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Design and fabrication of a helmet using sandwich of Areca nut husk fibre and Glass fibre of Bio-Composites with epoxy resin

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Abstract: A composite material consists of multiple chemically different materials joined together by an interface that differentiates them. It has been well known since ancient times that natural fibres are commonly used in components because of their inherent properties such as lignocelluloses, which is renewable, low cost, light weight and biodegradable. Present work is intended to design and fabricate of a helmet using sandwich of Areca nut husk /Glass fibre of Bio-Composites with epoxy resin**.** Experiments were conducted on sandwich of Areca nut husk fibre/Glass fibre of Bio-Composites to study their mechanical characterization. Finite Element analysis has been carried out to study the impact strength of helmet by dropping a weight of 3.5 kg from a height of 5 m, 20 m, 46 m and 80 m respectively.

***IndexTerms* – Composite material, Areca nut husk fibre, bio-composite, helmet, Finite Element Analysis.**

I. Introduction

A composite material consists of multiple chemically different materials joined together by an interface that differentiates them. It has been well known since ancient times that natural fibres are commonly used in components because of their inherent properties such as lignocelluloses, which is renewable, low cost, light weight and biodegradable. Many methods exist to extract natural fibres from animal, plant, and mineral sources.

Over the last thirty years' plastics and ceramics have been eminent emerging materials. Composites are penetrating and conquering new markets relentlessly, which is resulting in a rapidly increasing volume and number of applications. In terms of engineered materials, composite materials account for a significant portion of everyday products as well as sophisticated, specialized uses. The challenge now is to make composite materials cost-effective while still proving their worth as weight-saving material. A number of innovative manufacturing techniques are currently used in the composites industry in order to produce economically attractive composite components. Composites are clearly infeasible to overcome their cost hurdle solely by improving manufacturing technology. For composites to be competitive with metals, it is essential for the design, the material, the process, the tooling, the quality assurance, and the manufacturing to work together as one.

1.1 Natural Fibre

Natural fiber composites include Areca nut Husk, coir, jute, Sisal, flax, cotton, bamboo, hemp and banana etc (Figure 1.1). Natural fibers come from plants and natural fibers are environment friendly, lightweight, strong, renewable, low cost and biodegradable. The natural fibers can be used to reinforce each thermosetting and thermoplastic matrix. Thermosetting resins such as epoxy, polyester, polyurethane, phenolic are commonly used composites requiring higher performance applications and they provide good mechanical properties specifically in stiffness and strength at acceptably low-price levels. These composites are gaining importance because of their non-carcinogenic and bio-degradable. Natural fiber composites are cost-effective material.

1.1.1 **Animal fibre**: A spider's silk, wool, or hair is an example of an animal fibre that consists of extreme proteins. The fibres of silk are collected from dried saliva of insects during the preparation of cocoons. They are derived from hairy mammals such as sheep's wool, goat's hair, and horse's hair. Bird feather fiber and silk worm silk fiber are called Avian fibres.

1.1.2 **Mineral fibre:** There are only natural long fibres in mineral fibres. These mineral fibers are one of the categorized of mineral fiber. In ceramics, glass fibres can comprise glass wood or quartz, aluminum oxide, silicon carbides, and monocarbide are some of the other materials. Among metal fibres, aluminium fibres are the most common.

1.1.3 **Plant fiber:** Plant fibres are consisting generally cellulose and hemicellulose. Areca nut, jute, flax, ramie, sisal and hemp are the examples of plant fiber. The tensile strength of plant fiber is higher than that of other fibers, making cellulose fibres essential for paper and cloth manufacture. We can use the natural fibers to reinforce each with thermosetting and thermoplastic matrices. These composites require high performance applications in various fields. They provide good mechanical properties, with fix stiffness and strength, at acceptably low-cost levels. Considering the ecological aspects of material selection, we can replace synthetic fibers by natural ones is only a first step. CO2 gas which causes the emission of greenhouse effect into the atmosphere can be restricted and an increasing awareness of the completeness of fossil energy resources are leading to developing new materials that is completely based on renewable resources.

1.2 NATURAL ARECA SHELL NUT

Among all the natural fiber-reinforcing materials areca nut appears to be a promising material because it is less cost, availability is abundant and a very high potential perennial crop in India. It belongs to the species Areca catechu under the family palmecea and availability in East India. In India, areca nut cultivation is coming up on a large-scale nowadays. Areca is a flinty fibrous portion covering the endosperm. It constitutes 35-45% of the total volume of the fruit. Areca husk fibres are mainly composed of hemicelluloses and not of cellulose. Areca fibers contain 12 to 24 % of lignin, 40 to 64.8% of hemicelluloses, 4 % of ash content and remaining 7 to 25% of water content. The fibers adjoining the inside layer are irregularly lignified group of cells called hard fibers and the portions of the middle layer contain soft fibers. Areca fiber is extremely hemicellulose and is much higher than that of any other fibers. Coir has greater lignin content than fibers. Therefore, extensive planning for the disposal of this material is required. Areca Shell Nut is as shown in Figure 1.

Figure 1: Areca shell nut

1.3 HELMET

A helmet is a type of safe guarding gear worn on the head to guard against injury. Most of the helmets are made up of plastics. Recently, the vital environmental problem faced today is the non-degradable plastic waste. The enormous production and use of plastics in every part of our life has increased the plastic waste in massive scales. The waste disposal problems and to avoid the use of plastics have directed significant of the scientific research to bio-composite materials that can be easily bio assimilated.

All helmets aim to protect the user’s head by compelling mechanical energy and protecting against penetration. Their structure and protecting capability are altered in high-energy impacts. Beside their energy absorption capability, their volume and weight are also major issues, since higher volume and weight become greater the injury risk for the user’s head and neck. Every year many workers are killed or seriously injured in the fields of construction works and in industries, as a result of head injuries wearing an appropriate safety helmet significantly decreases the risk of injury or even death. Protective helmet could save your life. The effort of the project is to increase the strength of industrial helmet by making the modify material in existing one using natural fibres.

II. LITERATURE REVIEW

N. Muralidhar et al. (2019) studied areca nut ask fibre extraction, composite panel casting, and composite material mechanical characteristics. Because of their low cost and lightweight, composite materials are widely used in the marine, construction, and aerospace sectors, according to the authors. They searched for mechanical qualities including tensile strength, flexural strength, and impact strength in areca nut husk fibres in their study. The authors discover that a composite sandwich including glass fibre has a greater elastic modulus than a pure areca nut husk fibre composite and that an epoxy composite with fine fibres has a better tensile strength than an epoxy composite with coarse fibres.

Raghuveer H Desai et al. (2016) Cover all aspects of characteristics such as peanut fiber, chemical composition, and mechanical properties in their studies, which too Including the latest developments in Areca Nut Fiber Biological, Physical, and Chemical pre-maintenance to increase the strength of fiber, adhesion of fiber matrix, morphology, and nature. The author claims it is because of Areca's fiber So short, they can be used as short fiber or powder in a combination ingredient. They also found that extending the duration of the immersion of fiber. Surface maintenance will result in a decrease in fiber strength, with fiber losing 8% to 13% of their body weight because it soaks excessively, and it will be more flexible.

Vishal Jagota et al. (2013) studied how the FEM works, discretization of the Range, finding the element property assembling them imposed the boundary conditions of a simulation, and range of applications in their research work. The authors concluded that before 1960, the FEM was very difficult due to a lack of researchers, but after 1960, this situation changed dramatically. By the end of 1972, the FEM had become the most widely used method in engineering. It is still the dominant method today, and the machine formations error indicators elements are mentioned in their research study.

III. MATERIALS AND METHODLOGY

The raw materials used in our work and the details of processing of the composites and the experimental procedures followed for their mechanical characterization.

3.1 Areca nut Husk:

Areca nut husk fibre is a greater perennial crop that is plentiful and affordable when compared to other natural fibre reinforcing materials. Areca nut skin fibres are preferred since they are reusable, lightweight, thermally insulating, and stronger than glass (Figure 2). Composite properties are determined not only by the materials used, but also by the bonding between the fibre and the matrix. Because areca nut includes lignin with a slippery surface, admirable binding with the matrix can only be attained when the lignin layer is removed.

The areca husk nut fibre reinforced composites benefit greatly from recent composite material research. The tensile strength is more sensitive to matrix parameters, whereas the modulus is dependent on fibre qualities. Low anxiety fixation and fibre introduction are necessary to improve the toughness of a solid interface, whereas fibre concentration, fibre wetting in the matrix stage, and high fibre percentage determine elastic modulus. The finite element method is a computational methodology used to solve complicated engineering issues. It is mostly used in designing and developing a product when there are intricate geometries, complex dynamic loadings, and material property changes that cannot be achieved analytically. Mathematical equations are often analysed through significant idealisation and simplification.

Figure 2: Areca Nut Husk

3.2 Epoxy Resin:

Epoxy resins are classified as thermoset materials. These material is widely employed in structural and speciality composite purposes because it offers a great mix of qualities not seen in other thermoset resins. These are available in a broad variety of diverse forms, from low-viscosity liquids to high-melting solids, and may be used in a number of processes and applications. Epoxies have great strength, low shrinkage, good adhesion to diverse substrates, good electrical insulation, chemical and solvent resistance, cheap cost, and low toxicity. These are rapidly healed by a wide range of chemical species without the development of volatiles or by-products. Epoxy resins are also chemically compatible with harsh substrates and have a tendency to wet surfaces readily, making them ideal for composites purposes. Epoxy resins are one of the most common types of thermosetting polymers used as matrices for fiber-reinforced composite materials and structural adhesives (Figure 3). When creating an epoxy resin for a specific application, it is critical to understand how each of these components affects the physical and mechanical performance of the part during and after production. Epoxy resin is a popular polymer matrix for advanced composites that need stiffness, dimensional stability, and chemical resistance.

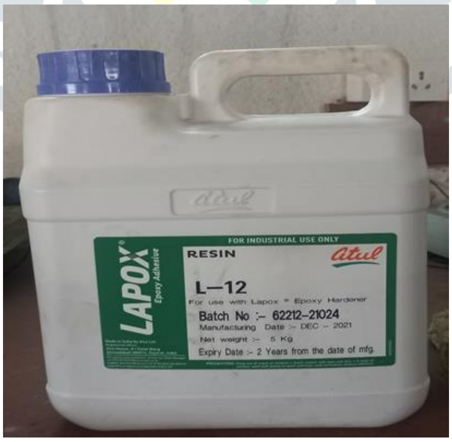

Figure 3: Areca Nut Husk

3.3 Hardener:

Hardener is an epoxy curing reagent. Hardener requires epoxy resin to commence normal curing. It is also known as a catalyst, as it is the ingredient that hardens the adhesive when combined with resin. The end qualities and compatibility of the epoxy coating for a particular environment are determined by the exact combination of epoxy and hardener components (Figure 4).

Figure 4: Hardener

3.4 Glass fiber:

Glass fibre is a low-cost material that's been on the market for years. The most common fibre reinforced composite is glass fibre. It can take the form of a roving, a sheet, or a three-dimensional object. The glass fibre material is highly rigid, stiff, transparent, and chemically resistant (Figure 5). Furthermore, the glass in fibre form has very high strength and exceptional flexibility. Glass fibres are employed in polymer matrix composites because of their great strength and flexibility. Glass fibre has a strong adherence. As a result, we always apply a quiet coating on top of the glass fibre to ensure that they are linked to the cross-linking and have flawless adherence. Many structural components, such as PCBs and other board items, are made from glass fibre reinforced composites.

Figure 5: Glass fibre Sheet

3.5 Sodium Hydroxide (NaOH):

The alkaline solution sodium hydroxide (NaOH) is used to amplify the surface morphology of natural fibres. Sodium Hydroxide is a transparent solid substance that is white in colour. Because of its corrosive impact on various things, it is commonly referred to as caustic soda. It decomposes proteins at room temperature and may cause chemical burns to human bodies. Where it wouldn't exist naturally, sodium hydroxide has been mass-produced for several decades from easily available basic materials and is utilised in a variety of manufacturing applications.

3.6 Fabrication of Bio-composite helmet

Hand layup of pre-impregnated woven fabrics is a significant component of the composite manufacturing sector, requiring the skills and knowledge of a human labour to mould flat forms into complicated shapes. It is effective for making high-performance, complicated components, but it is a costly and unreliable technique.

The helmet was created using the hand lay-up approach described below. Initially, an epoxy and hardener K6 combination is put on top of the outer mould helmet, followed by the glass fibre mould, which will serve as an adhesive for a bottom layer of areca nut husk fibre. These fibres are now crushed using the inside mould of the helmet to guarantee proper adhesion between reinforcement and fibres. After allowing for a settling time of approximately 9 hours, the mould was removed. After removing the very well and dried helmet from the mould, the additional materials were trimmed, flattened, and buffed by a woodcutter to create the required form and manufactured helmet shell depicted in figure 6.

Figure 6: Fabricated Bio Composite Helmet.

IV. DETAILS OF EXPERIMENTS:

4.1 Tensile Strength Test

A material's tensile strength is the highest amount of tensile stress that it can withstand before failing. The flat Areca fibre and Glass fibre reinforced composite specimen used for testing shown in figure 7. Dimensions of Areca fibre and Glass fibre reinforced composite is 250 mm × 25 mm × 5 mm. While conducting test a uniaxial load is applied to end of the specimen and the other end of the specimen is fixed. During examining a specimen, the ultimate tensile strength (UTS) or peak stress are common considerations. The tensile test is performed in the universal testing machine (UTM) as per ASTM-3039 standards.

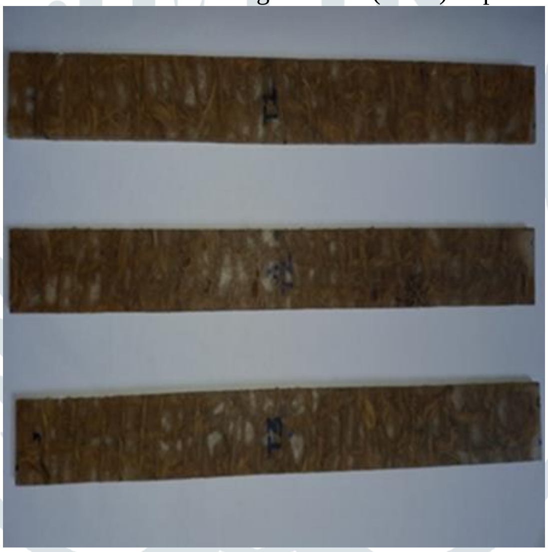

Figure 7: Flat Areca fibre and Glass fibre reinforced composite specimen used for tensile testing.

4.2 Flexural Test

In a flexure test, the stress is absorbed by a material immediately before its yield. A material with either a circular or rectangular cross-section is bent till fracture utilising a 3-point flexural testing method. The flexural strength of a material indicates the maximum stress sustained inside it at the time of fracture. Specimens for flexural strength were prepared according to ASTM D790 standard. Dimensions of Areca fibre and Glass fibre reinforced composite used for flexural strength test is 120 mm × 25 mm × 5 mm as shown in figure 8.

Figure 8: Flat Areca fibre and Glass fibre reinforced composite specimen used for Flexure testing.

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V. FINITE ELEMENT MODELLING:

The finite element approach is a statistical methodology used to solve complicated engineering challenges. It is usually used in design and product development when there are difficult geometries, complicated dynamic loadings, and material property changes that cannot be achieved numerically. Analytical solutions analysis is often carried out by significant idealisation and simplification. Design is based on experimental results from idealised structures and safety criteria derived from experience. Because design geometry is complicated and requires precise correctness, finite element analysis of geometrical figures is required. This necessitates a thorough understanding of the intricate objects' physical behaviours, which account for heat transmission capabilities, strength, and fluid movement, among other things. It's indeed essential to employ finite element analysis to anticipate achievement and design behaviour, determine the safety cushion, fix design flaws, and optimise the design.

The material considered for finite element analysis is Areca fibre and glass fibre reinforced composite. Table 1 gives the geometric parameters and material properties. The material properties shown below were obtained by conducting experiments. The commercial package AutoCAD is used to model the geometries of helmet is illustrated in figure 9.

Figure 9: Geometry model of helmet.

Table 1: Geometric parameters and engineering properties of helmet.

Description	Value
Length	210 mm
Width	45 mm
Depth	10 mm
Thickness	6 mm
Density	2100 kg/m^3
Modulus of Elasticity	10 GPa
Poisson ratio	0.28

Mesh Details of helmet finite element model has been given in Table 2. Helmets were tested by dropping 3.5 kg weight from a height of 5 m, 20 m, 46 m and 80 m. Figure 10 shows the helmet model meshing in ANSYS 2020 R2.

Table 2: Element and nodes details of helmet model.

Description	Elements	Nodes
Areca and Glass Reinforced Helmet	21170	21680

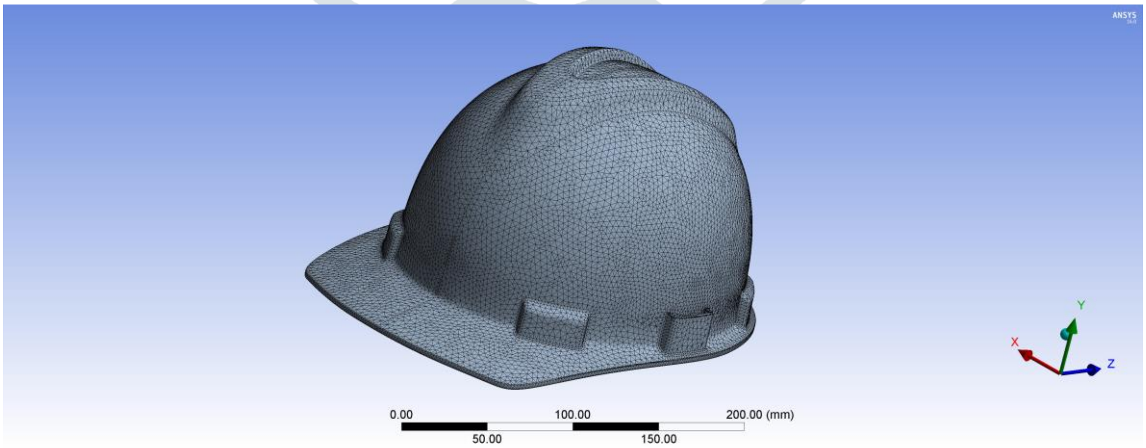

Figure 10: Helmet model meshing in ANSYS 2020 R2.

VI. RESULTS AND DISCUSSION

6.1 Experiment Results

Experiments were conducted on areca fibre/glass fibre reinforced bio composite helmet to study the mechanical properties like tensile strength, bending strength. The use of areca and glass fibre composite in industrial helmets can reduce the chances of serious damage to human skull and protect the workers from hazard. The results of the experiments are discussed below in Table 3, 4.

6.1.1 Tensile test

The average tensile strength and tensile load of the composite panel was 10.81 MPa and 1717 kg. The mechanical properties of the composite specimens are shown in Table 3. The stress verses strain plot of areca and glass reinforced composites is as shown in figure 11.

Table 3: Tensile test results.

Specimens	Tensile load(kg)	Tensile strength (MPa)
Sample 1	1800	9.82
Sample 2	1700	11.10
Sample 3	1650	11.50

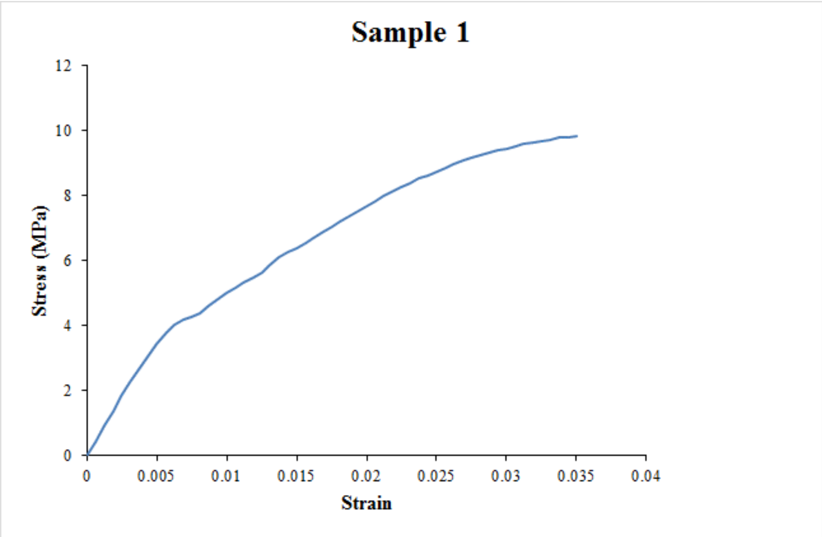

Figure 11: Typical Stress verses strain plot for areca and glass reinforced composite panel

6.1.2 Flexure test

The average tensile strength and tensile load of the composite panel was 10.81 MPa and 1050 kg. The mechanical properties of the composite specimens are shown in Table 4. The stress verses strain plot of areca and glass reinforced composites is as shown in figure 12.

Table 4: Bending test results.

Specimens	Flexure load (kg)	Flexure strength (MPa)
Sample 1	1000	55.25
Sample 2	1100	55.78
Sample 3	1050	55.81

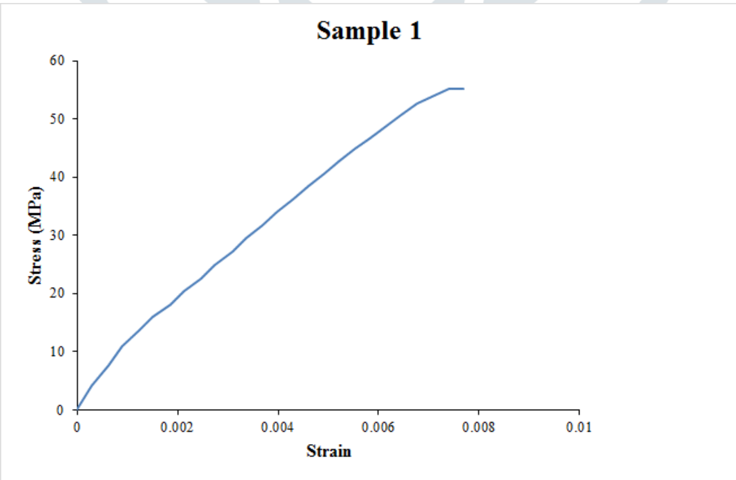

Figure 12: Typical Flexural test stress verses strain plot for areca and glass reinforced composite panel (sample 1)

The Stress versus strain plots for the flexural test specimens. Table 4 shows minor variations in the strength of flexural specimens and this is caused by fibre compatibility and epoxy mixture and also the presence of air voids was quite low in the compression specimen. However, fibre is good at taking compression loads, and this research shows that AFFF performs better for compressive load than tensile loads.

5.2 Finite Element Analysis Results

Finite Element Analysis was performed to observe the stress variation at top, front, back side of the areca and glass fibre reinforced bio composite helmet. This analysis considers four such heights 5 m, 20 m, 46 m and 80 m by using formula $V^2=2gH$ (where g - gravitational acceleration 9.81 m/s) the corresponding speeds are calculated as 10 m/s, 20 m/s, 30 m/s and 40 m/s respectively. The three-dimensional finite element analysis was performed using ANSYS software. ANSYS 2020 R2 Workbench was used for numerically simulating the impact test. A finite element model was created and then simulated under conditions that were comparable to those found in the experiments. An explicit dynamics model was developed. Figures 13-16 show the contour plot of von Mises stress for the applied velocity of 10 m/s, 20 m/s, 30 m/s and 40 m/s respectively.

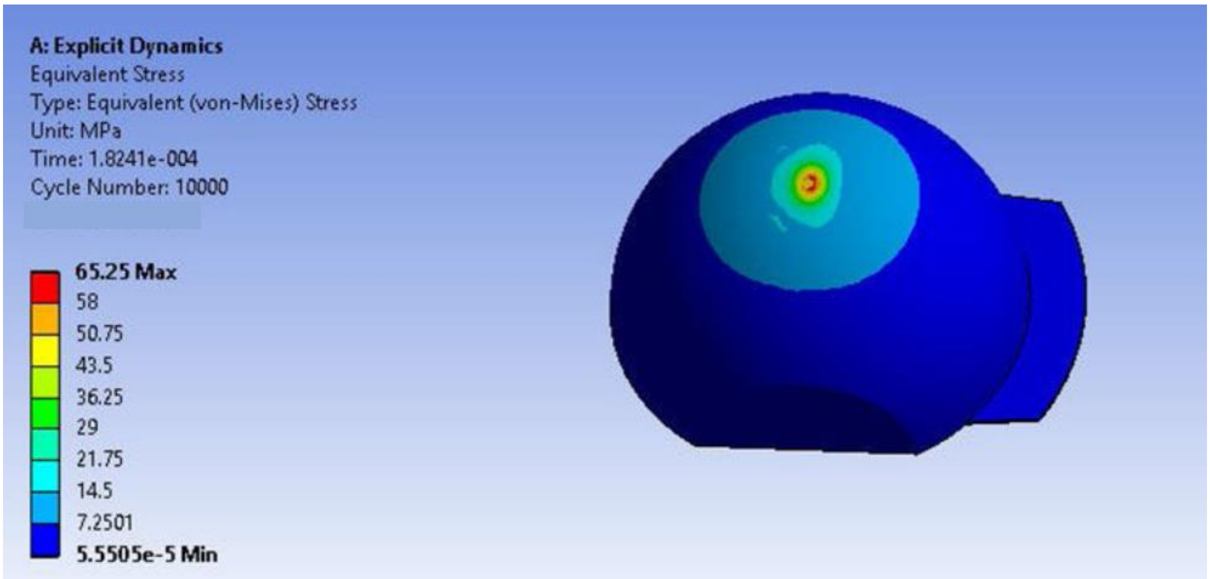

Figure 13: Stress distribution over the surface of helmet at speed of 10 m/s.

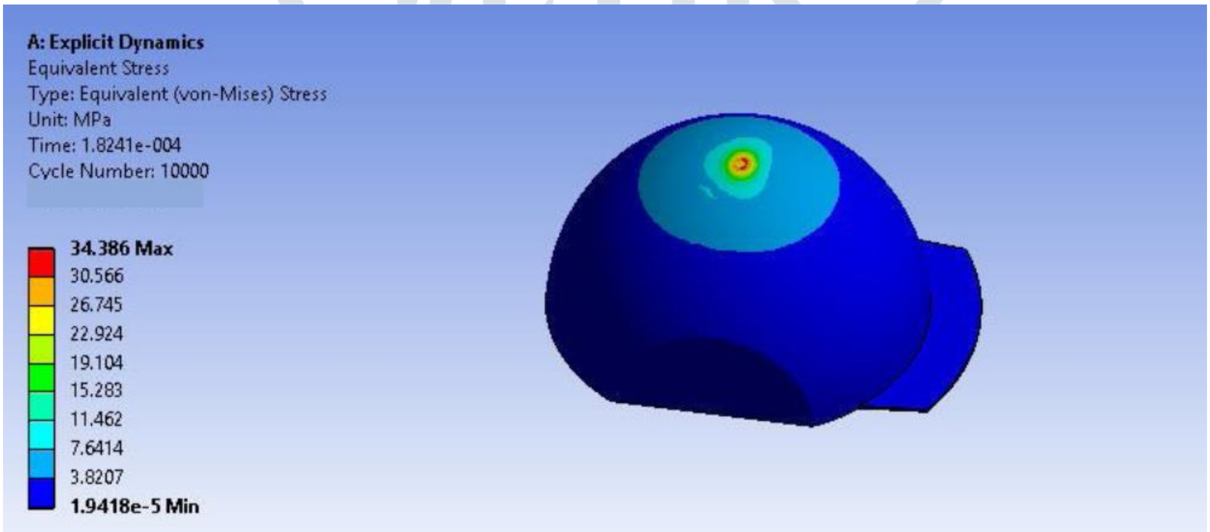

Figure 14: Stress distribution over the surface of helmet at speed of 20 m/s.

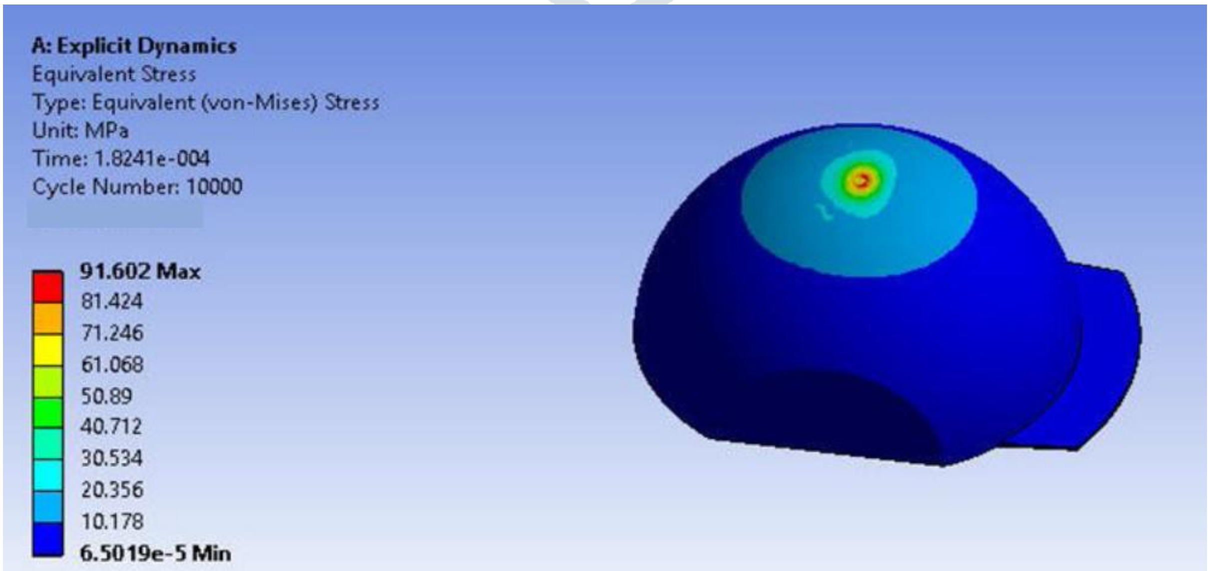

Figure 15: Stress distribution over the surface of helmet at speed of 30 m/s.

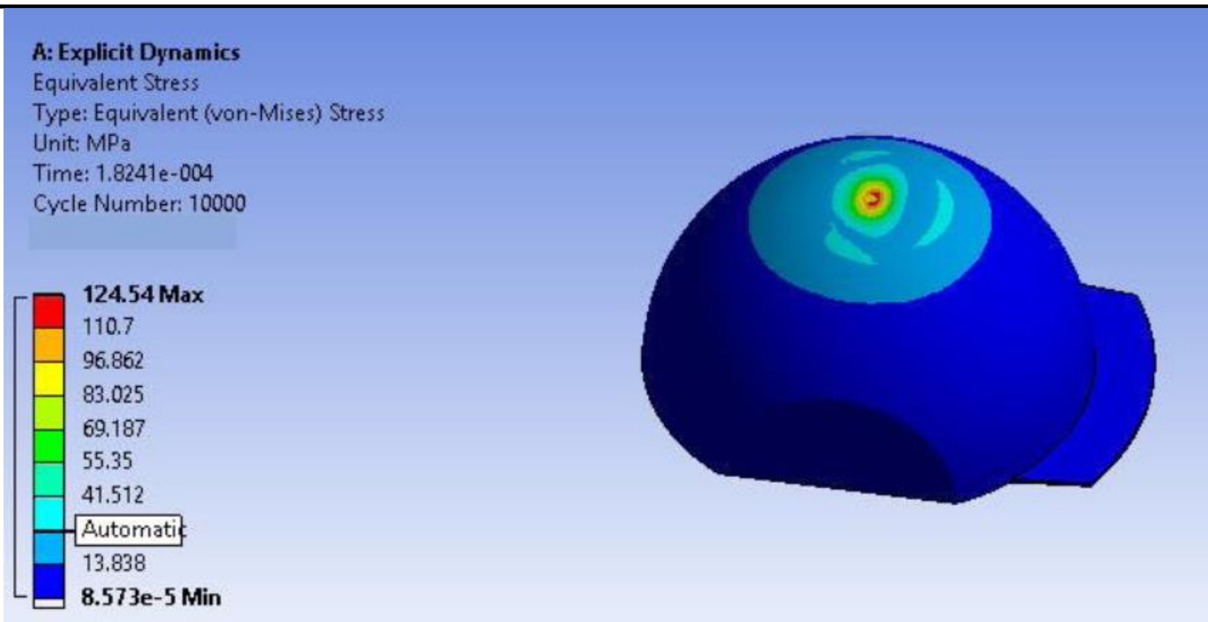

Figure 16: Stress distribution over the surface of helmet at speed of 40 m/s.

Table 5: Finite analysis result of Areca and Glass Fibre reinforced composite helmet

Parameters	**Velocity (m/s)**	**Areca and Glass Fiber Reinforced Helmet**			
		Top	**Front**	**Back**	**Side**
Max stress (MPa)	10	35	8	10	27
	20	65	37	40	60
	30	92	62	64	93
	40	125	94	97	146
Deformation (mm)	10	2	2	2	2
	20	4	4	4	4
	30	5	5	5	5
	40	8	8	8	8

Under the circumstances considered, the Areca and Glass fiber composite helmet showed efficiency when velocity of falling object is up-to 30 m/s since the maximum yield stress of human skull is about 125 MPa at top surface of helmet, 94 MPa at front surface of helmet, 97 MPa and 146 MPa on sides of helmet at 40 m/s. So, it summarized that areca and glass fiber composite material gives more rigidity to the human skull from impact load.

CONCLUSIONS

1. A simple hand lay-up technique has been successfully used to reinforce areca nut husk with epoxy resin and glass fiber. Our research aims to investigate the strength of natural fiber reinforced bio-composites based on tensile, impact, flexural and flexural tests.
2. The new composite produced with natural fibers of Areca nut husks as reinforcements provides good mechanical properties when compared to other composite matrix materials. Industrial and construction fields can use these bio-composite helmets.
3. The results of mechanical testing from the bio fabrication composite helmet show that the concept of using natural bean husk fibers cannot be used for helmet applications. However, there is a scope to optimize the fraction of the Volume of Natural Fiber Volume of cheap husks as reinforcements to achieve an increase in the mechanical properties of the helmet.
4. It is observed that the strengthening of the natural fiber of the bean husk and glass fiber has good mechanical properties and is comparable as conventional composite material.
5. Finite element analysis can be used as a reliable tool to analyse the stress and deformation of a areca and glass fibre reinforced helmets by carrying out a drop test.

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