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HYGROTHERMAL EFFECT ON HYBRID COMPOSITE BY USING FILAMENT WINDING PROCESS

Edynoor bin Osman

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EDYNOOR BIN OSMAN

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DECLARATION

I declare that this thesis entitled "Hygrothermal Effect on Hybrid Composite by using Filament Winding Process" 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.

Signature : ....

Author's Name : Edynoor bin Osman

Date : 15 August 2014

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 Master of Manufacturing Engineering (Industrial Engineering).

Signature :...

Supervisor Name : Assoc. Prof. Dr. Mohd Warikh bin Abd Rashid

Date : 14.8.2014

DEDICATION

To my beloved wife, Hazlinda bte Kamarudin, my lovely sons, Muhammad Daniel Haikal and Muhammad Daffy Danish also my cutest daughter, Nourish Zara Aleesya. Their source of my inspiration and strength in pursuit of excellence. To my mother, father, father in law who always pray for us happiness. Not forgotten also to my late mother in law. Thanks for all support and encouraged towards the end.

ABSTRACT

Nowadays, filament winding process has evolved in manufacturing of polymer composites industries. In addition, filament winding process of polymer matrix composite offered the most cost effective method, good part definition and correctly fibre placement that will give very high strength to weight ratio. In this project, a hygrothermal effect on Glass-Carbon/Epoxy hybrid composite were studied and revealed. The non geodesic pattern of filament winding was used with the winding speed of 15.24 – 30.48 linear metre/min. Fibre tensioning weight of 1 kg and winding angles of 30° is created in order to produce the wound samples of hybrid composite. The hybrid composite was wound by using the orientation of ± 30°with the total number of six (6) layers.While for hygrothermal effect has been carried out in humidity chamber for 3 days (72hrs). The controls temperatures of 60°C and 80°C has been set up as well as percentage of humidity 50%, 70% and 90% are used. From the testing result, hybridization of glass and carbon fibre shows the highest in tensile and flexure test which represent 90.27 MPa and 198.10 MPa respectively as compared to non-hybrid samples. Moisture absorption test shows most of the hybrid samples are gradually increased over heat and humidity. As a result, Glass-Carbon 80°C/90% shows the highest value of moisture absorbed, 0.77%. Meanwhile, the involvement of highest heat and humidity shows the decreased in value of tensile and flexure strength, 75.80 MPa and 157.15 MPa respectively. As thermal analysis results, shows the reduction of T_g with the increase of heat and humidity that indicate the effect of the hygrothermal. From fractography analysis by using Stereo Microscope Stemi 2000-C, Glass-Carbon/Epoxy 80°C/90% has shown catastrophic damage, big crack and longest delamination of fibre pull out, 10.39 mm. The criterion of fracture revealed that the involvement of heat and humidity give a big impact towards the mechanical and physical properties of hybrid composite material.

ABSTRAK

Pada masa kini, proses penggulungan filamen telah berkembang dalam industri pembuatan bahan rencam polimer. Di samping itu, proses penggulungan filamen yang bermatrikskan bahan rencam polimer menawarkan kos yang rendah, produk yang berkualiti tinggi dan penempatan orientasi serat yang tepat yang seterusnya akan memberikan kekuatan yang sangat tinggi terhadap nisbah berat. Di dalam projek ini,kesan higroterma pada kaca-karbon/epoksi bahan rencam hibrid telah dikaji. Penggulungan jenis non geodesic bagi penggulungan filament akan digunakan dengan kadar kelajuan 15.24 – 30.48 linear meter / minit. Kekuatan bagi penegangan serat adalah 1 kg serta sudut penggulungan 30^{o}digunakan bagi menghasilkan sampel bahan rencam hibrid ini. Bahan rencam hibrid akan dihasilkan dengan menggunakan sudut penggulungan ±30^{o}dengan jumlah keselurahan adalah enam lapisan. Justeru itu, kesan higroterma bagi sampel-sampel yang dihasilkan telah dijalankan di dalam kebuk kelembapan selama 3 hari (72 jam). Kawalan suhu 60^{o}C dan 80°C telah digunakan dengan peratusan kelembapan 50%, 70% dan 90%. Daripada hasil pemeriksaan, hibrid gentian kaca dan karbon menunjukkan nilai tegangan dan kelenturan yang tertinggi iaitu 90.27 MPa dan 198.10 MPa masing-masing berbanding sampel tidak hibrid. Ujian penyerapan kelembapan menunjukan kelembapan meningkat terhadap haba dan udara lembap. Hasil keputusan memperolehi, Glass-Carbon/Epoxy 80^{o}C/90% menunjukkan jumlah penyerapan kelembapan yang tertinggi iaitu 0.77%. Sebaliknya, penglibatan haba dan udara lembap menunjukan penurunan kekuatan tegangan dan kelenturan, 75.80 MPa and 157.15 MPa masing-masing. Daripada keputusan analisis terma menunjukkan pengurangan T_g dengan peningkatan haba dan kelembapan yang menunjukkan kesan yang higroterma. Daripada analisa patah dengan menggunakan Stereo Microscope Stemi 2000-C, Glass-Carbon/Epoxy 80^{o}C/90% menunjukan kerosakan teruk, retak besar dan gentian yang terpanjang tertarik keluar daripada matriks polimer iaitu 10.39 mm. Kriteria patah menunjukkan bahawa penglibatan haba dan udara lembap memberi kesan yang besar terhadap sifat mekanikal dan fizikal bahan rencam polimer hibrid.

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LIST OF ABBREVIATIONS

A	-	the radius
c	-	moisture concentration (g/mm^3)
t	-	time (s)
D	-	moisture diffusivity (mm^2/s)
Z	-	coordinate direction of diffusion (mm)
D	-	diffusion coefficient
M_∞	-	saturation level of water absorption
α_n	-	nth root of the zero order Bessel Function
$S^{½}$	-	square root of immersion time
J/m	-	Joule/metre
α	-	wind angle
D	-	Fibre diameter
L	-	Fibre length
PAN	-	polyacrylonitrile
UP	-	Unsaturated Polyester Resin (Thermoset)
EP	-	Epoxy Resin (Thermoset)
PEEK	-	Polyether Ether Ketone (Thermoplastic)
DGEBA	-	Diglycidyl Ether ofBisphenol A
SiC	-	Silicone Carbide

Al_2O_3	-	Aluminium Oxide
B_4C	-	Boron Carbide

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Nowadays, filament winding process has evolved to be the preferred in the composites industry. Filament winding is the most cost effective method, for producing pressure retaining structures from fibre reinforced polymeric composites. Although this method has been in use for an extended period of time, the heat and humid effect of filament wound product has only been investigated to a limited extend. In addition, there are limited investigative studies of the hygrothermal effect of hybrid composite.

So, the major consideration in this research is to study a hygrothermal effect towards mechanical properties of glass-carbon/epoxy hybrid composite. A filament winding techniques introduced in this study. The method is selected because of the tension developed during winding process is able to compact the fibres. It also will give good part definition and eliminate many surface problems such as blistering, porosity, cracking and splitting. Furthermore, filament winding also could produce specific orientations within the component would have higher specific density, which resulted in less void and air and was then sand thus utilize the anisotropic properties of the fibre to produce a highly product structure (Bannister, 2001). By filament winding, correctly fibre placement will give very high strength/weight ratio. Then, the study will be overview about the mechanical and physical properties of hybrid composite after doing hygrothermal conditioning. Finally, the contribution of hybrid composite will offered reduction in cost and strength to weight ratio. Moreover, it will give more alternatives to the composite people to do hybrid composite instead of focusing on single laminate fibre.

1.2 Problem statement

Even though hybrid composite material has many advantages and outstanding characteristic if compared to conventional polymer composite material, heat and humidity still remain as big factors that affected the mechanical and physical properties of hybrid composite. For instance, Soutis and Turkmen (1997) have investigated the humidity and temperature effects on the compression strength and failure mode of the T800/924C carbon–epoxy composite in the hot water. In the research, it determined the failure mode as an out of plane fiber buckling and also decreasing of the matrix strength in the high temperature. All polymer composites absorb moisture in a humid atmosphere and when immersed in water. The effect of moisture absorption leads to the degradation of fibre-matrix interface region which thus creates poor stress transfer efficiencies resulting in a reduction of mechanical properties (Yang et al., 1996). Besides, Wu et al. (2002) was observed that the maximum reduction in interlayer shear performance was occurred in the composite exposed deionized water while maximum decrease in the tensile performance exists by effect of the seawater. Also, chemical degradations in the fiber/matrix interface and it reduces the bending modulus and strength of the composite (Kootsookos and Mouritz, 2004). Furthermore, by increasing of seawater immersion time, failures in fiber–matrix interface and matrix failure increase in the composite specimen (Mehmet et al., 2013). In that case, if these materials are designed for exterior component applications such as tank, pipe and automotive part, high water uptake is mandatory. Therefore, it is important that the problems are investigated.

1.3 Objectives of study

i. To fabricate glass-carbon/epoxy hybrid composite by using filament winding process.

ii. To investigate the hygrothermal effect on physical and mechanical properties of glass-carbon/epoxy hybrid composite.

iii. To analyze the microstructure and thermal properties of glass-carbon/epoxy hybrid composite.

1.4 Scope of study

In this project, glass-carbon as reinforcement and epoxy resin as matrix material are selected for hybrid composite. Then, all these material will be undergoing filament winding process to produce the samples. The parameters used for the filament winding process are non geodesic winding with an angle of 30^{o} of glass-carbon/epoxy hybrid composite. In addition, hygrothermal conditioning will be applied to hybrid composite samples in accelerating heat and humidity. The used parameters are 60^{o}C and 80^{o}C of heat temperature and 50%, 70% and 90% of humidity percentage. As to overview the properties of the glass-carbon/epoxy hybrid composite, mechanical and physical testing are studied and analyzed. Finally, tested samples will be overview and investigate for its fracture criterion and surface fracture of glass-carbon/epoxy hybrid composite by microstructure analysis using Stereo Microscope Stemi 2000-C. Also, thermal analysis will be carried out in order to determine the characteristic of the hygrothermal effect to the hybrid samples.

In polymer matrix composite advanced processing technology, fibre placement is critical to achieve. Fibre placement in polymer matrix composite will determine the mechanical and physical properties of the composite. Therefore, filament winding is used because the excellence of fiber arrangement and placement in order to avoid any leakage of fibre misalignment in composites. In addition, high fibre content and compact composite structure can be achieved by filament winding process. Fibre volume fraction values showed a strong correlation with the applied winding tension (Mertiny and Ellyin, 2002). Indeed, Perreux et al. (2002) claimed that diffusion are occurs through the resin and at a sufficiently high fibre content there may no longer be a continuous resin path toward the centre of filament wound tube wall. It means that compact and higher fibre content will less possibility of moisture migration throughout the composite structure.

In general, glass fibre reinforced polymer (GFRP) become famous because of it cheaper and has widely used in many composite engineering fields. Besides that, carbon fibre reinforced polymer composite is the strongest and lightest polymer composite so far. Therefore, hybridization of glass-carbon composite is studied to produce composite products with lower cost, excellent mechanical and physical properties. It agreed by Abu Talib et al. (2010) that due to the cost constraint, a hybrid of layers of carbon–epoxy and E-glass–epoxy was introduced in an automotive hybrid drive shaft. In the nutshell, hybrid composite could be considered as a viable new combination of reinforcement in the composite materials field.

CHAPTER 2

LITERATURE REVIEW

2.1 Polymer Matrix Composite (PMC)

In the past few decades, the potential of composite materials was not fully realized. But since those early days a standing of, and confidence in mechanical performance has been evolving, with couples of powerful and updated simulation of software design, has allowed composite material being considered in many applications. Then, the new generations of production techniques with minimum cost of manufacturing have been available and flexible in a composite product produced. One of the new generations of composite product manufacturing is filament winding method coupled with the latest software of winding pattern. The process of filament winding can offer some of significant advantageous, such as economically produce composite products if the production process is fully automated and part is well designed with minimum defective (Bannister, 2001).

Polymer matrix composite such as glass fibre or carbon fibre reinforced composites offer better fatigue behavior because of micro cracks in polymer matrix are not freely propagate in composite product as compared in metal, it stopped at the fibre (Abu Talib et al., 2010). Normally, polymer matrix composite is less affected by stress concentration such as notches and holes as compared in metal. Recently, hybrid composites were highlighted as a new alternative of material composite and many research activities were focused on hybrid technology especially for the critical application such as in automotive, aerospace and engineering structural industry. As for example, Abu Talib et al. (2010) have been developing a hybrid, carbon/glass fiber-reinforced, epoxy composite drive shaft for automotive application. In addition, composite drive shafts have proven that they can solve many automotive and industrial problems that accompany the usage of the conventional metal.

2.2 Types of fibre reinforcement

There are many types of reinforcement available in the market and has commercially been used in the industry especially composite. The selection of reinforcement types as refer to Table 2.1, meanwhile its properties are listed in Table 2.2.

Table 2.1: Some common types of reinforcement (Samuel, 2011)

Form	**Size (µm)**		**Fabrication route**	**Example**
	D	**L**		
Monofilament (Large-diameter single fibre	100-150	∞	CVD onto core fibres (eg. of c and W)	SiC (SCS-6™) Boron
Multifilaments (tows or woven rovings with up to 14000 fibres per strand)	7-30	∞	Precursor stretching; pyrolysing; melt spinning	Carbon (HS & HM) Glass Nicalon ™ Kevlar ™
Short fibres (staple fibres aggregated into blankets, tapes, wool, etc.)	1-10	50-5000	Spinning of slurries or solutions, heat treatment	Saffil ™ Kaowool Fibrefrax ™
Whiskers (fine single crystal in loose aggregates	0.1 - 1	5-100	Vapour phase growth/reaction	SiC $Al_2 O_3$
Particulates (loose powder)	5-20	5-20	Steelmaking byproduct duct; refined ore; sol-gel processing, etc.	SiC, Al_2O_3, B_4C, TiB_2

* D= Fibre diameter
L= Fibre length

Table 2.2: Fibre properties (Samuel, 2011)

Fibre	Density Kgm^{-3}	Young's Modulus GPa	Poisson's ratio	Tensile strength GPa	Failure strain %	Thermal expansivity $10^{-6}K^{-1}$	Thermal conductivity $Wm^{-1}K^{-1}$
SiC Mono-filament	$3x10^{-6}$	400	0.20	2.4	0.6	4.0	10
Boron Mono-filament	$2.6x10^{-6}$	400	0.20	4.0	1.0	5.0	38
HM carbon	$1.95x10^{-6}$	Axial 380 Radial 12	0.20	2.4	0.6	Axial -0.7 Radial 10	Axial 105
HS carbon	$1.75x10^{-6}$	Axial 230 Radial 20	0.20	3.4	1.1	Axial-0.4 Radial 10	Axial 24
E-glass	$256x10^{-6}$	76	0.22	2.0	2.6	4.9	13
Nicalon™	$2.6x10^{-6}$	190	0.20	2.0	1.0	6.5	10
Kevlar™ 49	$1.45x10^{-6}$	Axial 130 Radial 10	0.35	3.0	2.3	Axial-6 Radial 54	Axial 0.04
FP™ fibre	$3.9x10^{-6}$	380	0.26	2.0	0.5	8.5	8
Saffil ™	$3.4x10^{-6}$	300	0.26	2.0	0.7	7.0	5
SiC Whisker	$3.2x10^{-6}$	450	0.17	5.5	1.2	4.0	100
Cellulose (flax)	$1.0x10^{-6}$	80	0.30	2.0	3.0	-	-

* HM = High Modulus
HS = High strength

Normally, carbon, glass and aramid fibres are used extensively in polymer composites whilst ceramic fibres, whiskers, and particles are being used to reinforce metal and ceramic matrices (Samuel, 2011). Hence, the role of the reinforcement in composites is to carry loads