Faculty of Mechanical Engineering

INVESTIGATION OF MECHANICAL PERFORMANCE OF WOVEN KENAF/GLASS HYBRID COMPOSITE METAL LAMINATE

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INVESTIGATION OF MECHANICAL PERFORMANCE OF WOVEN KENAF/GLASS HYBRID COMPOSITE METAL LAMINATE

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**A thesis submitted
in fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering**

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2021

DECLARATION

I declare that this thesis entitled "Investigation of Mechanical Performance of Woven Kenaf/Glass Hybrid Composite Metal Laminate" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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Date : ……………………………………….

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature	:	………………………………
Supervisor Name	:	Ts. Dr. Omar Bin Bapokutty
Date	:	………………………………..

DEDICATION

To my beloved family and friends.

ABSTRACT

In the past few decades, research and engineering interests have been shifting from monolithic materials to fibre reinforced polymer materials. The biggest advantage of composite materials is that they are lightweight as well as tough. By choosing the suitable combination of matrix and reinforcement, a new material can be produced that meets the requirements of a particular application. In order to improve the properties of existing composites, new research leads to the development of Fibre Metal Laminate (FML). Fibre Metal Laminates (FML) is a class of hybrid structure formed from the combination of thin metal layers and fibre reinforced composites bonded together. The increasing of environmental concerns and the need for high-performance materials lead to the development of natural and synthetic hybrid composites. Hybridization of natural and synthetic fibres in single matrix results in the enhancement of mechanical properties of the composite by taking the best advantages of one fibre to overcome the disadvantage of another fibre which consequently minimize the dependent on synthetic fibres. This work presents the effects of fibre stacking configuration on tensile and quasi-static indentation (QSI) and low-velocity impact (LVI) on kenaf/glass hybrid fibre metal laminates (FML). Two different hybrid stacking configurations of kenaf/glass metal laminates reinforced with polypropylene matrix were prepared through a hot compression process. Non-hybrid kenaf and glass metal laminates were also prepared for comparison. A tensile test was conducted according to ASTM E8, a QSI test was conducted according to ASTM D 6264 using 12.7 mm and 20 mm hemispherical indenters while an LVI test was conducted in accordance with ASTM D 7136. The tensile fractured surface of FML laminates was examined using scanning electron microscopy (SEM) while optical micrograph was used to investigate the failure mechanism of quasi-statically penetrated laminates. From the results, FMLs with the glass plies at the outer layers of composite [G/K_2/G] showed a positive hybrid effect as they displayed better tensile, penetration and impact resistance, compared to the non-hybrid kenaf and glass reinforced FMLs. For tensile test, [G/K_2/G] hybrid FML able to withstand higher strength compared to non-hybrid glass FML composites while for quasi-static indentation (QSI) test, [G/K_2/G] hybrid FML exhibit highest penetration load and energy absorption followed by non-hybrid glass FML [G_3], [K_2/G/K_2] and lastly [K_6]. Similar behaviour is noticed as QSI, [G/K_2/G] hybrid FML display good impact resistance in overall. It was observed that the overall performance of FML laminates decreases as the kenaf content in laminates increases. The potential of kenaf/glass hybrid FMLs in tolerating impact loads is evident. Thus hybrid structure can be used for impact loading applications while reducing the dependence on synthetic fibres. Overall, this study is an exploration of the potential applications of metal laminates reinforced with natural and synthetic fibre.

KAJIAN PRESTASI MEKANIKAL KENAF TERJALIN / KACA HIBRID RENCAM LAMINA LOGAM

ABSTRAK

Sejak beberapa dekad yang lalu, kepentingan penyelidikan dan kejuruteraan telah beralih dari bahan-bahan monolitik ke bahan polimer diperkuat gentian. Manfaat terbesar bahan komposit adalah ringan serta keras. Dengan memilih kombinasi yang sesuai matriks dan peneguhan, satu bahan baru boleh dihasilkan dengan memenuhi keperluan-keperluan satu penggunaan tertentu. Bagi meningkatkan sifat komposit sedia ada, penyelidikan baru membawa ke pembangunan Gentian Logam Berlamina (FML). Gentian Logam Berlamina (FML) ialah satu kelas struktur hibrid dibentuk dari gabungan lapisan-lapisan logam nipis dan gentian komposit yang diperteguhkan mengikat bersama. Peningkatan tahap kesedaran alam sekitar dan keperluan untuk bahan-bahan prestasi tinggi menjurus kepada pembangunan hibrid semula jadi dan komposit hybrid bersintetik. Penghibridan gentian sintetik dan semula jadi dalam matriks tunggal mengakibatkan peningkatan sifat mekanik rencam dengan mengambil manfaat terbaik satu gentian mengatasi kekurangan satu lagi gentian yang mana meminimakan kebergantungan gentian sintetik. Kerja ini membentangkan kesan konfigurasi tindanan gentian terhadap tegangan dan lekukan-statik (QSI) dan kesan hentamam halaju rendah (LVI) pada kenaf / gentian hibrid kaca berlamina logam. Dua hibrid berbeza konfigurasi tindanan kenaf lamina logam / kaca dikukuhkan dengan matriks polipropilena telah disediakan melalui proses mampatan panas. Kenaf bukan hibrid dan lamina logam kaca juga disediakan untuk perbandingan. Ujian tegangan dijalankan mengikut ASTM E8 dan ujian QSI mengikut ASTM D 6264 menggunakan pelekuk hemisfera dimensi 12.7 mm dan 20 mm. Ujian LVI dijalankan selaras dengan ASTM D 7136. Permukaan patah tegangan lamina FML diperiksa menggunakan mikroskop elektron imbasan manakala mikrograf optik digunakan untuk menyiasat mekanisma kegagalan kuasi-statik penembusan lamina. Satu kesan hibrid positif dalam $[K_2 / G / K_2]$ FML dengan lapisan kenaf diantara lapisan kaca serta dilapisi logam menunjukkan tegangan, QSI dan rintangan hentaman lebih baik daripada kenaf bukan hibrid dan kaca diperkukuhkan lamina FML. Dapat dilihat bahawa prestasi keseluruhan lamina FML berkurang apabila kandungan kenaf dalam lamina bertambah. Keseluruhan, kajian ini ialah satu penjelajahan mengenai potensi kegunaan untuk lamina logam diperkukuhkan dengan gentian sintetik dan semula jadi.

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LIST OF ABBREVIATIONS

AHP	-	Analytical Hierarchy Process
ARALL	-	Aramid Fibre Reinforced Aluminium Laminate
CARALL	-	Carbon Fibre Reinforced Aluminium Laminate
CFRP	-	Carbon Fibre Reinforced Polymer
CMC	-	Ceramic Matrix Composites
CO_2	-	Carbon dioxide
ECER	-	East Coast Economic Region
FML	-	Fibre-Metal Laminates
FRP	-	Fibre-reinforced Polymer
GLARE	-	Glass Fibre Reinforced Aluminium Laminate
HDPE	-	High Density Polyethylene
HVI	-	High Velocity Impact
JIS	-	Japanese Industrial Standard
LVI	-	Low Velocity Impact
MAPP	-	Maleic Anhydride Grafted Polypropylene
MMC	-	Metal Matrix Composite
NaOH	-	Sodium Hydroxide
OH	-	Hydroxide
PLA	-	Polylactic Acid

PMC	-	Polymer Matrix Composite
PP	-	Polypropylene
QSI	-	Quasi-static indentation
RMK	-	Rancangan Malaysia Ke
ROM	-	Rule of Mixture
SEM	-	Scanning Electron Microscopy
SiC	-	Silicon Carbide
Ti	-	Titanium
UB	-	Unit Break
UTM	-	Universal Testing Machine
UV	-	Ultraviolet

LIST OF PUBLICATIONS

Subramaniam, K., Dhar, M.S., Feng, N. and Bapokutty, O., 2017. The effects of stacking configuration on the response of tensile and quasi-static penetration to woven kenaf/glass hybrid composite metal laminate. *Polymer Composites*, 40(2), pp. 568-577.

CHAPTER 1

INTRODUCTION

1.1 Background

In line with the flourishing modern industries, demand for advanced composite structures has increased, especially for materials with better damage resistance and tolerance lead the way to produce fibre metal laminate (FML). FML refers to a class of hybrid composite structure that is based on a combination of layers of metal that sandwiched with layers of fibre-reinforced plastic, as illustrated in Figure 1.1. In 1950, the Fokker Aero structures of the Netherlands discovered that the bonded laminate structures could better prevent rapid fatigue crack growth, in comparison to monolithic materials (Chai and Manikandan, 2014).

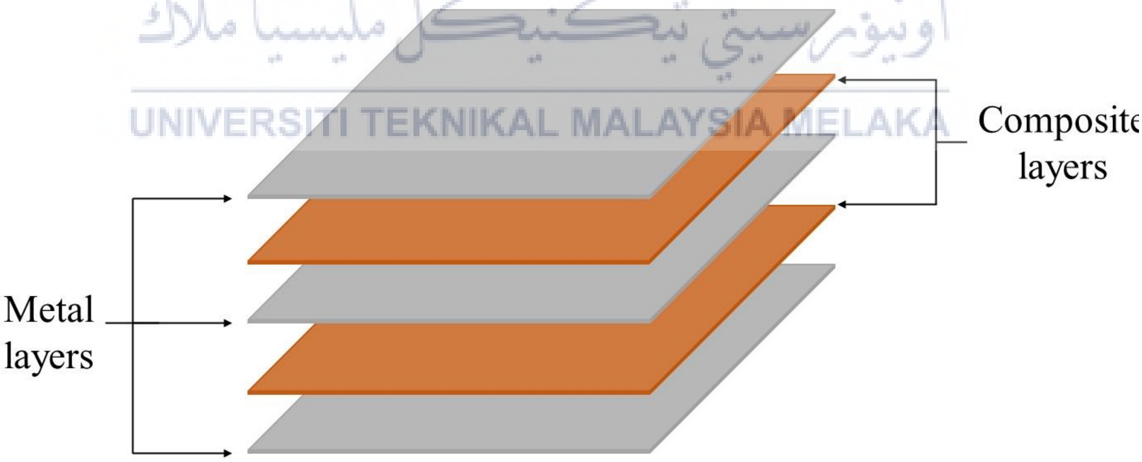

Figure 1.1: A sample lay-up of FML

Combining composite and metal layers as bonded structures offers exceptional fatigue, impact, and damage tolerance while having the advantage of being a light-weight material. Prior studies have reported that the fibres in the composite layers function as a barrier against crack propagation and to increase burn-through resistance, apart from providing damping and insulation, while the metal layers enhance ductility, impact resistance, and damage tolerance of the structure (Alderliesten, 2005; Cortes and Cantwell, 2006). Aramid reinforced aluminium laminate (ARALL) is the first generation of FML based on thermoset polymer matrix introduced by the Faculty of Aerospace Engineering at the Delf University of Technology in the Netherland (Villanueva and Cantwell, 2004). In the attempt to generate stronger and stiffer FMLs, several improvements were made to develop FML with varied types of synthetic fibres, such as GLARE (glass Fibre-reinforced aluminium laminate), and carbon and glass fibre forming CARALL (carbon Fibre-reinforced aluminium laminate), respectively (Sinmazçelik et al., 2011).

A comparative study on drop impact properties performed on GLARE, monolithic aluminium, and carbon Fibre-reinforced thermoplastic composite; Vlot et al. (1998) found that GLARE-FML displayed excellent damage threshold energies when compared to the two other materials. Moriniere et al. (2013) discovered that GLARE-FML displayed 86% of specific impact energy threshold, which was higher than aerospace-grade aluminium (2024-T3) in a study pertaining to impact behaviour of FML. Fan et al. (2011) investigated the thickness effect of woven glass Fibre-reinforced epoxy-based composite and FMLs on low-velocity impact by increasing the glass plies. They revealed that increment of plies in FML gave higher impact perforation resistance and energy absorbance in elastic and plastic regions.

Nonetheless, several commercial thermoset-based FMLs have been reported, such as extended polymer matrix curing time that escalates FML production cost. Hence, thermoplastic-based FMLs have been introduced with shorter fabrication time using the compression moulding technique, which eventually lowers the manufacturing cost. This offers superior energy absorption properties and high resistance impact loading. Several studies that investigated the impact properties of thermoplastic FML (Reyes and Cantwell, 2000; Abdullah and Cantwell, 2006; Carrillo and Cantwell, 2009) support the view that thermoplastic FML structure exhibits excellent energy absorption characteristics through extensive plastic deformation in aluminium and composites layers.

The issue of recycling thermoset based FML has received considerable critical attention. Although FML production is low due to usage mainly in aerospace industry, recycling FML should be taken seriously. Yang et al. (2012) asserted that landfills might be an option for FMLs due to the higher recycling cost than manufacturing, which should be prohibited in the future. Thus, many are seeking to devise a suitable recycling method that has a less environmental impact. Mechanical separation and thermal delamination methods were investigated by Tempelman (1999) to introduce a recycling option for GLARE, since it is commercially used in the aerospace industry. GLARE scraps can be thermally delaminated and efficiently cleaned to gain back the glass fibre, but aluminium is refined back to its original quality to generate new GLARE materials for the lower-level application.

Generally, synthetic fibres have higher strength, better durability, and good corrosion and water absorption resistance properties (Khan et al., 2010a). Khan et al. (2010b) added that glass fibre is the most commercially used material as reinforcement due to its lower cost and better physico-mechanical properties than Kevlar and carbon fibres. Although wide applications of glass fibres as reinforcement for composites have successfully contributed to numerous industries, there is a rise in environmental issue at the end of their useful life. The duration for complete degradation of glass fibre takes hundreds to thousands of years due to its strong covalent bonds that connect the atoms to form excellent chemical structure. Recycling operation for synthetic Fibre-reinforced composites is economically cost-effective and eco-friendly. Nevertheless, the low economic incentive to recycle composite material waste leads to sending it to landfills as it is relatively cheaper and as a consequence, results in landfill accumulation (Pickering, 2006).

Natural fibres have evoked the interest amongst researchers and industries for the past decades. The use of natural fibres as reinforcement material is growing due to their advantageous characteristics, such as biodegradable, acceptable strength and modulus, and cost-effective in developing materials for the engineering domain (Arthanarieswaran et al., 2014; Saba et al., 2016), unlike synthetic fibres that are hazardous to people's health and the environment. The kenaf (hibiscus cannabinus) fibre refers to a kind of natural fibre found abundantly in Asia. Kenaf bast fibre is lignocellulosic fibre. Generally, fibres that contain high cellulose content have high mechanical properties, wherein kenaf bast fibre and core fibre have cellulose contents as high as 60.8% and 50.6%, respectively (Ismawati, 2006; Du et al., 2008). Saba et al. (2015) highlighted that kenaf fibre could replace synthetic fibres (glass fibre) for specific mechanical applications with moderate loading condition. Nevertheless, in comparison to synthetic fibres, natural fibres are hydrophilic and possess lower modulus and strength (Alawar et al., 2009; Adekunle et al., 2011).

Recent studies have outlined the drawbacks of natural fibres that can be addressed by incorporating synthetic fibres within the same matrix to develop hybrid structures. The hybridisation of natural/synthetic fibres enhances materials' impact properties by taking the best advantages of both fibre characteristics. Natural/synthetic hybrid structures are partially degradable, recyclable, and reduce the usage of synthetic fibres. The performance of hybrid structures highly relies on several aspects: the content, the fibre, the fibre-matrix bonding, and the stacking sequence of both fibres (Jawaid and Khalil, 2011; Yahaya et al., 2014a; Saba et al., 2015). The literature vastly depicts that kenaf fibre incorporated in hybrid composites exhibits superior impact strength and displays its potential use in structural and automotive industries (Davoodi et al., 2010; Atiqah et al., 2014, Ramesh et al., 2016).