EXPERIMENTAL INVESTIGATION OF PURE BAMBOO PLATE UNDER QUASI-STATIC INDENTATION TEST

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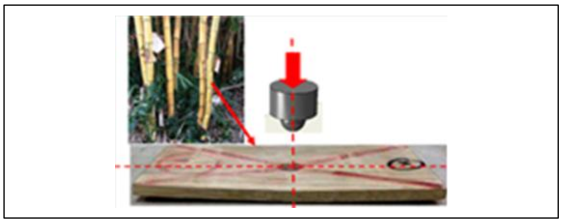
GRAPHICAL ABSTRACT



ABSTRACT

This paper presents analysis on quasi-static indentation test on pure natural bamboo. The aim is to investigate the damage characteristics of pure natural bamboo under low velocity impact. Pure bamboo has been fabricated to form a thin plate to be tested under quasi-static indentation test. The result shows that there is no damage on non-impacted area and the indentation depth on impacted area is relatively small. The pure thin plate bamboo then undergoes microscopic observations to observe the internal damage on the pure fibre. Throughout the microscopic observations, damage on pure natural fibre is almost similar to those experienced by other conventional composite materials, such as delamination and fibre fracture.

KEYWORDS

Bamboo; Impact; Natural Fibre; Eco-composite

INTRODUCTION

Composite material has been used as an alternative material to replace metal in aircraft and automotive industries due to its unique properties such as high strength to weight ratio. However, there has been interest in utilizing natural fibres as substitute of synthetic fibre [1-3]. Generally, natural fibre is obtained from animals, plant or mineral source, which is convertible into nonwoven fabrics such as paper [4]. Similar to agriculture, textiles has been necessary basic of human life. Cotton and silk are categorised as natural fibre and have been used since 2700 years B.C. [5]. The popularity of natural fibre has increased drastically due to its availability and environmental friendly character. Natural fibre has the advantages of weight saving, low need for raw material and being renewable [1].

Natural fibres such as bamboo have been widely used especially in China in construction sector [1]. An example is the development of suspension bridges in China [6]. The cables were made by using the exterior part of bamboo, which is four times stronger than its interior. Other than that, the bamboo is used in construction of buildings and boats. There are more than 1600 species of bamboo, with 64% found in Southeast Asia, 33% in Latin America and the rest in Africa Oceania [6]. Basically, bamboo can grow in a very short period. Bamboo is useful and it has various functions at different ages [6]. Bamboo suitable for constructions is between three to six years old. Natural fibre is not new in industries, only that there are not many studies related to pure natural fibre.

This study investigates the potential of bamboo as an alternative material in the aircraft and automotive industries. For the last three decades, composite material has been extensively used to replace metals as aircraft components due to its technical advantages such as strength to weight ratio. For instance, the latest commercial aircraft A350XWB consists of more than 50% composite materials in its primary parts such as fuselage and wing [7]. However, when it comes to real life situation, the characteristics of composite material due to impact damage should be considered as it may reduce the strength of the structure and cause permanent damages. In aircraft industries, damage caused by impact may be due to strike by objects such as falling tools during the maintenance (low velocity) or strike by bird (high velocity). For low velocity impact, the external surfaces may not show any visible damages but there may be damages that occur internally. The internal damages may be fibre destruction, delamination or matrix cracking. Fibre failure is the major cause of strength reduction, while delamination and matrix cracking is the minor strength reduction [8]. Indeed, there are a lot of studies that have been carried out to investigate the behaviour of the conventional fibre [8-10]. However, the damage impact study on natural fibre i.e. bamboo is very few in open literature as the focused is put more on its fracture mechanics behaviours [11].

As there are some interests to use natural fibres such as bamboo for automotive application [3], it is important to well understand the damage behaviour of natural fibres due to impact loading. For precaution, it is better to recognize the common damage behaviour of natural fibres before performing any impact damage studies. Thus, the aim of this study is to investigate the damage behaviour of pure natural fibre; in this study is pure laminated bamboo, under static indentation test. This is because, damages due to indentation are generally very similar to damage due to impact as reported in [9-10]. Moreover, it will be informational to take note of the damages that occur from the beginning of the test. The indented area will be further analysed through microscopic scanning in order to investigate and observe the internal damage that occur around the indented area.

Materials And Methods

A quasi-static indentation test had been carried out to investigate the characteristics of pure natural bamboo. In order to have detailed analysis, the specimens were scanned using scanning electron microscope (SEM) to have clearer view on the internal damage that might be present during the indentation tests.

Specimen

The bamboo was obtained around Universiti Teknologi Malaysia (UTM), Johor, Malaysia. The bamboo is known as Hawaiian Gold Timber Bamboo, as shown in Figure 1. As the bamboo was cylindrical in shape, the bamboo was cut into a plate having non-uniform thickness. Then, the skin of the bamboo was removed. Next, the non-uniform bamboo plate underwent sanding process until a flat plate specimen is obtained. The final dimension of the specimen was 100 mm long with 40 mm width and having thickness of 4 mm, as presented in Figure 2.

Figure 1: Hawaiian Gold Timber bamboo

Figure 2: Flat plate specimen of pure bamboo

Experimental Test

Quasi-static indentation test was performed to investigate the displacement of indentation that would occur on indented area and also the damages that might present. Quasi-static test was used as it is easy to control and the damages behaviour (indentation, crack etc.) that occurred during the test could be tracked along the test. The test was carried out by using the Universal Instron testing machine in compression testing mode as implemented in [9]. The specimen was placed on a simple rectangular frame as displayed in Figure 3. The displacement of the impactor was controlled by the feed of the test machine's crosshead and the loading speed was set at 3 mm/min. The maximum indentation was set up to 8 mm. The load was set up to be unloaded after the load underwent displacement of 8 mm. The displacement was measured using Linear Variable Differential Transformer (LVDT) as this instrument would allow more accurate values than the displacement measured by the test machine. The LVDT was installed parallel to the vertical axis and attached to the crosshead. The load cell in the test machine would provide the force signal to act on the specimen.

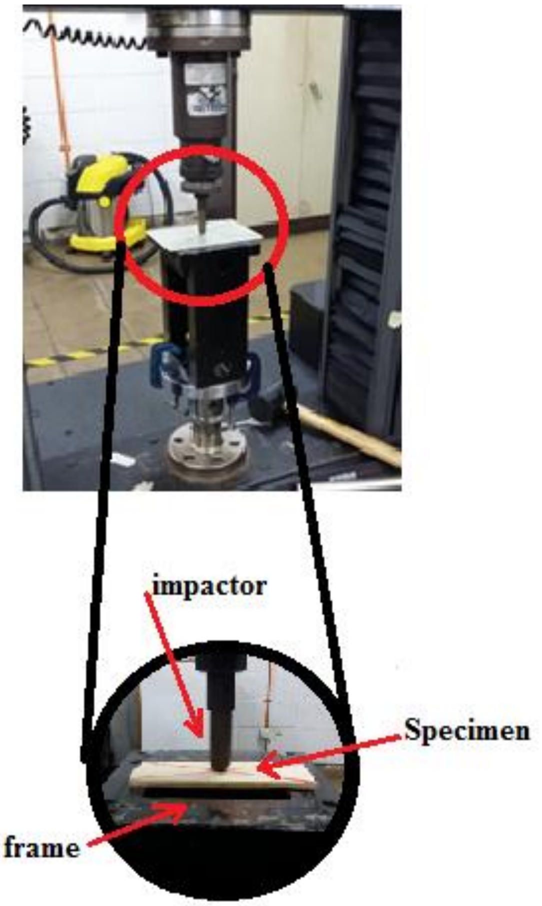


Figure 3: Test setup

Post-mortem analysis

After the quasi-static indentation tests had been performed, the tested specimens were submitted for post-mortem analysis using scanning electron microscope (SEM). The aim was to observe the internal damages. The specimens were cut out through the centre of the indented area.

Figure 4 illustrates the section of specimen that had been cut for microscopic analysis. These specimens were then cut into small samples with sized 10 x 10 mm, to focus on the indented area. Before being analysed under SEM, these samples were coated with gold. The expected damages were delamination and fibre breakage.

Figure 4: Preparation of specimen microscopic scan

Result and Discussion

Load displacement curve

After performing the tests, several curves of load versus displacement were plotted as shown in Figure 5. The curves show the maximum loads that could be sustained by the pure natural bamboo and also at point where the damage occurred. Two specimens were tested which were specimen B1 and B2. Basically, the shape of the curves was as expected based on the previous studies [9-10]. The load sustained by the specimen seemed to increase gradually as the displacement increased. For specimen B1, there was decrement in force at displacement approximately 6.2 mm. This indicated that there were damages on the fibres. Specimen B1 could sustain a maximum load of 950 N while specimen B2 could sustain 700 N of load. There was a huge difference between maximum loads that could be sustained by both specimens, although both were fabricated from the same bamboo.

For further investigation, both specimens were then retested on the same spot and labelled as B1-A and B2-A. For specimen B1-A, there was drastic decrement of load at displacement of 7.8 mm because the specimen eventually broke into two pieces during the second impact. Moreover, Figure 5 shows that the maximum load that could be sustained by specimen B1-A dropped to 900 N. The decrease of load might be due to permanent damage that occurred in the first test. However, for specimen B2-A, the maximum load that could be sustained seemed to have a small increment. Again, this shows the dispersion of the tests between specimen B1 and B2 which was approximately 28%. The dispersion might be due to the surface finish of the specimen which can only be verified by further investigation.

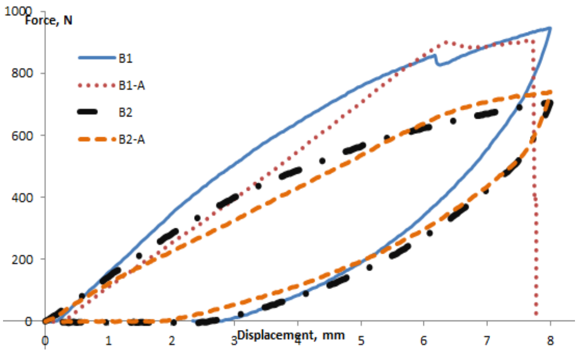


Figure 5: Load against displacement curve

Referring to Figure 5, the maximum load that could be sustained by the pure natural bamboo was less than 1000 N. According to previous studies on conventional composites [9-10], the maximum load than could be sustained was about 5000-7000 N. This shows a very large difference in term of strength between conventional and pure bamboo fibre. This might be due to the absence of the matrix. Generally, conventional fibres are reinforced with matrix that increases the material properties such as strength, toughness etc. Therefore, it is recommended in the future to hybridize bamboo fibre with suitable matrices.

The difference might be also due to the direction of the fibre. Bamboo has only single direction of fibre and there is no transverse direction of fibre. Therefore, the fibre has no transverse strength to sustain the load that is applied on it. Figure 6 shows the different orientation of conventional and natural fibre. For example, conventional woven fibre has two different orientations on the plies, which are 0° and 90° and arranged similar to a mat.

In the test, he maximum load for the bamboo structure seemed to slightly decrease (<5%) when experiencing multiple indentation loads on the same tested area. The reduction of the strength is believed due to the internal damage that occurs after experienced the first test as reported previously [10].

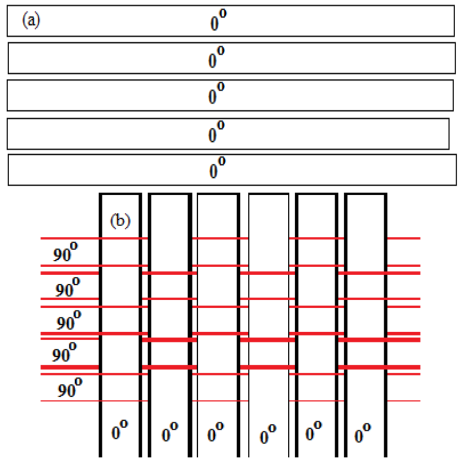


Figure 6: Different orientation of conventional fibre and laminated bamboo fibre (a) Natural fibre (b) Conventional fibre

Damage Mechanism

The physical result obtained for pure bamboo was different for each specimen. Figure 7 illustrates the damage that occurred on specimen B2, while Figure 8 illustrates the damage on specimen B1. For specimen B2, there was no big difference for the damage from first and second impact. The side view showed no increment of permanent indention after the second impact, as shown in Figure 7b. The increment of indention might be too small as it could not be seen with naked eyes. This also indicates that pure bamboo is ductile as the specimen will only bend rather than having crack or other types of damage.

However, in the second re-indentation test for specimen B1-A, it was broken into two pieces after the displacement reached 7.8 mm resulting from the drastic propagation of the intra-laminar damage in the fibre direction, as presented in Figure 8b. The half part of specimen B1-A was then further analysed under SEM to observe the behaviour of internal surface of the tested specimen.

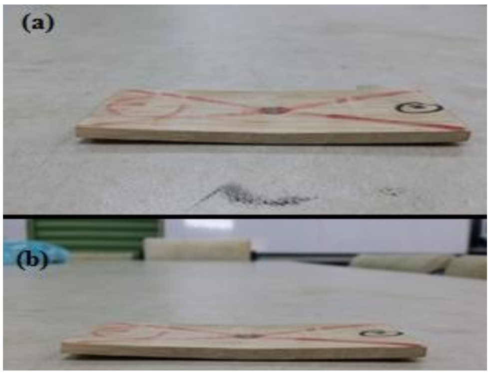


Figure 7: Damage on pure bamboo, B2 (a) First impact, (b) second impact on same specimen and impact point

Figure 10 shows the internal surface of bamboo under SEM. Basically, permanent indentation would occur due to debris resulting from fibre breakages. As shown in Figure 10, the debris was eventually trapped into the delamination area, which prevented the material from returning to its original position. Although the specimen was a pure laminated bamboo without any matrices and interfaces, it was observed that the delamination still occurred and propagated through the fibres direction, which is similar to the behaviour of matrix cracking in other conventional fibres.

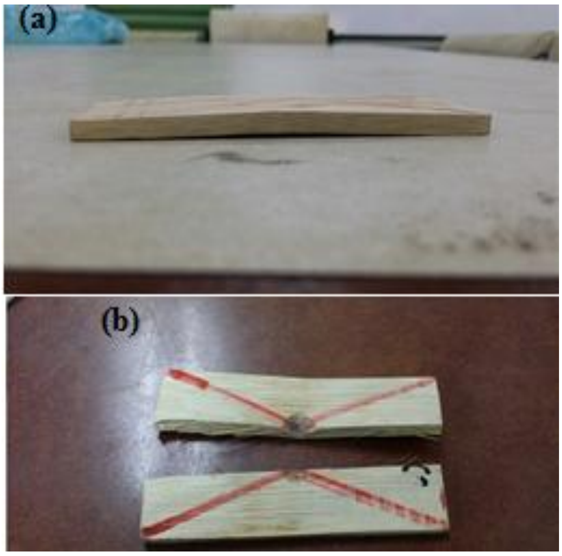


Figure 8: Damage on pure bamboo, B1 (a) First impact, (b) Retest on same specimen and spot

Figure 9: Half part of the specimen after second impact

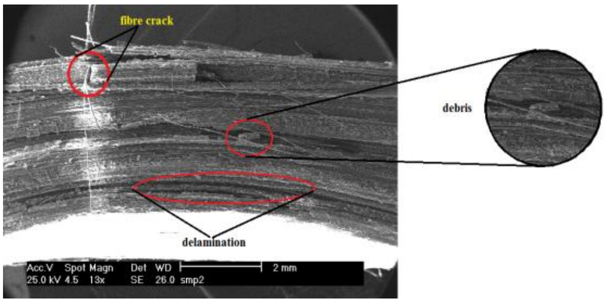


Figure 10: Internal surface of bamboo after being impacted under SEM

Conclusion

Throughout this study, the behaviour of pure laminated bamboo under indentation test has been investigated. From microscopic observation, it has been observed that natural fibre experience the same damage as conventional fibre. The common damages that can be clearly seen are the fibre breakage and delamination (cracking along the fibre direction, also known as matrix cracking for conventional fibres). Through this investigation, the most visible damage that can be seen experienced by the pure laminated bamboo is the permanent indentation that occurs on the indented area. However, it is interesting to note that the damages only occur on the indented area. Nevertheless, the bamboo might have already experienced internal damages from the first impact, which leads to have more damages during the second impact. The non-indented area shows no indentation or damages. This observation indicates that bamboo fibre is a ductile material with high fracture toughness, meaning it has high ability to absorb high impact energy without having severe destruction.

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