International Journal of Advanced Technology and Engineering Exploration, Vol 9(95)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2021.875131

Research Article

Experimental study of the effect of impact energy on open face helmet fabricated using woven bamboo and jute fiber reinforced with epoxy composites

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Received: 31-October-2021; Revised: 15-October-2022; Accepted: 18-October-2022

Abstract
Helmets provide safety and protection to human beings and prevent head injuries during accidents. Helmets fabricated by metals/ polymers or ceramic composites are used as shields or guards for a wide variety of applications like motor racing, construction work, manufacturing industries, mining, refinery, public strikes, defense, bike riding, etc. The road transport department has made it mandatory to wear a helmet for all bike riders. Natural fibers like bamboo, sisal, coir, jute, etc. are getting more research interest as reinforcement in polymer composites. These fibers are very attractive due to being light in weight, nontoxic, low cost, abundantly available, low energy inputs, ease of fabrication, and eco-friendly. The current investigation is focused on the fabrication of an open-face helmet by using natural fiber composites. This composite is prepared by selecting a suitable combination of woven bamboo and jute as fibers and epoxy as the matrix. The fabricated helmet is cured for 48 hours and then subjected to drop tests to study the impact energy absorbed. The drop test was carried out and showed that the maximum permissible load is about 147.55kN and the impact energy absorbed is found to be 2144.90 kJ. The hybrid composite of 10% bamboo and 20 % jute along with 70% matrix material yield better impact energy-absorbing properties.

Keywords
Bamboo fiber, Jute fiber, Epoxy, Open-face helmet, Drop weight test.

1.Introduction
Helmets are used in civilian life for recreational activities and sports. In 900 BC, the oldest known helmet was used by Assyrian soldiers [1]. The material of helmet was thick, and made up of leather or bronze, which is used to protect from blunt objects, sword blows and arrow strikes in Combat [2]. The helmet has been used as protective equipment to safeguard the human head from impacts induced due to accidents, construction works, military activities, etc [3]. Of all industries, the construction sector experiences the most occupational traumatic brain injury (TBI) [4, 5]. To provide protection, the materials utilized to make the helmets should have remarkable rigidity and good shock-absorbing capacity.

In addition, the material of the helmet must absorb the majority of the collision's energy and minimize the pressures that reach the rider's head. The qualities of the material used to make the helmet determine these components in considerable part [6].

Composites derived from plastics have shown excellent benefits like lightweight, strength, chemical resistance, and stability. These composites are used in medium-range applications, such as a few in aviation, electronics, and sports. But the major drawback of these materials is environmental problems like waste disposal and non-biodegradability [7].

One of the most promising materials is natural fiber-reinforced composites due to their lightweight, good strength, less cost, ease of fabrication, abundantly available, eco-friendly, and easy disposable[8].

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Due to the dense availability of natural fibers such as sisal, bamboo, pineapple, jute, bamboo, coir, banana [9], etc. has given importance to the development of bio-fiber composites [10]. Hence several researchers have been motivated to use eco-friendly composites which are biodegradable [11]. Once a product's life cycle is complete, it can either be burned or composted [12]. The fibers used in the current work are woven Jute (bast fibers) and woven bamboo (grass fibers), has better bonding and compatibility due to the carbon-hydrogen (CH) stretch functional group between them and their mechanical properties.

In the present study, the Bureau of Indian Standards (BIS) used for helmets from January 2019 has been adopted to analyze the optimum material and thickness. The main objective of the work is to fabricate a simple open-face helmet using woven bamboo and jute fibers reinforced with epoxy composites. The quantitative comparison of the respective values of the damage resistance parameters for composite materials was the other goal. The jute, bamboo fibers, and epoxy resin were purchased from the vendors. A study is made on its suitability for helmet applications.

Seven chapters make up the complete manuscript. Through the introduction in the first portion, the purpose and inspiration for the current research were briefly stated. The literature review in the second section provided in-depth background research. Utilizing materials, the rule of combination, the open-face helmet's construction, the computer-aided design model, and the composition of the helmet, the current study target was achieved in the third section. Concerning the experimental setup, turn to section four. The fifth and sixth sections explain the results and discussion that make up the summary of the substantial research conducted as part of the current investigation. Section seven brought the whole thing to a conclusion.

2.Literature review

According to a study[13] when the BIS standard of 19.5 kN force is applied to examine the helmet in static and dynamic loading, the chin side of the helmet experiences the least strain energy and deformation, signifying that the head will receive the most force. Therefore, impact testing on composite helmets can be done in different ways [14], but the three most prevalent are: gas gun, drop weight, and pendulum. Drop weight methodology was used in this investigation because the equipment was readily available. By absorbing mechanical energy and preventing penetration, all helmets make an effort to protect the user's head. High-energy impacts change their structure and potential for protection. In addition to their capacity for absorbing energy, their volume and weight are significant factors considering that greater volume and weight enhance the user's risk of head and neck injuries. Neurosurgeons developed anatomical helmets at the end of the 20th century that fit the interior structure of the head. To increase the level of impact protection for the human head, several studies have recently concentrated on the material selection and configurational geometry for the helmet. The helmet is made up of two fundamental parts: the outer shell and the liner foam, depending on its primary use. About 70–80 percent of the weight of the helmet comes from the outer shell [15].

Fiber-reinforced polymers (FRP), such as carbon fiber-reinforced plastics (CFRP), glass fiber-reinforced plastics (GFRP), and kevlar fiber, are employed for the external shell. Alternatives for the helmet's interior lining include micro-agglomerate cork (MAC) and expanded polypropylene foam (EPP) [16]. The injured members of the motorcycle crew varied in the accident because the accident circumstances are diverse [17]. This splits the harm into six parts, including the head, abdominal, spine, chest, legs, and arms. The majority (71%) of fatal injuries in automobile accidents are brain injuries. Nearly all of the deceased and injured individuals received fatal head injuries. The analysis of all head injury cases reveals that the most likely site of injury is the forehead. As per the study, because of not wearing the helmet or not wearing the helmet properly many have lost their lives while on the motorcycle crew. The head damage has been significantly reduced after wearing a high-quality helmet [18]. There is a need for a change in the present child health agenda since road safety has received little attention. For children and young adults aged 5 to 29 years, road traffic accidents are currently the leading cause of death [19].

An attempt is made to create the helmet by hand-laying up Vakka and bamboo strands in the right proportions, yielding a helmet shell construction [20]. The findings indicated that hybrid composites could have potential applications in helmets. A unique helmet design concept, consisting of the usage of aluminum honeycomb as reinforcement material for the helmet liner, was also investigated [21]. For the engineered bamboo industry, hybrid bamboo-wood composites provide promising, cost-effective strategies that will result in marketable building products [22]. Several design strategies for increasing the thermal properties of safety helmets were identified to be beneficial [23]. To achieve the requirements outlined in standards, motorcycle helmet manufacturers base their designs on the speed utilized in energy absorption tests [24]. Using two separate decay test techniques, the effects of varied bamboo/plastic polymer ratios on resistance to fungal assault were evaluated [25]. The effect of fiber volumes on the tensile, flexural, and hardness properties of hybrid composites has been studied experimentally [26]. As the number of bamboo layers in the hybrid composite grew, so increased moisture absorption and thickness swelling. Thickness swelling and moisture absorption in hybrid composites are intermediate between bamboo and jute fiber composites [27]. The 2020 helmet-use promotion effort was effective in raising both helmet use and accurate helmet use, according to researchers [28].

A study of the literature on hybrid composite materials revealed that little research has been done on the characterization of hybrid composite for helmet or structural applications. The current study's goal is to recognize the hybrid composite open-face.

3.Materials and methods

The details of constituent materials for the fabrication of open-face helmets are explained below.

3.1Bamboo

Bamboo fiber is a biomaterial that is favorable to the environment. It is a species of the Bambusae family [29, 30]. The composition of bamboo fibers is mainly cellulose up to 70%, lignin about 32%, and hemicelluloses. In comparison to other natural fibers, bamboo fiber is fragile. As a result, different procedures for extracting the fibers are used. The bamboo fiber used for the composite is extracted by any of these three methods, they are steam explosion processing, chemical processing, and mechanical processing [31]. In the fabrication process of the helmet, the woven bamboo fibers are borrowed from the vendor. Later it is subjected to 0.1N NaOH solution treatment and dried [32]. This is done to enhance the composite material's adhesion properties. *Figure 1* shows the extracted raw fibers from the bamboo plant and *Figure 2* shows the woven bamboo fibers.

Figure 1 Bamboo fibers in their natural state

Figure 2 Bamboo fiber woven

3.2Jute

The composition of jute fiber is Cellulose 65%, hemicelluloses 14-20.4%, lignin 12-13% pectin 90.2%. It is an optimistic or promising reinforcement material. Jute fibers are extracted by the mechanical process [33]. In the fabrication of the helmet, the jute fibers were borrowed from the vendor, and later they are subjected to 0.1N NaOH solution treatment and then dried at room temperature. *Figure 3* shows the extracted raw fiber from the jute plant and *Figure 4* shows the woven jute fiber [34].

Figure 3 Natural jute fiber

Figure 4 Jute woven fabric

3.3Epoxy

The epoxy matrix in the plastic industry is identified as a thermosetting resin. Epoxy resin exhibits the following properties [35],

1. It has high chemical resistance.
2. It serves as an effective electrical insulator.
3. Because of the minimal shrinkage, while cooling, it has high dimensional precision.
4. It adheres well to a wide variety of substrates.
5. Fabrication is simple and inexpensive

Lapox L12 and K6 hardeners are used in the present investigation.

Table 1 lists the physical characteristics of the various research constituents.

Table 1 Material properties

Property	Bamboo	Jute	Epoxy
Density (kg/m3)	1.4	1.45	1.2
Tensile Strength MPa	400-800	393-773	70-80
E-Modulus GPa	11-30	13-54	3.45GPa
Poissons ratio	0.3	0.35	0.35

3.4Rule of mixture

Rule of the mixture is used for the fabrication process. As shown in Equation (1), the volume fraction of the composite material is equal to the sum of the matrix and fiber volume fractions [36].

$$V_c = V_f + V_m \quad (1)$$

V_f = percentage of fiber component volume
V_m= Quantity of Matrix
V_c= Composite Volume

3.5Composition of the Open-face helmet

Based on the volume fractions the requirements for the fabrication of an open-face helmet are made and shown below.
Total volume of helmet= 332920.3 x 10^{-9} m^3
Bamboo fiber used= 10%
Jute fiber used= 20%
Amount of matrix used= 70%
Number of jute layers= 2 layers
Number of bamboo layers = 2 layers

3.6Helmet computer-aided design (CAD) model:

The physical model of the helmet is created using CATIA version 5 software. The dimensions are in millimeters as per standards. *Figure 5* shows the various views of the open-face helmet model.

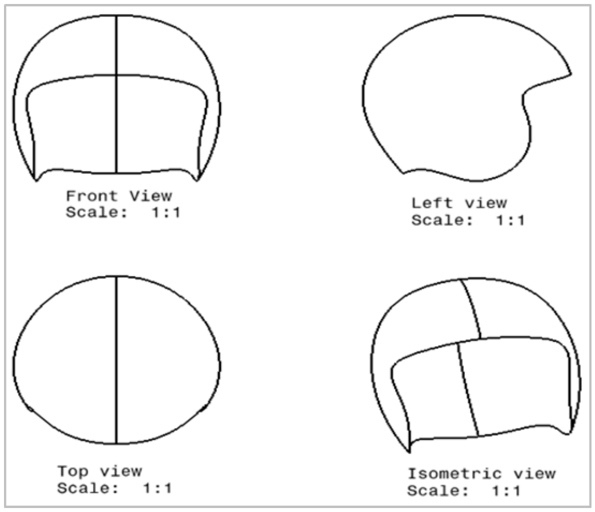


Figure 5 Different views of Helmet

3.7Fabrication of composite by hand layup technique

The hand layup approach is easy to use [37], involves less tooling, and is less costly. Fabrication of composite is carried out by using the following procedure.

1. The mold surface is neatly cleaned and dried using a neat cloth.
2. The dried surface of the mold is coated with gel to prevent the composite material to adhere to the surface and also helps for easy removal.
3. The known fraction of reinforcements (jute and bamboo) is placed in the mold cavity with the required orientation.
4. A known volume of epoxy resin is applied carefully on the surface of reinforcements.
5. A roller is used to distribute the resin uniformly and remove the entrapped air at the time of pouring.
6. The composite is dried and subjected to curing for 48 hours.

Figure 6 shows the flow chart of the fabrication of open face helmet.

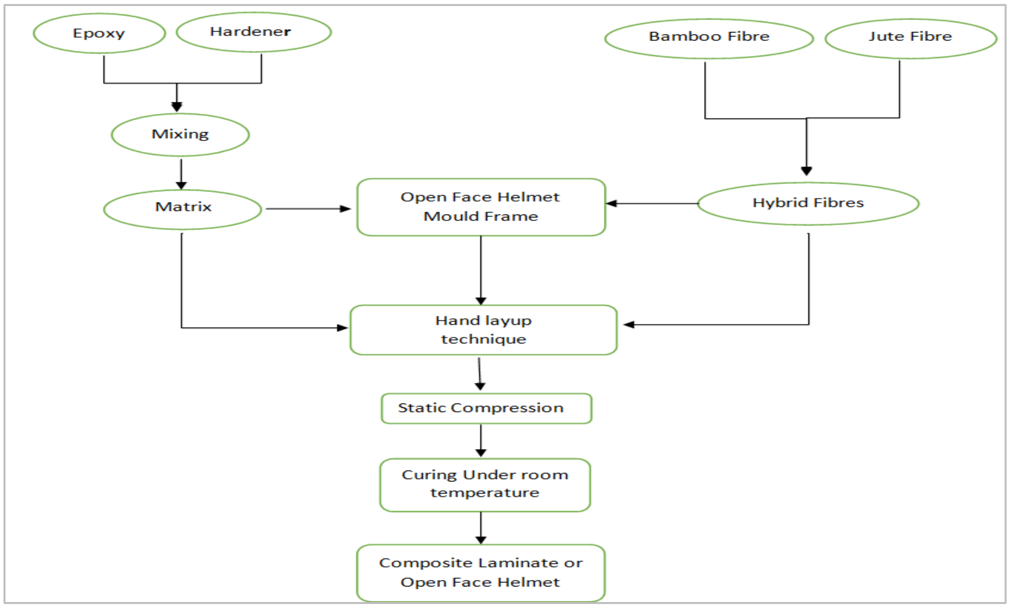


Figure 6 Flow chart of the open-face helmet

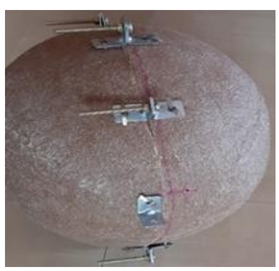
3.8Fabrication of open-face helmet

In the fabrication of the open-face helmet, 30% of reinforcement and 70% of the matrix is utilized. In the 30% of reinforcement 20% jute woven fiber and 10% bamboo woven fiber is taken into consideration. In the calculations, it is seen that each of the two layers of bamboo and jute fiber is used. On the mold box as shown in *Figure 7(a)*, the gel coat is applied and a foil is used to make it easier to remove the helmet from the mold as shown in *Figure 7(b).* After that, one by one layer based on stacking sequence i.e., B-bamboo, J-Jute (BJBJ) is taken on the helmet along with the resin as shown in *Figure 7(c).* The pressure is applied to the helmet with another mold as shown in *Figure 7(d)* and clamped. It is kept for curing.

(a)The gel is sprayed on the mold

(b) Foil is applied to the mold

(c)Fabricated Full Face Helmet



(d)The pressure is applied to the helmet

Figure 7 Fabrication process of helmet

4.Experimental details

4.1Experimental set-up of drop weight test:

The experimental setup and specifications for carrying out a drop-weight impact test are shown in *Figure 8*. The test is performed in accordance with ASTM D 7136[36], which is a standard set forth by the American Society for Testing and Materials (ASTM). A piezoelectric accelerometer is used in conjunction with a drop weight of a specific mass. The drop mass is manually raised to the necessary height. The specifications of the machine are shown in *Table 2*.

After setting up the experiment's data collection equipment, the drop weight is released using the load-releasing mechanism. The safety rods built inside the machine were used to lift and support the drop mass that was attached to it. The drop weight impact test is conducted for the composite fabricated helmet shell, where the fit is attached to the hammer of mass 460N and the drop of mass is set up at the height of 1.5m, and the velocity range of 5.42m/sec is set up in the machine. This drop weight test is conducted to determine the maximum load and the maximum energy absorbed by the helmet shell when the load is dropped from a certain height on the top surface of the helmet.

Figure 8 Impact test rig with helmet

Table 2 Specifications of the setup

Greatest drop height	5.8m
Maximal speed	10.77m/s
Drop Mass	60-120kg
Highest Capacity	6960 Joules

5.Results

The characteristics of drop tests are of great need due to their substantial application which involves impact loading. The drop weight test was performed on the fabricated bio-composite helmet. According, to BIS standard the upper limit of impact load for drop weight test is 19.5kN but due to the restriction of the fixture or test rig, the test is conducted with a drop mass of 460N.

The impact load vs displacement for the bio-composite open-face helmet under investigation is shown in *Figure 9*. The helmet can withstand a maximum load of about 147.55kN, according to the results of the drop weight test. By post-processing of acquired data after the test was conducted and the energy absorbed by the helmet is 2144.90kJ.

Figure 10 shows the force against the time curve for the open-face helmet under testing. The area under the graph is equal to the impulse during the collision. It is also called an impulse graph. An impulse will result in a change in momentum and hence a change in velocity. Fpeak is the maximum load carried by the helmet.

Figure 11 shows the velocity against the time graph for the open-face helmet. Initially, when the test is carried out due to the sudden impact the helmet withstands the highest load. The graph indicates that the maximum velocity (Vmax) of 8.31m/s was taken by the helmet at 0.001 sec. Later as the time increases the velocity decreases. This is due to the delamination of fibers and weak bonding between the fibers.

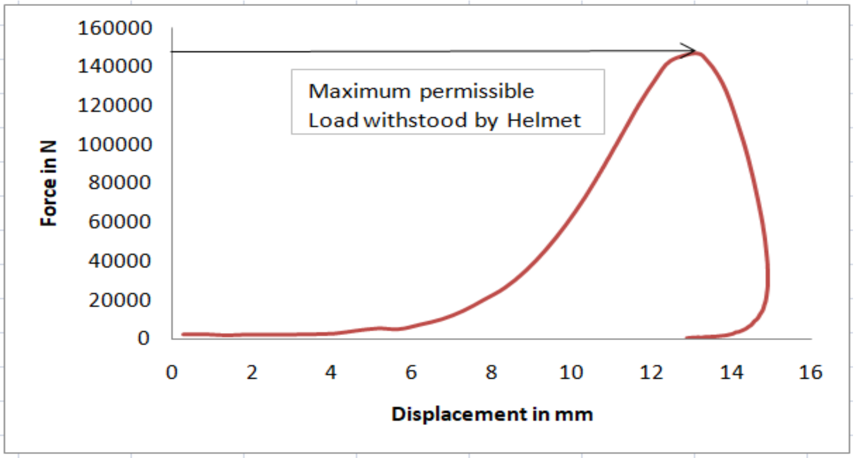


Figure 9 Force v/s displacement graph for drop test of open face helmet

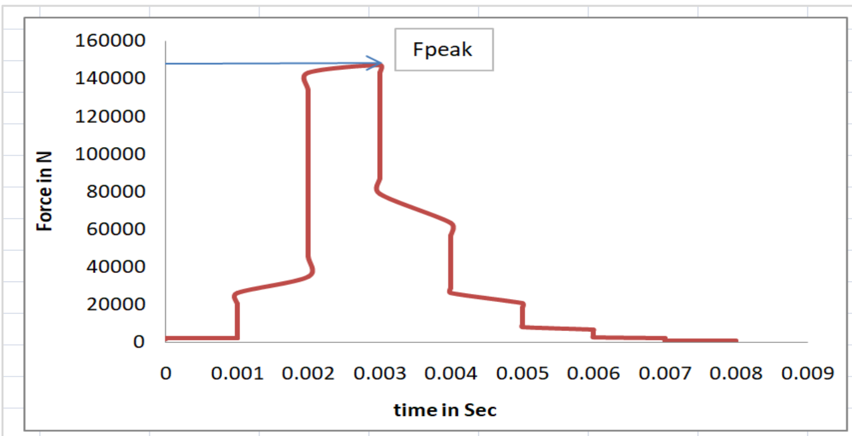


Figure10 Force Vs time curve for drop test of open face helmet

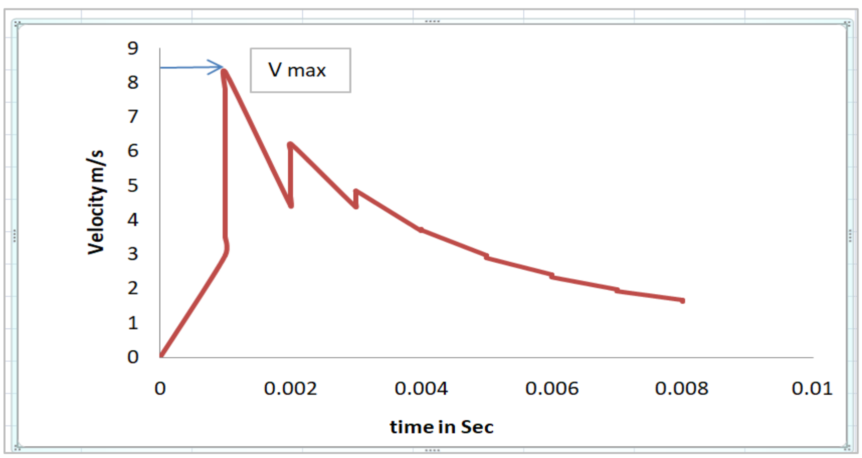


Figure 11 Velocity Vs time curve for drop test of open face helmet

6.Discussions

In the current work, the biocomposite that is jute and bamboo fiber have been effectively reinforced with epoxy resin. The drop weight testing result of the fabricated simple open-face helmet signifies the idea of implementing bamboo and jute fiber capable of the fabrication of the helmets with 30% reinforcement (10%B+20%J) and 70% matrix ratio. Also, the appreciable weight is reduced for the helmet. The drop test is being carried out and showed that the maximum permissible load is about 147.55kN and the impact energy absorbed by post-processing is found to be 2144.90 kJ. The implementation of natural fibers in the composite materials makes it ecological and this material can be used as a substitution for synthetic fibers.

By the data obtained and when compared with other investigators, the parameters obtained in the present work are twice the reference data [38, 39], and also energy absorbed by the material is more. This is due to the better interlaminar bonding of the composite material. Hence the fabricated bio-composite helmet by woven hybrid natural fibers composites would protect from head injuries and save the rider's life when an accident takes place while riding. The significance of a suitable helmet shell material should be emphasized because absorbing energy can reduce the risk of injury to the rider.

Limitations of the current work include the use of 70 percent epoxy, which can be increased or decreased, for successful component binding. Hand layup approaches were utilized in this investigation due to a lack of funding; nevertheless, researchers could use other automated synthesis processes that have considerable effects.

A complete list of abbreviations is shown in *Appendix I.*

7.Conclusion and future work

The reported effort in improving the materials used to create open-face helmets is presented in this overview. The current materials used to create helmets will soon be replaced based on the results that show them to be successful. If the existing materials are reinforced with natural fibers, composite materials, matrix composites, synthetic fibers, etc., they will be more beneficial. The hybrid composites performed with a high level of stability. Compared to the materials that were previously employed, the manufacture of these materials gives helmets durable strength. It can be used as an alternative material for helmets, according to an assessment of the literature on natural fiber-reinforced composites. the development and technical requirements of bamboo and jute fiber-reinforced epoxy composites, which can be used to make open-face helmets.

Researchers, material scientists, businesspeople, and engineering students are working to develop novel materials that could replace the current plastics used in the manufacture of helmets. Future potential is found in the development and application of advanced natural fiber composites, which leads to the discussion that provides the way for the creation of new materials. Between researchers, scientists, and manufacturers, technological development has led to a violent struggle. Reducing the usage of plastics, this conflict leads the way toward a solution that helps not only the production of safety helmets but also the environment. The persistence and unceasing efforts of material scientists, entrepreneurs, and researchers will result in the continuous improvement of new materials that can replace the current materials.

Acknowledgment

We acknowledge the RRGI, Principal, and management's generosity in providing the funding necessary to complete this research.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Shankara Reddy R: Study conception, supervision, writing review, and editing. **Radhakrishna R Kumshikar:** Conceptualization, investigation, design, data collection, data curation, writing-original draft, investigation on challenges on draft manuscript preparation. **Ravikumar T:** Data collection, conceptualization.

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Appendix I

S. No.	Abbreviations	Description
1	ASTM	American Society for Testing and Materials
2	BIS	Bureau of Indian Standards
3	BJBJ	B-bamboo, J-Jute
4	B	Bamboo Fiber
5	CAD	Computer-Aided Design
6	CFRP	Carbon Fiber Reinforced Plastics
7	EPP	Expanded Polypropylene Foam
8	FRP	Fiber Reinforced Polymers
9	GFRP	Glass Fiber Reinforced Plastics
10	J	Jute fiber
11	MAC	Micro-Agglomerate Cork
12	TBI	Traumatic Brain Injury