PROPERTIES ENHANCEMENT EFFECT OF THE ELECTROSPRAYED CARBON NANOTUBE COATING ON GLASS FIBRE /EPOXY LAMINATED COMPOSITE

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2019

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By

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Thesis submitted in fulfillment of the requirement for the degree of

Master of Science

June 2019

DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled "Properties Enhancement Effect of The Electrosprayed Carbon Nanotube Coating on Glass Fibre / Epoxy Laminated Composite". I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or University.

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ACKNOWLEDGEMENTS

In the name of ALLAH S.W.T. the beneficent, the Merciful, who has given me the patience, strength, and ability to complete this research successfully. All perfect praises belong to ALLAH S.W.T.alone, lord of the world. May His blessing be upon Prophet Muhammad S.AW and members of his families and companions.

First of all, I would like to express my gratitude towards my supervisor, Prof. Hazizan Mohd Akil who has given me useful guidance, encouragement and assistance throughout this study. I would also like to thank Muhammad Razlan Zakaria for helping me patiently during the course of the project. My deep gratitude goes to all the lecturers, technicians and staffs who have directly or indirectly involved in this project.

I would like to express my warm appreciation to my parents, Mr. Mohamamd Khairuddin and Mrs Nor Akhmar bt Ismail, I can never repay their endless love and support. I am deeply indebted to them and I truly wish that I have made them proud. They kept me going whenever I feel difficult and strangled. Not forgetting my special acknowledgement to my loving husband, Muhammad Safwan bin Hamzah who has been supporting me from start till the end. Thank you for keeping me motivated, listening to my ramblings, and all your encouragements which had kept me going.

This project couldn't have come to a success without the support and help from all of you. For that I sincerely thank you for your contribution and apologize if I have caused any inconvenience during the process of this project. I have spent wonderful time with all of you.

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LIST OF ABBREVIATIONS

ACT	Alkoxysilane compound
ASTM	American Society for Testing and Materials
Al_2O_3	Aluminium Oxide
AIBN	Azobisisobutyronitrile
BN	Boron Nitride
B_2O_3	Boron Trioxide
CNTs	Carbon Nanotubes
CTAB	Hexadecyltrimethylammonium Bromide
CVD	Chemical Vapor Deposition
CMC	Ceramic Matrix Composite
C-glass	Calcium Aluminoborosilicate
CTE	Coefficient of Thermal Expansion
CaO	Calcium Oxide
CF	Carbon Fibre
CSM	Chopped Strand Mat
DTAB	Dodecyltrimethylammonium Bromide
DGEB-	Diglycidyl Ether Bisphenol-A
DTG	Derivative Thermogravimetric
EDP	Electrospray Deposition
E-glass	Soda Lime Borosilicate
FRP	Fiber Reinforced Polymer
Fe_3O_4	Ferric Oxide

GF	Glass Fibre
HDPE	High Density Polyethylene
ILSS	Interlaminar Shear Strength
IFFS	Interfacial Shear Strength
LED	Light-emitting Diode
MWNTs	Multi-walled Carbon Nanotubes
MMC	Metallic Matrix Composite
MgO	Magnesium Oxide
Na_2O	Sodium Oxide
NaOH	Sodium Hydroxide
NMP	N-Methyl 2-Pyrrolidone
PMC	Polymer Matrix Composite
PS	Polystyrene
PE	Polyethylene
PAN	Polyacrylonitrile
PMMA	Polymethyl Methacrylate
PEO	Polyethyene Oxide
PVA	Polyvinyl Alcohol
RTM	Resin Transfer Molding
SRIM	Structural Reaction Injection Molding

S-glass	Magnesium Aluminosilicate
SiO_2	Silicon Dioxide
SWCNTs	Single-walled Carbon Nanotubes
SEM	Scanning Electron Microscope
SDS	Sodium Dodecyl Sulfate
TGA	Thermogravimetric Analysis
Triton X-100	Octyl Phenol Ethoxylate
UV	Ultra Violet
UTM	Universal Testing Machine
UTS	Ultimate Tensile Strength
VARTM	Vacuum Resin Transfer Molding

LIST OF SYMBOLS

ε_0	Capacitance
cm	Centimeter
ε"	Dielectric Loss
ε'	Dielectric Constant
ºC	Degree Celcius
ρ	Density
G	Gauge
g	Gram
GPa	Gigapascal
Hz	Hertz
hr	Hour
In.	Inches
kV	Kilovoltage
K	Kelvin
kN	Kilo Newton
kHz	Kilo Hertz
MPa	Megapascal
ml/hr	Millilitre per hour
mm	Millimetre
µl/hr	Microlitre per Hour
MHz	Mega Hertz

mV	milivoltage

LIST OF SYMBOLS

%	Percent
C	Vacuum Permittivity
W/mK	Watt Per Metre Kelvin
Wt%	Weight Percentage
W	Watt

KESAN PENGHASILAN KAEDAH SEMBURAN ELEKTRO TERHADAP PENINGKATAN CIRI-CIRI KOMPOSIT KARBON NANOTIUB / GENTIAN KACA EPOKSI LAMINAT

ABSTRAK

Dalam kajian ini,pengisi nanotiub karbon (CNTs) telah dimasukkan ke dalam komposit polimer iaitu tenunan gentian kaca / epoksi laminat berlapis dengan menggunakan teknik semburan elektro dan telah menghasilkan peningkatan terhadap ciri-ciri bahan komposit. Sifat-sifat mekanik nanokomposit ditentukan pada spesimen Acuan Pemindahan Resin Vakum (VARTM) bagi menjalankan gujian tegangan dan lentur. Kesan kepekatan muatan pengisian nanotiub karbon (0.1, 0.2, 0.3 %) dan voltan semburan elektro (10, 15, 20 kV) ke arah pemendapan nanotiub karbon pada permukaan tenunan gentian kaca / epoksi nanokomposit telah diperiksa. Morfologi taburan nanotiub karbon antara serat gentian kaca dan epoksi dianalisis oleh Pengimbas Mikroskop Elektron (SEM) dan ujian tegangan dan kelenturan. Voltan semburan elektro yang digunakan adalah parameter kritikal bagi menghasilkan pengisi nanotiub karbon pada tenunan gentian kaca / epoksi berlapis komposit dengan taburan yang seragam tanpa agglomerasi. Beberapa formula komposit berlapis disediakan untuk tujuan analisis dan gentian kaca tenunan tulen sebagai sampel kawalan dihasilkan menggunakan Acuan Pemindahan Resin Vakum (VARTM). Secara amnya, sifat kekuatan dan ketegangan serat kaca tenun (CNTs) lebih tinggi daripada nanokomposit epoksi serat tenunan gentian kaca tulen. Peningkatan ini berkaitan dengan penyebaran nanotiub karbon (CNTs) yang baik dan seragam ke permukaan gentian kaca yang membantu meningkatkan lekatan antara antara nanokomposit laminat. Penumpuan dan voltan semburan elektro yang digunakan adalah berbeza dan kekuatan tegangan dan lenturan spesimen telah dibandingkan. Penggunaan sebatian hibrid CNTs-nanokomposit epoksi serat tenunan gentian kaca tulen telah dibuktikan mampu meningkatkan sifat mekanikal, haba dan dielektrik. Epoxy / GF / CNTs laminates komposit mempamerkan peningkatan kekuatan tegangan sehingga 6.7% dan modulus tegangan sebanyak 4.9% berbanding dengan laminates Epoxy / GF masing-masing. Kekuatan lenturan juga meningkat sebanyak 40.2%, modulus lentur sebanyak 51.5%, kekonduksian terma sebanyak 5.7% dan pemalar dielektrik sebanyak 6.20%. Kesimpulannya, kesan kepekatan muatan pengisian 0.2 % nanotiub karbon dengan penggunaan voltan semburan elektro maksima pada 20 kV adalah formulasi terbaik untuk digunakan bagi menghasilkan komposit nanotiub karbon tenunan gentian kaca / epoksi berlapis dengan menggunakan teknik semburan elektro.

PROPERTIES ENHANCEMENT EFFECT OF THE ELECTROSPRAYED CARBON NANOTUBE COATING ON GLASS FIBRE /EPOXY LAMINATED COMPOSITE

ABSTRACT

In this study, the fillers carbon nanotubes has been added into the glass fibre/epoxy laminated composite by using the electrospraying techniques and had significantly improved the composite properties. Mechanical properties obtained for nanocomposite laminates were determined on the vacuum resin transfer molding specimen both in tensile and flexural testing. The effect of carbon nanotube concentration (0.1, 0.2, 0.3%) and applied voltage of electrospray (10, 15, 20 kV) towards the deposition of carbon nanotube on the woven glass fibre surfaces were examined. The morphology of carbon nanotube dispersion between glass fibre and epoxy were studied by Scanning Electron Microscope (SEM) and tensile and flexural testing respectively. The applied voltage of the electrospray is a critical parameter in producing the uniform dispersion of the carbon nanotubes fillers on glass fibres/epoxy laminated composite without agglomeration. Several formulations of laminated composite was prepared for testing and pure woven glass fibre as control samples and using Vacuum Resin Transfer Molding (VARTM). Generally, the strength and stiffness properties of the CNTs woven glass fibre are superior than the pure woven glass fibre epoxy laminates composite. The presence of finer dispersion of carbon nanotubes formed onto the surface of woven glass fibre leads to the interfacial adhesion improvement between the laminate composite. The concentration and applied electrospray voltage were varied and the mechanical properties of specimen were compared. It was found out that the addition of MWCNT using electrospraying techniques improves the mechanical, thermal and dielectric properties of Epoxy/GF/MWCNTs laminates. Epoxy/GF/MWCNTs laminates composites exhibits improvement in the tensile strength by up to 6.7% and tensile modulus of 4.9% compared to Epoxy/GF laminates respectively. Apart from that, flexural properties are greatly improved for Epoxy/GF/MWCNTs together with improvement in thermal conductivity by 5.7% and dielectric constant by 6.20%. In conclusion, the effect of 0.2% carbon nanotube concentration with maximum electrospray voltage utilization at 20 kV is the best electrospraying formulation to use to produce the glass fibre epoxy laminated composite.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The success of technology development nowadays depends on advancement in the field of materials. A large number of research mostly focused on the designing the new materials that can satisfy the changing in customer needs. The discovery and revolutionary of advanced composite materials have contributed to its application in various sectors such as aviation and aerospace, automotive and maritime due to its capabilities in improving the required engineering properties and also economic financial benefits.

Composite materials can be classified as composition of two or more dissimilar materials where fibres are embedded into the matrix of another material with a different interface between them. An enhanced best qualities material can be produced as the outcome from the combination of fibres and matrix together. Anand and Joshi (2015) studied the working principles of the composite materials is based on the role of fibres as load carrying members while the matrix function in transferring load between the matrix and fibres according to the desired orientation and location.

Fibre-reinforced polymer (FRP) is one type of advanced composite material consist of a polymer matrix and fibres as reinforcement that have high strength and modulus (Masuelli et al., 2013). The fibres are commonly made up from carbon, glass, or aramid, and some other natural fibres such as wood or paper and asbestos. The application of fibre-reinforced polymer (FRP) materials continue to grow and established as primary and secondary components in aircraft industry for largest aerospace manufactures such as

Airbus and Boeing. In addition, the incorporation of the fibre reinforced polymer materials into the automotive and transportation sectors compared to the use of conventional metals structures which help to reduce the carbon oxide pollution in the environment and it is also a cost effective approach. The characteristic of fibre reinforced polymer (FRP) that is light in weight can be translated directly to improve the fuel efficiency. Carbon nanotubes has the tensile strength of approximately one hundred times higher compared to steel, while its specific weight is about six times lower (Kumar and Ando, 2010).

The composite materials are designed to fit the requirement of aircraft structures which require characteristics such as lightweight, easily constructed, exhibit high specific stiffness and specific strength, non-corrosive and can be tailored accordingly to fulfil performance requirements. Fibre reinforced polymer (FRP) is an advanced composite materials that provides an opportunity to be applied in aircraft body structures manufacturing. Some research reported that mechanical performances of fibre reinforced polymer that are ideal to be used in manufacturing lighter structures because of its high stiffness and high strength to weight ratios (Rathnakar and Shivanan et al., 2013).

Glass fibre is one of the most popular material used as reinforcement for polymeric matrix composites (Etcheverry et al., 2012) due to its unique properties which possess high modulus to weight ratios, higher impact strength and excellent surface finish, compared to other fibre reinforced composite which makes it suitable to be used extensively in industries (Mondol et al., 2016). However, one of the main obstacles that need to be overcome in the use of conventional glass fibre laminated composite is the interaction between the matrix and glass fibre. Stability and strength of the polymer-fibre interphase are factors that mainly determined the glass fibres properties. When the adhesion between the matrix and fibre is weak, the glass fibres does not act as a reinforcing material effectively. Despite of the excellent properties that fiber reinforced composites exhibit, it still require improvement in tensile and compressive strength in various fiber direction. Problems such as toughness and compatibility for fibres and matrix in a composite. Several factors that influence the fibres reinforced polymer composites's energy dissipation are fibres orientation, fibres volume, matrix material, moisture, temperature, including both thickness of lamina and composites (Sathishkumar et al., 2014).

Designing a composite structure requires a good laminate design in order to ensure the composite capability to withstand loads during throughout service conditions without deteriorating its performance. Designing laminates is an early stage to determine the laminate properties by considering parameters such as ply thickness, fibre orientation, volume fractions and stacking sequence in order to optimize the composite's properties. There are some challenges in the development of glass fibre epoxy laminated composite reinforced with interlayer of multi walled CNTs film such as delamination that is caused by poor interlaminar strength of the thin layer of carbon nanotubes in the transverse direction.

Incorporation of carbon nanotube multi-walled CNTs in polymer nanocomposites has also become one of the challenges for researchers due to its dispersion in polymer matrix. It is difficult to disperse agglomeration of MWCNTs into individual CNTs in the polymer matrix because of its lack of adhesion between the MWCNTs and the polymer matrix and also due to strong van der Waals force interactions. Many efforts have been done to improve the performance of glass fibre reinforced epoxy laminated composite (Rathnakar and Shivanan, 2013). The addition of nanoparticles such as carbon nanotubes can be utilised to reinforce polymers and improved the interfacial adhesion of the polymer