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Study of the Thermogravimetric and Dynamic Mechanical Analyses of Fibre Metal Laminate Composites

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Research Article

Abstract

Investigating the novel hybridization of natural and synthetic fibre in developing Fibre Metal Laminate (FML) and producing advanced composite materials is becoming most recent research domain among the material's scientists and engineers. The thermal stability and functional temperature of the two composites were study. The two composites were fabricated in a mould using a traditional method (hand lay-up) cured at room temperature and post-cured in an oven at 80ºC for 3 hours. The stability of the composites was obtained by monitoring the weight change as the composite is heated at the constant rate carried out using the standard properties test equipment that includes TGA and DMA machine. The result of the test shows a remarkable increase in the properties in terms of the percentage residue after the composites undergoes TGA, flax composites was 29.75% greater than Kenaf composites in the TGA test. The kenaf composite is 0.5% greater than flax composite storage modulus at a higher-temperature. Conclusively, the composites considered in the study can be used as the component in fire designated zones of automobile and aerospace such as in engine nacelle as compared with only natural fibre and other types of metal/metal alloy.

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Keywords
Aluminium alloy; epoxy; hybrid composite; natural fibre; synthetic fibre

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1. Introduction

Fibre-metal laminate (FML) composite is the type of composite that contains a thin sheet of metal/metal alloy with reinforced fibre bonded together with either thermoset or thermoplastic polymer matrix. The metal/metal alloy mostly found on FML was aluminium, magnesium, titanium among others with their alloys; while the fibre was either synthetic or natural; the synthetic fibres are carbon fibre, glass fiber and Kevlar (aramid), etc, whereas there are many different types of natural fibres that includes flax, kenaf, coir, date palm, cotton, hemp, bamboo, jute, abaca, kapok, etc. FML combine the advantages of metal/metal alloy, reinforced fibre and the polymer matrix (Mohammed & Abu Talib, 2021). FML composites find different application in industries; due to it is high performance as a component in constructing different structural components (Mohammed & Abu Talib, 2020; Asundi & Choi, 1997; Vogelesang & Vlot, 2000). These types of composites were fabricated to succeed the monolithic aluminium alloys due to fatigue crack initiation and growth with time (Mutasher, 2006). There are many factors that make
FML composite exceptional, among were low thermal conductivity, high strength fire resistant properties among other (Mohammed, 2023).

Natural fibres find application in automobile and aerospace industries on different researchers due to its availability, low cost, eco-friendly and lightweight in nature; likewise. the mechanical and physical properties of some types of natural fibre are very similar to that of synthetic fibres, but has some limitations that affect its performance as a composite that includes moisture absorption, low strength among others (Mohammed & Abu Talib, 2021).

The hybridisation of natural and synthetic fibres yield a composite with an excellent thermal, mechanical and impact properties with good stiffness and strength and resistant to crack fatigue growth, it also improves the safety of fabricating the composites whereby it reduces the respiration problem during fabrication (Ashori, 2008; Asundi & Choi, 1997; Mohammed *et al.*, 2018; Prabhakaran *et al.*, 2013; Sivakumar *et al.*, 2017). It is reported by Salman *et al.* (2015) that, bast fibre was most acceptable natural fibre for hybridisation, been used in form of matting and cord; this type of fibre has a flexible and fine structure that can be tailored in a different form
and can easily be machined. Many researchers have done much on hybrid composite between natural and synthetic fibres such as those reported by Bandaru *et al.* (2015) on the effect of hybridisation on the ballistic impact behaviour of hybrid composite armours. The hybrid composite requires a free moisture absorption, excellent fatigue resistant, free from corrosion and good stiffness and strength with good impact strength (Chang *et al*., 2008; Mohammed, 2022a; Vogelesang & Vlot, 2000)

This research study of the FML composite consists of a natural fibre (kenaf and flax), synthetic fibre (carbon fibre), and sheets of aluminium alloy 2024-T3 that are used at the front (top) and rear (bottom) face of the reinforced composites bonded together using an epoxy resin/hardener. The hybridisation yields a thermal property required for the composites under study. Components with good thermal stability were considered as in aircraft and in automobile and some other machineries that have an application at high temperature (Mohammed 2022b). The main objective of the study is to investigate the thermal properties of FML.

2. Materials and Methods

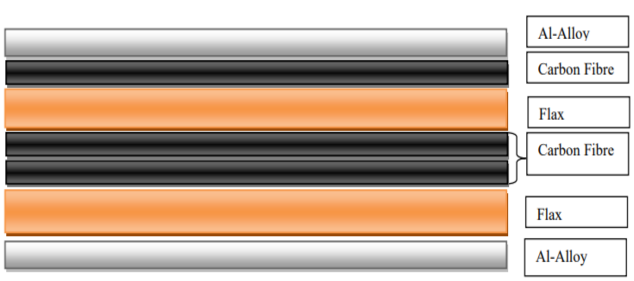
Three types of materials were used in fabricating the composite with HL002 TA/TB epoxy resin/ hardener as the matrix. The materials used were Aluminium alloy 2024-T3 (metal), woven carbon fibre (synthetic fibre) and flax & kenaf fibre (natural fibre) as the reinforce fibre. Each one of the two composites fabricated uses one type of natural fibre. The number of layers used and the thickness of each material was shown in Table I for the composites fabricated.

Table I: Materials used with their Thickness

Materials	Material Thickness (mm)	Layers
Woven Carbon	0.25	8
Flax	0.7	2
Kenaf	0.7	2
Aluminium Alloy	0.4	4

The composites were bonded with epoxy resin/hardener in the ratio of 70:30 for the resin to hardener from the supplier, while 75:25 is the weight ratio of polymer to fibre.

In the fabrication process, two sheets of aluminium alloy were used as the front and rear face of each composite fabricated. The first composite consists of four woven carbon fibre and two plies of flax, while the second composite consists of four woven carbon fibre and two plies of kenaf. The FMLs composites were stacked and arranged as indicated in the schematic diagram of Figure 1 and the woven carbon fibre was unidirectionally laid in the composites. The composites were fabricated in the mould of 400mm x 400mm x 4mm, using a hand lay-up method. The epoxy resin/hardener was mixed accordingly and spread on each layer by use of brush.
The fabricated composites were compressed using a cold compression machine and allowed to cure for 24 hours at room temperature and post cured for 3 hours in an oven at 80°C.



(a) Carbon Fibre Flax Reinforced Aluminium laminate

(b) Carbon Fibre Kenaf Reinforced Aluminium Laminate

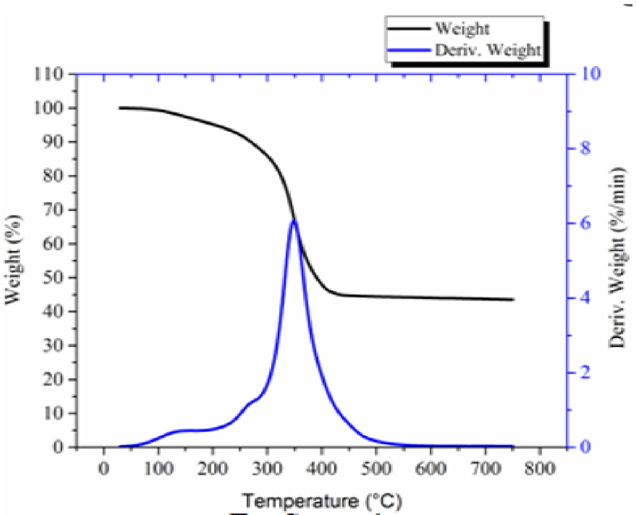
Figure 1: Composites Arrangement

The TGA and DMA were conducted on the FML, the two tests were conducted in order to differentiate the heat transfer in the composites, also to determine the thermal behaviour of the epoxy for the two composites.
TGA was performed using a thermogravimetric machine Q500 V20.13 Build 39, TA Instrument to distinguish the main thermal degradation and the melting temperature in each FML composites. The test uses using thermo-balance coupled to a mass spectrometer and undergoes temperature changes from ambient (25ºC) to 750ºC using different heating rates from 10-40ºC/min; the test was conducted using a nitrogen gas as the fluid (60ml/min). Five samples were cut 15 mg each for the test and the average result was recorded. The test was conducted to determine the physical behaviour (mass change) of the polymer in each composite as the temperature change.
DMA was conducted to find the visco-elasticity of the polymer of each composite, it uses dynamic mechanical analysis machine Q800 V20.24 Build 43 Module DMA Multi-FrequencyStrain InstSerial 0800-1072 Clamp Dual Cantilever, five samples of 35mmx10mmx4mm were cut for the test. Complex moduli were determined in this test and a glass transition temperature of each composite was located. The test was performed in bending mode of multiple frequencies with a 5N dynamic force that is oscillating at fixed frequency (60Hz) and amplitude of 12.0 MinOscF. The relaxation spectra were recorded in the temperature range between 25 and 190 ºC, at a heating rate of 5 °C/min. The properties test was carried out in Institute of Tropical Forestry and Forest Product (INTROP) University Putra Malaysia.

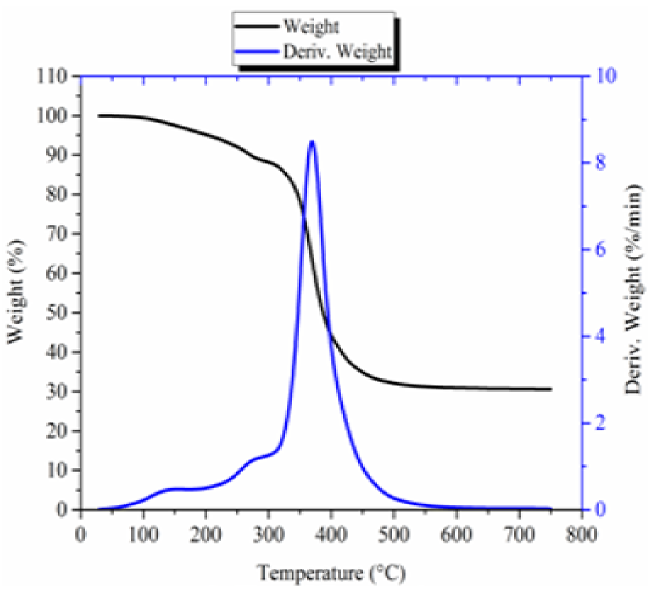
3. Results and Discussions

Figure 2 shows the TGA test analysis of the two composites under study.
It was observed that the characterisation curve of TGA and DTG of the two-hybrid FML composites shows the same behaviours for the percentage weight loss and temperature range with similar DTG curves. As the temperature increases in the test, the loss of mass was observed up to a certain temperature around 350°C where the mass loss was observed to be stable. The early degradation of the composites was observed at a temperature of about 120 - 150ºC around 2.5 weight percent in the composites due to the low boiling of polymer and moisture content that escaped during the

melting and drying process of the composites, degradation was continuously observed as the temperature of the test was increased up to the total degradation of the composite, this phenomenon was reported by Brazier and Nickel (1975); Sircar and Lamond (1975); Yang et al. (1993).



(a) Flax Composite



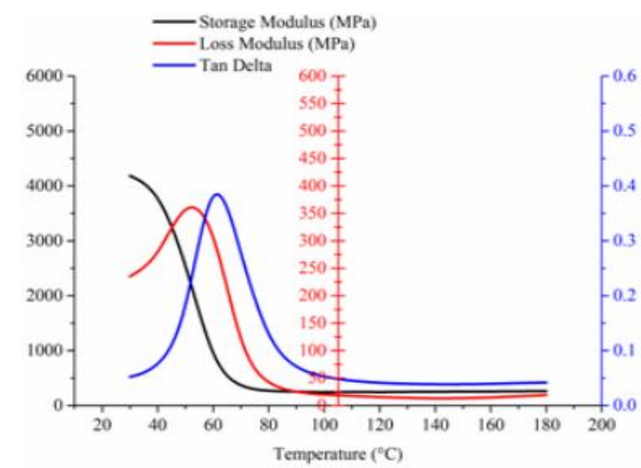
(b) Kenaf Composite

Figure 2: TGA Test Analysis for two FML composites

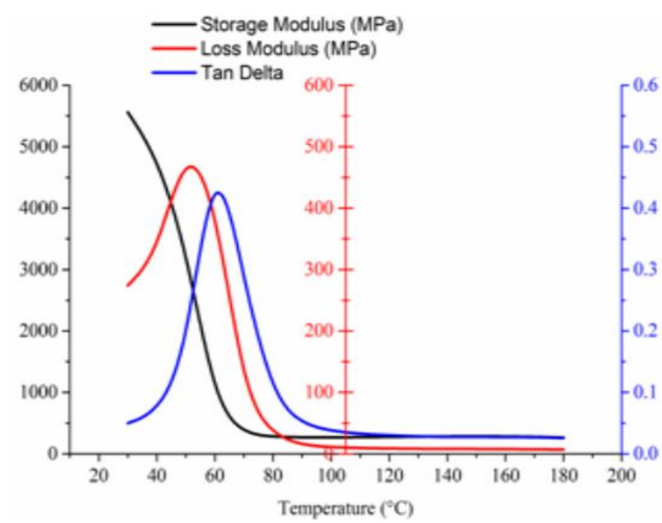
The residue obtained from each composite after the test shows that flax composite supersedes the kenaf composites by 29.75%. The flax composites recorded the percentage weight residue of 43.56% while the kenaf composite has 30.60%., the result was in agreement with the result obtained by Mohammed et al.., (2018); Díez-Pascual et al. (2011); Samakrut et al. (2008). The thermal decomposition of the samples was observed due to the escape of the moisture that resulted to the melting and drying of some contents in the composites.

Around a temperature of 300ºC to 400ºC, the highest decomposition of the two composites sample was notice, whereas the major degradation around 270ºC to 340ºC.

The DTG inflection point and the thermal decomposition temperature of the two composites were observed as 350ºC, 345ºC for flax FML composite and 370ºC, 355ºC for kenaf FML composite. The residual material in each composite after the test was the fibres and a small portion of the metal, whereas the polymer undergoes complete degradation. The peak value of temperature from the two composites from the DTG curves were around 345ºC to 365ºC. After the test analysis the major residue in each composite was the fibre and little aluminium alloy, whereas the epoxy resin/hardener completely undergoes degradation. Therefore; based on the thermal stability, the analyses of the two composites have low stability than the matrix polymercounterparts as reported in Mohammed *et al*., (2017). This was due to the cohesion of matrix with fibre.



(a) Flax Composite



(b) Kenaf Composite

Figure 3: DMA Test Analysis for two FML composite

Figure 3 shows the DMA test analyses of the two FML composites considered in the study.It was observed that the characterisation curve of the DMA test analysis for the two hybrid FML composites shows almost the same behaviour for the three properties in the test (Storage modulus, loss modulus and the damping within the system), whereby the glass transition temperature from loss modulus of the two composites were deducted and the values for the two composites range between 65ºC to 70ºC due to high mobility of the polymer at lower temperature, which also indicate the rapid fall of the storage and loss modulus due to incorporation of the reinforced fibre with matrix and by the morphology and composition of the materials as reported by Joseph *et al*. (2003); Samal *et al*. (2009).

It was observed that the characterisation curve of the DMA test analysis for the two hybrid FML composites shows almost the same behaviour for the three properties in the test (Storage modulus, loss modulus and the damping within the system), whereby the glass transition temperature from loss modulus of the two composites were deducted and the values for the two composites range between 65ºC to 70ºC due to high mobility of the polymer at lower temperature, which also indicate the rapid fall of the storage and loss modulus due to incorporation of the reinforced fibre with matrix and by the morphology and composition of the materials as reported by Joseph et al. (2003); Samal et al. (2009). A negligible change in modulus was observed at a temperature between 90ºC to 100ºC in all the composites, which indicates that the composites have a well-distributed stiffness, the result was in agreement with the result reported by Díez-Pascual et al. (2011); Sandler et al. (2002). Warrier et al. (2010) reported that the interfacial interaction between the reinforced fibres and the matrix affect the degradation of the composite as observed in this study. The study revealed that Kenaf composites have higher values of storage modulus of 5561 MPa, while flax composite has 4185 MPa at the starting temperature and 264 MPa and 262.8MPa at high temperature respectively.

The two curves of the storage modulus of the two composites shows almost the same characteristics with an astonishing fall around 55ºC and 65ºC. Also, higher stiffness of matrix was notice due to relation between matrix and the reinforced fibres as reported in Mohammed et al., .20117). The composites make-up and morphology influence the elastic storage energy which in turn affect the storage moduli of the two composites. At ambient temperature, the kenaf FML composite yield more storage modulus than flax FML composite. This difference was due to more cohesion forces and uniformly distributed load that is between the kenaf fibre, carbon fibre and the matrix. Also, there is more internal porosity in the kenaf FML.

Difference of glass transition temperature of the two FML composite was due to the interaction of matrix with natural and artificial fibre. Lower transition temperature was observed because the composites use a thermoset polymer without adding binder for matrix movement restriction.

The kenaf FML produces high peak value of the ratio of loss to the storage (tan δ) with lower transition temperature with almost 12% as in shown in Figure 3. The tan δ was affected by the visco-elastic energy dissipation in the matrix shear stress and the nature of elasticity of the fibre, with a peak temperature between 65ºC to 68ºC that correspond to matrix relaxation.

The kenaf FML composite present the highest loss modulus value of around 480 MPa, while flax FML composite present around 370 MPa. This result shows that more matrix movement more loss modulus value.

4. Conclusion

In the present work, a comparative property analyses of the FML composites of natural fibre, synthetic fibre and a metal alloy was study. The properties test results obtained shows that the fibre metal laminate composites under study will be capable to be used as a structural component due to its high strength and stiffness with good thermal stability. The properties tests result indicates that flax composite for TGA presents good properties result than the kenaf composite. Almost, the two composites considered show the same properties with the same behaviour during the test for DMA. It is clearly seen that a greener fibre would be used in near future to replace the synthetic fibres due to its low cost, properties and it is abundant in nature, required less fabrication process. It is recommended that this type of hybrid laminate composites be used on different components that required moderate properties in the near future to reduce the cost of the component and to increase the usage of natural fibres in the industries.

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