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PAPER

Investigation of natural fibre metal laminate as car front hood

Noordiana Mohd Ishak[1], Sivakumar Dhar Malingam[1,*], Muhd Ridzuan Mansor[1], Nadlene Razali[1], Zaleha Mustafa[2] and Ahmad Fuad Ab Ghani[3]

[1] Centre for Advanced Research on Energy, Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2] Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[3] Fakulti Teknologi Kejuruteraan Mekanikal Dan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[*] Author to whom any correspondence should be addressed.

E-mail: noordianaishak@yahoo.com, sivakumard@utem.edu.my, muhd.ridzuan@utem.edu.my, nadlene@utem.edu.my, zaleha@utem.edu.my and ahmadfuad@utem.edu.my

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Abstract

Due to the increasing awareness on environmental impact and the needs towards sustainability, weight reduction of the vehicles is one of the most promising solutions to improve fuel efficiency towards achieving the reduction in carbon dioxide emissions. Fibre metal laminate is one of the lightweight material that inherits advantages of metal and fibre reinforced composite. Therefore, the drive of this study is to determine the effect of water absorption on tensile properties, thickness swelling and forming analysis of the natural fibre metal laminate. Fabrication of natural fibre metal laminate consists of two layers of kenaf woven fabric in polypropylene matrix and aluminium 5052-O as the skin. The results show that the natural fibre metal laminate absorbs 0.67% water and has 0.91% thickness swelling. The water content has minimal effect on the tensile properties of the natural fibre metal laminate. While for the forming analysis, the natural fibre metal laminate has higher formability compared to an aluminium sheet and has a higher potential to be formed into complex shape.

1. Introduction

Olivier et al (2017) pointed out that global gross greenhouse gas emissions continued to grow around 0.5% in 2016 (±1%), corresponding to 49.3 gigatons in carbon dioxide emissions. The increase in oil consumption in 2016 is consistent with the rise in CO_2 emissions from the transportation sector. In view of the increasing recognition of the environmental effects and the need for sustainability, the mandatory legislation provided by the European Union (EC 443/2009) declared that no more than 130 g of CO_2 per kilometre (g CO_2/km) should be released by all new cars registered in the European Union as of 2015.CO_2 emissions can be minimised from a vehicle by incorporating weight reduction, aerodynamic drag, rolling resistance, and an improved motor powertrain performance (Kelly *et al* 2015). Weight reduction of vehicles is one of the most promising options for achieving a reduction in CO_2 emissions that increases fuel efficiency by approximately 6–8 per cent for every 10 per cent of vehicles weight reduction (Joost 2012).

Fibre metal laminate (FML) as shown in figure 1 is a lightweight metal and fibre-reinforced composite material inheriting the advantages of both materials (Vlot and Gunnink 2011). FML has superior physical and mechanical properties compared to monolithic metal structures and is widely used in aerospace applications for weight savings (Li *et al* 2016). Some of the studies performed to investigate FML properties are shared here. Li *et al* (2018) investigate the effect of fibre form on the impact response of FML-based titanium. Hamill *et al* (2018) examine the galvanic corrosion and mechanical behaviour of FML, consisting of alternating layers of bulk metallic glass and carbon fibre reinforced polymer. Sherkatghanad *et al* (2018) has suggested a revolutionary approach to mass production of FML sheets. Yang *et al* (2018) studied simulation of the impact response effect of fibre stacking series, thickness, and incident angle of FML. Ng *et al* (2017) explored the fatigue efficiency of the

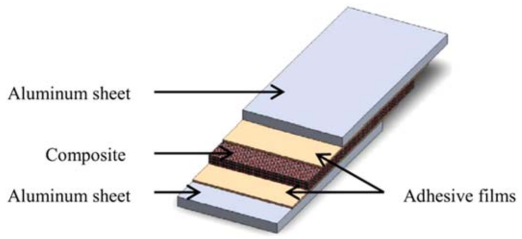


Figure 1. Fibre Metal Laminate (Sivakumar *et al* 2018) John Wiley & Sons. © 2017 Wiley Periodicals, Inc.

hybrid FML structure. Subramaniam *et al* (2019) examine the impact of stacking structure on woven kenaf/glass composite metal laminate tensile and quasi-static penetration. Sitnikova *et al* (2016) studied the FML blast failure modes. Fu *et al* (2015) examine the rate of elasto-plastic post-buckling and release of energy for thermal-mediated FML beams.

Due to its lightweight and high performance, FML is a well-known material in aerospace application and being used as structural material, fuselage, wing skin panel and cargo door (Bahei-El-Din and Botrous 2003, Beumler *et al* 2006, Alderliesten and Benedictus 2008, Alderliesten 2009, Sinmazcelik *et al* 2011). Hence, to comply with the legislation to increase awareness on environmental impact in the automotive industry, utilisation of the FML as the automotive components are indeed appropriate and need to be studied. Car front hood is one of the appropriate component to apply the FML structure. Previously, authors have made the selection of the material which consists of selection of natural fibre and thermoplastic matrix for the fibre reinforced composite (Ishak *et al* 2016, 2017) and provide several solutions for the application of natural FML as car front hood (Ishak *et al* 2018a, 2018b). In conjunction with the studies, further investigations will be conducted to ensure the success of the application. Therefore, this study aims to determine the effect of water absorption on tensile properties, thickness swelling and forming analysis of the natural FML.

2. Materials and FML fabrication

The natural fibre-reinforced (NF) composites are made of kenaf-woven fabric with an areal density of 295 g m^{-2}, supplied by the National Kenaf and Tobacco Board in Malaysia with an average thickness of 1 mm. Polypropylene (PP) granules with a density of 0.9 g cm^{-3} were obtained from Al Waha Petrochemical Company and the Aluminium 5052-O with a thickness of 0.5 mm was attained from Novelis Inc. Modified PP adhesives were used to bond the aluminium alloy to the NF composite.

Fabrication of the natural FML was carried out by compressing the PP to the form of a sheet with a thickness of 0.5 mm. PP sheets were then stacked with two layers of kenaf woven fabrics using a frame mould and compressed at the pressure of 3.5 MPa at a temperature of 180 °C for 15 min, followed by a cooling process for 20 min to fabricate the NF composites. Two layers of kenaf woven fabrics proposed by the authors in prior study (Ishak *et al* 2018b) have been continued in current work.

To increase the aluminium sheet ductility it was annealed at the temperature of 343 °C for 2 h followed by the cooling process at a rate of 10 °C per hour. The surface of the aluminium sheets was then roughened evenly using 80 grit size sandpaper to improve bonding interface between aluminium and NF composites.

FML 2/1 design has been created in a frame mould with a measurement of 200 mm × 200 mm × 3 mm by piling the aluminium layers into the composite. Between the aluminium and NF composite interfaces, PP adhesives were mounted. At 1 MPa and a temperature of 165 °C for 5 min, the mould then was compressed and cooled for 20 min. Figure 2 shows the stacking during fabrication process.

3. Experimental procedure

This section explains the detailed method that was used to investigate the natural FML behaviours.

3.1. Water absorption test

The water absorption test is conducted to determine the water absorption behaviour of the natural FML with comparison to NF composite. Water absorption is one of the factors that affect the natural FML performance as car front hood. Rectangular specimens of 76.2 mm × 25.4 mm were used for water absorption and thickness swelling test as advocated by the ASTM D570. During water absorption experiments the samples were submerged in distilled water at room temperature. At 24 h intervals, the specimens were withdrawn from the

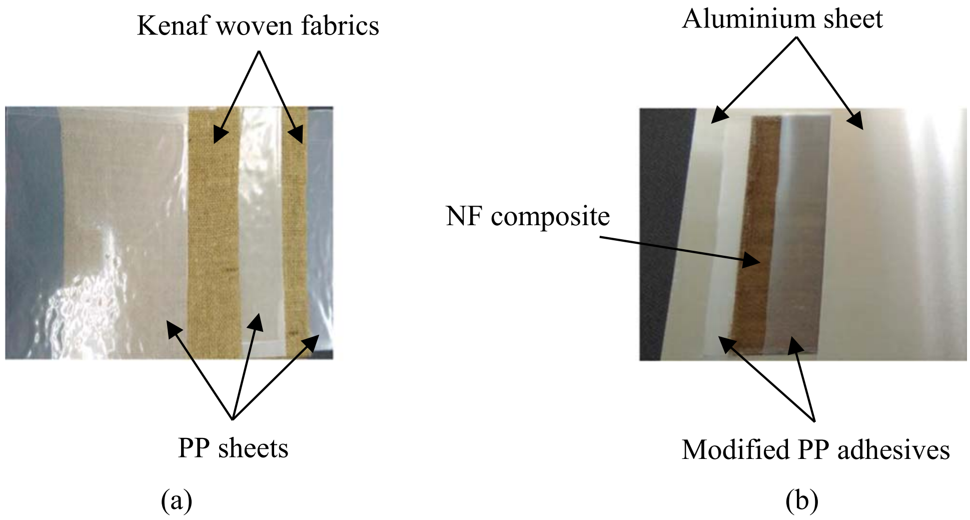


Figure 2. (a) PP sheets were stacked with kenaf woven (b) Stacking the aluminium layers to the NF composite.

water and all surface water was wiped out with a dry cloth and immediately measured by digital weights. The test was continued until the saturation state was reached. Three specimens of natural FML and NF composite was prepared to get the average values. The percentage of water absorption was determined using weight difference equation (1) and the average value was reported. W_t represents the weight of the specimen at time t and W_o is the initial weight of the specimen.

$$Water\ absorption,\ W_a(\%) = \frac{W_t - W_o}{W_o} \times 100 \tag{1}$$

3.2. Thickness swelling

Thickness swelling test in accordance to ASTM D570 is carried out to determine the thickness of the natural FML and the NF composite after being immersed in distilled water. The thickness swelling of the specimens was measured at an interval of 24 h until the saturation state was reached. The percentage of thickness swelling was determined by the difference in thickness between the specimens soaked in water and the dry specimens using equation (2). T_t is referring to the thickness of the specimen at time t and T_o is the initial thickness of the specimen.

$$Thickness\ swelling,\ T_s(\%) = \frac{T_t - T_o}{T_o} \times 100 \tag{2}$$

3.3. Tensile test

Specimen with a dimension of 200 mm $\times$ 25 mm were used for tensile test of the natural FML and NF composite in accordance to ASTM 3039. The tensile test was conducted using a universal testing machine, equipped with 10 kN load cell with 100 mm gauge length at a crosshead speed of 2 mm min^{-1}. The tensile test was conducted for natural FML and NF composite before and after water absorption condition. The test was conducted three times and the average values were recorded.

3.4. Forming analysis

In the industry stamp forming is used to form the car front hood. Forming analysis is conducted to determine the maximum forming limit of the natural FML without necking or fracture during stamp forming process. Stretch forming using Nakajima test was carried out to determine the formability of the natural FML. The test was carried out on hydraulic press testing machine with 100 mm hemispherical diameter punch. Specimen was held at 250 kN blank holder force and a constant punch speed was used to deform the test specimen. Hourglass specimens for natural FML forming analysis were prepared with widths, 20 mm, 30 mm, 40 mm, 60 mm, 80 mm, 100 mm, and 200 mm as shown in figure 3(a). Circle grid analysis, figure 3(b), was used for the determination of the forming limit curve (FLC). Circles with 2.5 mm diameter were etched on the natural FML surface. The major (e_1) and minor (e_2) strains were calculated through the measurements of the diameters of the deformed ellipses using equations (3) and (4). L_f is referring to the final length, W_f is final width and D_o is the original diameter of the circle.

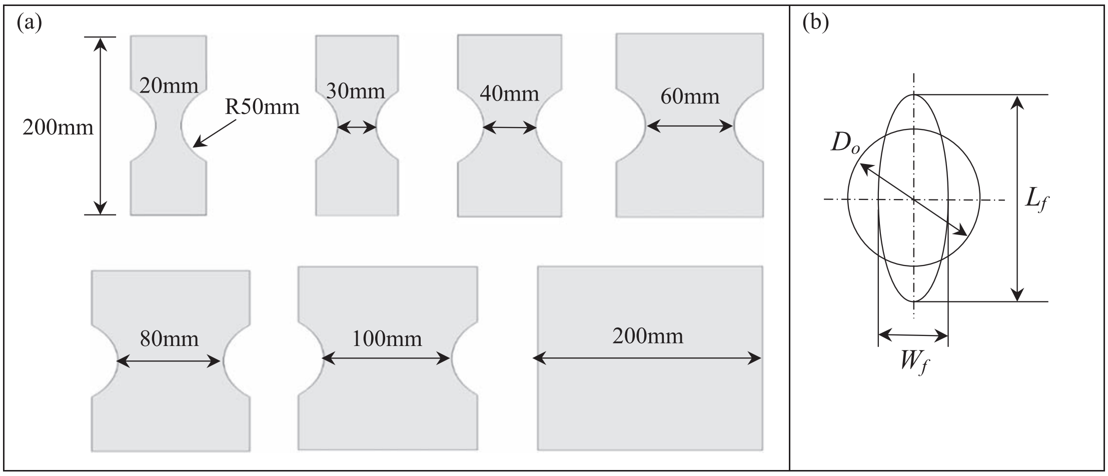


Figure 3. (a) Specimens for FLC Test, (b) circle grid.

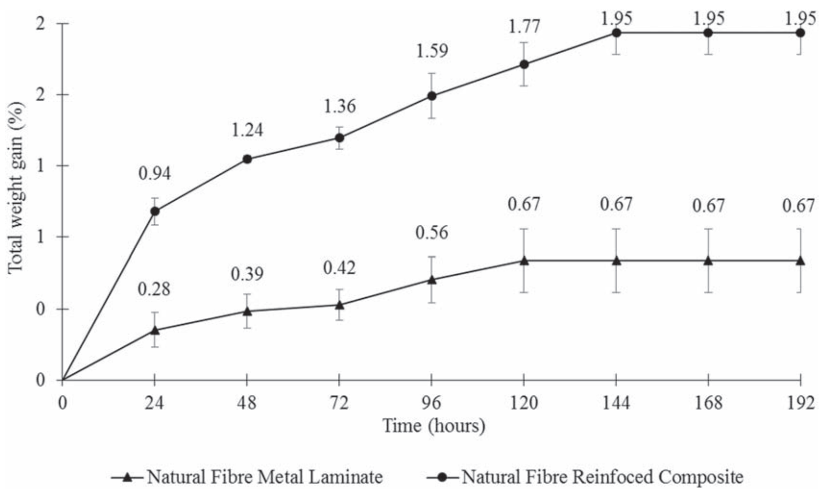


Figure 4. Water absorption of natural FML and NF composite.

$$Major\ strain,\ e_1(\%) = \frac{L_f - D_o}{D_o} \times 100 \tag{3}$$

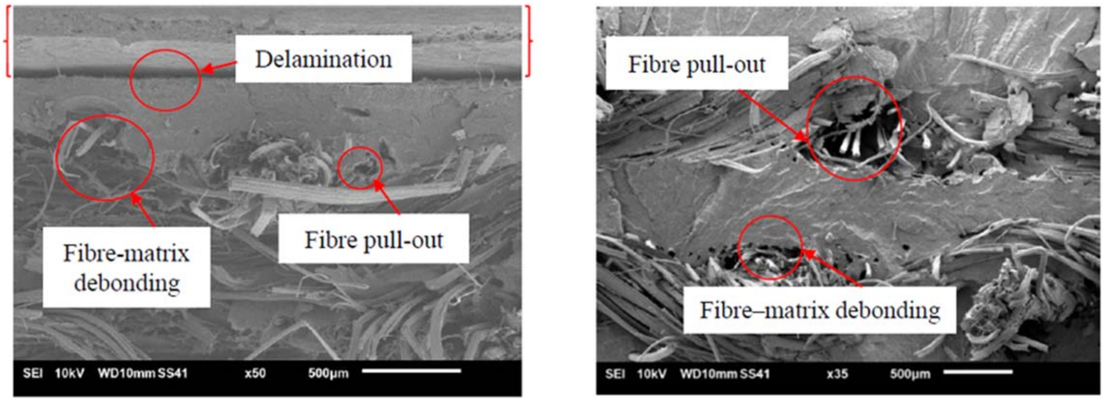
$$Minor\ strain,\ \ e_2\ (\%) = \frac{W_f - D_o}{D_o} \times 100 \tag{4}$$

4. Results and discussion

4.1. Water absorption

The behaviour of water uptake of the natural FML and NF composite are shown in figure 4. The results show that the NF composite absorb water up to 1.95% water content after 192 h compared to natural FML which only reached up to 0.67%. It is observed that the overall amount of water absorbed for natural FML was lower than 1% compared to NF composite. The high water absorption of the NF composite is due to the hydrophilic feature of the natural fibre that attracts water molecules.

Whereas, for the natural FML, the aluminium as the outer skin has provided a barrier against water absorption and only the vulnerable edges section can still absorb the water. In addition, the use of PP as the enhanced polymer and adhesive is appropriate because it is hydrophobic (Deng *et al* 2010), responsible for low water absorption values. Botelho *et al* (2006) reported, the absorption of moisture in FML composites is lower than polymer composites even under comparatively harsh conditions due to the aluminium outer layer barrier. It shows that the natural FML is durable and have lower degradation effect on the humidity that could affect the car front hood performance. Ishak *et al* (2018b) has suggested several solutions to protect the vulnerable edge



(a) (b)

Figure 5. SEM micrograph of tensile fracture of (a) natural FML and (b) NF composite at wet condition.

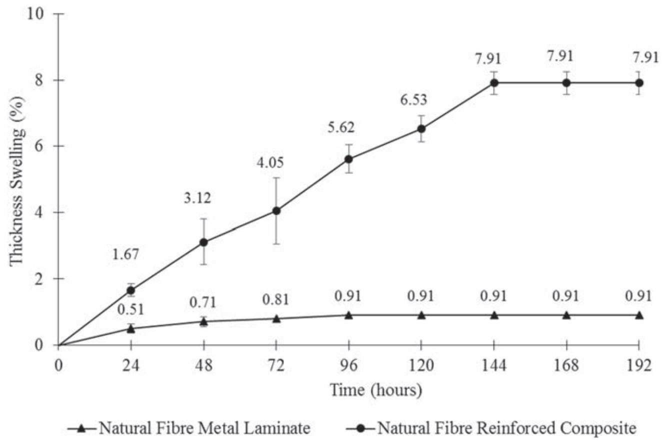


Figure 6. Thickness swelling of natural FML and NF composite.

from humidity such as applying polymer plastic film shrink wrap, remove the excess layering at the edge of the FML so that the inner and outer closure layers can be joined together to simplify the hemming process and add the edge guard to cover the exposed edge of the car front hood and help protect the edges from water.

Natural FML and NF composite fracture surfaces were studied using SEM to determine the failure mechanism that could be associated with the tensile properties of both specimens. Pani *et al* (2019) indicated that it is necessary for SEM to investigate the topography of materials such as fibre matrix debonding, fibre separation at the interface, fibre fragmentation, fibre cracking, etc figure 5 displays the SEM micrograph of the natural FML and NF composite tensile fracture in wet conditions. Large fibre-matrix debonding and fibre removal were found in both specimens and the aluminium of the natural FML appears to delaminate due to the load being moved to aluminium and NF composite (figure 5(a)). Figure 5(b) shows that the NF composite has a high fibre debonding matrix and a fibre pull-out that shows low tensile strength properties. This is due to the loose adhesion between the fibre and the NF composite matrix leading to a decrease in load carrying power (Sathishkumar 2016). However, the SEM micrograph of the tensile fracture of the natural FML shows less debonding of the fibre matrix and fibre removal, which shows the higher tensile strength properties of the natural FML.

4.2. Thickness swelling

Figure 6 showed the percentage of thickness swelling of the natural FML and NF composite versus different immersion time. The results showed that the thickness swelling has a similar trend to the water absorption behaviour where the percentage of thickness swelling values of NF composites increases with an increase of immersion time. It is observed that the overall amount of thickness swelling for natural FML was low which is 0.51% compared to NF composite with thickness swelling of 7.91% after 192 h. Thickness swelling is related to water absorption. As NF composites are exposed to water, the hydrophilic nature of natural fibre draws water

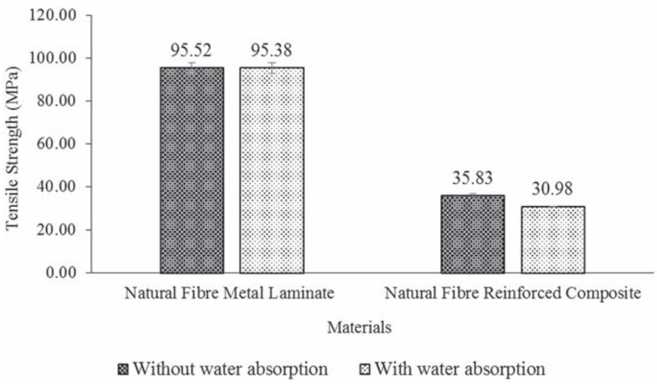


Figure 7. Tensile strength of natural FML and NF composite.

Table 1. Tensile strength and Young modulus of natural FML and NF composite.

	Natural Fibre Metal Laminate		Natural Fibre Composite	
	Without water	With water	Without water	With water
Tensile Strength (MPa)	95.52	95.38	35.83	30.98
Young Modulus (GPa)	18.13	17.97	6.07	4.65

molecules to cellulose molecules that contributes to the build-up of moisture within cell walls, which often tends to be swelling (Singh and Palsule 2013). As a result of swelling, fibre-matrix debonding, matrix cracking and fracture along the interface occur (Dhakal *et al* 2007).

4.3. Tensile properties

Figure 7 and table 1 show the tensile strength and Young modulus of the natural FML and NF composite at dry and after 192 h of water absorption. The natural FML has a tensile strength of 95.52 MPa with Young modulus 18.13 GPa at dry condition and tensile strength 95.38 MPa with Young modulus 17.97 GPa at saturation state. For NF composite, the tensile strength at dry is 35.83 MPa with Young modulus; 6.07 GPa and at the saturation state, the tensile strength is 30.98 MPa with Young modulus; 4.65 GPa. Incorporating metal layers into the fibre reinforced composites enhanced the tensile properties (Kuan *et al* 2011). The tensile strength reduced by 0.15% and 13.54% for the natural FML and NF composite respectively after water absorption. The water content forms voids at the fibre/matrix interface which reduce the load transfer from matrix to fibre and lead to the reduction of the tensile properties (Singh and Palsule 2013).

4.4. Forming analysis

Figure 8 showed the failure limit diagram of natural FML and aluminium sheet. It can be seen that the FLC of natural FML are higher than the aluminium sheet, which confirmed that the natural FML have higher formability compared to the aluminium sheet. The natural FML has a larger major and minor strain before failure compared to aluminium. This revealed that the natural FML has a potential to be formed into complex shapes than aluminium sheet. Study by DharMalingam *et al* (2010) has shown that the FML strain distribution behaviour is more robust, providing more even thickness for the shaped component and allowing for higher levels of dimensional tolerance that enable the FML to develop into more complex parts than monolithic aluminium. Meanwhile, for the guideline for the forming process in of car front hood in, Figure 8 showed the safe and failed area for the natural FML. Through this FLC, the range of safe limit for stretch forming, critical zone where necking and fracture will occur and strain level were determined for natural FML.

5. Conclusions

Through this study, the effect of water absorption on tensile properties, thickness swelling and forming analysis of the natural FML had been studied. The results showed that the natural FML absorbed only 0.67% water and has 0.91% thickness swelling. The water content has minimal effect on the tensile properties of the natural FML. The tensile strength reduced by 0.15% and 13.54% for the natural FML and NF composite respectively after

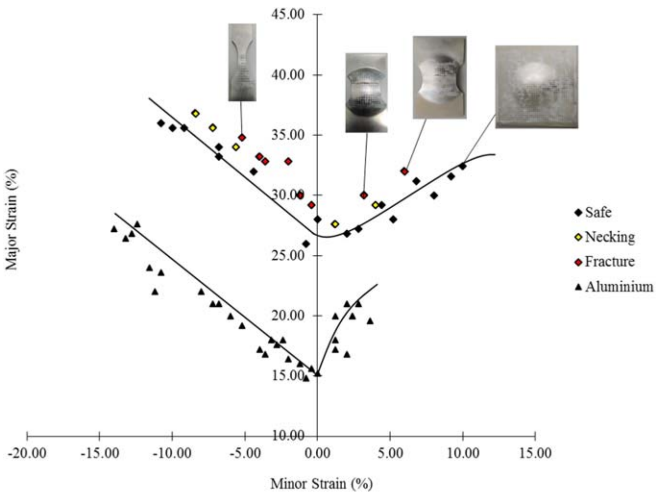


Figure 8. Forming Limit Curve for natural FML and Aluminium sheet.

water absorption. From the forming analysis, the natural FML have higher formability compared to the aluminium sheet and have a higher potential to be formed into complex shapes.

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ORCID iDs

Sivakumar Dhar Malingam https://orcid.org/0000-0001-7968-1950

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