Influence of barely visible impact damage on post-impact residual flexural properties of hybrid Fibri Rock – Aero Eco-composites

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Abstract

This study experimentally investigates the effects of barely visible impact damage (BVID) under low-velocity impact and its influence on post-impact residual flexural properties of hybrid flax-basalt Eco-composites Fibri Rock –Aero of 2 and 4 mm in thickness using drop weight impact and 3-point bending tests. The damage-induced was characterised by X-ray micro computed tomography (X-ray μCT) technique. The results show that the post-impact residual flexural strength (PI-RFS) and modulus of the composites are dependent on their thickness and incident impact energies employed. A significant damage was evident for both types of specimens caused by microscopic inter-laminar delamination and cracks induced especially at the highest incident energy with a noticeable reduction on PI-RFS and modulus.

Keywords: BVID, post-impact residual flexural strength, hybrid flax-basalt Eco-composites Fibri Rock –Aero, delamination.

1. Introduction

Natural biocomposites, among other classes of Fibre Reinforced Plastic (FRP) composites have gained wide applications due to their enhanced inherent properties. The main attributes of natural fibre composites (NFCs) are high specific strength, stiffness and reduced concerns with health and safety during processing [1-3]. Hybridisation of two or more fibers is one technique in which the benefits of each reinforcing material can be combined to achieve a composite that demonstrates better mechanical performance and improved environmental impact leading to sustainability [4].

Recent works conducted around this topic include, but are not limited to, BVID under low-velocity impact [2,5] and post-impact residual flexural strength (PI-RFS) tests [6] on natural NFCs. However, these reports do not cover experimental investigation into the effects of BVID on PI-RFS of variable thickness using drop weight impact and 3-point bending tests successively, at different incident energy levels. The flexural after impact (FAI) test is a convincing method to measure the residual properties of impacted composites. The main objective of this study was to investigate the effects of various thickness and energy levels on the low-velocity impact behaviour and post-impact residual flexural properties of basalt/flax Polyfurfuryl Alchhol (PFA) hybrid composites.

2. Experimentation: Materials and methods

2.1 Materials

Combination of flax and basalt fibres were hybridised with Polyfurfuryl Alchhol (PFA) bio-resin to fabricate hybrid composites, FibriRock (produced and supplied by EcoTechnilin) which requires low temperature and moulding pressure leading to reduced tooling cost. It is a green sustainable material requiring low energy during PrePreg manufacturing. Flax: basalt: resin weight ratio was of 30: 35: 35 wt. %.

2.2 Processing

The material was prepared by Eco-Technilin SAS by making a needle punched flax/basalt configuration.

2.3 Falling weight impact test

A low-velocity falling weight impact was employed with a hemispherical nose impact up with a diameter of 20 mm on an Instron CEAST 9350 drop weight tower fitted in the impactor of total impact mass of 3.15 kg. The machine was equipped with anti-rebounding system. BVI tests were performed on square specimens of dimensions 100 mm by 100 mm with thickness of 2 and 4 mm at three impact energies: 5, 10 and 15 Joules (J). For examples, in real-life situations or practical scenarios, these impact energies could be experienced in the following automobile/aerospace sectors: flying road side and runway debris, low velocity ice, metal tip, small tool, bird and ground hail impacts. The test was conducted in accordance with the British Standard BSEN ISO 6603-2 recommendations [7].

2.4 Post-impact flexural test

The post-impact flexural strength and modulus were determined by using a Zwick/Roell Z030 universal machine in a three-point bending mode, a cross-head speed of 2 mm/min. The test specimens were 70 mm long, 15 mm width and 2 and 4 mm thick.

2.5 Impact-damage characterisation

The impacted specimens were imaged using X-ray μCT (Nikon XT H 225), using projection number of 3600, cut off frequency of 2.4999 Hertz, equal voxels number of 1000 at x, y and z directions, mask radius of 18.3403 mm, with scale and scaling of 1.0 and 10^3, respectively. The voxel size was 0.1148 mm.

3. Results and discussion

3.1 BVID analysis and characterisation

The force-time, force-displacement and energy-time traces subjected to different energy levels (5, 10 and 15 J) are shown in Fig. 1. Fig.1 (a_1) shows the influence of energy on the damage initiation of 2 mm specimen. Fig. 1 (a_2) shows a similar trend but with some distinct contrast on energy absorption pattern due to increased specimen's thickness. The applied energy was not sufficient to fully penetrate the specimens. The peak force for 2 mm specimens impacted at 5, 10 and 15 J energies are shown in Fig. 1 (b_1) were recorded 1217, 1406 and 1266 N, respectively. For 4 mm specimens, Fig. 1 (b_2) at 5, 10 and 15 J of impact energy levels, the impact forces were recorded at 1883, 2888 and 3048 N, respectively, an evidence of a significant increase in contact force with an increase in thickness. Figs. 1 (c_1 and c_2) display force-displacement for both 2 and 4 mm specimens. A distinct trend of increased deflection with increase in energy levels is observable for both specimens. This behaviour tends to happen due to the ductile nature of this composite where a large proportion of the energy dissipates. The deflection and the absorbed energy increases with an increase in the impact energy (Figs. 1 (b_1 and b_2). The deflection for 2 mm specimens are higher than 4 mm but contact force is significantly lower for 2 mm specimens compared to 4 mm.

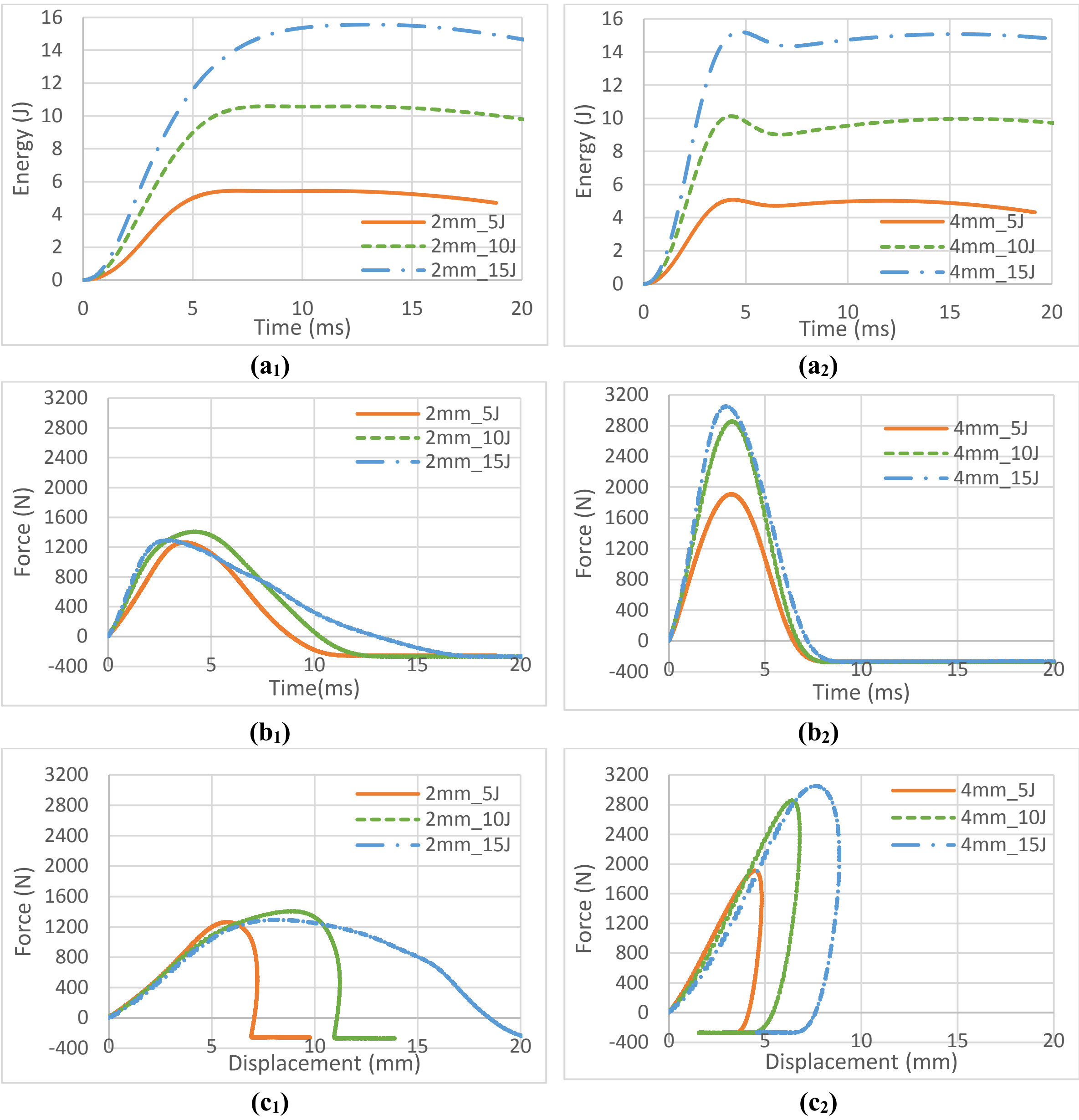
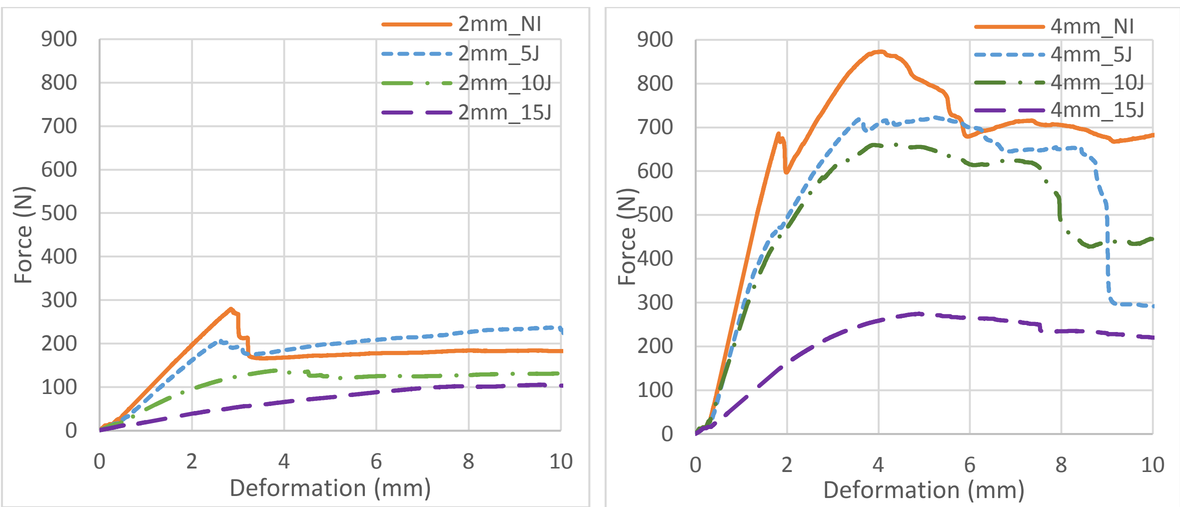


Fig. 1. Impact test results (a): energy-time traces, (b): force-time traces and (c): force-displacement traces

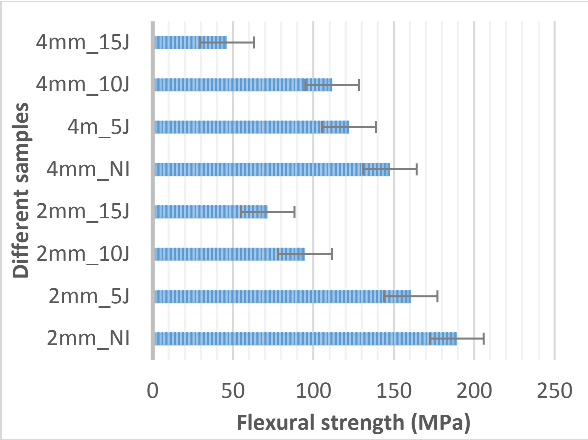
3.2 Post- impact flexural residual property analysis and characterisation

Post-impact flexural results (force-displacement) and their corresponding flexural strength and modulus have been depicted in Figs. 2 (a_1) and (a_2). The force-displacement curves, the peak forces were recorded to 864 N for non-impacted specimen. The load decreases with the increase in energy to 722, 655 and 273 N, corresponding to each three impact energy levels (5, 10 and 15 J) for 4 mm specimens. Similarly, decrease in force with an increase in energy level can be observed for 2 mm specimens but with much lower forces compared to 4 mm specimens. This behaviour is attributed to increased deflection with the increase in energy promoting micro- cracks and reducing the stiffness of the post-impacted composite structures.

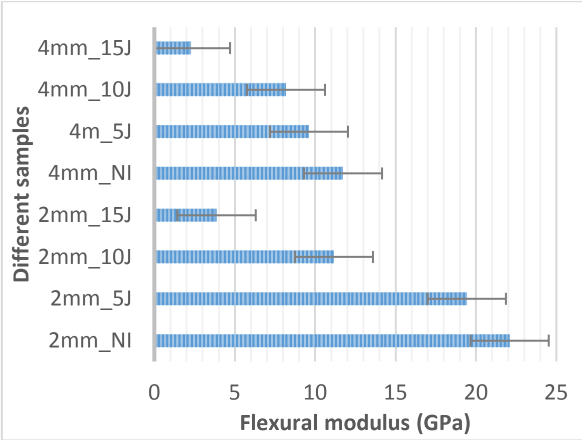
The flexural strength (Fig. 2 (b_1) and (b_2), for 2 mm non-impacted specimens is recorded at 189.16 MPa, whereas 160.42 MPa (a decrease of 15.19%) was recorded for 5 J impacted specimen, showing no significant effects at lower energy level. However, it was decreased significantly from 189.16 to 71.50 MPa (approximate drop by 62%) for 15 J impacted specimens. For 4 mm specimens, the non-impacted strength was recorded at 147.49 MPa and at 5 J impacted specimens, the strength was recorded at 122.03 MPa (reduction by 17.26%). However, for 15 J impacted specimens, the strength was reduced by 69%. Similar trend can be observed for post-impact flexural modulus values for both specimens (Fig. 2 (b). This behaviour can be related to stress concentration due to impact loading. As the energy level increases, the stress concentration near the impacted zone also increases. Therefore, the drop in flexural modulus with impacted specimens is attributed due to the loss of stiffness and increase in the deflection due to BVID. Furthermore, it is significantly evident and encouraging that the results for 4 mm fibri rock sample exhibits higher flexural (strength and modulus) properties when compared with common hemp FRP bio-composite sample of higher 5 mm thick under same energy levels of 5 and 10 J, used by Scarponi et al. [8].



(a_1) (a_2)



(b$_1$)

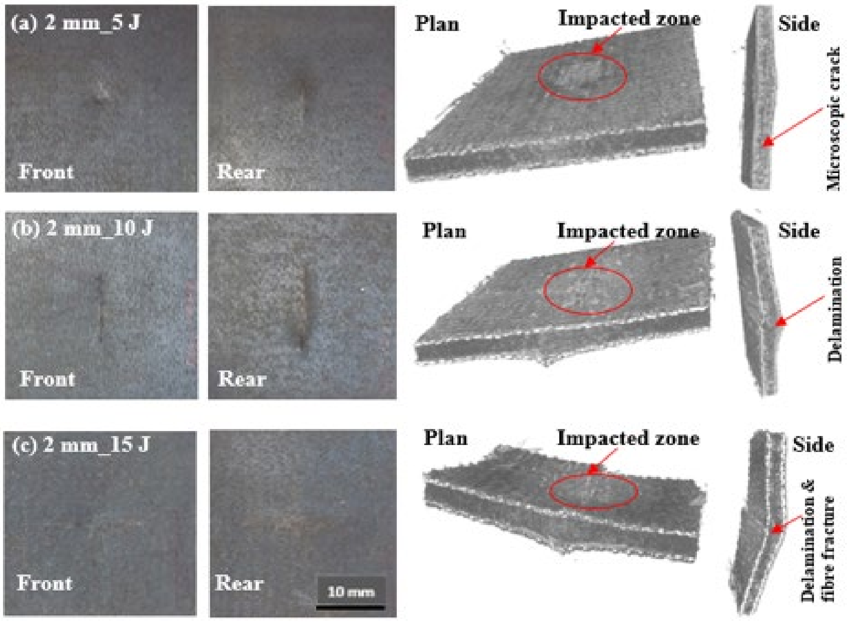


(b$_2$)

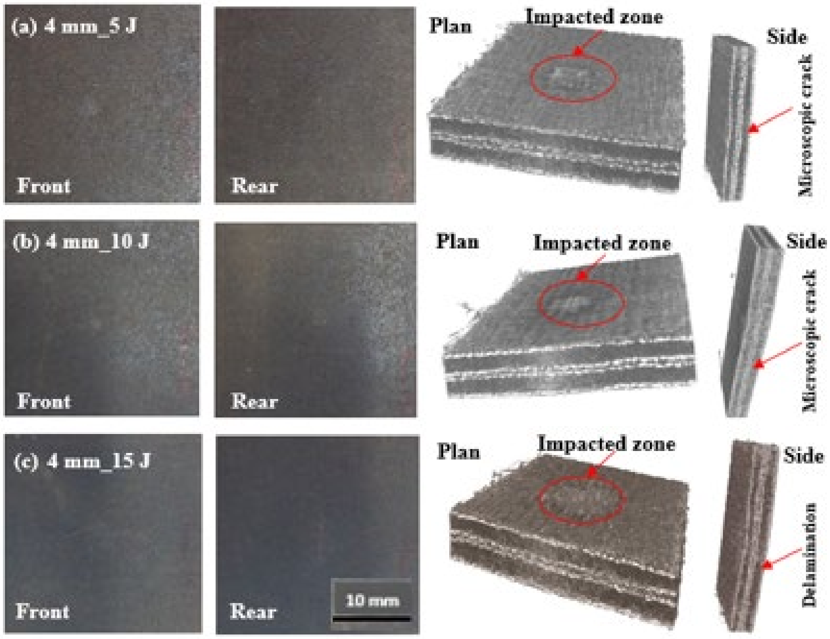
Fig. 2. Flexural test results (a$_1$ and a$_2$): load-deformation for 2 and 3 mm specimens at 5, 10 and 15 J incident energy levels; (b$_1$and b$_2$): Flexural strength and modulus for impacted and non-impacted specimens at 5, 10 and 15 J energies.

3.3 Impact and post-impact damage characterisation using µCT

X-ray µCT micrographs for front and rear faces as depicted in Figs. 3 (a) and (b) reveal that at the impacted zone, there is no visible damage present. However, the side view clearly reveals that there is damage initiated and propagated from the side of the non-impacted face and extends towards the impacted face with the increase of impact energy for both 2 and 4 mm samples. The fractured line indicates that the failure mechanism consists of delamination and micro-crack at the inner layers of flax fibre and PFA matrix (Figs. 3 (a) and (b)). The impacted front faces under visual inspection hardly show any damage. However, the µCT images of the rear faces show increased damage with the increased in energy level. This shows that even 5 J of energy was sufficient to initiate micro-cracks. For 10 and 15 J impact energies, further damage is observable at the rear faces showing delamination, and fibre fractures on the outer layers. The micro-cracks at the rear faces seem to move into the direction of fibre alignment. The µCT images show that the damage is more prevalence on the rear faces and at the higher energy level, the delamination and inter-laminar de-bonding are observed. The results show that a correlation between the increases in energy applied and the damage extent. The higher extent of damage at the rear faces would be the non-visible areas of composite structures in the real life scenarios.



(a)



(b)

Fig. 3. X-ray µCT micrographs of the samples depicting their impacted zones and resultant microscopic cracks at plan and side views, respectively with different energy levels (a) 2 mm and (b) 4 mm thick specimens.

4. Conclusions

Based on the results obtained, there was a significant reduction on PI-RFS and stiffness at 15 J energy level. For 2 mm thick specimens, the 15 J energy reduced the flexural strength and stiffness by 62% and 82%, respectively compared to non-impacted specimens. Similarly, for 4 mm thick specimen, the reduction on residual flexural strength and modulus at 15 J energy level was by 69% and 83%, respectively. Conclusively, the findings from this study has established that FibriRock has a significant potential to be used in critical engineering applications due to its low cost tooling with low energy manufacturing process leading towards more low cost sustainable composite with promising mechanical (impact and flexural) properties when compared with common existing biocomposites.

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