EFFECT OF THERMOPLASTIC MESH INCORPORATION ON THE MECHANICAL AND PHYSICAL PROPERTIES OF FIBRE REINFORCED LAMINATE STRUCTURES

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

by

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Date : 22 June 2016

APPROVAL

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

.....

(DR. MOHD YUHAZRI BIN YAAKOB CEng MIMechE)

ABSTRAK

Kajian ini memberikan tumpuan kepada sifat mekanikal dan fizikal ke atas kesan menggunakan jaring termoplastik sebagai tetulang kedua dalam struktur komposit berlapis. Melalui kajian persuratan menunjukkan bahawa jaring termoplastik banyak digunakan sebagai alat dalam peralatan perubatan dan juga alatan rumah, tetapi tiada digunakan dalam sistem penghasilan struktur komposit. Kajian ini akan menggunakan gentian kaca jenis E dalam bentuk ayaman sebagai bahan tetulang utama dan di gabungkan bersama jaring termoplastik. Kedua-dua bahan tetulang tersebut akan diikat oleh resin poliester menggunakan proses bag tekanan. Faktor pembolehubah dimanipulasi dalam kajian ini adalah berkaitan dengan reka bentuk susunan tetulang yang dikategorikan kepada dua kumpulan, iaitu kumpulan pertama adalah meningkatkan penggunaan lapisan jaringan termoplastik. Manakala kumpulan ke dua pula melibatkan pengalihan kedudukan lapisan jaring termoplastik dalam struktur komposit yang tetap. Sifat-sifat mekanikal dan fizikal sampel yang dihasilkan akan dikaji mengikut piawaian ASTM. Akhir sekali, morfologi patah sampel dianalisis menggunakan mesin mikroskopi elektron untuk melihat ciri-ciri ikatan antara muka bahan pengikat terhadap bahan penguat. Keputusan kajian ini menunjukkan peningkatan tengagan (2.854 MPa) dan kekerasan (78.5 H_d) boleh dicapai dengan memasukkan jaring termoplastik kepada kedudukan yang keenam. Manakala, kedudukan yang kesepuluh boleh meningkatkan fleksibiliti (160.377 MPa) dan penyerapan tenaga (40.10 J). Selain itu, ciri-ciri rintangan air dan penyerapan tenaga juga dipertingkatkan. Melalui penyelidikan ini, pembentukan komposit hibrid ini boleh ditambahbaikan untuk aplikasi dimana memerlukan syarat fleksibiliti yang tinggi, penyerapan tenaga yang tinggi dan permintaan kalis air.

ABSTRACT

This research mainly focused on the mechanical and physical properties of fibre laminated structures when thermoplastic mesh used as the secondary reinforcement. From the several studies, the thermoplastic mesh mostly used in the field of biomedical and furniture application. However, it is haven been used to produce the composite structure. In this research, the development of hybrid composite was manufactured by using the woven roving E-glass fibre as the main reinforcement while thermoplastic mesh used as secondary reinforcement. Both of these reinforcement was bind with polyester resin via the vacuum bagging process. The manipulate variable in this research was the design of lamina arrangement which categorised into two group. The first group was manipulated by increasing the plies of thermoplastic mesh whereas the second group was shift the position of thermoplastic mesh layer in the fixed number of plies in composite structure. The mechanical behaviour of the prepared sample was investigated according to ASTM standard. The fracture morphology of the specimen tested was analysed by scanning electron microscopy in order to observe the interphase between matrix and reinforcements materials. From the overall obtained result, the design of shifting thermoplastic mesh obtained greater enhancement compared to increase number of thermoplastic mesh. The 6^{th} layer of insertion of thermoplastic mesh layer was obtained highest tensile strength (2.854 MPa) and hardness (78.5 H_d). While 10^{th} layer achieve better flexibility (160.377 MPa) and energy absorption (40.10 J) compared to the others design. With the insertion of thermoplastic mesh, the characteristic of water resistance have been enhanced. Via this research, the development of this hybrid composite could be used for the applications where required higher flexibility, higher energy absorption and water-proof demand.

DEDICATION

Dedicated to my beloved father, Yap Eng Kim,
my appreciated mother, Tan Siew Lan,
my adored brother, Yap Wei Jin, Yap Hong Jin and Yap Zhi Jin,
my teammate, Yeap Hong Kheng, Tew Huei Theng, Ngu Ung Hie and Lim Reo Sei,
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LIST OF ABBREVIATIONS

GFRP	-	Glass Fiber-Reinforced Polymer
TP	-	Thermoplastic
PPS	-	Polyphenylene sulphide
HT	-	High tenacity
C	-	Carbon
PCL	-	Polycaprolactone
A1	-	Wire mesh with one layer
A2	-	Wire mesh with two layers
A3	-	Wire mesh with three layers
A4	-	Wire mesh with four layers
A5	-	Wire mesh with five layers
B1	-	Carbon fibre sheet (width = 10mm)
B2	-	Carbon fibre sheet (width = 20mm)
HY1	-	Hybrid carbon fibre sheet (width = 20 mm) + wire mesh with two layers
HY2	-	Hybrid carbon fibre sheet (width = 20 mm) + wire mesh with two layers (width = 100 mm)
ASTM	-	American society for testing and materials
RM	-	Ringgit Malaysia
MEKP	-	Methyl Ethyl Ketone Peroxide
PP	-	Polypropylene thermoplastic mesh without resin
PP-R	-	Polypropylene thermoplastic mesh with resin
CV 1	-	E-glass fibre with one ply
P01	-	Sample one with one plies of thermoplastic mesh
P02	-	Sample one with two plies of thermoplastic mesh
P03	-	Sample one with three plies of thermoplastic mesh
P04	-	Sample one with four plies of thermoplastic mesh
P05	-	Sample one with five plies of thermoplastic mesh
CV 11	-	E-glass fibre with 11 plies
S01	-	Sample with placed the thermoplastic mesh at 6^{th} layer

S02	-	Sample with placed the thermoplastic mesh at 7^{th} layer
S03	-	Sample with placed the thermoplastic mesh at 8^{th} layer
S04	-	Sample with placed the thermoplastic mesh at 9^{th} layer
S05	-	Sample with placed the thermoplastic mesh at 10^{th} layer
UTM	-	Universal testing machine
UTS	-	Ultimate tensile strength
W_n	-	Weight of composite samples after immersion
W_d	-	Weight of the composite samples before immersion.
T_1	-	Thickness after soaking
T_0	-	Thickness before soaking
OM	-	Optical microscope
SEM	-	Scanning electron microscopy

LIST OF SYMBOLS

^{0}	-	Degree
%	-	Percent
MPa	-	Mega pascal
GPa	-	Giga pascal
^{0}C.	-	Degree Celsius
m	-	Meter
kg/dm^{3}	-	Kilogram per cubic decimeter
kg/m^{2}	-	Kilogram per square meter
mm	-	Millimeter
mm/min	-	Millimeter per minutes
g/cm^{3}.	-	Grams per cubic centimeter
kN	-	Kilo newton
kV	-	Kilo volt
:	-	Ratio
kNm/kg	-	Kilo-newton meter per kilogram
J	-	Joules

CHAPTER 1
INTRODUCTION

This chapter briefly describe the historical background of mesh and laminated composite material. The ideas generation for research problems normally arise from a range of sources such as a theory, the media or other research studies. Thus, several problems are stated so that the enhancement can be done in this research. Besides, the objectives needed to be achieved and scopes of this research have been specially mentioned and explained in this chapter.

1.1 Background of Research

Composite is consolidation of two or more constituent materials to achieve or improve the specified structural properties. Application of composite materials can manufacture an ideal and high performance of finished product. According to Jadhav *et al.* (2015), composite materials brings the advantages of high strength, high stiffness, superior fatigue life, corrosion resistance, low density, and the excellent formability can lower the manufacturing costs due to fewer details parts and fasteners. Botan *et al.* (2015) expressed that the mechanical properties of the composites is rely on microstructural. Geometries, selection of elements type, distribution and properties of phases and constituents in composite might influence the mechanical behavior of the composite due to the interface quality. The interface is characterized by a strong bond between the fibers and resins. The stress concentration will focused into the reinforcement rather than the matrix as the interface strongly bonded with reinforcement body. This phenomena resulted as the matrix is less loaded and durability becomes longer.

Bakare *et al.* (2015) has discovered that most of the preparation of fibre reinforcement composite is using epoxy resins, polyester resin, vinyl ester resins or from plant oil resins, which have the excellent mechanical properties. Furthermore, Cawse (2015) also concluded that the thermosetting resins is preferred compared to thermoplastic resin due to reduced levels of solvent-induced micro crack formation. The formation of micro cracks can penetrate to varying depths within the resin. Physical strength of the finished composite part may become deleterious due to the formation of micro cracks

Ozsoy *et al.* (2015) describes that the glass fibre-reinforced polymer (GFRP) bind with thermoset resin is an interesting combination due to the reason of economically desired. Glass fibre-reinforced composites is preferred materials among the composites researchers due to the several factors such as capability applied at low temperatures, high strength properties and capability with working under terms of difficult service. According to an investigation of Benessalah *et al.* (2015), the mechanical characteristic of finished product especially the wet specimens becomes better after addition of the glass-fibres. Except the enhancement of shear strength, the utilization of fibres also provides better properties in terms of resistance against deformations applied load. The product that often face the high impact load mostly are applied with the fibre.

Hybrid composites is material that incorporated with different type of fiber in a single matrix. According to Chamis *et al.* (1977), the structure of hybrid composites where formed by adhesively bonded fiber/resin and fiber/metal matrix composites could provided the high strength and lightweight performance. In addition, Kini *et al.* (2015) also expressed that hybrid composite materials have broad-scale of engineering application due to the perspective of high strength to weight ratio, ease of fabrication and economical. Besides, this types of composites also offer improvement in mechanical properties such as impact strength, tensile strength and compressive strength which cannot achieved in conventional composite materials.

In recent year, several studies have investigated effectiveness on properties of composite by adding mesh. Basically, there are many types of mesh such as wire mesh,

metal mesh, and thermoplastic mesh and so on. These types of mesh is utilized based on their specific characteristic. According to Marwaha *et al.* (2014), the thermoplastic mesh was applied for immobilization due to minimally restrictive devices, such as tape and straps, and more rigid devices, such as thermoplastic mesh or vacuum-locking bags, allow for easily customizable immobilization. Sheehan and Tierney (2011) also expressed that a geometrically aperture protective splint device containing re-mouldable thermoplastic material that can be used as a composite splint material for immobilization, bracing protection or support of limbs and body parts on human and animals.

Welded mesh carries the properties of flexibility and controlled manufacturing to suit any structural requirement; high and consistent quality with mesh delivered just-in-time to site; reduce cost; reduce the material wastage. Wire mesh has been used as ground support in mining since the 1950's. Nowadays, wire mesh also widely used in manufacturing field especially in construction due to its physical and mechanical properties. While the steel wire mesh also often used for rock surface support in mines (Morton *et al.*, 2007).

Hand lay-up technique is one of the method used in fabricate laminated composite. Hand lay-up can be said as the simplest fabrication technique used in manufacturing process. The dry reinforcements are arranged and placed carefully in the prepared mould and then poured by the resin. Applied resin during the hand lay-up can be distributed evenly by using a roller (Barbero, 2010). In contrast, Fiore *et al.* (2011) stated that vacuum bagging technique can applied for all the composite structures have been made with lamination. The final characteristic of composite laminate that manufactured through vacuum bag technology resulted better quality and performance when compared to hand lay-up technology.

Studies on the welded or wire mesh-epoxy composite were carried out by scholars a decade ago (Qeshta *et al.*, 2014; Zheng *et al.*, 2015). These studies implemented to analyze the performance of composite with the addition of mesh.

However, there are still no scientific experimental research on the effectiveness of properties when thermoplastic mesh inserted into the laminated structure. Thus, the

development of thermoplastic mesh in fibre reinforced laminate structure becomes an interested topic to be explored in detail to obtain the information about the effect of thermoplastic mesh in fiber reinforced laminated composite structural and strength via physical and mechanical testing.

1.2 Problem Statement

Nowadays, composite structure are under prodigious attention for advanced engineering application due to excellent strength and stiffness, lightweight and reduced energy cost. However, there still have several factors which could affect the quality and performance of the composite products. Thus, the reliability-based design optimization of composite structures is currently a very important area of research (Kimiaeifar, 2015). For an example, there have a case studied on the performance of hybrid composite by using carbon fibre as reinforcement. The hybrid composite laminated with 50 % carbon fibre reinforcement provide the best flexural strength properties when the carbon layers are placed at the exterior. The author also examined the tensile strength would affected by different stacking direction (Zhang *et al.*, 2012). However, these studies concluded that the hybrid composite product are more preferred due to the improvement of performance can be achieved.

Wire mesh is widely applied in concrete building. Various type of size and permeability of wire mesh will dominate in various application such as the vegetable strainers normally use the thinner mesh size whereas the larger mesh size is used as conveyor belt in an industrial training. However, the wire mesh structure with millions of tiny holes per square meter is difficult to establish the flexible multi-body dynamic model. Thus, the analysis of mechanics properties of the wire mesh structure faces huge challenges. Bi-axial tensile test showed that the mechanics of the woven mesh structure has the strongly orthotropic characteristics. The orthotropic characteristic was identified based on the boundary element method.

According to Hasselbruch *et al.* (2015), the open metallic structures like perforated plates and wire meshes enable reinforcement and stabilization of the fiber

structure, even if inserts are integrated into the composite. The author also conclude that the addition of mesh between the metal and thermoplastic polymer can obtain an improved interface bonding.

Qeshta *et al*. (2014) also investigated on flexural performance of the specimen bonded with wire mesh layers as well as hybrid of wire mesh-epoxy-carbon fibre composite. The obtained result shows that the use of wire mesh is an efficient way in improving the flexural performance of the specimen. From this perspective, the addition of mesh in composite material can improve the flexural properties. Thus, there was contributed an idea whether the flexural performance of the laminated composite would increase or decreased as insert the thermoplastic mesh which has high ductility behaviour.

The engineers is always find the ways to manufacture the high performance product with the lower assembly costs. Kohl (1988) state that the lower cost of plastic has enhances the availability as substitutes for additional construction materials. This is an effective way and economical desired reinforcing of plastics to increase strength while maintaining a cost advantages. Thus this studies leading to the need of determining on mechanical strength of the composite after inserting thermoplastic mesh.

There are many studies in the literature in which wire or welded mesh-epoxy based laminated composite. However, there is still no specific research that using the thermoplastic mesh as secondary reinforcement in a laminated composite. In conclusion, by considering all these matters, there are a motivation to be spelled-out of implement this research. This is due to no previous researcher have been detected in the literature review or known to has available in the commercial market.

1.3 Objectives

The objectives for this projects includes:

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

(b) To study the effect of thermoplastic 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 Scopes

The scope of this research as follow:

(a) Study the properties of the composite when thermoplastic mesh used as secondary reinforcement in laminated composite structure.

(b) This research is conducted by fix the arrangement of 0/90 degree orientation of the composite laminate.

(c) To determine the effect of physical and mechanical behavior of the hybrid composite by manipulate the number of plies of thermoplastic mesh

(d) To define the strength of the hybrid composite by shifting the position of insertion of thermoplastic mesh within 11 plies of composite lamina.

(e) For this research, the vacuum bagging technology is used as fabrication method in making the composite laminate.