LOW VELOCITY IMPACT BEHAVIOUR OF PINEAPPLE LEAF FIBRE REINFORCED POLYLACTIC ACID BIOCOMPOSITES

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ABSTRACT: In this study, impact performance of biocomposites fabricated from pineapple leaf fiber reinforced polylactic acid subjected to low-velocity impact loading is presented. The biocomposites were fabricated using compression moulding technique, in which two grades of the polylactic acid matrix materials were considered. Following these, the biocomposites were subjected to dropweight impact testing as per ASTM 3767. In general, it was found that the maximum impact force and total energy absorbed increased linearly with an increase in the impact velocity. Moreover, at velocity of 3 m/s, the PLA 6100D based biocomposites exhibit slightly higher energy absorbed in comparison to those of the PLA 3251D biocomposites, with a value of 16.25 J and 15.74 J, respectively. In addition, more severe damages are observed for the 3251D PLA based biocomposites due to brittle nature of the material, leading to weaker impact properties in comparison to those of the PLA 6100D based biocomposites, as evident in the images of the front and back impact surface.

KEYWORDS: *Drop Weight; Pineapple Leaf Fibre; Polylactic Acid; Biocomposites; Low Velocity Impact*

1.0 INTRODUCTION

With rising concern on the negating effect to the environment that synthetic fibers and conventional composite materials, which are typically non-renewable and non-degradable resources have brought about the need to develop an alternative or substitute materials which are renewable, biodegradable and environmentally friendly [1-2]. Natural fibres reinforced polymer composites have been the focus of academician, engineers and research industries with their attractive and advantageous features such as lightweight, non-toxic, low densities, recyclability, low cost and biodegrability over traditional composite materials [3-5].

Moreover, well-known limitations of synthetic fibres such as Kevlar, glass and carbon to degrade upon disposal as well as high processing cost and harmful to the environment has emerged natural fibres as cost effective substitute for synthetic fibres [6]. However, one of major drawbacks of natural fibres reinforced composites is their low impact strength relative to those of the synthetic fibres reinforced composites [1] . Nonetheless, in comparison to other conventional materials such as steel, composites exhibit much higher stiffness to weight ratio and high strength to weight ratio; these have attracted more demand for uses in widespread applications[7-8].

Natural fibres such as pineapple leaf fiber (PALF) is chosen as a reinforcement material due to high cellulose contents, in the range of 70 to 82 % and low lignin contents, that is between 5 to 12 % in comparison to other type of naturals fibres [9-11]. Introduction of surface modification on natural fibres are proven to improve the adhesion interface between the fibres and matrices [2-3, 12-13]. Surface modification by chemical treatment such as bleaching, acetylation and alkaline treatment are found to be promising methods to enhance the fiber-matrix adhesion at the interface by increasing roughness of fiber surface through removal contaminants, lignin and waxy elements as well as disrupting moisture absorption process through of OH group coating in the fibres [5].

During their service life, composites are widely exposed to numerous loading condition. For example, low impact velocity can occur on composites, such as when an object such as hand tools or runway debris dropped onto composites and flying piece can impact the composites structure. Therefore, it is essentially important to understand the composites ability to withstand such impact loading condition. An understanding of the damage effect caused by low velocity impact is also a vital subject to be investigated. Usually, low velocity impact cause impact damages such as delamination, which can reduce the structural integrity of the composites materials significantly [1, 7]. Matrix failure and fibre breakage could also be observed if the impact energy is high enough to hit the composites [7]. However, the impact resistance of composites materials is more complex to be understood, since it involves different failure mode including fibre breakage, delamination at the interface, matrix cracking and fibre pull out [1].

To-date, numerous amount of published research works is reported on mechanical and thermal properties of natural fibre reinforced composites [3, 5, 10, 14, 18]. Nonetheless, there is still limited published work dedicated to dynamic behaviour of such materials, including low velocity impact testing. Moreover, majority of published literature on low velocity impact response is based on synthetic fibre reinforced composites such as glass and carbon fibre reinforced composites. Among the early published literature on natural fibre reinforced composites subjected to low velocity impact is the work by Santulli and Caruso [15]. In their paper, impact damage on flax/epoxy laminates by hand lay-up via drop weight impact testing was studied. It was found that hemp fibres reinforced composites have the potential to replace semi-structural fibreglass laminates in terms of impact resistance.

Meanwhile, Dhakal et al. [1] studied impact response of jute/methacrylate soybean oil biocomposites subjected to low velocity impact. Their experimental findings suggest that both the fibre orientation and thickness variation have a significant influence on the impact resistance of the jute/MSO composite material. The results show that the total absorbed energy and maximum peak load increase linearly with an increase in the thickness. More recently, Scarponi et al. [16] studied the low velocity impact behaviour of hemp fibre reinforced bio-based epoxy, considering the damage tolerance and progression, from the presence of barely visible impact damage (BVID) threshold up to perforation. Correlation with traditional epoxy matrix suggest that the superior toughness of the bio-based epoxy matrix composites together with high damage tolerance suggest their propect for applications in structural applications, with the establishment of an enhanced interfacial bonding between the fibre and the matrix.

In this work, low velocity impact response of PALF reinforced PLA biocomposites was studied using a drop weight impact tester. In addition, the effect of using different PLA grades as matrices for the pineapple leaf fibres in the biocomposite systems was also investigated. The samples were subjected to impact velocities of 1, 2 and 3 m/s. The impact history curves generated were studied and analysed to understand the impact response of such biocomposites. These include the load-time histories, energy absorbed as well as damage progression with varying polymer matrix and impact velocity.

2.0 METHODOLOGY

2.1 Materials

PLA 6100D and 3251D pellets were supplied by NatureWorks, LLC, USA. Pineapple leaf fibres from Josephine species was supplied from Pontian, Johor. The fibre loading used in this work is 30 wt.% which is optimum fibre loading as reported in literature [17]. The main properties of PALF and PLA are given in Table 1. Sodium Hydroxide, (NaOH) was purchased from Merck Chemicals Sdn. Bhd.

2.2 Fibres Surface Treatment

PALF fibres were surface treated with 5% sodium hydroxide (NaOH) in order to remove any impurity. By eliminating natural and artificial contaminations the NaOH treatment improved the adhesive nature of the fibres surface by creating a roughed surface structure [10].

2.3 Fabrication of the Biocomposites

PLA and PALF were oven dried overnight at a temperature of 80°C and 60°C respectively, to remove any presence of absorbed moisture and evade defects and voids formation during the fabrication process. Prior to fabrication of the composites, PLA pellets were hot pressed into 1 mm thin plate in thickness by compressing moulding with dimensions of 200 mm (L) x 200 mm (W) x 1 mm (thickness) at a temperature of 175°C and a pressure of 200 psi, with a total contact time of 20 minutes, followed by cooling under zero pressure. Following this, the thin plates were used to produce composites by using hand lamination. Here, 30 wt.% of PALF of long fibres were sandwiched in between the 1 mm thick PLA plate compression moulded at a temperature of 175°C and pressure of 1700 psi, for a total contact time of 10 minutes, prior to cooling under zero pressure. The biocomposites were cut into dimensions of 50 mm x 50 mm x 3 mm for drop weight impact testing. The PLA film was collected and stored at ambient conditions.

2.4 Drop Weight Impact Test

Drop weight impact test was carried out using an INSTRON CEAST 9340 at room temperature, in accordance with ASTM 3979 (Figure 1). In this study, a 12.7 mm diameter steel hemispherical indenter was used, with the impact velocities of 1, 2, and 3 m/s using an impactor mass of 3.602 kg. A catcher mechanism was activated to avoid multiple damage on the samples. The impact load, impact time and energy absorbed were determined from five specimens per batch. The specimens were placed on two supported stage and load were applied.

Figure 1: An experimental set-up for drop weight impact test using an INSTRON CEAST 9340 machine

3.0 RESULTS AND DISCUSSION

The experimental results are reported in terms of load-time histories, maximum impact force, energy absorbed and damage patterns to characterize the impact response of PLA/PALF based biocomposites. The average results from five repeated samples of drop weight impact testing for the 3251D and 6100D PLA-based biocomposites are presented in Table 1. The impact response of PLA/PALF based biocomposites in terms of force against time and energy against time are shown in Figures 2 and 4, respectively.

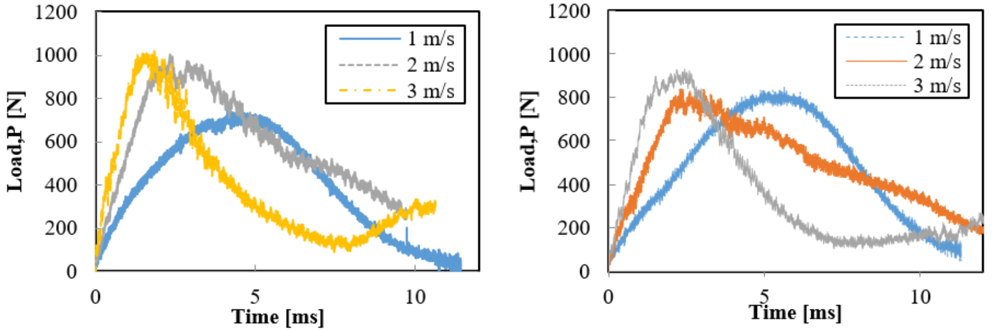
3.1 The Impact Response of Biocomposites with Varying PLA Matrix

Figure 2 shows typical force-time traces following drop weight impact tests on the biocomposites using PLA matrix of 3152D and 6100D grades, at impact velocities of 1, 2 and 3 m/s. The plot shows a linear increase in the load value with time up to the maximum force, Pmax which then decrease with time, which is associated with the reduction in the biocomposite material's stiffness due to the presence of damage at increasing load level [19].

Additionally, the maximum force for the 6100D PLA-based biocomposite samples was recorded at impact velocity of 3 m/s, with an average value of 1215.09 N at 3 m/s. This result suggests the ability of 6100D PLA-based biocomposites to sustain much higher maximum impact force, Pmax in comparison to those of the LT 3251D-based biocomposites as illustrated in Figure 3, with a maximum Pmax of only 1052.98 N.

Table 1: Average impact test results for various samples of PLA/PALF biocomposites

Properties	Sample	Impact velocity (m/s)		
		1	2	3
Peak Load (N)	6100D	978.14 ±71.77	1147.76 ±133.21	1215.09 ±83.80
	3251D	882.3 ±57.02	950.11 ±32.85	1052.98 ±117.26
Total Energy (J)	6100D	1.73 ±0.08	7.54 ±0.38	16.25 ±0.71
	3251D	1.59 ±0.11	7.65 ±0.36	15.74 ±0.76



(a) (b)

Figure 2: Load-time curve of PALF reinforced PLA biocomposites with (a) 6100D and (b) 3251D

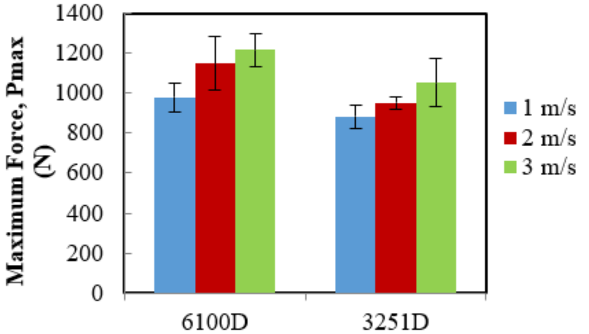
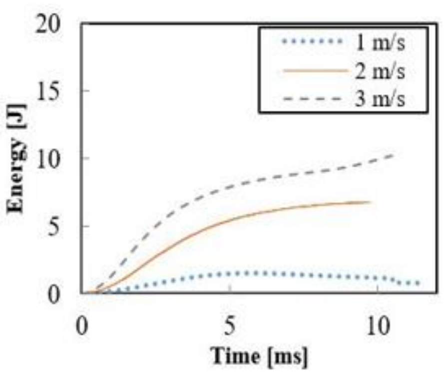


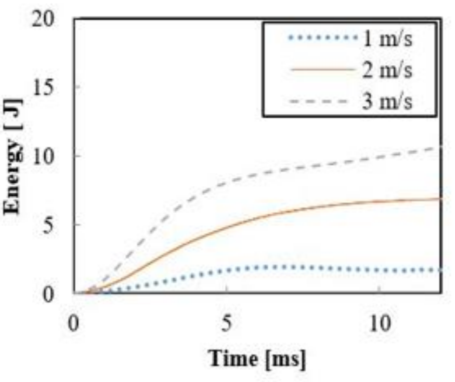
Figure 3: Pmax value for the 6100D-based and 3251D-based biocomposites

Another important finding in this work is the energy absorbed. The influence of velocity on the biocomposites' energy absorption is presented in Figure 4. The corresponding energy plots from the experimental results show a strong influence of velocity on the amount of absorbed energy. As can be seen from the graph above, the energy absorbed increase in a linear mode with increasing velocity. At velocity of 1 m/s, the biocomposites exhibit the lowest absorbed energy. At increasing velocity of 3 m/s, the biocomposites exhibit much higher absorbed energy for both grades of PLA based biocomposites, with a maximum energy absorbed values of 16.25 J and 15.74 J for the 6100D and 3251D-based biocomposites.

The instrumented drop weight impact testing requires a very small time scales. The time taken for the damage initiation and propagation through the whole samples to the point of perforation is approximately between 1-3 ms for 6100D and the shortest time taken for 3251D is 0.8-1 ms as shown in Figure 4. This result suggests that the impact duration is influenced by the impacted speed and matrix architecture.



(a)



(b)

Figure 4: Energy-time curves of PALF reinforced PLA biocomposites for (a) 6100D and (b) 3251D

3.2 Damage Characteristic of the Biocomposites with Varying PLA Matrix

Figures 5 and 6 show the impact damage characteristics of representative 6100D-based and 3215D-based biocomposites samples subjected to impact velocities of 1, 2 and 3 m/s. In general, at 1 m/s, visual observation shows the presence of barely visible impact damage (BVID), which is typically associated with delamination of the matrix for both types of PLA based biocomposites. The damage area formed at the front surface is due to localized damage when the samples are in direct contact with the indenter.

At increasing impact energy, which yielded in higher impact energy, as evident in Figure 5, it is apparent that the 6100D-based biocomposites samples suffered full penetration of the indenter, which occurred at impact velocities of 2 and 3 m/s, respectively. Here, the biocomposites samples suffered greater damage, typically associated with matrix cracking and fibre fracture. Measurement of the impact damage area yielded in a total maximum damage area of 199 mm^2 and 373.8 mm^2 following impact at 2 and 3 m/s.

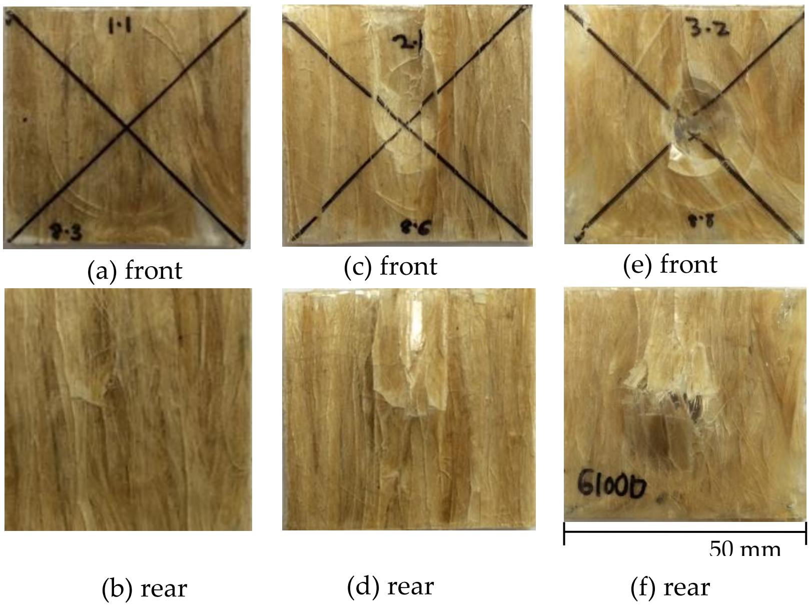


Figure 5 : Damage profiles of 6100D-based biocomposites following low-velocity impact at different velocities with (a)-(b) 1 m/s, (c)-(d) 2 m/s and (e)-(f) 3 m/s

For the 3251D-based biocomposites, as depicted in Figure 6, full penetration of the indenter is observed when the samples were subjected to impact velocity of 3 m/s, showing more brittle fracture. Measurement of the impact damage area revealed much higher total maximum damage area present in comparison to those of the 6100D-based biocomposites, with the value of 458 mm^2 and 966 mm^2 when subjected to impact velocities of 2 and 3 m/s. Such observation is possibly due to the brittle nature of the 3251D PLA matrix, causing greater amount of matrix cracking, delamination and fibre fracture [1]. Moreover, presence of defects such as voids could also yield in poorer mechanical performance causing delamination and poor adhesion at the interface between fibre and matrix interface [1, 7, 18, 20].

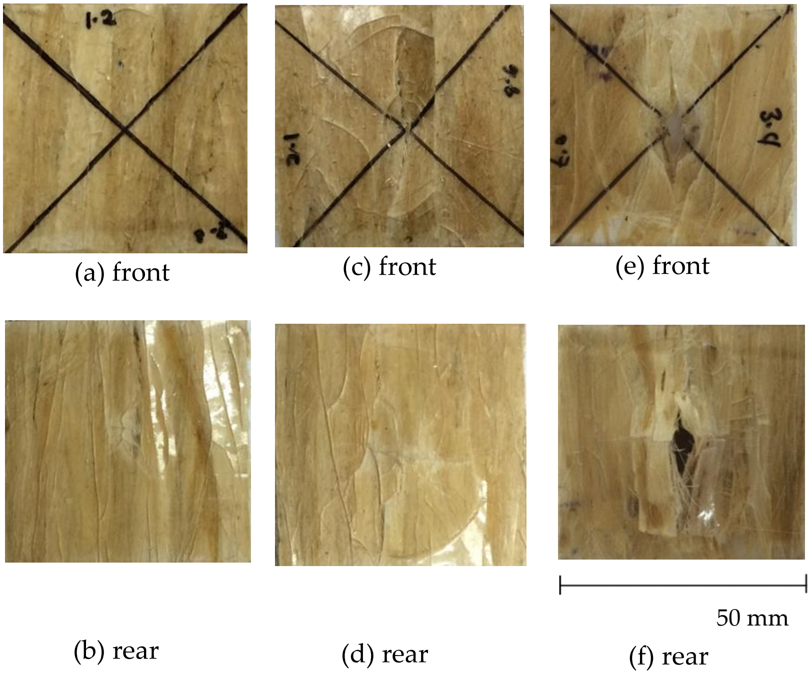


Figure 6: Damage profiles of 3215D-based biocomposites following low-velocity impact at different velocities with (a)-(b) 1 m/s, (c)-(d) 2 m/s and (e)-(f) 3 m/s

4.0 CONCLUSION

This paper presents an experimental investigation on the impact response of pineapple leaf fibre reinforced PLA biocomposites, using two grades of PLA matrix materials. Overall, the 6100D-based biocomposites exhibit superior impact properties, in terms of maximum impact force, energy absorbed and smaller damage area measured from visual observation on front and rear surface of the samples. In addition, the 3251D-based biocomposites showed inferior impact properties with presence of more severe damage at increasing impact velocity (such as 3 m/s). Such observations are possibly due to brittle nature of the matrix material which lead to relatively weaker impact properties in comparison to those of the 6100D PLA matrix materials biocomposites. Moreover, the presence of defects could also yield in poorer mechanical performance causing delamination and poor adhesion at the interface between fibre and matrix interface.

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