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# Influence of Kenaf Fibre Orientation Effect on the Mechanical Properties of Hybrid Structure of Fibre Metal Laminate

**L. F. Ng[1]*, D. Sivakumar[1,2], K. A. Zakaria[1,2], O. Bapokutty[1,2] and Sivaraos[3]**

*[1]Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,*
*76100 Durian Tunggal, Melaka, Malaysia*
*[2]Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,*
*76100 Durian Tunggal, Melaka, Malaysia*
*[3]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya,*
*76100 Durian Tunggal, Melaka, Malaysia*

## ABSTRACT

Efforts to reduce manufacturing cost and negative environmental impacts have seen the mixture of natural fibre with synthetic fibre in composite structures. However, there are limited studies on the notch effect and fibre orientation on mechanical properties of hybrid fibre metal laminate (FML). In this study, tensile properties of FML with notch and different fibre orientation were investigated. The hybrid FML incorporated with kenaf fibre at the middle layer was compared with FML with three layers of E-glass fibre. Kenaf fibre and E-glass fibre used were in plain woven form. The FML in 2/1 configuration was manufactured through hot press manufacturing method to bond layers of annealed aluminium 5052 to the composite. Tensile test was conducted in a quasi-static manner according to ASTM E8. The results showed FML with three layers of glass fibre exhibited higher tensile strength compared with hybrid FML. However, the introduction of kenaf fibre in hybrid FML reduces the notch and fibre orientation sensitivity compared with glass fibre reinforced FML.

*Keywords:* Fibre metal laminates, fibre orientation, hybrid, mechanical properties, notch effect

## INTRODUCTION

Fibre Metal Laminate (FML) as shown in Figure 1 has been used in a wide variety of applications especially in the aerospace industry over the last decades. The FML is made of alternative layers of metallic alloys and polymer composites bonded using an adhesive agent. Thermosetting-based FML was developed in Delft University of

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*E-mail addresses:*
nglinfeng@yahoo.com (L.F. Ng),
sivakumard@utem.edu.my (D. Sivakumar),
kamarul@utem.edu.my (K. A. Zakaria),
omarbapokutty@utem.edu.my (O. Bapokutty)
*Corresponding Author

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Technology to overcome the disadvantages of aluminium alloys and polymer composites. It combines the advantages of metallic alloys and polymer composites (Pawar et al., 2015). The development of FML overcomes poor fatigue and corrosion characteristic of metal and low tensile and impact strength as well as reparability in composites (Sinmazcelik et al., 2011).

In recent times, FML is being considered for several applications in the automotive field due to its outstanding impact properties and fatigue crack resistance as well as strength to weight ratio compared to conventional aluminium alloy. Previous experimental work on FML with glass fibre reinforced polypropylene composite had shown this structure provides excellent resistance under low and high impact loadings (Reyes & Cantwell, 2000). Glass fibre reinforced epoxy (GLARE) FML was proven to have superior tensile strength than monolithic aluminium at high strain rate (Zhu & Chai, 2012). Furthermore, Vogelesang and Vlot (2000) found that fatigue crack growth rate in FML was one tenth or one hundredth compared with monolithic aluminium. Cheah (2010) stated that 10% weight reduction in vehicle can reduce 7% energy consumption. Glass fibre reinforced polypropylene FML is found to be lighter than aluminium alloys and steel up to 30% and 65% respectively (DharMalingam et al., 2014; Subesh et al., 2015).

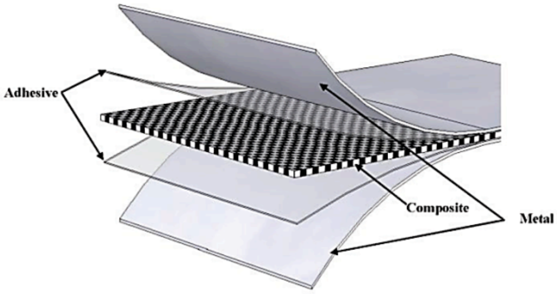


*Figure 1.* FML structure (DharMalingam & Kalyanasundaram, 2013)

In order to reduce  energy consumption and negative impact on the environment, natural fibres such as kenaf, flax and jute fibres together with thermoplastic are explored in FML fabrication. Natural fibres have a relatively lower density and biodegradable characteristic compared with synthetic fibre, and are a good candidate to substitute synthetic fibre (Shinji, 2008). The main limitation in natural fibre is its hydrophilic behaviour which results in poor compatibility with thermoplastic matrices and low mechanical strength (Fiore, 2015). One way to overcome its limitations is through hybridization of natural fibre with synthetic fibre. It had been shown that hybridization of natural fibre with synthetic fibre can reduce hydrophilic behaviour, therefore, improving the tensile strength and impact properties of the composite structure (Khalil, 2009).

In the transport industry, holes are drilled for assembly purposes but this eventually affects the service performance of the structure. There are limited studies that address the notch effect and fibre orientation on the mechanical properties of FML. Pawar et al. (2015) on their analysis of drilling hole in GLARE found 2-fluted drill provided the best quality in the drilling of GLARE without delamination and acceptable burr formation compared with 3-fluted, 4-faceted and 8-faceted drills. A study by Qi et al. (2015) on the effect of fibre orientation on mechanical properties of carbon fibre reinforced aluminium matrix composite, concluded that fibre orientation had a significant effect on the ultimate tensile strength of the composite. There are not many studies on bio-based hybrid FML and therefore, in this study, tensile test at the quasi-static rate was conducted to study the effect of notch, fibre configuration and fibre orientation on the mechanical response of bio-based hybrid FML.

## MATERIALS AND METHODS

Plain weave woven kenaf fibre, 295 g/m$^2$ in areal weight, was obtained from Lembaga Kenaf dan Tembakau Negara. Meanwhile, plain weave woven E-glass fibre with an areal weight of 600 g/m$^2$ was obtained from ZKK Sdn. Bhd. Homopolymer polypropylene (PP) granule with a density of 0.9 g/cm$^3$ was supplied by Al Waha petrochemical company. The coupling agent, Maleic Anhydride Polypropylene (MAPP), was provided by Sigma-Aldrich Co Inc. Skin layers of FML, aluminium 5052-H32, was obtained from Novelis Inc. The thickness of aluminium used was 0.5 mm. Modified polypropylene with a density of 0.91 g/cm$^3$ was used as an adhesive agent to bond aluminium skin layers to composite.

### Preparation of FML

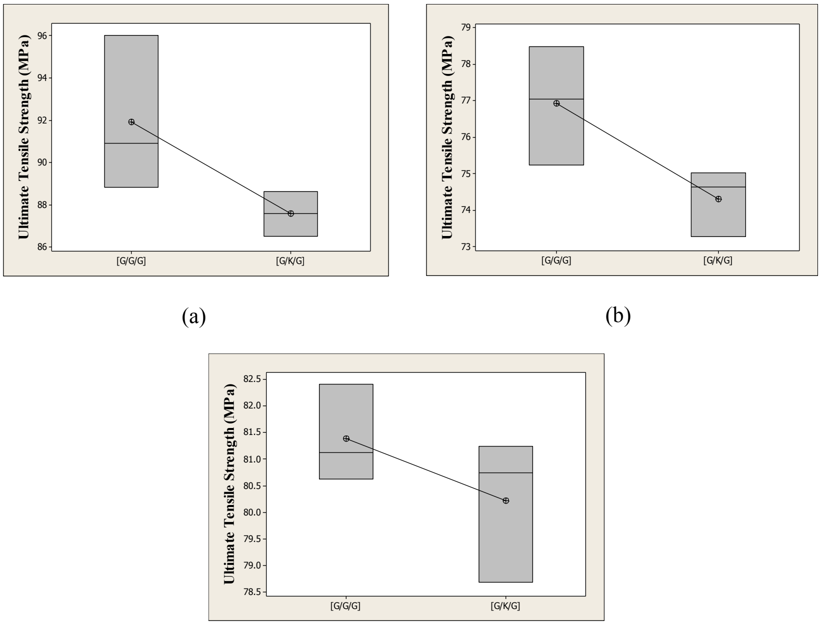
A composite with a thickness of 3 mm was manufactured using GOTECH hydraulic hot press machine. PP was first mixed with 3 wt% of MAPP using HAAKE Rheomix OS internal mixer at 175°C and 50 rpm. This process was aimed at improving the adhesion between thermoplastic matrix and reinforcement thereby boosting its mechanical properties (Agung et al., 2012; Fabiola et al., 2010). The mixtures were then compressed to form PP sheets with 0.5 mm thickness. Three layers of woven fibre were aligned according to their warp direction. PP sheets were stacked between the layers of fibre and the entire stack was compressed at 3.5 MPa hydraulic pressure and temperature of 175˚C to form composite panels. The total fibre volume fraction for composites was controlled at around 22%. The FML was prepared through hot press compression method. Aluminium 5052-H32 was first annealed at 345ºC using Nabertherm N41/H furnace. The FML with 2/1 configuration was stacked as shown in Figure 1 in a picture frame mould and adhesive agents were located at the bilayer. The configuration was then hot compressed at a controlled temperature of 170ºC and pressure of 1 MPa. Glass fibre reinforced FML was represented as [G/G/G] whereas hybrid FML was represented as [G/K/G]. The produced FML panels were cut according to ASTM D3039. Some of the specimens were drilled to form 4 mm diameter hole.

### Mechanical Test

A tensile test was conducted at a quasi-static cross-head displacement rate of 2 mm/min according to ASTM D3039 standard using Instron 8802 Universal Testing Machine (UTM). The tensile properties of notched specimens were determined in accordance with the net crosssectional area. Failed specimens were then analysed using Scanning Electron Microscope (SEM).

## RESULTS AND DISCUSSION

The tensile behaviour of glass fibre reinforced thermoplastic FML are compared with FML which is hybrid of natural fibre and synthetic fibre. Figure 2 shows the boxplot for FML and hybrid FML. The results show the effect of kenaf fibre is not significant for un-notched specimens (p-value = 0.122) and specimens with ±45º fibre orientation (p-value = 0.287) whereas notched specimens (p-value = 0.073) are close to being statistically significant at a confidence level of 95%. Figure 3 shows the stress-strain curve for un-notched FML specimens. From Figure 3, failure mechanism for both FML shows the combination of tensile behaviour of aluminium and composite. Failure of the specimens started in composite followed by aluminium layers. Glass fibre reinforced thermoplastic [G/G/G] FML exhibited higher tensile strength than hybrid [G/K/G] FML. Since glass fibre is stronger than natural fibre, FML has higher ultimate tensile strength compared with hybrid FML. The ultimate tensile strength and modulus of FML and hybrid FML were found to be 91.9 ± 3.7 MPa, 23.6 ± 0.3 GPa, 87.6 ± 0.9 MPa and 23.1 ± 1.3 GPa respectively.



(a) (b)

(c)

*Figure 2.* Boxplot for FML and hybrid FML: (a) un-notched; (b) notched; and (c) ± 45º fibre orientation

Figure 4 shows the stress-strain curve for notched FML specimens under tensile test at quasi-static rate. Notch develops stress concentration in the specimens, thus, reducing their tensile strength. The presence of notch reduced the ultimate tensile strength of FML and hybrid FML by 16.3%, from 91.9 ± 3.7 MPa to 76.9 ± 2.6 MPa and 15.2%, from 87.6 ± 0.9 MPa to 74.3 ± 1.6 MPa respectively. The tensile behaviour of FML implied that glass fibres are more sensitive to notch effect compared with kenaf fibre. Notch develops damage in the layer of glass fibres and kenaf fibre. When the load increases, the damage starts to propagate around the notch due to high stress concentration. The higher notch sensitivity of glass fibres is because they mainly depend on the matrix for stress transfer whereas kenaf fibres are able to transfer stress across their filaments through sliding friction. The cell walls of natural fibres consist of helically wound cellular microfibrils (John & Anandjiwala, 2008). This alignment of kenaf fibre allows the fibres closely hold together under tensile test and hence, stress can be transferred efficiently thereby postponing failure in the notched hybrid FML.

Figure 5 shows the stress-strain curve for FML with ±45º fibre orientation. The results showed the ultimate tensile strength for both FML with ±45º fibre orientation was lower compared with FML with 0º/90º fibre orientation. Ultimate tensile of 0º/90º [G/G/G] FML was higher by 10.5% compared with ±45º [G/G/G] FML. Meanwhile, ultimate tensile of 0º/90º [G/K/G] FML is higher than ±45º [G/K/G] FML by 10.2%. When the load is applied to the specimen, ultimate tensile strength of both FML with ±45º fibre orientation is dominated by matrix behaviour whereas the ultimate tensile strength of both FML with 0º/90º fibre orientation is governed by fibre properties. Fibre is considered to fully reinforce the matrix when the load is applied along the fibre axial direction, hence it is the main carrier of the load. However, when the fibre orientation is ±45º, it is affected by tensile stress and shear stress which weakens the reinforcement effect. The presence of shear stress reduces the bearing capacity of fibre to fully carry the load. It was observed [G/G/G] FML ultimate tensile strain was higher than hybrid FML for ±45º fibre orientation and vice versa for 0º/90º fibre orientation.

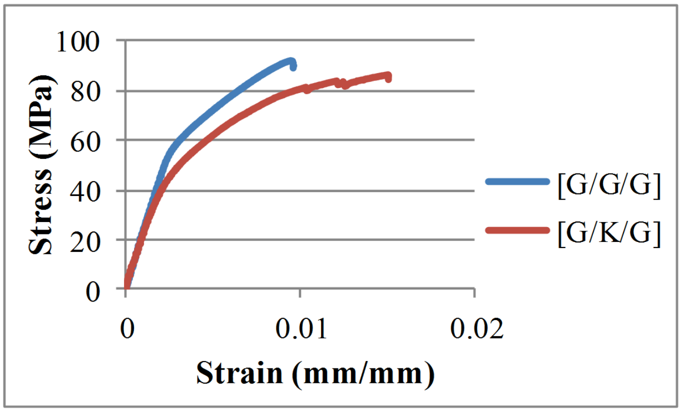


*Figure 3.* Stress-strain curve for un-notched FML

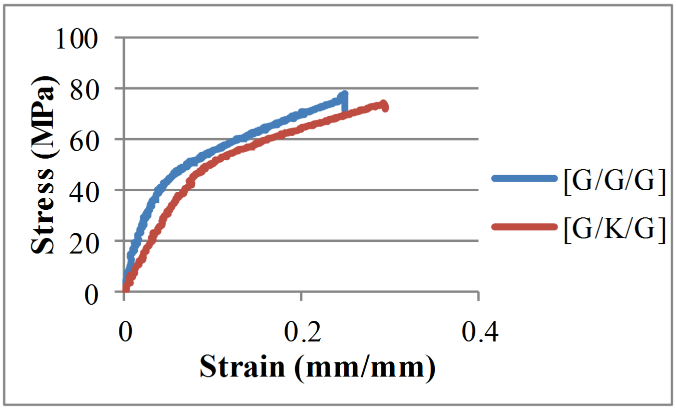


*Figure 4.* Stress-strain curve for notched FML

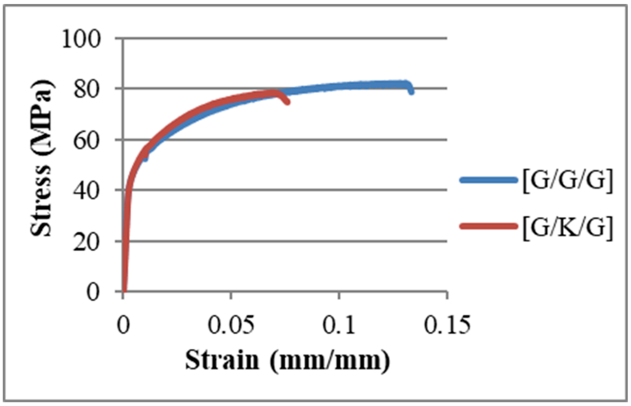
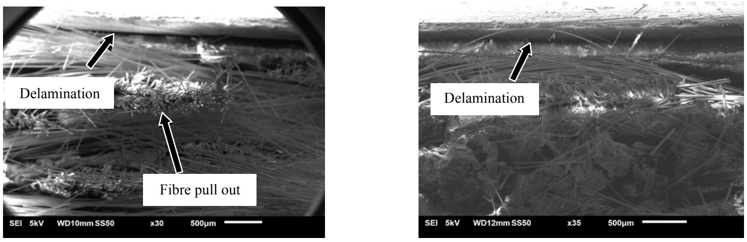


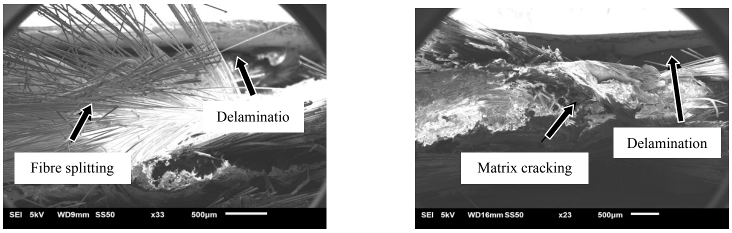
*Figure 5.* Stress-strain curve for un-notched FML with ±45º fibre orientation

Figure 6 and Figure 7 show the damage mechanism of tensile failure for FML with 0º/90º and ±45º fibre orientation which can be characterised by delamination, fibre pull out and matrix cracking. The introduction of kenaf fibre does not significantly affect the failure mechanism. Fibre splitting was observed in glass fibre for every failed FML specimens. However, fibre splitting behaviour cannot be observed in kenaf layer either in FML with 0º/90º fibre orientation or FML with ±45º fibre orientation. This is due to the mechanical interlocking behaviour of woven kenaf layer.



(a) (b)

*Figure 6*. Typical tensile fracture view of failed FML specimens with 0°/90° fibre orientation under SEM: (a) [G/G/G]; and (b) [G/K/G]



(a) (b)

*Figure 7*. Typical tensile fracture view of failed FML specimens with ±45º fibre orientation under SEM: (a) [G/G/G]; and (b) [G/K/G]

## CONCLUSION

This study investigated the effect of notch, fibre orientations and fibre configuration on the tensile properties of FML. Two fibre configurations were considered: FML with three layers of woven glass fibre [G/G/G] and FML with hybridization of one layer of kenaf fibre with glass fibre [G/K/G]. The mechanical properties of hybrid FML were relatively lower than glass fibre reinforced FML irrespective of notch and fibre orientation effect. The introduction of notch reduces the ultimate tensile strength of FML in both configurations. However, the notch sensitivity of hybrid structure of FML was relatively lower than glass fibre reinforced FML. The FML with ±45º fibre orientation showed reduced ultimate tensile strength in comparison to FML with 0º/90º fibre orientation due to shear stress which causes damage to the fibre and hence, weakens the fibre strength. Overall, the hybrid structure of FML shows less notch and fibre orientation sensitivity compared with glass fibre reinforced FML.

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