TENSILE PROPERTIES OF WOVEN KENAF FIBER REINFORCED POLYPROPYLENE HYBRID ALUMINIUM-COMPOSITE

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ABSTRACT

Concern on environmental impact of emission from the automobile and the uncertainties in fuel price has led to the development of lighter materials. Hybrid metal-composite is a sandwich structure which is lighter than its constituent monolithic metal. In this study, hybrid aluminium-composite (HAC) was fabricated using plain weave woven kenaf fiber reinforced polypropylene matrix composite sandwiched in between aluminium 6061-O using hot compression method. Tensile test was conducted on the HAC with two different fiber loading and fiber orientation. The fiber loading were with 1 mm pitch (X-type) and 5 mm pitch (Y-type) and the orientation were 0° and 45°. The result shows that tensile strength had been increased with the increment of fiber loading, where X-type tensile strength is higher than Y-type. Meanwhile, 45° fiber orientation gives higher tensile strength compared to 0°. The images of the fracture type experienced by the HAC after the tensile test was also observed.

Keywords: tensile, woven kenaf, hybrid metal-composite, natural fiber, fiber-metal laminate.

INTRODUCTION

Currently, conventional materials such as metal and aluminium alloy are used in most industries especially in marine, aerospace and automotive. These materials are widely used in the structural applications of the automobiles and commercial aircraft. However, the concern on the environmental impact of emission of the automobile and the uncertainties in fuel price had led to the new research on lightweight materials. Therefore a solution is needed to increase the efficiency, reduce fuel consumption and contaminant emissions besides achieving light weight coupled with safety performance of the candidate material (Reyes and Kang 2007; Reyes and Gupta 2009).Institute for Energy and Environmental Research (Helms 2004) studies revealed a weight reduction of 100 kg of a standard car reduces greenhouse-gas emissions by approximately nine grams of CO_2 equivalent per kilometer. This proves that reduction of mass can significantly contribute to the reduction of greenhouse-gas emissions from cars.

Hybrid metal-composite (HMC) is a form of sandwich structure which sandwiches composite in between layers of metallic alloy. It is known as fiber-metal laminate (FML) when the composite is reinforced with fiber. The excellent properties of hybrid metal-composite such as high impact resistance, superior corrosion resistance, good fire resistance and light weight makes the use of HMC being extensively explored (Reyes and Gupta 2009; Carrillo and Cantwell 2009; Abdullah *et al.* 2014).

Carrillo and Cantwell (2009) research showed, tensile result on self-reinforced polypropylene (Curv) based hybrid metal composite exhibited a ductile behavior while glass reinforced polypropylene (Twintex) based showed a less ductile behavior. The laminates were influenced by the constituent material. On the other hand, the ultimate tensile strength and strain at fracture was mainly dominated by the aluminium alloy. However, Baskararajan and Senthil (2012) reported that the FML mechanical properties such as tensile and flexural are depends on layer thickness. Mahesh and Senthil (2014), compared three different orientation of aluminium laminated Glare which are chopped strand mat, woven roving and 45° mat stitches. They found the strength of FML are influenced by orientation and volume percentage of fiber.

Nowadays, research in composite materials is moving towards the usage of natural fiber in order to go green. The common natural fiber used in green composites are jute, coir, hemp, flax, bamboo, sisal, pineapple, ramie and kenaf. The studies from Vasumathi and Murali (2013) which combined a portion of natural fiber into an existing FML(jute with CArbon Reinforced ALuminium Laminate, CARALL and CArbon Reinforced Magnesium Laminate, CARMAL) resulted in increasing tensile strength with the increment in the number of layers. There are very limited studies on woven natural fiber HMC. Fulton *et al.* (2011) stated woven fabric has good stability in both warp and weft directions.

The objectives of the present work are to develop HMC made of woven kenaf fiber reinforced polypropylene composite with Aluminium 6061-0 as the skin. To study the effect of fiber loading and fiber orientation on the tensile strength and failure of the fabricated HAC panel.

EXPERIMENTAL PROCEDURE

Material

The composite panel was fabricated using plain type woven kenaf fiber mat with 0.91 g/cm^3 density polypropylene as the matrix and maleic anhydride grafted polypropylene (MAPP) as binder. The metal skin used is Aluminium 6061-0 which is commonly used in the production of vehicles. Modified polypropylene glue with melt flow rate of 5-8 g/10 min was used as an adhesive to glue the skin to the composite.

The woven kenaf fiber is divided into fiber pitch of 1 mm (X-type) and 5 mm (Y-type), fiber orientation of 0° and 45°. The respective fiber mass for each layer of square (200 x 200 mm) sample is shown in Table-1. The image for woven kenaf fiber sample is shown in Figure-1.

Table-1. Description of kenaf fiber in composite panel.

Sample	Description	Mass of fiber (g)
X-0	Pitch 1 mm Angle 0°	15.45
X-45	Pitch 1 mm Angle 45°	15.19
Y-0	Pitch 5 mm Angle 0°	5.07
Y-45	Pitch 5 mm Angle 45°	5.18

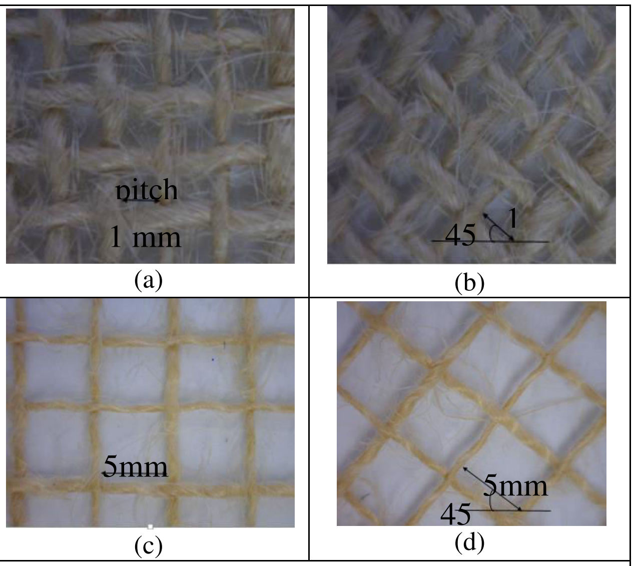

Figure-1. Woven Kenaf Fiber.
(a) Pitch 1mm Angle 0°, (b) Pitch 1mm Angle 45°,
(c) Pitch 5mm Angle 0°, (d) Pitch 5mm Angle 45°

Preparation of composite

The woven kenaf fiber is placed into a 200×200 × 1 mm stainless steel picture frame mold with the mixture of polypropylene and MAPP powder. The picture frame mold was heated to 180°C using hot press machine without pressure for 4 minutes followed by pressure of 50 kg/cm^2 for 6 minutes. The composite panel was cooled for 30 minutes. The woven kenaf fiber reinforced polypropylene composite panel produced has a nominal thickness of 1 mm.

Fabrication of HAC

The 200×200×2 mm (length×width×thick) HAC panel are made by placing a single ply of 1 mm thick woven kenaf fiber reinforced polypropylene composite in-between the 0.5 mm thick aluminium 6061-O sheets. An adhesive layer of modified polypropylene glue is applied to each bi-material interface to form the laminate structure as shown in Figure-2. The laminate is placed in a hot press and heated at 155°C for 10 minutes with pressure of 10 kg/cm^2 followed by cooling to ambient temperature under pressure.

Four HAC (X-0, X-45, Y-0 and Y-45) panels were fabricated.

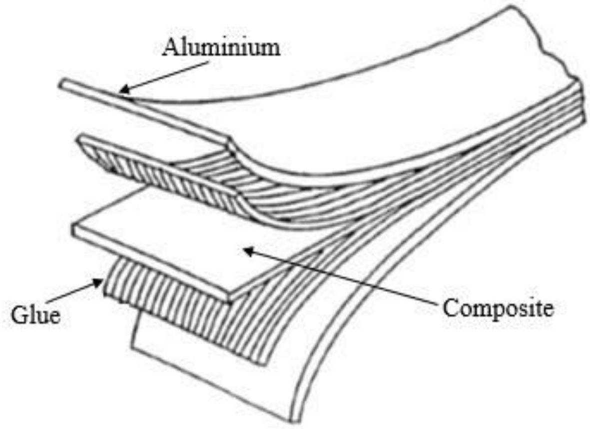

Figure-2. Structure of hybrid metal-composite (Asundi and Choi 1997).

Tensile test

The tensile test for HAC was conducted according to ASTM E8. Figure-3 shows the water jet cut dog bone specimens (a, b, c, d and e) from one HAC panel. Tensile test was performed using universal testing machine, Instron 5585. The specimens were tested at speed rate of 2 mm/min.

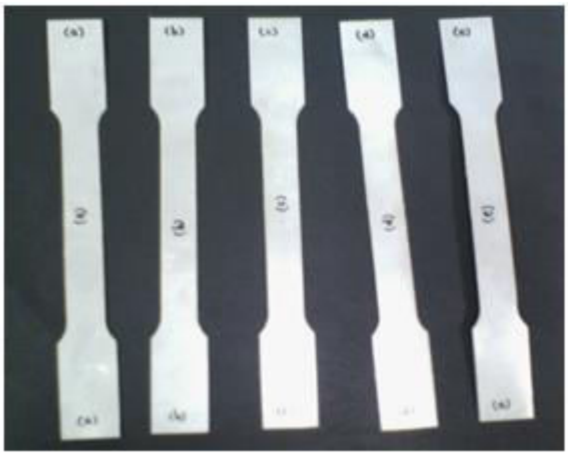

Figure-3. Dog bone shape of HAC specimen.

RESULTS AND DISCUSSIONS

Mass reduction analysis

The average value of mass for 2 mm thick dog bone shaped specimens are presented in Table-2. Average monolithic aluminium sample weights 15.33g while the HAC samples are lighter than monolithic aluminium by 30.07% to 37.51% based on the fiber pitch and orientation. Sample Y-0 is the lightest among the HAC since it has the least fiber content. The total mass of the HAC is dependent on the constituents given by the mathematical formula,

$$M_{HAC} = M_m + M_f \quad (1)$$

where M_{HAC}represents the total mass for HAC, M_m represented the mass of the matrix and M_f is the mass of the fiber. Since the density of fiber is 1.2-1.4 g/cm^3 which is higher than the PP matrix (0.91 g/cm^3) from equation (1) increase in fiber will increase the HAC mass.

Table-2. Average mass for the specimens.

Sample	Mass of specimen (g)	% weight reduction compared to Al
Al	15.33	-
X-0	10.06	34.38
X-45	10.72	30.07
Y-0	9.58	37.51
Y-45	9.82	35.94

Tensile properties

Table-3 shows the average tensile results for the developed hybrid metal-composite. The table indicates that sample X-45 has the highest ultimate tensile strength of 71.296 MPa, while sample Y-0 shows the lowest at 46.184 MPa. The elongation at break for the HAC indicated the highest elongation experienced by X-0 HAC with 9.528% while Y- 0 HAC exhibited the lowest at 1.43%.

Figure-4 demonstrated a typical engineering stress-strain curve for the developed HAC. The stress-strain curve for all the laminates exhibited in almost linear response up to maximum stress at which the composite fractured in brittle manner. However, X-0 HAC experienced a longer strain before rupture but shows less ultimate tensile strength compared to X-45 HAC. This is due to the problem in the fabrication process of woven kenaf fiber reinforced composite in X-0 HAC. The polypropylene matrix has disturbed the fiber orientation and shifted each fiber yarn closer towards another. This resulted in the superior tensile strain of X-0 sample compared to X-45 HAC.

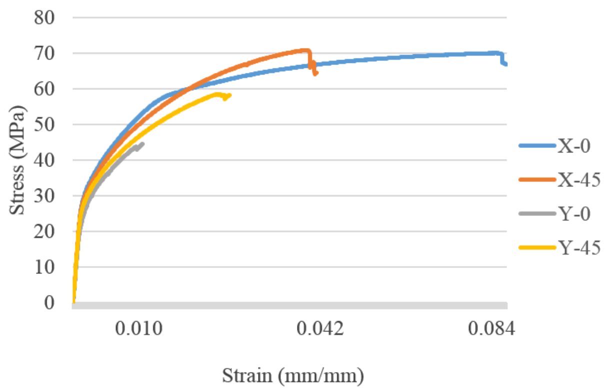

Figure-4. Stress-strain curve for HAC.

Table-3. Tensile results for HAC.

Sample	Ultimate strength [MPa]	Yield strength [MPa]	Tensile strain [mm/mm]	Load [N]	Elongation Fewqwe`
X-0	70.436	32.702	0.084	1760.874	9.528
X-45	71.296	31.874	0.042	1782.348	4.502
Y-0	46.184	29.706	0.010	1154.590	1.430
Y-45	61.834	30.854	0.034	1545.830	3.928

Effect of fiber loading

Figure-5 is extracted from Table-3. The differences between X-type and Y-type were highlighted in Figure-5 where 1 mm pitch gap shows higher tensile strength than 5 mm pitch gap of woven kenaf HAC. It is noted that fiber loading is described in term of mass as in Table 1. The results shows that more fiber loading resulted in higher tensile strength.The study from Cortes (2013) which investigated the thermoplastic fiber-metal laminates over thermoset reveals that the tensile strength of FML system is strongly depends on the composition of the composite within the layer. Based on Reyes and Cantwell (2000), the result found that the tensile strength is increasing rapidly with the increment in volume fractions. In this study, sample X with 1 mm pitch has the highest fiber mass thus resulted in higher tensile for the HAC type.

HAC specimens gain the strength from fiber bridging in order to prevent cracks from developing further due to tensile load. Higher fiber loading increases the tensile strength.

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Effect of fiber orientation

Figure-5 also demonstrates differences in fiber orientation between 0°and 45°, and the effect of ultimate tensile strength for the HAC. Fiber orientation of 45° for both X-type and Y-type indicated higher ultimate tensile strength compared to HAC with 0°.Somehow, the result of this study contradicts Takamatsu, *et al.* (2003) study which states 0° fiber orientation has higher tensile than 45° for GLARE 3 hybrid system. Similar results were observed by Moussavi-Torshizi *et al.* (2010)where 0° fiber orientation improved yield stress and ultimate tensile stress on aluminium and glass/Kevlar fiber hybrid system.

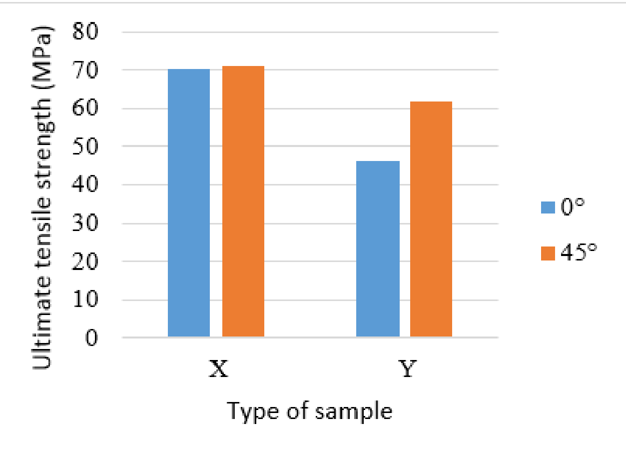

Figure-5. Difference in fiber loading and orientation.

Failure analysis

The optical observation on failed HAC specimens was performed using Dino-Lite Digital Microscope. The failure of the HAC in tensile were analysed and classified into several failure type such as (a) composite fracture; (b) delamination; and (c) total HAC failure.

Most of the HAC specimens only broke in the composite part while the aluminium remain in good condition as shown in Figure-6(a). It might be due to woven structure of the kenaf fiber used. The woven structure design will increase the tensile strength of a dry fabric; however it may change due to some factor such as tension and contraction. This may not affected the dry fabric but will clearly viewed in the form of composite (Saiman *et al.* 2014).

Meanwhile, only few HAC specimens experienced delamination when failed. Many of the other specimens did not show any delamination after tensile test thus proved that the hybrid system had very good adhesion between aluminium and composite. Figure-6(b) indicates delamination between composite and aluminium for sample X-45.The delamination is closely related to the bridging effect. Smaller bridging effect is expected to have greater delamination (Takamatsu *et al.* 2003).

The results revealed that total HAC failure were experienced for Y-type which indicates fracture in both aluminium and composite panel as shown in Figure 6 (1c and 2c). It was found that some HAC exhibited failure in both aluminium and composite plies however did not break off. In this case, the specimen did not separate into two part since the fiber in composite is still connected.Closer examination on the specimens which was broken (Figure-2c) observed fiber pull-out in the fractured composite part.

During experiment, aluminium plies in the HAC system did not show any formation of necking before failure. The finding is consistent with Reyes (2007), which found no necking on the hybrid system as normally found in aluminium alloy and other thermosetting-based hybrid system.

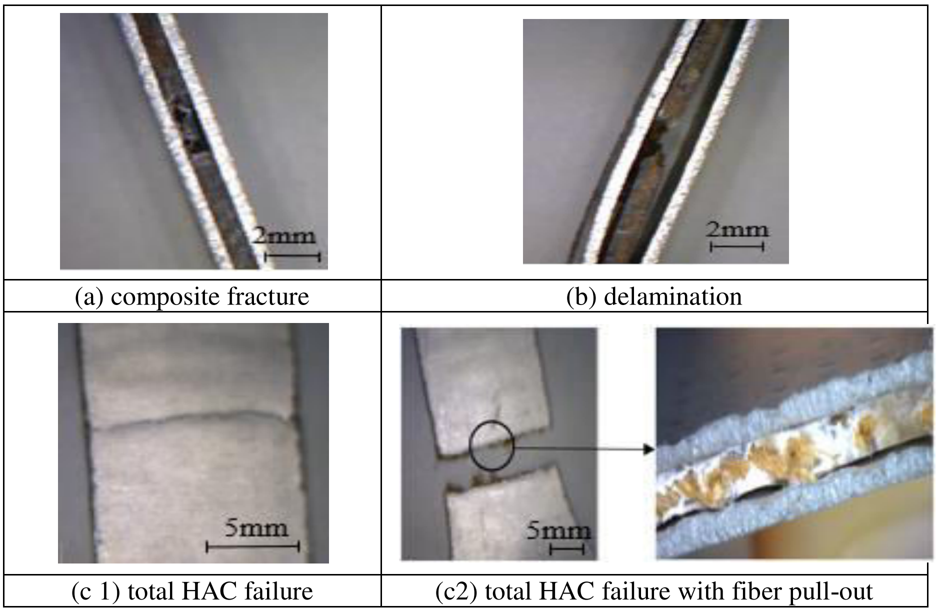

Figure-6. Type of failure of HAC after tensile test.

CONCLUSIONS

In conclusion, the hybrid aluminium - composite (HAC) made of woven kenaf fiber reinforced polypropylene composite with aluminium alloy has been successfully fabricated using hot press compression method. HAC is almost 40% lighter than monolithic aluminium. HAC X-45° exhibit highest tensile strength of 71.296 MPa. The tensile properties of the hybrid system depend on the constituent materials. Both aluminium and kenaf reinforced polypropylene composites reveals a brittle behavior. Furthermore, the increasing of fiber content showed an increment in tensile strength. The fiber orientation of 45° exhibited higher tensile strength compared to 0°.

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