A study on impact behaviour of a novel oil palm fibre reinforced metal laminate system


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A STUDY ON IMPACT BEHAVIOUR OF A NOVEL OIL PALM FIBRE REINFORCED METAL LAMINATE SYSTEM

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ABSTRACT

Recently, researchers and industries have shown an increased interest in, natural fibres due to their advantages compared to synthetic fibres as it is environment friendly and low cost engineering materials. Low velocity impact response of fibre metal laminate (FML) based on short oil palm empty fruit bunch fibres according to weight percentage of 0%, 10%, 20%, 30%, 50% and 60% has been investigated. The specimens were prepared and tested using impact pendulum tester according to ASTM E-23 standard. The impact resistances of the various laminates were benchmarked with monolithic aluminium. Flat wise impact energy is almost equivalent with monolithic aluminium. This work shows that this type of FML can be used as a substitute to aluminium panels.

Keywords: fibre metal laminate, impact toughness, charpy impact test, hybrid composite structure.

INTRODUCTION

Recently, researchers and industries have shown an increased interest in natural fibres due to their advantages compared to synthetic fibres as it is an environment friendly and cost effective option for making low cost engineering materials. The environmental issues that is alarming the present scenario of the world leads to the development of alternative materials substituting the traditional non-recyclable materials such as carbon fibres and glass fibres based thermoset composites. Thus the environmentally friendly natural fibre thermoplastic composites are widely introduced to industries as they have many advantages compare to thermoset composites, excellent mechanical properties and corrosion resistance.

Oil palm fibre is one type of natural fibre which is found abundantly in Southeast Asia (Hassan *et al.* 2010). Oil palm fibre reinforced thermoplastic composites have some disadvantages; it is becoming extremely difficult to ignore the existence of hydrophilic nature. Due to the presence of a hydroxyl group (-OH) in the lignocellulosic components, results in water absorption and disrupts the interfacial bonding between fibres and matrices in the composite material, which leads to poor mechanical properties. Various treatments, such as using compatibilizers and adhesion promoters, fibre-surface and hydrothermal treatments, and the duralin process, can help to tackle the hydrophilic nature. Oil palm fibre have the ability to be reinforced with synthetic polymers such as polypropylene (PP), polyester (PE), polyvinyl chloride (PVC), phenolformaldehyde (PF), and polyurethane (PU) (Hassan *et al.* 2010).

The recent research on the mechanical properties of oil palm empty fruit bunch (OPEFB) fibre has provided insights of the fibre tensile strength and its elastic modulus. In comparison to other natural fibres, the OPEFB fibres are useful for engineering application with moderate loading condition (Gunawan *et al.* 2009). Thus, oil palm fibre reinforced composites could be of use in many industrial applications.

FML is a class of hybrid composites structure formed from the combination of metal layers sandwiching a fibre reinforced plastic layer as shown in Figure-1. In 1950, Fokker Aero-structures of Netherlands found that such bonded laminated structures successfully prevented the rapid fatigue crack growth than the monolithic materials. (Chai and Manikandan, 2014).

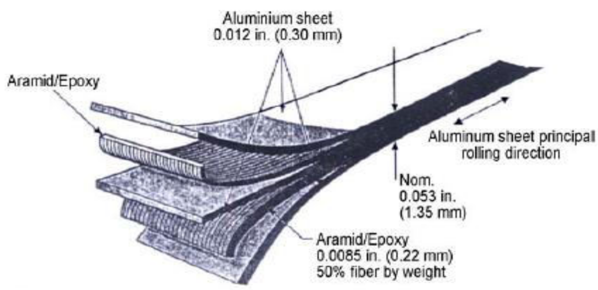


Figure-1. A sample of FML layup (Source: Khalili *et al.* 2005).

These laminated structures which are combination of composites and metals, provides excellent fatigue, impact and damage tolerance while having the advantage of low weight. The existence of fibres in the composite layers will act as a barrier against crack propagation and increase the burn through resistance as well as damping and insulation properties, while the metal layers help the ductility and impact resistance and damage tolerance (Cortes and Cantwell, 2006; Alderliesten, 2005).

Krishnakumar (1994) noted ARALL system (aramid fibre/aluminium) is relatively higher in strength to monolithic aluminium alloy. A number of works have investigated the impact response of FML systems (Vlot and Gunnink, 2001; Reyes, 2001; Compston *et al.*, 2001; Vlot, 1996). They undertook a wide range of static low and high velocity impact tests on ARALL, GLARE (glass fibre/aluminium) and CARE (carbon fibre/aluminium) as well as their constituent materials. They concluded that the post-impact damage zone in FML was smaller than for fibre reinforced composite materials.

Carrillo & Cantwell (2009) studied the impact energy absorption characteristics of thermoplastic matrix FML based on a self-reinforced polypropylene composite and 2024-O aluminium alloy. The dynamic properties of the FML were investigated in order to evaluate the effects of varying impact energy on the development of damage in the hybrid materials. Based on the findings they concluded the impacted plates exhibit a high level of energy absorption, with damage taking the form of thinning in the aluminium ply and fracture in the composite layers.

They are still lack of literature on natural fibre based FML system. In this paper, we will study the effect of OPEFB fiber loading on low velocity impact behavior of thermoplastic FML based on OPEFB reinforced polypropylene composite and 6061-O aluminum alloy.

MATERIALS AND METHODS

Composite Fabrication

The OPEFB fibres was treated with 2wt% of Sodium Hydroxide (NaOH) solution at room temperature for 30 minutes to remove the lignin, hemicellulose, wax, and oils covering the surface of the fibre. The treated OPEFB fibres were filtered out and washed several time with tap water until all NaOH was eliminated. Then, the treated OPEFB fibres were dried at room temperature overnight. The dried OPEFB fibre was cut using scissors to the length of 10 to 20 mm. Polypropylene (PP) used as the matrix for the composite was purchased from Basell Asia Pacific Ltd, Selangor, Malaysia, has a density of 0.946 g/cm^3. Maleic anhydride grafted polypropylene (MAPP) as coupling agent was fixed at 3wt% in this research. The OPEFB composite composition is shown in Table-1.

The OPEFB fibres composite were melt compounded by using Haake Polymer Lab OS Rheodrive 16 internal mixer having barrel temperatures ranging from 170℃ to 190℃ from the feeding zone to the die zone, respectively. The six type of OPEFB fibre composite by weight was then extruded, crushed and pelletized. OPEFB composite panel is made using picture frame mould of 200 mm (length, *L*) × 200 mm (width, *W*) × 1 mm (thickness, *T*) by compression moulding process.

Table-1. Composition of OPEFB composite.

FML	MAPP (wt %)	PP (wt %)	Fibre (wt %)
0	3	97	0
10	3	87	10
20	3	77	20
30	3	67	30
50	3	47	50
60	3	37	60

FML Fabrication

A modified polypropylene adhesive film was placed across the composite metal interface sandwiched between the 0.5 mm thick Aluminium 6061-O and composite as shown in Figure 2. The assembly undergo a preheat process at 155 °C for 2 minutes. Later it is pressed at 0.4 MPa while maintaining the temperature for 6 minutes and the heating source is terminated while maintaining the pressure till the temperature is dropped to 80° C. FML panels with nominal thickness of 2 mm was produced.

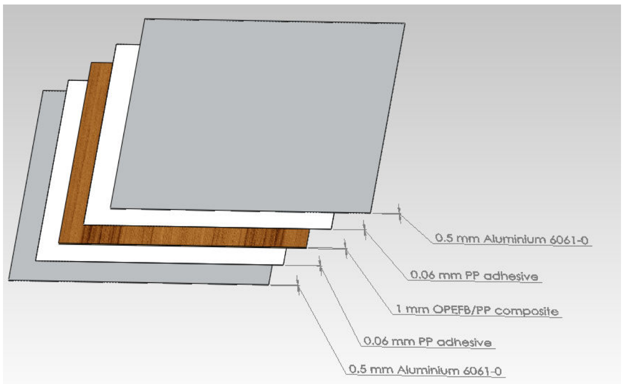
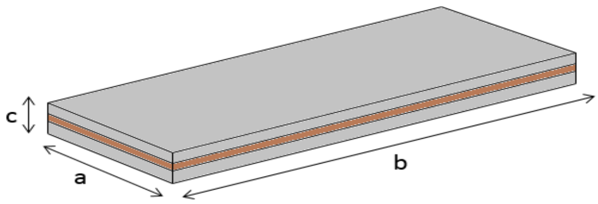


Figure-2. Typical stacking sequence of OPEFB fibre reinforced FML.

Test Specimens

The FML specimens for charpy impact test were extracted from the original plates by means of water jet cut. The dimension of the test specimen is in accordance to ASTM E 23 standard as shown in Figure-3.



ASTM	Dimension (mm)		
	a	b	c
E-23	10	55	2

Figure-3. ASTM E23 dimension for Charpy impact test.

Experimental Set up

INSTRON CEAST 9050 pendulum impact test was used to test the impact properties of the FML and monolithic metal. This equipment has the capability to test specimen up to 50 Joules. The test is conducted using Charpy hammer which is calibrated according to ASTM E- 23 in ambient temperature (25±3ºC) and relative humidity of 30±2%. The specimens are tested in two different orientations which are edge and flat wise. Figure 4 (a) and (b) shows the schematic diagram of edgewise and flatwise Charpy impact tests, respectively. The impact test was repeated three times to obtain an everage.

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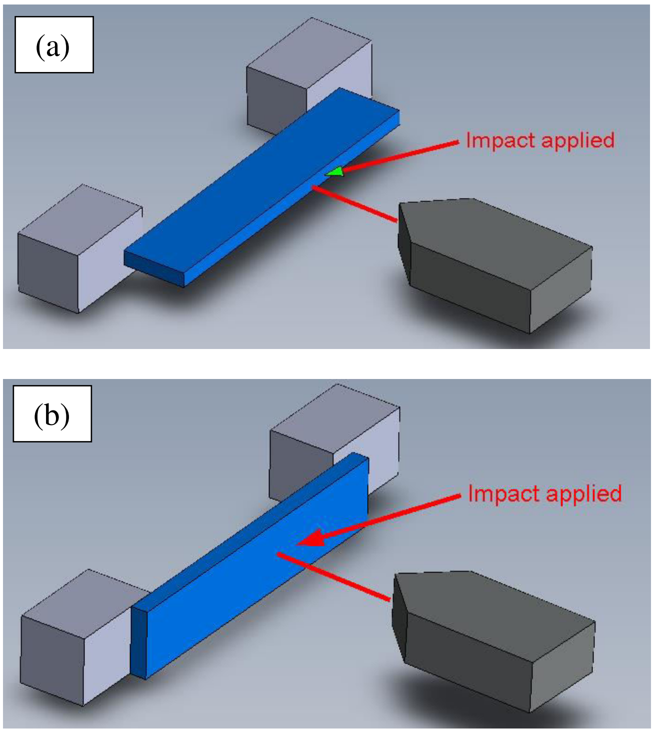

Figure-4. Schematic diagram of impact (a) edgewise and (b) flatwise.

RESULTS AND DISCUSSIONS

FML Mass Measurement

Prepared test specimens were taken to measure the mass for FML composition 0% to 60 % and benchmarked with aluminium 6061-O with the thickness of 2mm. Figure-5 shows the specimens average mass in percentage difference compared to aluminium 6061-O. Aluminium is define as 100 % in the graph and compared FML with different compositions. The line graph shows nearly 30% reduction by weight for all composition including 0% fibre FML compared to 2mm thick aluminium sample. This result justify the statement OPEFB fibre reinforce FML is lighter compared to monolithic aluminium.

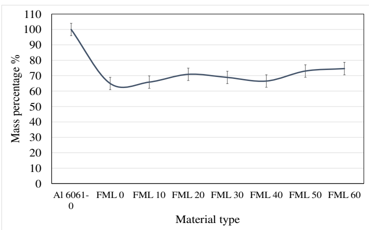

Figure-5. Mass percentage difference between Aluminium 6061-O and FML.

Impact test

Flat Wise Test

Figure-8 presents the comparison of impact energy absorbed on flatwise orientation for each composition of FML and aluminium. From the result obtained, 2mm thick aluminium shows the highest impact energy absorbed of 116.27 kJ/m^2 while 0.5 mm thick aluminium only absorbs 76.35 kJ/m^2. FML impact energy increases with increase in fibre loading up to 30wt% thereafter there is a slight drop of 10% in the energy absorbed for loading 50wt% and 60wt%. The initial increase of fibre loading eliminates the content of voids in the FML composites thus contributed to the improvement of impact strength of the FML (Ban 2015). Further fibre loading reduces the matrix to hold the fibre together causing the drop in energy absorbed. The different in energy absorbed between monolithic aluminium and 30wt% FML is only 2% whereas it is 10% compared to 60wt% FML. This shows FML can be a substitute for monolithic aluminium for flat wise impact structures.

Edgewise Impact

Figure-6 presents the impact energy absorbed during Charpy test on edgewise orientation for all FML composition and aluminium 6061-O. The trend of edgewise impact result is similar to the flatwise impact. The 2 mm aluminium alloy 6061-O absorbs the highest impact energy compare to other FML and 0.5 mm thick aluminium alloy. Among FML the highest impact energy absorbed was by 30wt% at 220.7 kJ/m^2. 2 mm thick aluminium alloy absorbs 1.5 times more energy compared to FML 30wt%, shows that aluminium alloy has superior strength to resist impact at edgewise orientation.

Comparison Flat and Edgewise Impact Test Result

Figure-7 compares the edgewise and the flatwise impact result obtain from the Charpy impact test. In general, the 2 mm thick aluminium alloy, is much stronger compared to FML especially in edgewise impact.

Aluminium alloy can resist impact 3.8 times more in edge wise compared to flatwise while FML 30wt% absorbs 0.94 times more for the similar orientation.

Higher fracture energy was observed for edgewise orientation compared to flatwise orientation where edgewise impact loading shows a strong directionality of the impact response. The higher energy absorbed at edgewise impact is due to large width orientation. Moreover, in term of layer orientation edgewise is presumed to act as crack divider while flatwise as crack arrestor. According to Es-Said *et al.* (2000), in the crack arrestor orientation each layer acts as a road block against the total fracture. Initially the crack will break layer by layer till final fracture. While in the crack divider orientation, the initial crack is divided into multiple smaller cracks that then have to continue through the remaining specimen and all layers. In this study, the flatwise impact acts as crack arrestor, the absorbed impact energy is low due to the layer by layer resistant to impact

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where the composite and aluminium material resist the impact individually. Compared to edgewise impact or crack divider the combination of composite and aluminium by layer resist the impact together which results more energy absorption than flatwise impact orientation.

Failure Analysis

According to Mishra *et al.* (2003), the impact strength is defined as the ability of a material to resist the fracture under stress applied at high speed. The impact properties of composite materials are directly related to its overall toughness. In this study, the FML failure after impact is observed by using Dino-Lite digital microscope. Liu and Malvern (1987) cited the properties of fibre, matrix and the inter phase region, affect the threshold energies or stresses required to initiate the different failure modes induced by impact.

Figure-8, 9 and 10 shows the impacted specimens. The impact properties of FML are highly influenced by many factors including interfacial bond strength, the matrix and fibre properties. Brittle fracture is characterized by flat fracture surface through both composite matrix and fibres without any fibre pull out whereas ductile fracture shows relatively rough surface with fibre pull out indication plastic deformation of the matrix.

In this study, the failure of the specimen after impacted as in Figure-8 shows the FML 0 wt % is hinged almost reaching to the brittle fracture where the matrix damaged at edgewise impact. Matrix damage is the first type of failure induced by a transverse low-velocity impact.

FML with 30 wt% fibre loading in Figure-9 for edgewise and flatwise impact indicates typical fracture features consisting fibre debonding and fibre pullout where it absorbs better impact energy compare to other FML. Meanwhile Figure 10 shows delamination occurs at 60 % fibre loading, produce by the interlaminar stress which leads to composite breakage in the FML.

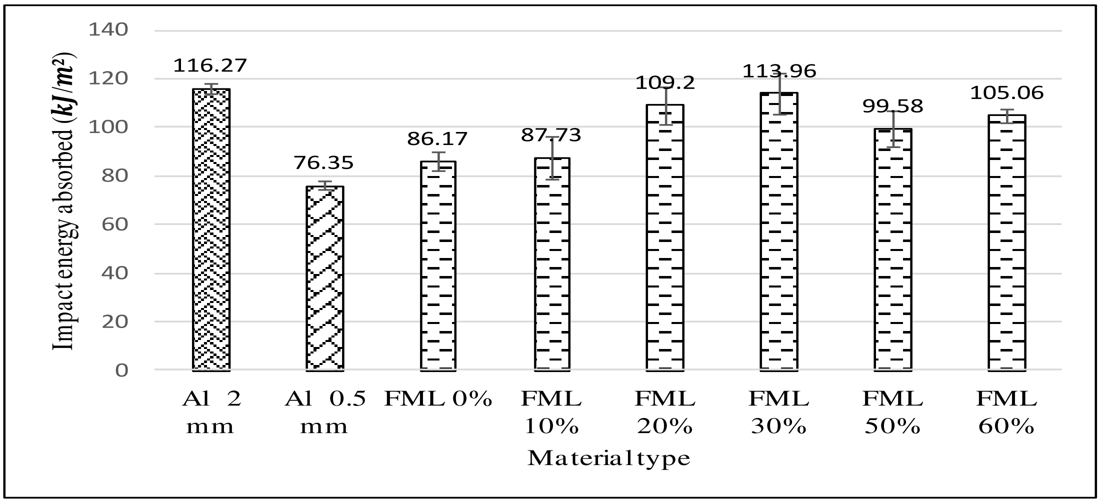

Figure-6a. Comparison of impact energy absorbed on flatwise orientation.

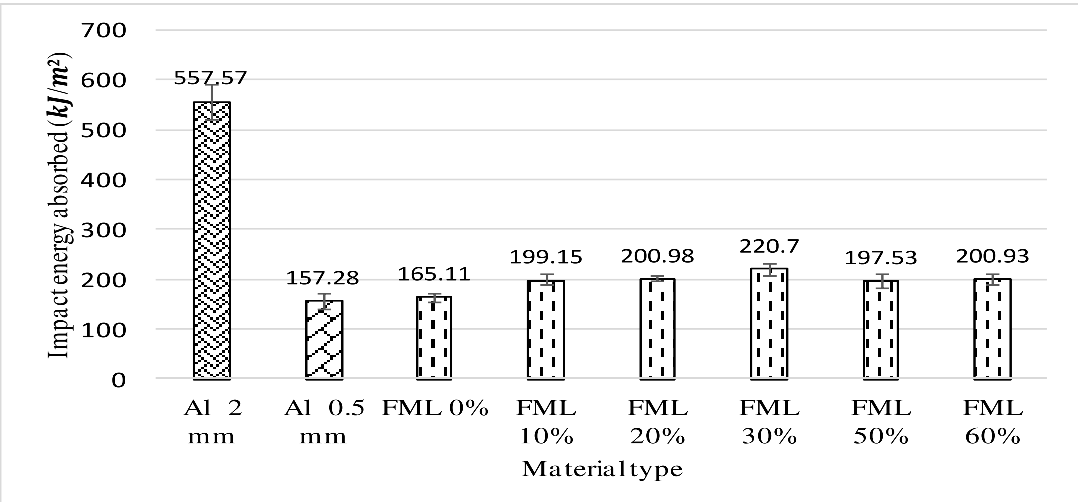

Figure-6b. Comparison of impact energy absorbed on edgewise orientation.

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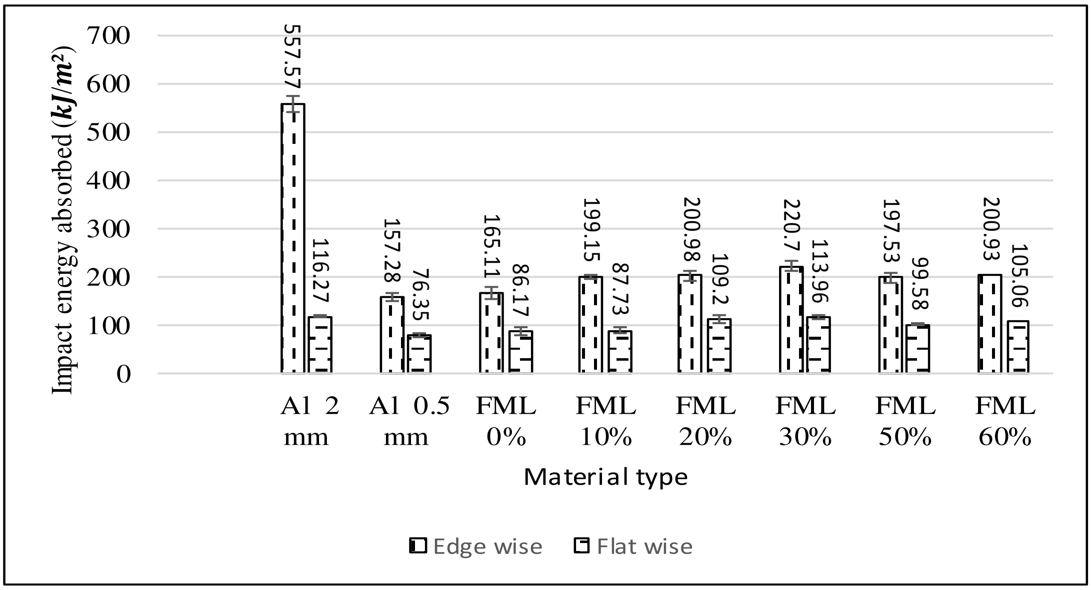


Figure-7. Edgewise and the flatwise impact result comparison.

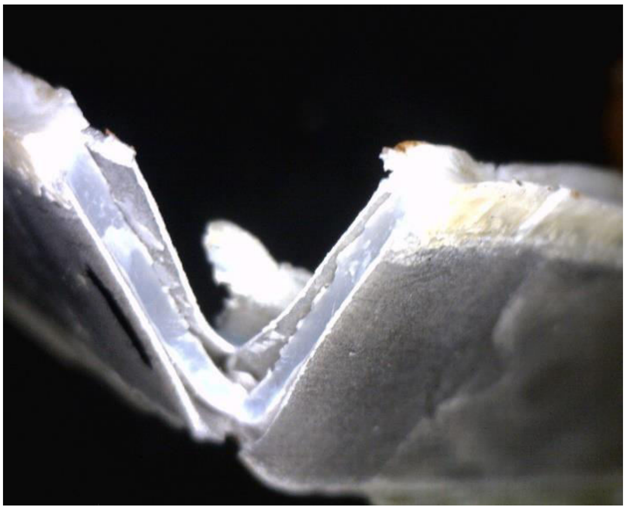


Figure-8. FML 0wt% fracture on edgewise impact.

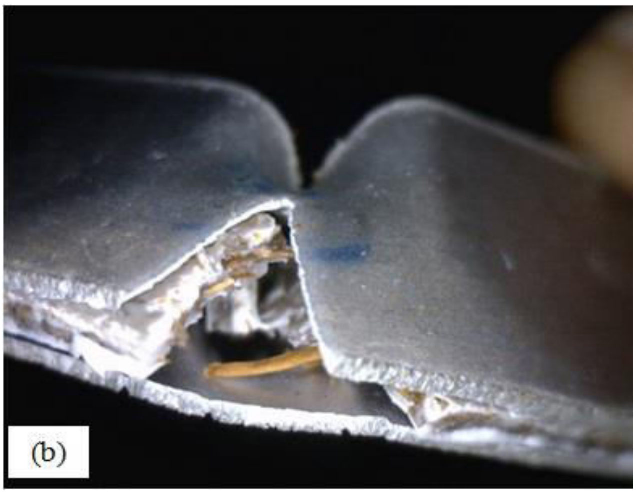
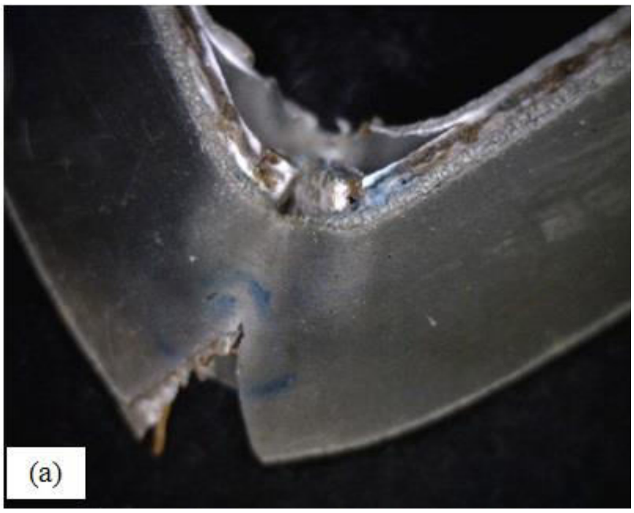
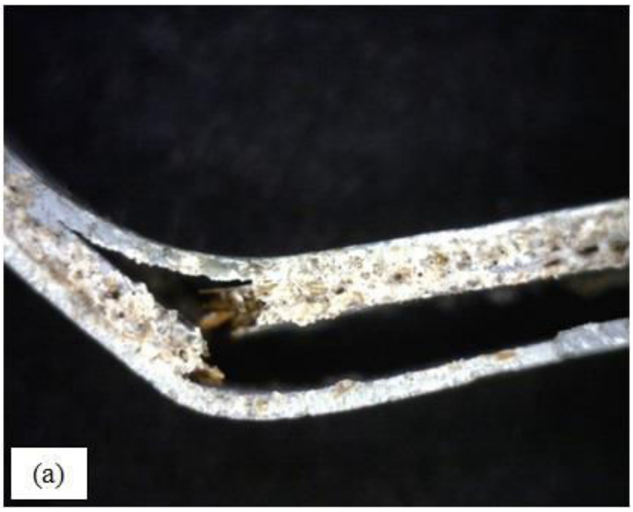


Figure-9. 30wt% OPEFB fibre FML (a) Flatwise impact; (b) Edgewise Impact.





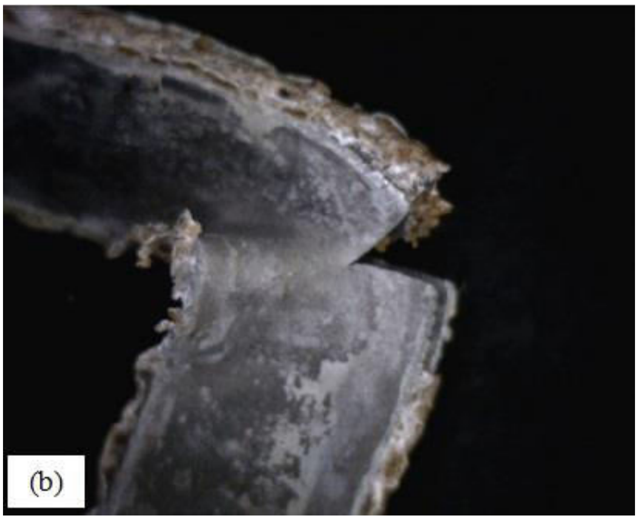


Figure-10. 60 wt% OPEFB fibre FML, (a) Flatwise impact; (b) Edgewise Impact.

CONCLUSIONS

A study on the impact properties of a thermoplastic fiber–metal laminate has been conducted. OPEFB fibre FML structure have very good flatwise impact properties compared to 2 mm thick monolithic aluminium. The different in impact energy is from 2% to 26% with FML 30wt% having the smallest different. FML is about 30% lighter than aluminum. This OPEFB fibre structure is environment friendly and renewable.

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