UNIVERSITI TEKNIKAL MALAYSIA MELAKA

THERMAL BEHAVIOR OF NATURAL FIBER MAT HYBRID COMPOSITE FOR TOOLING MATERIALS

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 a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Engineering Materials) (Hons.). The members of the supervisory committee are as follow:

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(MISS CHANG SIANG YEE)

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(PROF. DR. QUMRUL AHSAN)

ABSTRAK

Pengeluar industri aeroangkasa memerlukan peralatan yang bersaiz besar untuk menghasilkan komponen earoangkasa. Penggunaan peralatan gentian sintetik komposit adalah lebih ringan berbanding peralatan logam tetapi ia mahal and sukar untuk di kitar semula. Projek ini bertujuan untuk memperkenal gabungan gentian semulajadi dengan gentian sintetik untuk menghasilkan bahan peralatan. Projek ini adalah untuk fabrikasi jut/ kaca gentian bertetulang epoksi komposit lamina dengan mengubah orientasi gentian dan menyusun urutan melalui kaedah sapuan tangan dan pembalut vakum, mencirikan tetulang dari segi fizikal dan mekanikal dan haba untuk menyiasat perubahan bentuk dan kestabilan dimensi komposit apabila terdedah kepada haba berulang kali. Orientasi lamina diubah (0/90º) dan (-45/45º), dan disusun sehingga 7 dan 9 lapisan dengan urutan yang berbeza. Komposit lamina di uji dari segi penyerapan air, lenturan dan pendedahan kepada haba berulang kali. Pemeriksaan mikroskopi juga dijalankan untuk melihat mod kegagalan lenturan komposit lamina sebelum dan selepas terdedah kepada haba. Ia telah mendapati tanpa mengira orientasi dan susunan urutan,jut/kaca gentian bertetulang epoksi komposit lamina memiliki kepadatan yang rendah dan kapasiti penyerapan air yang tinggi menyebabkan pembengkakan pada lamina komposit. Ujian pendedahan kepada haba 180º C berulang kali telah menyebabkan pengurangan kestabilan dimensi yang disebabkan oleh pekali yang berbeza pengembangan haba (CTE) bahan dan penguraian awal pada komposit lamina. Degradasi membuktikan kekuatan lenturan komposit lamina bekurang selepas 15 kitaran haba. Walau bagaimanapun, kekukuhan komposit lamina menunjukkan peningkatan dan ini boleh dikaitkan dengan kesan pengerasan belaku selepas terdedah kepada haba berulang kali. Mod kegagalan menunjukkan nyahikatan, delamination dan serat penyambung di kenalpasti pada komposit lamina.

ABSTRACT

Aerospace industry manufacturers require large tools to fabricate large aerospace components. The use of synthetic fiber reinforced composite tooling provides a lightweight solution as compared to metal tooling, yet it is expensive and not recyclable. This project serves to introduce natural fiber as partial replacement in synthetic fiber composite for tooling materials. This project aimed to fabricate jute/glass fiber reinforced epoxy laminate composite by varying fiber orientation and stacking sequence through hand lay-up and vacuum bagging technique, characterize the physical and mechanical behaviors of the fabricated laminate composite and investigate the deformation behavior associated with dimensional stability of the composite when subjected to thermal cycling. The orientation of the laminae varied at (0/90º) and (-45/45º), and stacked up to 7 and 9 plies with different sequence. The laminate composite was subjected to water absorption, flexural and thermal cycling testing. Microscopy examinations were also carried out to observe the deformation behaviour as well as the flexural failure mode of the laminate composite prior to and post thermal cycling. It was found that the regardless of orientation and stacking sequence, jute/glass fiber reinforced epoxy laminate composite possessed low density and high water absorption capacity which caused swelling on the laminate composite. The thermal cycling test conducted at 180°C resulted in reduction of dimensional stability due to different coefficient of thermal expansion (CTE) of the constituent materials and initial degradation of the laminate composite. Degradation was evidenced as the flexural strength of the laminate composite reduced after 15 thermal cycles. However, the stiffness of the laminate composite showed improvement and this can be attributed to effect of further curing that took place in the composite after thermal cycling. The failure mode showed debonding, delamination and fiber bridging on laminate composite.

DEDICATION

To my beloved parents, supervisor, co-supervisor, siblings, lecturers and friends.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

ASTM	-	American Standard Test method
CTE	-	Coefficient of thermal expansion
DSC	-	Differential Scanning Calorimetry
FRP	-	Fiber Reinforced Plastics
NASA	-	National Aeronautics and Space Administration
PLA	-	Poly (lactic acid)
PMC	-	Polymer Matrix Composites
PVC	-	Polyvinyl chloride
SE	-	Secondary electron
SEM	-	Scanning Electron Microscope
SiO_2	-	Silica
SME	-	Society of Manufacturing Engineers
TGA	-	Thermogravimetric Analysis
UTM	-	Universal Testing Machine
UV	-	Ultra-violet light
M_i	-	immersion weight
M_o	-	original weight
M_w	-	weight gain
P_{max}	-	maximum load at failure (N)
σ_{max}	-	maximum stress
ºC	-	degrees Celsius
^{0}F	-	degrees Fahrenheit
W/mK	-	thermal conductivity
m/m/ ºC	-	coefficient of thermal expansion
g/cm^3	-	density
kJ/kg.K	-	specific heat

J/g.K	-	thermal mass
in	-	inch
mm	-	milimeter
µ	-	micron
GPa	-	gigapascal
MPa	-	megapascal
$MPam^{1/2}$	-	fracture toughness
%	-	percent

CHAPTER 1
INTRODUCTION

This chapter introduces the background, problem statement, objectives as well as the scope of the study.

1.1 Background

Nowadays, the aerospace industry manufactures increasingly larger components which require the use of larger tools. High performance, cost effective materials are used to produce the tools to ensure the quality of the end-product and sustainability of the tooling. Traditionally, metals have been used as tooling materials for composite processing. However, the weight of metal tooling has become an issue particularly for manufacturing of large aerospace components. Consequently, lightweight materials would be preferred to accomplish this task. Introduction of hybrid composite materials as tooling materials has weight advantage over the metals and produces stronger components. Hybrid composite which is made of two or more different kinds of fiber in single matrix, provides better combination of properties than composite containing single fiber (Callister., 2006).

At present, synthetic fiber reinforced composite is widely used by manufacturers to produce tooling. The drawbacks of the synthetic composites tooling are associated with its high cost and limitation of recyclability. Satyanarayana *et al.* (2009) as cited in Jawaid *et al.* (2011) highlighted that glass fiber costs approximately 1200 –

1800US$/tones which is almost twice the price of the natural fibers. Besides, according to National Composite Network (2006), the issue of recycling composite poses great impact on the environment. This is due to the lack of clear and well-developed recycling routes (logistics, infrastructure and recycling technologies). Additionally, disposal of carbon or glass fiber by incineration is detrimental to our mother earth (Nishino *et al.*, 2003).

To circumvent the problem, green hybrid composite tooling is an alternative by partial replacement of the synthetic fiber with the presence of natural fiber in the composite tooling. Incorporation of natural fibers in the composite presents a number of advantages such as low tool wear, low density, cheaper cost, abundance availability and the most importantly its biodegradability (Akil *et al*., 2011).

Natural fiber reinforced composites have found applications in automobile and furniture industries as the composites possess comparable mechanical properties to that of glass fiber reinforced composites (Sabah *et al.*, 2012). Thus, the venture of green hybrid composite into composite tooling is highly promising. Among the natural fibers available in the market, jute, flax and coir show the prominent properties in engineering applications.

Though so, the challenge of utilization green hybrid composite tooling lies on the difference of thermal mass and coefficient of thermal expansion between the natural and synthetic fiber. The varying fiber orientation and stacking sequence of glass and natural fiber significantly affects the hybrid composites (Patel *et al*., 2011). Ahmed and Vijayarangan (2008) revealed that the arranging jute fiber plies at the middle of the hybrid composites led to improved flexural strength. According to Tezvergil *et al*. (2003), the direction perpendicular to fiber orientation resulted in high coefficient of thermal expansion in the polymer matrix. In this regard, proper composite design is very crucial in determining the performance of the proposed green hybrid composite tooling.

1.2 Problem Statement

During the manufacturing of aerospace components, tooling used is usually made of carbon fiber or glass fiber reinforced epoxy composite which is difficult to be recycled or disposed. As a green hybrid composite tooling, the incorporation of natural fiber and synthetic fiber in these tooling materials could lead to new venture in tooling industries. Tooling material is subjected to repeated thermal cycling during in service and is likely to induce distortion on the tooling due to the difference in thermal mass and coefficient of thermal expansion between the natural fiber and synthetic fibers. However, no studies have been undertaken to determine thermal history of the natural fiber in composite. Besides, hybrid configuration is also important to achieve optimum result by varying the fiber orientation and the stacking sequence of natural fiber/glass fiber laminae in order to overcome the dimensional instability, low thermal degradation and moisture absorption of hybrid composites associated with natural fibers.

1.3 Objectives

1. To fabricate natural fiber/ glass fiber reinforced epoxy hybrid composite by varying fiber orientation and stacking sequence of natural and glass fiber laminae through hand lay up and vacuum bagging techniques.

2. To characterize the physical, and mechanical behavior of natural fiber/ glass fiber reinforced epoxy hybrid composite in order to establish structure – property relationship.

3. To investigate deformation behavior associated with the dimensional stability of natural fiber/ glass fiber reinforced epoxy hybrid composite subjected to thermal cycling for the application in composite tooling.

1.4 Scope

In this research, jute fiber mat and E-glass fiber mat were used as reinforcement in the epoxy laminate composite. The laminate composite was fabricated through hand lay up and vacuum bagging techniques by varying the stacking sequence of fiber laminae and fiber orientation ($0^{\circ}/90^{\circ}$ or $45^{\circ}/-45^{\circ}$). Two composite systems encompassed of different laminate layers were produced, that were 7 and 9 plies. For characterization of raw materials, Scanning Electron Microscopy (SEM) is used to determine the fiber morphology. Meanwhile, the physical testing is carried out in terms of the density measurement and water absorption capacity. On the other hand, the dimensional stability of jute/glass fiber reinforced epoxy laminate composite is measured after subjected to 15 cylces of thermal cycling. The thermal cycling is carried out at $180^{0}C$ for a period of 10 minutes and subsequent cooling at room temperature. From the aspect of mechanical testing, Universal Testing Machine (UTM) is employed to study the flexural behavior of the laminate composite prior and post thermal cycling. The fracture mode of the laminate composite is then analyzed through microscopic observation.

CHAPTER 2
LITERATURE REVIEW

A literature review on previous research work in various areas which is relevant to this research is presented in this chapter.

2.1 Tooling

In manufacturing applications, tooling required to fabricate most composite parts can be subdivided into several major category including ply layup tools, skin or mould forms, curing aids, handling tools, drilling and trimming tools, assembly tools, mould and mandrels (National Aeronautics and Space Administration, NASA, 1990). However, mould which used forming composite part is known as tools. In aerospace industry, mold is widely used during hand lay-up process. According to NASA (1990) cited major factors must be considered in design and fabrication of tooling for structural and mechanical components are:

i. Dimensional tolerance control and configuration stability – low coefficient of thermal expansion (CTE) is required.
ii. Location of part in structural reliable assembly to give the lowest possible cost.
iii. Contour and size of the part.
iv. Control the fiber orientation.

v. Other factors: cost, tool service life, heat up rate, total energy requirements, production rates and related facility costs.

From Lucas and Danford (2009) also had highlighted tooling is critically important where mold tool must be low-cost, rigid and durable and offer a CTE that matches of the composites part. (Stewart, 2010) also had mentioned the tooling must be cost effective, UV resistant, damage to tolerance and able to resist environmental degradation in maintaining the dimensional and stability of tooling. Therefore, long lead times and material availability is also growing concerns with alloy-based tools.

2.1.1 Metallic Tooling

Traditionally, high performance composite parts are formed can be made of metals typically Invar, aluminum or steels. Invar 36 (36% nickel) or Invar 42 (42% nickel) which are well-known metal tooling materials composed low carbon austenite steel alloy with very low CTE (from 0.5 - $6 \times 10^{-6} \mathrm{in/in/°F}$). Invar refers to the metal's 'invariable' dimensional properties. The production of metal tooling can withstand to repeated cycles and maintain good surface finish and dimensional accuracy. Thus, metal tooling such steel can produce high-volume of composite parts because durable and coefficient of thermal expansion which close to that of reinforced plastics used to mould the part (Stewart., 2010). By the way, tools costs and complexity is increased as the part performance requirement and numbers parts to be produced increased. Even metal tool are able to withstand many thousands production cycles, the major drawback of metal tool is relatively heavy when composite manufacturers producing the large scale of composite part.

2.1.2 Composite Tooling

Due to the excessive weight of metal tooling resulted many manufacturers have turned to composite tooling. Cadden and Sadesky (1998) stated composite mould tooling has several basic advantages. For instance, composite tooling is a low cost because the composite prepreg materials can be laid on plaster model and then cured, the CTE of tooling materials is compatible, and graphite mould tools provide uniform temperature distribution which allows the composite part heated up evenly and prevent internal residual stress. In addition, if damage occurs new tool can be fabricated rapidly and economically from original master model. Table 2.1 provides some properties for most commonly used tooling materials.

Table 2.1: Typical Properties of Tooling Materials (Source: Cadden and Sadesky, 1998).

Material	Thermal Conductivity, (W/m.K)	Coefficient of Thermal Expansion (m/m.K)	Apparent Density (g/cm^3)	Specific Heat (kJ/kg.K)	Thermal Mass (J/g.K)
Graphite	400	1.5 – 2.0	1.78	0.25	0.44
Aluminum	1395	13.0	2.70	0.23	0.062
Steel	350	6.7	7.86	0.11	0.86
Nickel	500	6.6	8.90	0.11	0.98
Carbon-Fiber/ Epoxy	24 – 42	0 – 1.5	1.50	0.25	0.38
Fiberglass/Epoxy	22 – 30	7 – 13	1.9	0.3	0.57
Ceramics (MgO, Al_2O_3 Gypsum)	10 – 80	3 – 6	1.6 – 3.9	0.84 – 1.50	1.2 – 5.3