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Impact Behaviour of Laminated Bamboo, E-Glass and Hybrid Bamboo/E-Glass Fibre Composites

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Abstract: Natural fibres are currently used as a mutually reinforcing fibre foundation. One of their prospects, particularly that which is said to be good in mechanical reinforcement, is bamboo fiber. This study focuses on developing a high-quality bamboo that can withstand high load and high impact application, that utilize and promote green technology and local crops production of bamboo in Malaysia. The work scope was focusing on the impact performance of bamboo fiber as natural fiber, E Glass fiber as synthetic fibers, and combination of both bamboos with E Glass Fiber as hybrid composites. The developed laminated hybrid bamboo was hit by a hard object named impactor in the drop impact testing procedures. The analysis gives the sound of the impact properties that can be absorb with optimal load before the specimen penetrated or failures. Configuration of 6,12,18 layers of woven bamboo and 6,12,18 layers of woven E-Glass, in order of thicknesses 9 mm, 18 mm, 22 mm and 4 mm, 7 mm and 10 mm, respectively were fabricated by hand lay-up. The thickness of each and individual strips of woven bamboo and E-Glass used in the range of 1.5-2.5 mm thicknesses. The results showed that the impact performance of the hybrid bamboo/E-Glass had outperformed the non-hybrid bamboo/E-Glass. The developed hybrid bamboo composites show highly potential use for ballistic application in replacing metal armor.

Keywords: Woven bamboo, glass fibre, hybrid bamboo/E-Glass, laminated composite, mechanical properties.

1. Introduction

Bamboo composites are widely used and explored by researchers all over the world. In Malaysia, there are an abundance of abandoned resources. The bamboo is becoming strong, once it is combined with woven E glass fiber to combat the ballistic impact from bullet. However, the study did not further explore in term of impact behavior. To study whether the developed bamboo composites can have good energy absorption and what type of structure arrangement that can give optimal energy absorption needed to be studied. A review on impact properties on hybrid composite for structural application is highlighted in Safri et al. [1]. However, none was reported for the case of bamboo laminated hybrid with e glass composites was reported. A review on thermomechanical behavior of bamboo was detailed in [2]. The significance of using natural fibers as a reinforcement material in composites such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, banana, etc., used from time immemorial as a source lignocellulose fiber are more often applied as the reinforcement of composites [3] and as a viable choice as reinforcing material in composites [4]. Rassiah et al. [2], had successfully map the mechanical properties of the bamboo in 3D views that would allow the researchers to evaluate the most maximum performance of bamboo parts in terms of its mechanical properties [5]. Moreover, the research conducted had explored the developing bamboo in form of strips. The strips of bamboo were then woven onto each other to produce

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a layer of bamboo [6]. Ali et al. [7] also had successfully investigated the fatigue and fracture of the bamboo. Such information is vital in the industry whether to apply a bamboo composite as new construction material. Recent advancements made by Ali et al. [8] successfully improved on the effect of woven bamboo arrangement towards increasing the ballistic limit. The idea is to hybrid woven bamboo with woven E glass fiber to combat the ballistic impact from a travelling bullet. The work shows experimentally that laminated hybrid bamboo composites had survived and pass the ballistic impact limit test known as V50 and NIJ tests, the results showed that the developed composites was qualified to be registered as the combat armor panel. To better explore and look for its potential, this newly developed bamboo composites do that it can be used for future energy absorption materials that will maintain and retain its strength while also being light in its weight. The hypothesis is to characterize the Impact Behavior of bamboo composites whether it has what it takes to be an energy absorber and can be used for automotive or defense industries for defense vehicle technology. Ultimately, the study will give strong impact to the body of knowledge on the capacity advanced hybrid natural woven bamboo materials towards application in military defense. It is expected to promote the Malaysian made composites as well as economic potential of bamboo that is available in Malaysia. The objectives or the main study aims to analyses the energy absorption of the developed bamboo composites while maintaining their strength and other properties. Based on previous research, this hybrid bamboo composites had gone through multiple tests such as bullet impact, tensile, flexural, etc. Study of impact damage and failure are important so that continuous structure health monitoring can be performed to deter any major incident and catastrophic failure. It is crucial to understand the response to impact, impact energy and impact force absorbed by the material before its failure in order to produce an effective design for a structure [9]. For more in-depth research, this study is about impact test using weight-impact test machine which is to characterize and analyses the energy absorption, performance, and mechanical properties of the composites. Ultimately the work will give us sound basis decision whether the material can be applied in anti-ballistic application especially in defense industry.

2. Materials

Woven bamboo (WB), Woven E-glass (WG), and Unsaturated Polyester (UP) are used to create laminated hybrid bamboo/glass fiber composites in this research. Each substance has its unique set of characteristics. As a result, each material's function will alter depending on its qualities. WB is used as the natural fiber, WG is used as the synthetic fiber, and UP is used as the composite matrix.

2.1 Woven Bamboo

The extraction process of bamboo plants starts by cutting the bamboo into strips with dimension 1.5mm. Then the strips were dried in oven to reduce the moisture in the bamboo. By applying traditional handmade method, the fibers are used for the fabrication of the woven bamboo. Fig. 1 illustrated the woven E-glass fiber prior to its combination with unsaturated polyester of epoxy amite 100 (A) and slow hardener (B).

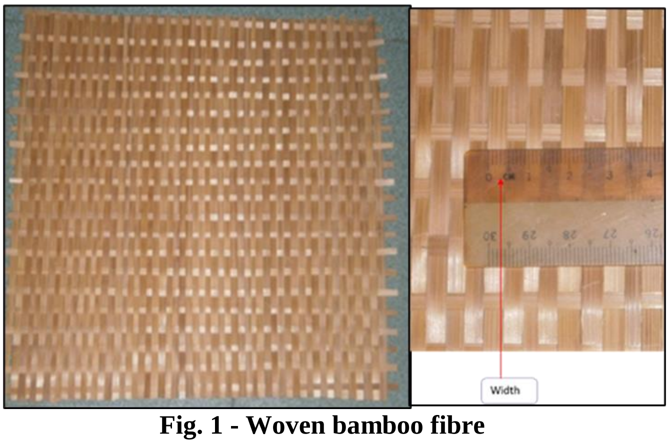


Fig. 1 - Woven bamboo fibre

2.2 Woven E-glass

Fiberglass is reinforced with fibres. Typically, the glass fibre is flattened to form a sheet, then randomly placed, or woven into a cloth. Glass fibres may be manufactured from a variety of various kinds of glass depending on their intended usage. It is evident that fiberglass is a robust, lightweight material that is less fragile. Fiberglass is unique in its capacity to be molded into a variety of intricate forms. Additionally, fibreglass has a higher specific resistance than steel. Therefore, fiberglass production increased as it can be used in many applications due to its advantages. Fig. 2 illustrated the woven E-glass fibre prior to its combination with unsaturated polyester of epox amite 100 (A) and slow hardener (B).

Fig. 2 - Woven E-glass fibre

3. Experimental Design

Hand lay-up technique were used to construct the hybrid composite specimens in this research. Moreover, the weaved bamboo strips were each dried for 6 hours at 60 degrees Celsius in an oven. This is required to remove any excess moisture or liquid inside the bamboo fibre strips. Both fibres were chopped into the specimen's dimension (300 mm x 300 mm) after the braided bamboo was heated. Then, using unsaturated polyester (UP), both fibres was laminated with a fixed ratio by volume as shown in Table 1. along with their respective layer configurations according to the specimen structure arrangement and layer configuration. The weight of each woven bamboo and E-glass fibre were weighted on a scale. The total weight would then be divided into the mix ratio of both EpoxAmite (A) and 103 Slow Hardener (B).

Table 1 - Handling properties of EpoxAmite (A) and 103 slow hardener (B)

Handling description	Properties
Mix Ratio by Volume	3A: 1B
Mix Ratio by Weight	100A: 28.4B
Mixed Viscosity	650
Specific Gravity	1.10
Specific Volume	25.2
Pot Life	55
Thin Film Working Time	180
Cure Time (hours)	20 - 24
Colour of Mixture	Clear Yellow

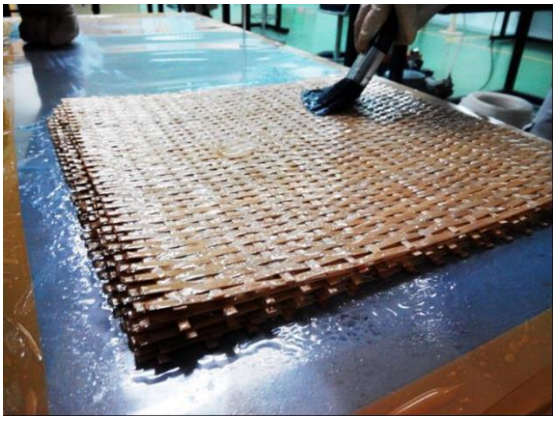


Fig. 3 - Hand lay-up technique of applying the UP onto each layer of woven bamboo and E-glass fibre

The laminated specimen was then place on a flat table to be let sit for curing process. To reduce the amount of air trapped inside the laminated fibre composites and to ensure that the unsaturated polyester to be spreaded evenly across the fibre composites, a 10kg load steel plate was placed on top of the laminated fibre composites. Fig. 4 shows the laminated fibre composites left unattended for 24 hours for the curing process of the unsaturated polyester.

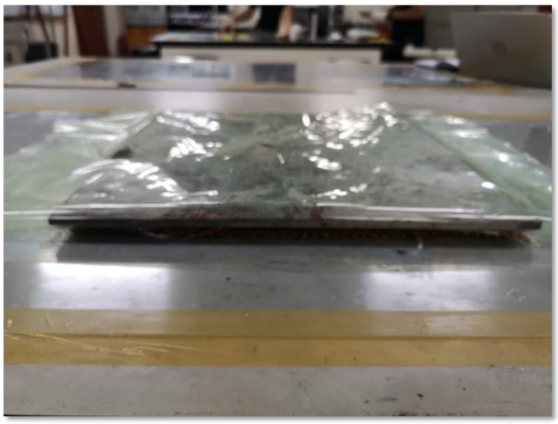


Fig. 4 - 10kg steel plate placed on the laminated fibre composites

3.1 Sample Design

In order to understand the impact performance of Bamboo and E Glass fiber, the study proposed seven types of configuration of specimens. Each specimen consisted of its own amount of layer of configurations. Each type of sample of configuration had three different number of layers of woven bamboo and E-glass fiber. The samples are depicted as shown in Table 2. The woven bamboo fiber WB consisted of 6, 12 and, 18 layers, while the woven E-glass fiber WG consisted of 6, 12 and, 18 layers. The hybrid E-glass / woven bamboo (WG/WB) fiber however consisted of ratio of 18/4 layers of WG/WB, respectively. Fig. 5 (a) and (b) show the bonded woven bamboo and woven E-glass by the unsaturated polyester. The samples were then subjected to an equal cut of 4 pieces each measuring at 10 cm X 10 cm (Length x Width) for the load impact test.

The samples were cut into 4 equal pieces measuring at 100 mm X 100 mm (Width X Length) with various thickness depending on each number of layers of configuration. The cutting process were done with a hand grinder as the cutting tool, the specimen was situated onto a vise for the purpose of keeping it stable, aligned correctly and safe while cutting. The woven bamboo fibers were found to be thicker than woven E-glass fibers due to its physical shape and structure that prevents it to be flatten as well unlike the woven E-glass fibers. The woven E-glass fiber tends to be shaped better than the woven bamboo fibers as it had very low rigidity. Although, that would not be of any concern as the specimen conducted for the load impact test were square shaped for the ease of the load impact test. The combination of woven bamboo and E-glass fiber composites were accustomed to the previous research on NIJ bullet-proofing test conducted by previous researcher. The hybrid bamboo/E-glass fiber composites acted as the benchmark for the impact test befitting for its comparison in energy absorption of each layer of configuration of the bamboo and E-glass fiber composites.

Table 2 - Specimen weight and configurations

Types of layer arrangements *WB = Woven bamboo *WG = Woven E-glass	Number of layers of each material	Total Layers	Total weight of woven fibres (g)	Thickness (mm)
WB	6	6	279.4	9
WB	12	12	510.0	18
WB	18	18	864.4	22
WG	6	6	324.6	4
WG	12	12	648.7	7
WG	18	18	972.7	10
WG/WB	18/4	22	954.7	12

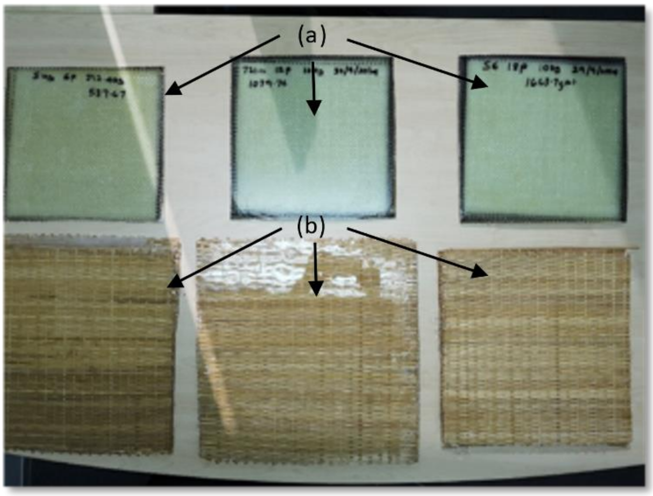
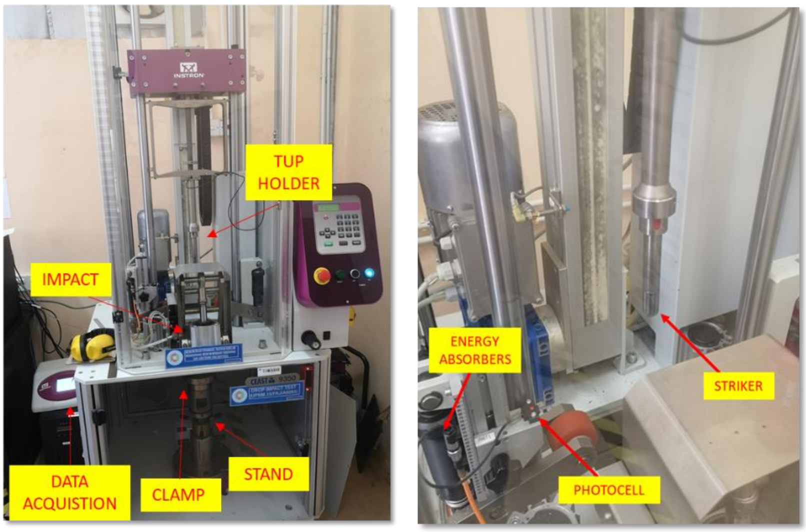


Fig. 5 - (a) Woven E-glass fibre; (b) woven bamboo fibre

3.2 Impact Test and Data Analysis

The drop impact test was used to assess the properties and behavior of the laminated hybrid bamboo/glass fiber composite during the impact in order to evaluate its drop impact features and performance. Low energy absorption is the most problematic since it may alter the composite structure, causing matrix and fiber cracks as well as delamination. Drop impact is one of the most effective methods for determining the mechanical characteristics of composites to fully comprehend their performance. The test was carried out using the Instron CEAST 9350 as shown in Fig. 3. The analysis of the energy absorption and mechanism of composites failure was investigated.



(a) (b)

Fig. 6 - (a) Instron CEAST 9350 load impact test machine; (b) hemispherical striker

The mechanism of the load impact test machine CEAST 9350 used a hydraulic pneumatic motor system for the spooling of the striker to impact the specimen situated inside test chamber. The striker utilised by the impact machine was spherical shaped via 20mm in diameter tup as depicted in Fig. 6 (b). The physical instrumentality of the crosshead positioning system was also equipped with a smart computer brain called the Data Acquisition System. The photocell sensor for data acquisition shown in Fig. 6 (b) functioned as the sensor that collected the reading of the velocity and impact energy response of the specimens.

4. Results and Discussion

The fabricated woven bamboo and woven E-glass combined with epoxy resin to form a fibre composite plates were subjected to a load impact test. The drop weight impact tests had derived the data of load impact energy, force and velocity. Results shown by figures below depicted the energy [J] and force [N] against time [ms] that were used to investigate on how each fibre composite plates reacted to different ranges of load impact energy, the damage mechanism were also further studied. Impact test conducted on the INSTRON CEAST 9350 had a 20 mm in diameter spherical striker end rod with a mass of 5.5 kg, punched through the fixed placed specimens. The damage inflicted on the specimens were further discussed.

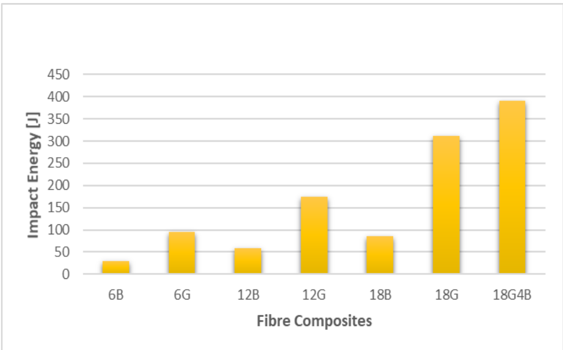
The amount of transferred energy to the fiber composite plates by the striker increased with time, where it would then reach its maximum value. The transferred energy would then decrease and reached a constant value after it had absorbed the initial impact energy. Once the load had increased in value, the fiber composite plates would then start to deform with some irregular movement and oscillation of the striker upon hitting its target. However, the irregular movement and oscillation striker does not interfere the result as there were anti-rebound energy absorber mechanism to prevent it from hitting the specimen more than once. This phenomenon could be indicated that either it was able to sustain the impact energy or it had suffered from a deformation which included of a semicircular-shaped indentation together with fractures, delamination, breakage, and even complete or partial penetration of the whole fibre composite plates. These deformation could be justified by a study of low and high impact behaviour of thermoplastic and thermoset by Haibao et al. [10] where an extensive series of delamination and displacement had occurred when subjected to high-velocity impact tests.

4.1 Energy Response of Impact and Force

The peak impact energy absorbed of fibre composites is illustrated in Fig. 7 (a). The specimen 6 WB had reached a maximum of 28 J of impact energy before it had failed. 6 WG however had doubled the amount of impact energy experienced by 6 WB by reaching at a maximum of 94 J of impact energy. Doubling 6 WB thickness at 12 WB, the peak impact energy had increased at up to 59 J while the 12 WG had surpassed the impact energy of 12 WB by 3 folds at 173 J. 18 WB had been partially penetrated by the impact test at 84 J of impact energy wheas the 18 WG had retained its properties while being struck at 312 J of impact energy. The difference between 18 WG and hybrid fibre composite of 18/4 WG/WB might not be as plentiful although the damage mechanism viewed upon impact test showed a sign of significant difference between those two.

The peak force during impact test were also studied. It was difficult to measure the maximum force due to the rigidity of the fibre composites of WG and hybrid WG/WB where the striker had reflected of its surface unable to cause any further damages. Both 18 WG and 18/4 WG/WB impact energy had peaked not far from each other at 21826 N and 21597 N respectively.

a



b

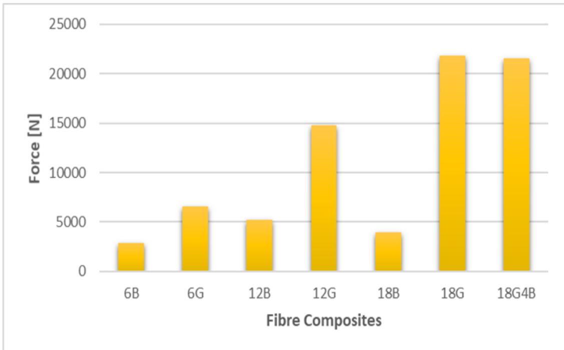


Fig. 7 - (a) Peak impact energy [J]; (b) peak force [N]

Fig. 8 represented the range of load impact energy exerted on the surface of each of the specimens. As the amount of layer increased, so does the amount of total impact energy it was able to withstand. The velocity of the impact moves proportionally as the load impact energy. Evidently, most of the specimen had survived the impact test. The 6 WG outperformed the 6 WB in the load impact test by 10 folds by comparing its impact energy, while being more than 2 times thinner its thickness. The strength of laminated woven E-glass surpassed the performance of the laminated woven bamboo by being thinner than its thickness. The occurrence of failures is indicated when there was a partial or full penetration or severe delamination and fibre breakage present upon impact on the specimens.

4.2 Composites Surface Due to Impact

The result of the load impact test had significantly altered the surfaces of the fibre composites. In this section, the damage mechanism occurred on the surface of the woven bamboo (WG), E-Glass (WG), and bamboo/E-glass hybrid (WG/WB) fibre composites was observed to further in-depth study on the relationship of damage surface and its impact behavior. The hemispherical-shaped striker on the middle of the impacted fiber composite plates resembled a round-shaped crater on the surface of the fiber composite plates. In this experiment, the impact load tests significantly relate to the characterization of the impact energy of the laminated bamboo, E-glass and, hybrid bamboo/E-glass fiber composites.

The failure modes of the impact test consisted of delamination, shear plug, fiber breakage and fractures and, penetration could be observed right after the impact tests. The failure mechanisms vary from one layer of configuration of the fiber composite plates to another, as the combination of different thickness and materials had different physical properties. There was certain penetration occurred at high impact energy and velocities. The damaged and perforated fiber composite plate was then compared to the 18/4 WG/WB hybrid bamboo/E-glass fiber composites based on previous research conducted [8] where it also had gone through the load impact test.

✓ : Withstand the Impact
→ : Untested
✖ : Failure Occurs

Fibre Composites \ Impact Load (J)	6	16	26	36	46	56	66	76	86	96	106	126	146	166	186	206	246	286	326	366	406
6WB	✓	✓	✖																		
12WB	→	→	✓	✓	✓	✖															
18WB	→	→	→	→	→	✓	✓	✓	✓	✖											
6WG	→	→	→	→	→	→	✓	✓	✓	✓	✖										
12WG	→	→	→	→	→	→	→	→	→	→	✓	✓	✓	✓	✓	✖					
18WG	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	✓	✓	✓	✓	✖	
18/4 WG/WB	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	→	✓	✓	✓	✖

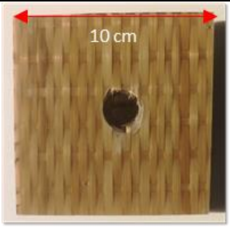
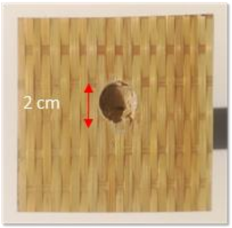
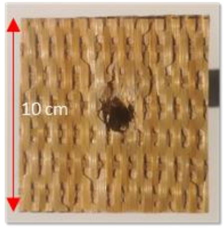
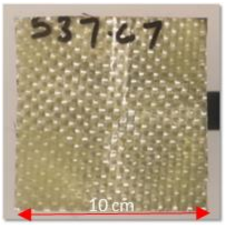
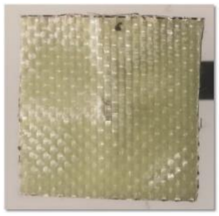
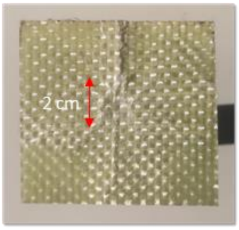
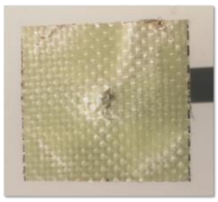
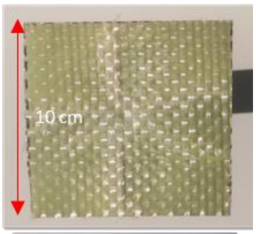
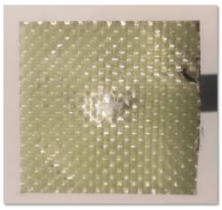
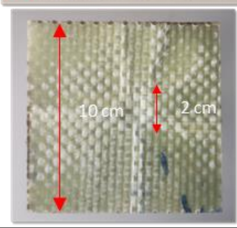
Fig. 8 - Comparison of each layer of configuration of WB, WG, and WG/WB fibre composites impact energy performances on impact test

The penetration on the surface had caused the rear surface to absolute shattered and penetrated the rear surface. Moreover, the deformation could also be seen on the rear surface of the 6 WB which indicated the severe penetration it had experienced upon impact. This had ultimately caused the specimen to fail the impact test at 26 J of impact energy. No significant delamination phenomenon had occurred however despite previous impact test. at 86 J of impact energy as depicted in Table 2, it was shown that on the front surface, there was a significant penetration that had taken place. The impact on the front surface had caused a shear plug region on the rear surface. Slight indentation could be observed on the front surface of the 6 WG which led to bending on the surface caused by the initial impact energy at 106 J, this is 3 times more peak energy absorbed compared to of a laminated 24-ply Kevlar composite at an impact energy of 50 J as tested by a research conducted by Kounain et al. [11]. On the rear surface however, it is to be observed that a minimal fiber pullout had transpired.

The fiber composite 12 WG at 186 J of impact energy had slightly bent along the creases of the impact energy as illustrated by the white lines protruded across the front surface of the 12 WG. The rear surface had also indicated the bending had protruded to the upper right corner of the surface, whereas fiber pullout had occurred on the center of the opposite surface of the impact. Severe delamination and fiber breakage could also be seen from the side view of the 12 WG where there was a misalignment of the matrix. the damage following the final impact test of 18 WG at 326 J of impact energy. As observed in Table 2, the center of the impact had caused an implication of slight breakage of the fiber composite. The fiber composite had slightly bent along the creases of the impact energy as illustrated by the white lines protruded across the front surface of the 18 WG at 326 J of impact energy. The rear surface had also indicated the fiber pullout occurrence on the center of the opposite surface of the impact. Slight delamination and fiber breakage could also be seen from the side view of the 18 WG although not as drastic. The performance of 18 WG at 10.6 mm of thickness can be compared directly to a laminated E-glass/epoxy at 5 mm of thickness composite where under lower impact velocity at 7.51 m/s, its maximum value of impact was at 150 J which had been partially penetrated [12] whereas the 18 WG was not.

The impact behavior of the 18/4 WG/WB under the impact energy of 406 J had generated fiber wrinkles on the front surface of the specimen. Moreover, fractures of the bamboo fiber layer and epoxy lamination had appeared on the rear surface. The fracture of the rear surface had also extended to the right side of the surface. The hybrid 18/4 WG/WB were found to be performing at a far more superior than that of the 22-ply Glass/2ply Kevlar hybrid where the glass/Kevlar hybrid was penetrated at 32 J of impact energy [11] meanwhile the 18/4 WG/WB had survived the impact without suffering from severe penetration at 406 J of impact energy.

Table 3 - Effect of impact test of Fibre composites

Series	**Impact Energy (J)**	**Impact Velocity (m/s)**	**Front Face**	**Rear Face**
6WB	26	3.2		
12 WB	56	4.6		
18 WB	86	5.5		
6 WG	106	5.8		
12 WG	186	7.9		
18 WG	326	10.6		
18/4 WG/WB	406	11.9		

5. Conclusions

In conclusions, it is observed that, the impact strength of bamboo composites successfully obtained. The optimal impact absorption reading was recorded for the case of 18 layers, which consists of bamboo alone. It is also discovered that, the impact performance of 18/4 WG/WB hybrid bamboo/E-glass composites register 4 folds' stronger than the 18WB non-hybrid bamboo at 406 J compared to 96 J. This is evidently that the specimen had survived the impact test without suffering from any severe penetration at higher impact energy. It is worth to mention that the level of blunt trauma following the impact could be seen differently at different stage of impact energy tests and specimen type in addition, some have no blunt nor indentation present on the surface while some have had severe blunt trauma. The addition of bamboo fiber layers in the E-glass fiber had significantly suppress the impact load obtained to absorb the impact energy and had reduced the damage it had consumed.

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