MECHANICAL AND PHYSICAL ANALYSIS ON THE EFFECT OF COMMERCIAL ALUMINIUM MESH IN FIBRE REINFORCED LAMINATE STRUCTURES

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This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) (Hons.)

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as part a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Materials) (Hons.). The member of the supervisory committee is as follow:

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(DR. MOHD YUHAZRI BIN YAAKOB CEng MIMechE)

ABSTRAK

Jaring aluminium mempunyai rintangan yang baik terhadap kakisan dan penyerapan kelembapan, ketumpatan yang rendah, ringan dan juga kos efektif. Walaubagaimanapun, kebanyakkan kajian tidak menggunakan jaring aluminium dalam rekaan hibrid polimer matriks komposit. Oleh itu, tujuan kajian ini adalah untuk mengkaji kesan ke atas susunan jaring aluminium dalam struktur lamina komposit dengan reka bentuk tertentu iaitu jaring aluminium dalam urutan selang dan kesan jaring aluminium tunggal dalam urutan susunan tertentu dalam sistem lamina komposit. Rekaan komposit hibrid berlapis ini dihasilkan menggunakan teknik beg tekanan dimana resin poliester, gentian kaca-E dan jaring aluminium digunakan sebagai pengikat, tetulang utama dan tetulang kedua. Ujian mekanikal dan fizikal seperti tegangan, lenturan, impak, kekerasan, ketumpatan permukaan, penyerapan air dan pembengkakan ketebalan telah dijalankan untuk menentukan tingkah laku jaring aluminium dalam reka bentuk yang berbeza. Tambahan pula, mod kegagalan telah dikaji dengan menggunakan imbasan elektron mikroskop dan mikroskop optik. Secara umumnya, kemuluran jaring aluminium menyebabkan komposit berlapis hibrid berkelakuan mulur lalu menyebabkan kekuatan yang lebih rendah muktamad tegangan, kekuatan tertentu, modulus dan kekakuan Young. Ia juga didapati bahawa pesongan dan tenaga penyerapan lebih besar dengan ujian tiga titik lenturan dan ujian kesan Charpy. Selain itu, ketebalan sampel memberi kesan ketumpatan permukaan dan sifat kekerasan Shore D dimana peningkatan dalam ketebalan membawa kepada peningkatan dalam kedua-dua sifat ini. Selain daripada itu, peralihan jaring aluminium dari kedudukan ke-7 ke kedudukan ke-9 menunjukkan prestasi yang baik dengan memberi ketegangan yang lebih baik dan kekerasan untuk sampel. Delaminasi, tarik-keluar gentian dan aluminium tarik keluar ialah mod kegagalan yang biasa ditemui yang dapat dijelaskan oleh ikatan antara muka antara matriks dan tetulang bahan. Oleh itu, dapat disimpulkan bahawa jumlah lapisan aluminium mesh meningkat, sampel menyebabkan kemuluran yang lebih baik. Selain itu, sampel menunjukkan pengurangan kemuluran apabila jaring aluminium tunggal beralih daripada lapisan tengah ke lapisan bawah.

ABSTRACT

Aluminium mesh has good resistance to corrosion and moisture absorption, low density, lightweight as well as cost efficient. However, most research did not utilize the aluminium mesh in the fabrication of hybrid polymer matrix composite. Therefore, the purpose of this study was to investigate the effect on sandwiching the aluminium mesh in fibre reinforced laminate structure with specific design which was sandwiched aluminium mesh in alternate sequence and single aluminium mesh in specific stacking sequence in the composite laminate system. The designed hybrid laminated composites were fabricated via vacuum bagging technique where polyester resin, woven roving E-glass fibre and aluminium mesh were used as the matrix, primary reinforcement and secondary reinforcement material respectively. Mechanical and physical testing such as tensile, flexural, impact, hardness, areal density, water absorption and thickness swelling were carried out to determine the behaviour of aluminium mesh in different designs. Furthermore, the failure mode was studied by using scanning electron microscopy (SEM) and optical microscopy. Generally, it was found that the ductility of aluminium mesh has made the hybrid laminated composite to behave in ductile manner, thus resulted in lower ultimate tensile strength, specific strength, Young's modulus and stiffness. Despite the drop, the hybrid laminated composite has greater deflection and energy absorption upon testing by three point bending test and Charpy impact test. Besides, thickness of samples strongly affect the areal density and Shore D hardness properties where an increase in thickness leads to an increase in both of these properties. Other than that, shifting aluminium mesh from 7^{th} position to 9^{th} position showed good performance for most samples. In addition, gives better stiffness and hardness to the sample. Delamination, fibre pull-out and aluminium pull-out were the common failure mode found which can be explained by the interfacial bonding between the matrix and reinforcement materials. Hence, it can be concluded that as the amount of aluminium mesh layers increases, the sample resulted in better ductility. Additionally, the samples showed reduction in ductility when single aluminium mesh shifted from the middle layer to the bottom layer.

DEDICATION

I dedicate my degree work to my beloved family and many friends. A special gratitude to my loving parents, Yeap Kim Hoe and Chia Bee Ding, whose words of encouragement and giving me moral support. My sister, Yeap Hooi Ping has always give me words of advice.

I also dedicate this degree work to a special friend, Tew Huei Theng, who has been a constant source of support and encouragement. I will always appreciate all she has done for helping me in achieving my goal.

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LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
CV 1 ply	-	Control variable E-glass reinforced polyester
CV 11 plies	-	Control variable 11 plies laminate
CV Al	-	Control variable aluminium mesh
CV ALR	-	Control variable aluminium mesh reinforced polyester
EMI	-	Electromagnetic interference
FML	-	Fibre metal laminate
FRP	-	Fibre-reinforced polymeric
GLARE	-	Glass laminate aluminium reinforced epoxy
LPA	-	Low profile additive
MEKP	-	Methyl ethyl ketone peroxide
ML 1	-	One aluminium mesh in alternative stacking sequence
ML 2	-	Two aluminium mesh in alternative stacking sequence
ML 3	-	Three aluminium mesh in alternative stacking sequence
ML 4	-	Four aluminium mesh in alternative stacking sequence
ML 5	-	Five aluminium mesh in alternative stacking sequence
OM	-	Optical microscope
PAN	-	Polyacrylonitrile
PCL	-	Polycaprolactone
PMC	-	Polymer matrix composite
PMMA	-	Polymethyl methacrylate
RC	-	Reinforced concrete
RM	-	Ringgit Malaysia
SEM	-	Scanning electron microscope
SM 1	-	Single aluminium mesh at 10^{th} position in the laminate
SM 2	-	Single aluminium mesh at 9^{th} position in the laminate
SM 3	-	Single aluminium mesh at 8^{th} position in the laminate
SM 4	-	Single aluminium mesh at 7^{th} position in the laminate
SM 5	-	Single aluminium mesh at 6^{th} position in the laminate
UV	-	Ultraviolet

LIST OF SYMBOLS

%	-	Percent
ρ	-	Density
µm	-	Micrometre
Cm^3	-	Cubic centimetre
d	-	Wire diameter
E	-	Young's modulus
g/cm^2	-	Gram per metre square
g/cm^3	-	Gram per metre cube
GPa	-	Giga pascal
kg/m^3	-	Kilogram per metre cube
kN	-	Kilo newton
L	-	Length
g	-	Gram
m	-	Metre
mm	-	Millimetre
MPa	-	Mega pascal
^{o}	-	Degree
^oC	-	Degree celsius
p	-	Pitch
M	-	Mass of composite
A	-	Area
T_0	-	Thickness before soaking
T_1	-	Thickness after soaked
v	-	Volume
vl. %	-	Volume percent
w	-	Wire spacing
W_0	-	Conditioned weight
W_1	-	Wet weight
wt. %	-	Weight percent

CHAPTER 1

INTRODUCTION

1.1 Research Background

Hybrid composite is formed when a matrix is reinforced with two or more types of reinforcement materials (Dong and Davies, 2015). Hybrid composite is able to improve the original characteristics of the constituents. According to Kaleeswaran *et al.* (2014), there are several variables affecting the compound such as type of matrix, type of reinforcement materials, thickness of layers and number of layers.

Studies on hand lay-up process by Moezzi *et al.* (2014) and Guermazi *et al.* (2014) clearly conclude the condition of use in affecting the composite laminates. Basically, it is due to the fibre, matrix and the bonding between these two components. Hand lay-up technique most commonly used due to simple processing method (Barbero, 2010; Mallick, 2008). Result can be enhanced by using rollers to densify the stacked layers (Chawla, 2012). Further improvement in mechanical properties is possible by using bag moulding or autoclave curing said by Campbell, 2010.

Prathima and Jaishankar (2015) defined wire mesh as a typical form of reinforcement in which the reinforcing elements are arranged and dispersed. The wire meshes come in various weave patterns said by Liu *et al*. (2015) and Xu *et al.* (2015). The wire meshes can either be a welded type or chainlink type (Hoek *et al.,* 2000). In addition, common type used wire mesh are welded wire mesh, woven wire mesh, hexagonal wire mesh and expanded wire mesh explained by Lalaj *et al.* (2015). Besides, the size is often measured in term of wire spacing, wire diameter (Hasselbruch and Zoc, 2015) and geometry shape (Patil *et al.,* 2015). Wire mesh can be made of different materials such as aluminium, steel or thermoplastic.

Aluminium mesh has been used to toughen and promote erosion resistance in polymer reinforced composites in ice-protection system for aircraft structure (Ahmed *et al.,* 2009). Erosion rate is controlled by the proportion of matrix used in glass/PPS laminate and usage of impregnated mesh decreases the rate of erosion. Besides, Martikainen (2007) found that the relatively good thermal conductivity of aluminium mesh gives advantages to detect a quick small change in temperature. Such characteristic allow moisture to be formed on the surface of aluminium mesh which suitable to be used as fog mesh. However, effect of multilayer mesh is yet to be answered.

Metal mesh has superior friction and hysteresis damping mechanism (Lee *et al.,* 2012) have been used as bearing damper (Al-Khateeb and Vance, 2001) and vibration damper in gas turbine engine for aerospace application (Ao *et al.,* 2006). Utilizing steel wire mesh or welded wire mesh in ferrocement laminates application has been a trend due to improvement in compressive strength (Arora *et al.,* 2014). For example, ferrocement jacketing (Kaish *et al.,* 2015), ferrocement enhanced plain concrete beams (Qeshta *et al.,* 2014) and bitumen ferrocement (Patil *et al.,* 2015).

Besides, thermoplastic mesh has been widely use in engineering application in medical field to produce immobilization device as it is more rigid compared to immobilization using tapes or strapes (Marwaha *et al.,* 2014). Furthermore, availability of thermoplastic mesh mask in the market which deformable at lower temperature has been broadly used said by Coppens e*t al*. (2004). Ability to be molded and fitted to the patient's features and dimensions provide good accuracy in fixed position for repetitive treatment periodically. Alternating the dimension of thermoplastic mesh in barricading the formation of cell-laden scaffold enhances the mechanical properties (Schuurman *et al.,* 2011; Moroni *et al.,* 2006).

In most studies, researchers were interested in erosion resistance, thermal conductivity and electrical conductivity to use aluminium wire mesh in engineering application. On the whole, there are no scientific research has been done on using aluminium mesh as secondary reinforcement material in composite laminate system. Therefore, this research is motivated by innovation of sandwiching the aluminium mesh in between the laminate ply. The effect of increasing number of aluminium mesh layer used will be investigated so as to observe the enhancement result. At the same time, there is also a need to find optimum and look at the phenomenon that might happen if aluminium mesh is shifted under specific condition. Thus, this research is vital to fabricate a hybrid composite laminate. On the other hand, all previous researchers found correlation between matrix and fibre were based on the bonding and adhesivity of both. Hence, the failure mechanism will also be analysed by using SEM after performing a few type of mechanical and physical testing.

1.2 Problem Statement

Wire mesh has been widely used in the field of civil engineering where steel wire mesh is highly favourable in enhancing compressive and flexural properties. For an instance, Prathima and Jaishankar (2015) claims that the use of wire mesh improved up to 30 % and 37 % for first crack and ultimate strength respectively in the field of ferrocement application. In addition, number of wire mesh used also play a vital role in obtaining the desired properties. Mesh oriented at 90 ^{o} and 0 ^{o} yield highest modulus due to the high volume fraction in the direction of loading whereas oriented at 45 ^{o} result in lower modulus (Arif and Kaushik, 1999). It is believed aluminium mesh might produce the same result when aluminium mesh is sandwiched between the laminate ply. Aluminium mesh comes in different wire diameter and grid size just like characteristic of steel wire mesh, thus the transfer of load in the laminate system might be affected by the orientation of the mesh and will be a new field of study.

Various stacking sequences have a large impact on the mechanical properties of the formed laminate structure. Thus, Arthanarieswaran *et al.* (2014) conducted a research on hybrid combination of randomly oriented natural fibres, such as banana and sisal fibres with glass fibres. However, natural fibres has its weaknesses which result in higher moisture absorption, poor surface characteristics and quality variations. Flexural properties highly depend on the glass fibres due to high fraction of load absorbed by glass fibres. Furthermore, improper adhesion between the fibre and matrix and presence of the void will lead to laminate failure. Alternative secondary reinforcement material should be revised where aluminium mesh can be a good option. Application of aluminium mesh into hybrid polymer matrix composite will be an interesting field of study where innovative idea is made possible. Aluminium mesh is able to compensate the weakness of natural fibre which might possibly enhance the mechanical properties.

According to Wu and Yang (2005), GLARE is a type of fibre metal laminate (FML) where consist of alternating thin layers of metal sheets and fibre-reinforced epoxy prepreg. GLARE laminates are vulnerable to environmental condition such as temperature and humidity. Such condition increases the ease of delamination between the prepreg and metal layers. An alternative method has been investigated by Kaleeswaran *et al.* (2014) where aluminium sheet is replaced with aluminium mesh. However, the tensile test result indicated that the system becomes more brittle as number of layers of aluminium and glass fibre increases. Therefore, a suitable number of aluminium mesh and glass is needed to be verified. In addition, incorporation of aluminium mesh in polymer matrix composite laminate can be a replacement to the current existing GLARE laminates. At the same time, aluminium mesh is more cost effective compared to aluminium sheet because less material used to make aluminium mesh.

Based on the highlighted statement, it can be seen that previous studies had not used aluminium mesh as secondary reinforcement in the enhancement of polymer matrix composite laminate. Although there is an author who uses aluminium mesh in fibre metal laminate system, it is a different field of study from this research. Thus, it can be concluded that this research is new and given the chance to innovate new materials in structural applications. This research will be focusing on sandwiching the aluminium mesh in fibre reinforced laminate system in order to investigate the performance of the hybrid composite laminate formed.

1.3 Objectives

The objectives of this research are as follows:

(a) To fabricate a hybrid laminated composite via vacuum bagging technique to specific laminated design.

(b) To determine the effect of aluminium mesh layer arrangement in the polyester laminated hybrid composite via mechanical and physical testing.

(c) To investigate the failure mode behaviours after mechanical and physical test.

1.4 Scope

The main focus of this research is to innovate a laminated hybrid composite which in the field of polymer matrix composite. Aluminium mesh will be used as the secondary reinforcement instead of natural fibre or a synthetic fibre. Cost of material is one of the considerations, thus the raw materials will be budget yet with desirable properties. Polyester resin is chosen because of the low cost and has good flexibility in processing. E-glass fibre will be used as the primary reinforcement material due to cost effectiveness, insensitive to moisture and has a wide range of working temperature. Such properties will lead to the end product to have lower moisture absorption, which may result in lower chances of delamination. Besides, cost of aluminium mesh is lower than any synthetic or natural fibres and with good properties like ductility and light weight. Shear failure will not be covered as it is not the main concern in this research, thus fibre and aluminium mesh will not be oriented to 45 ^{o}. Fibre and aluminium mesh will only be oriented to 0 ^{o} and 90 ^{o} because the end product will have better mechanical properties. Other than that, the fabrication method will only cover vacuum bagging technique due to better mechanical properties can be obtained. The laminated hybrid composite will be designed into 2 groups which are aluminium mesh in alternative sequence and single aluminium mesh in different position. First group, the aluminium mesh will be sandwiched in between the plies with an increasing number of aluminium mesh which is from 1 to 5 layers. As for secondgroup, only 1 layer of aluminium mesh will be used by changing the position of the aluminium mesh in the system. Hence, the fabricated sample will be consisting of a maximum number of 11 plies. To evaluate the effect of the incorporation of aluminium mesh in the laminate system, mechanical testing such as tensile testing, flexural testing and impact testing will be performed. Areal density, hardness and water absorption and swelling will be covered as the physical testing. Further study and understanding of bonding is possible by using scanning electron microscopy (SEM), in order to get a good view of the surface topographical between the laminate ply and the aluminium mesh.

1.5 Rationale of Research

Composite products have many advantages over metal, ceramic and plastic products. However, the cost of fabrication and raw materials can be a main concern. This research will help to develop a hybrid composite laminate by sandwiching the aluminium mesh in between the laminate ply. Cost of raw material will be reduced because aluminium mesh is cheaper compared to other metal materials. Furthermore, it will be an innovation in the composite laminate field. Based on previous research, steel wire mesh has been widely used in civil engineering in ferrocement application to increase mechanical properties. Such an idea can be implemented into polymer matrix composite laminate to obtain better mechanical properties by incorporation of aluminium mesh. Besides, different type of mesh can be studied to understand their major application. The information obtained can create a general idea of the existence type of mesh that can be used. Generation of idea is made possible where different type of mesh can be incorporated into the laminate system to study the effect of the incorporation. Other than that, new knowledge can be attained and the experimental result can bring improvement in the engineering field. With the aid of experimental results, new idea can be developed by using the appropriate number of aluminium mesh layers to yield the desired mechanical properties for structural application. Thus, alternative material is available for use. Comparison between the mechanical yield of different number of aluminium mesh layer used and stacking sequence of the