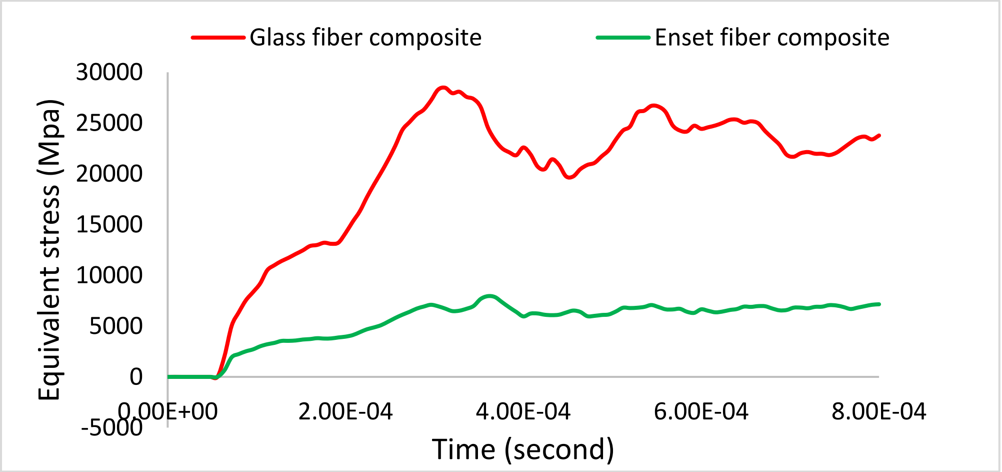

Figure 13c. Equivalent stress for glass and Enset fiber composite material at V_0=200m/s

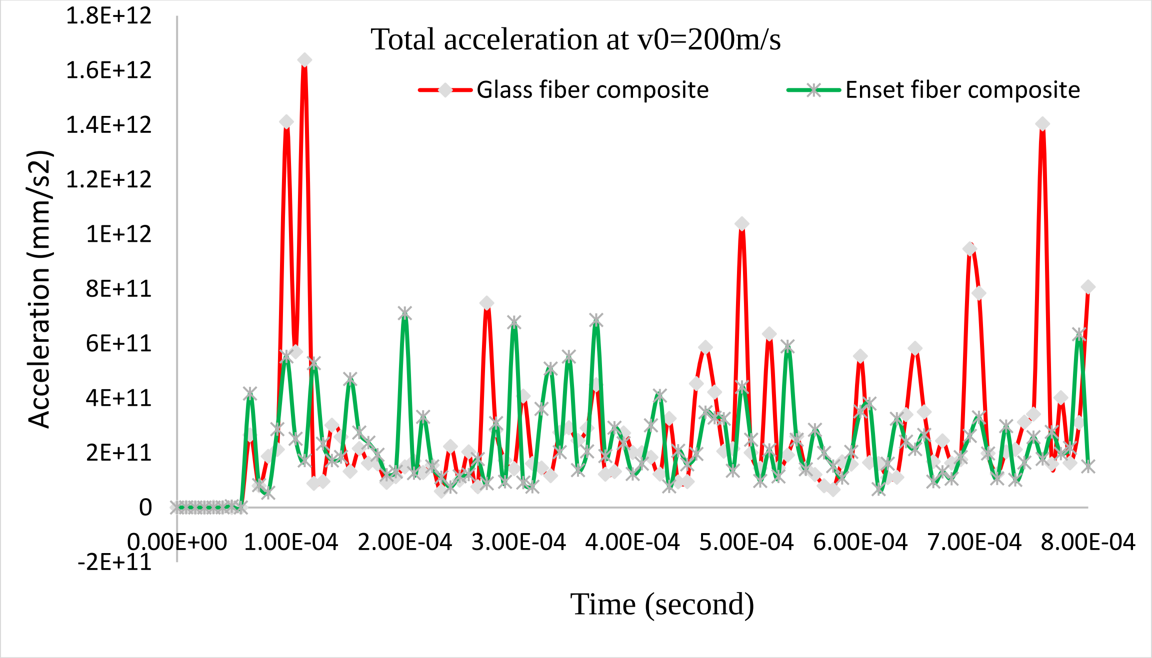

Figure 14 Total acceleration of the vehicle body during crash at v_0=200m/s

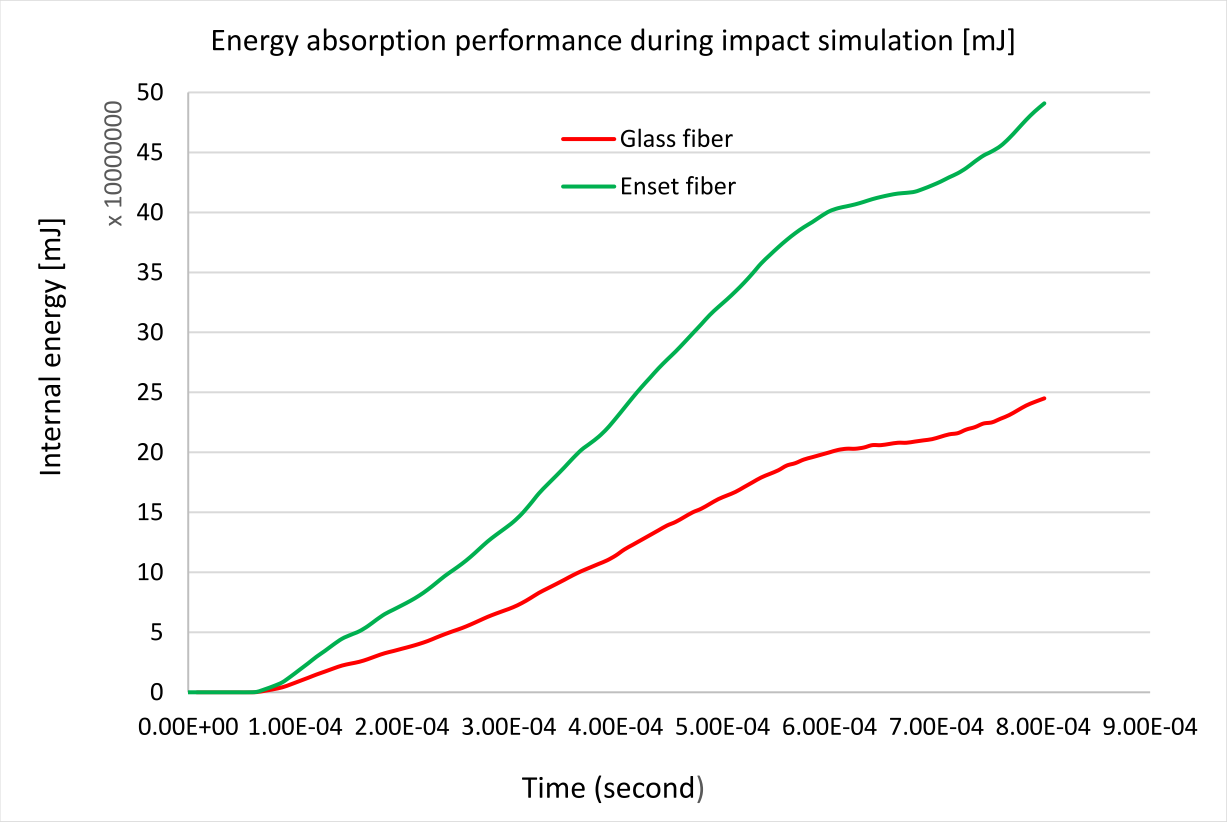

Figure 15 Energy absorption performance of Enset and Glass fiber composite materials

Table

Table 1 Enset fiber Material setup on ANSYS [14 ,22]

Property	Value	Unit
Density	1400	Kg/m^3
Modulus of Elasticity	19650	MPa
Poisson’s Ratio	0.175	
Bulk Modulus	10070	MPa
Shear Modulus	8381.7	MPa