UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF HYBRID BIOCOMPOSITE SYNTHESISED WITH MULTI-WALLED CARBON NANOTUBE FOR FINITE STRAIN APPLICATION OF AEROSPACE STRUCTURES

KHAIRUL IZWAN BIN ISMAIL

CHARACTERIZATION OF HYBRID BIOCOMPOSITE SYNTHESISED WITH MULTI-WALLED CARBON NANOTUBE FOR FINITE STRAIN APPLICATION OF AEROSPACE STRUCTURES

By

KHAIRUL IZWAN BIN ISMAIL

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

June 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

CHARACTERIZATION OF HYBRID BIOCOMPOSITE SYNTHESISED WITH MULTI-WALLED CARBON NANOTUBE FOR FINITE STRAIN APPLICATION OF AEROSPACE STRUCTURES

By

KHAIRUL IZWAN BIN ISMAIL

June 2018

Chairman : Assoc. Prof.Mohamed Thariq Bin Hameed Sultan, PhD
Faculty : Engineering

Generally, synthetic-natural hybrid composites are being introduced to lessen the use of synthetic fibres in composites as well as to deal with the drawbacks of natural fibres in biocomposites. The combination of both properties, from synthetic and natural fibres, results in hybrid biocomposites with surpass properties compared to its elements. Meanwhile, the use of nano-fillers in composites, as reported, can either enhance or diminish the properties of composites, depending on several factors. Therefore, this research was intended to study the effects of multi-walled carbon nanotube (MWCNT) concentration, on the properties of hybrid biocomposites. In this study, high cost synthetic fibres, i.e. glass, carbon and Kevlar, were respectively hybridised with the natural fibre of flax. The epoxy matrix used was modified with 0%, 0.5%, 1.0%, 1.5% and 2.0% of multi-walled carbon nanotubes (MWCNTs) to fabricate five different types of composites for each hybrid combination. In terms of mechanical properties, hybrid flax-carbon biocomposites with 1.0% MWCNT exhibit the highest tensile strength, while these same hybrid combinations possess the highest flexural strength at 0.5 % MWCNT. Analysis of the thermal properties suggested that the inclusion of MWCNT lowered the thermal stability as these nanofillers enhanced the heat diffusion, thus speeding up the degradation. Comparison between the different stacking sequences of hybrid flax-carbon and flax-glass with 1% of MWCNT showed that the flax surface are penetrated by the impactor at 15 J, while the glass and carbon surfaces were both penetrated at 20 J. The higher strength residue of hybrid flax-glass compared to flax-carbon, analysed through the compression after impact testing, was in a good agreement with the less severe damage found on the flax-glass composites.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENCIRIAN HIBRID BIOKOMPOSIT SINTESIS BERSAMA KARBON NANOTIUB UNTUK APLIKASI KEKUATAN TERHADAP STRUKTUR AEROANGKASA

Oleh

KHAIRUL IZWAN BIN ISMAIL

Jun 2018

Pengerusi : Prof. Madya Mohamed Thariq Bin Hameed Sultan, PhD
Fakulti : Kejuruteraan

Umumnya, hibrid komposit sintetik-semulajadi telah diperkenalkan untuk mengurangkan penggunaan serat sintetik dalam komposit disamping untuk memperkukuh kelemahan serat semulajadi dalam biokomposit. Gabungan kedua-dua ciri daripada serat sintetik-semulajadi menjadikan ciri-ciri komposit tersebut lebih baik jika dibandingkan dengan individu elemen tersebut. Manakala, penggunaan pengisi-nano dalam komposit mampu mempertingkatkan atau menyusut ciri-ciri komposit bergantung kepada bebraa factor seperti yang telah dilaporkan. Oleh itu, kajian ini menjurus untuk mengkaji kesan kuantiti karbon nanotiub terhadap ciri-ciri hibrid komposit. Dalam kajian ini, serat sintetik seperti serat kaca, karbon dan Kevlar, telah dihibridkan bersama serat semulajadi iaitu flax. Epoksi yang telah digunakan telah diubahsuai dengan 0%, 0.5%, 1.0%, 1.5% dan 2.0% karbon nanotiub untuk menghasilkan lima jenis komposit yang berbeza bagi setiap gabungan hibrid. Dalam aspek ciri-ciri mekanikal, hibrid biokomposit flax-karbon dengan 1.0% karbon nanotiub menunjukkan peningkatan tertinggi bagi ketegangan, manakala gabungan hibrid komposit yang sama turut menunjukkan keputusan tertinggi dalam kelenturan pada 0.5% karbon nanotiub. Analisa daripada ciri-ciri haba menunjukkan bahawa kehadiran karbon nanotiub mengurangkan kestabilan haba disebabkan karbon nanotiub menyokong pembakaran dengan cepat. Perbandingan antara perbezaan lapisan hibrid biokomposit flax-karbon dan flax-kaca bersama 1.0% karbon nanotiub menunjukkan bahawa permukaan flax telah tembus pada pemberat dengan peringkat tenaga 15 J, manakala permukaan sintetik telah tembus pada peringkat tenaga 20 J. Sisa kekuatan yang lebih tinggi oleh hibrid flax-kaca berbanding flax-karbon, telah dikaji melalui ujian mampatan selepas impak, mempunyai persamaan yang baik dengan tahap kerosakan pada flax-kaca komposit.

ACKNOWLEDGEMENTS

All praise to Allah almighty, and May peace and blessing be upon His beloved Prophet Muhammad S.A.W, on the household of the prophet, and on his faithful companions. I agree that I am truly benefited from this project as it helped me gain valuable exposures and experiences over the entire project.

First and foremost, I would like to extend and express my sincere love and appreciation toward my mother, Rafeah bt, Abd. Rahman and beloved father, Ismail b. Harun for their support and sincere Doa to Allah, so that my quest for knowledge would be granted by Allah.

I also would like to utter my deep and sincere thankfulness to my supervisor for this project, Assoc. Prof. Ir. Ts. Dr. Mohamed Thariq b. Haji Hameed Sultan. He inspired me greatly to work on this project. Through his wide knowledge and logical ways of thinking, he has brought great value for me. The willingness to motivate me contributed tremendously to it. I am also grateful to my supervisors for sacrificing precious time to explain things and give constructive comments. Also, I would like to extend my sincere thanks and appreciation to Dr. Ain Umaira, Nurul Farah Noryatim, Muhamad Hasfanizam Mat Yazik and all the individuals whose names are not mentioned in this acknowledgement, but who have helped me in one way or another. Last, but not least, special thanks are penned to my friends for their unfailing love and support. May Allah's grace and bounty be upon them. Amen.

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Mohamed Thariq Bin Hameed Sultan, PhD, PEng, CEng, PTech
Associate Professor
Department of Aerospace Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Abd Rahim Bin Abu Talib, PhD, PEng, PTech
Associate Professor
Department of Aerospace Engineering
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohammad Jawaid, PhD
Research Fellow
Laboratory of Biocomposite Technology
Institute of Tropical Forestry and Forest Product
Universiti Putra Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No.: Khairul Izwan Bin Ismail, GS47447

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Associate Professor Dr. Mohamed Thariq Bin Hameed Sultan

Signature: _____
Name of Member of Supervisory Committee: Associate Professor Dr. Abd Rahim Bin Abu Talib

Signature: _____
Name of Member of Supervisory Committee: Dr. Mohammad Jawaid

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
CMC	Ceramic matrix composites
DMA	Dynamic mechanical analysis
DSC	Differential scanning calorimetry
EP	Neat epoxy
E’	Storage modulus
E’’	Loss modulus
FESEM	Field emission scanning electron microscope
FRP	Fibre reinforced polymer
FTIR	Fourier transform infrared spectroscopy
GF	Glass fibre
HDPE	High density polyethylene
HDT	Heat deflection temperature
ISO	International Organization for Standardization
MAPP	Maleic anhydride polypropylene
MDF	Medium density fibreboard
MMC	Metal matrix composites
NDE	Non-destructive evaluation
NFRP	Natural fibre reinforced polymer
PBS	Poly butylene succinate
PLA	Polylactic acid
PMC	Polymer matrix composites
PP	Polypropylene
PS	Polystyrene

PVC	Polyvinyl chloride
SEM	Scanning electron microscopy
SBS	Short Beam Shear
TGA	Thermo-gravimetric analysis
Tg	Glass transition temperature

CHAPTER 1

INTRODUCTION

1.1 Introduction

The emergence of composites in the materials industries has reduced the dependency on the use of metals, which are heavier, essentially limited in design, susceptible to corrosion, and highly expensive in maintenance. Automotive and aerospace applications are among the critical industries which have demands for lightweight with high strength materials (Gururaja & Rao, 2012). The replacement of metals with fibre reinforced polymers (FRP) in aircraft framework, such as the wing and fuselage, has increased in the development of any new models. For example, the newest model of the Airbus A350 XWB used 52% of composites in its whole structure, which shows the high reliability of composites in this structural application. By 2025, manufacturers involved in car production are reducing the weight of their vehicles which can reduce the petrol usage. It was suggested that carbon and glass fibre composites can offer 50-70% and 25-35% mass reduction respectively over mild steel. An estimated 6-7% fuel savings can be achieved with a 10% mass reduction.

Due to their magnificent performances, synthetic fibres have been extensively used in FRP composites for daily life applications. In spite of that, some issues arise regarding the health and environmental aspects. The inhalation of synthetic fibres during fabrication can cause breathing difficulties, while renewability, degradability and recyclability are almost impossible for all types of synthetic composites (Ramesh, Palanikumar, & Reddy, 2017; Sanjay, Arpitha, & Yogesha, 2015). The high production cost of synthetic fibre as well as its composites drives researchers' attention to introduce lower cost materials with comparable properties to the synthetics (Wambua, Ivens, & Verpoest, 2003).

In an effort to develop new, high performance materials, natural fibres possess outstanding mechanical properties with low production cost, low density, light weight and environmentally friendly benefits, which can overcome the drawbacks of synthetic fibres (Jarukumjorn & Suppakarn, 2009; Malkapuram, Kumar, Negi, & Yuvraj Singh Negi, 2008). Flax fibres, extricated from the bast underneath the surface of the stem of the flax plant, are used commercially in the textile industries. In naturally based composites, studies of flax fibres have been reported with different views as to their potential applications. One of the reported studies suggested an alkaline treatment of flax fibres as being most effective and simplest methods to enhance fibre-matrix bonding, resulting in

better flexural properties of the flax/epoxy composites (Charlet & Béakou, 2011).

In attaining superior properties for flax-reinforced composites, the idea of hybridising flax fibres with the synthetics emerged similarly with other natural-synthetic hybrid composites, such as kenaf/kevlar and bamboo/glass hybrid composites (Nayak, Mohanty, & Samal, 2009; Yahaya, Sapuan, Jawaid, Leman, & Zainudin, 2014). In the study of any hybrid composites, with the fibres in fabric or mat form, the stacking sequence is one of the factors which varies the performance of the composites. Stacking sequence of natural and synthetic fabric has been seen effects on tensile performance of hybrid composites. By some means, the greater hybrid interface turns out into the improving fracture toughness and inter-laminar shear strength of hybrid composite compared to the non-hybrid, fully glass fibre reinforced composites (Y. Zhang, Li, Ma, & Yu, 2013). This hybridisation results in composites which are comparatively cheaper and equally as strong as the fully synthetic composites (Ramesh, Palanikumar, & Reddy, 2013).

Apart from the superior abilities of the fibres, the good performance of the polymer matrix does contribute to developing the properties of the composites. Previously, a lot of research studies have been conducted to modify the polymer matrix, such as polyamides, polyurethane, epoxy and polypropylene, by adding either nanoparticles or fillers to develop the strength, modulus, thermal stability, and fire retardant of the composites (Chikhi, Fellahi, & Bakar, 2002; S. Kim, Pechar, & Marand, 2006).

Carbon nanotube (CNT), a type of carbon material with one dimension, generally can be segregate into two groups, single-walled and multi-walled CNTs (Yakobson & Avouris, 2001). Even though there are many research on CNTs as filler in polymer nanocomposite, their outstanding performances are still inconsistent due to the dispersion difficulties in the polymers. However, the incorporation of CNTs in most of the polymer composites results in better mechanical and thermal properties (Ma, Siddiqui, Marom, & Kim, 2010a; Mittal, Dhand, Rhee, Park, & Lee, 2015; Y. Zhou, Pervin, Lewis, & Jeelani, 2008).

In this research work, the outcomes of different concentrations of CNTs on the mechanical properties of the flax hybrid with different synthetic fibres were experimentally analysed. The dispersing method of CNT in the epoxy was standardized during the fabrication of all panels.

1.2 Research Background

Carbon nanotubes are used as the additive in a composite product (polymer nano-composite), whilst adding other synthetic fibres such as carbon, glass, Kevlar, and natural fibre such as flax, at the same time making other comparisons between the percentages of multi-walled carbon nanotubes (0wt%, 0.5wt%, 1wt%, 1.5wt% and 2wt%) by weight. Comparisons are made because studying the suitability and comparing the performance of composites that can turn into new materials are important to engineering applications.

This study is also performed to achieve some improvement by studying the effects of CNT distribution and dispersion on the reliability of the cracks in fibre-reinforced polymers (FRPs), and the mechanical loading will also be discussed. The method considered for this study is the wet lay-up process, which is typically used as the composite industry's processing method. This conventional method is used to produce the samples for testing.

Especially in aerospace applications, the implementation of CNT is predicted to have a massive significance on future space vehicles (Khan & Kim, 2011). This is due to their impressive countenance, which include all aspects of thermal, electrical and mechanical properties. Attention is drawn to the future utilization of CNT, which may comprise composite material application, lightning protection for aircraft, aircraft icing mitigation, the reduced weight of airframes/satellites, and the alleviation of the challenges related to future space launch (Volder et al., 2013). This research work also studies the impact of CNT in aerospace applications, as well as any other engineering applications, the current and expected challenges related to their usage in aerospace sciences and large scale manufacturing.

1.3 Problem Statement

Composite plays crucial part in the advancement of the aerospace industry. However, the use of synthetic fibres has created issues such as high cost, low renewability, low biodegradability and low recyclability. These concerns can be overcome by replacing or reducing these synthetic fibres with plant fibres, which would reduce the cost and may allow for such material to be recyclable.

Furthermore, the use of CNT as reinforcement in composite manufacturing has become more commonplace in recent years. Even if it is not to be the main chosen reinforcement, it can still provide new topics for improvement and innovation in composites, although, these are still in the research stage. This research work focuses on creating a new hybrid material with a matrix modified with CNT.

CNT is known to have many virtues as mentioned (Baur & Silverman, 2007; Thostenson, Ren, & Chou, 2001). This work is concerned with developing new potential for a new hybridized material using composite matrix material made from CNT, which can be used as an innovation by replacing the synthetic reinforcement. Furthermore, the research work is designed to enhance the material's properties by combining synthetic fibre and natural fibre, for example glass fibre and flax fibre.

1.4 Objectives

Based on the literature reviews of previous works, it was found that the area in which research can be conducted is in the field of investigating the influence of embedding CNT in natural composite laminates as well as the impact analysis of the above mentioned laminates. Therefore, the objectives of this research work are as follow:

I. To study the effect of CNT loading in biocomposites.
II. To analyse the mechanical properties of hybrid biocomposites modified with MWCNT through a series of quasi-static laboratory tests.
III. To determine the suitability of CNT in newly developed composite materials for structural applications.
IV. To access the impact and after-impact properties of hybrid biocomposite modified with MWCNTs by performing LVI test and CAI test.

1.5 Research Scope

A hybrid biocomposite of reinforced epoxy modified with CNT is a combination of synthetic and natural fibres, in which the epoxy resin used for the manufacturing process of the hybrid biocomposite has been modified with MWCNT. In this research work, certain work was necessary to achieve the objectives. The work scope of this research is given below:

i. Modification of the resin with MWCNT.
ii. Fabrication of the hybrid biocomposite by the wet lay-up method.
iii. Checking of CNT dispersion by FESEM.
iv. Identifying the mechanical performance through a series of quasi-static tests (Tensile test, Flexural test, Impact test, Compression After Impact test and Thermo-gravimetric Analysis (TGA).

CNT was discovered in 1991 by the Japanese Physicist, Sumio Iijima, and has become the most interesting development for the nanoscience community. CNT is known to have outstanding performances. It is very small but gives

good advantages. Figure 1.1 shows some developments of CNT and graphene in industry; A) Publications, issued patents and annual production. B) to E) Selected CNT products: Composite bicycle frame, antifouling coatings, printed electronics and electrostatic discharge shielding.

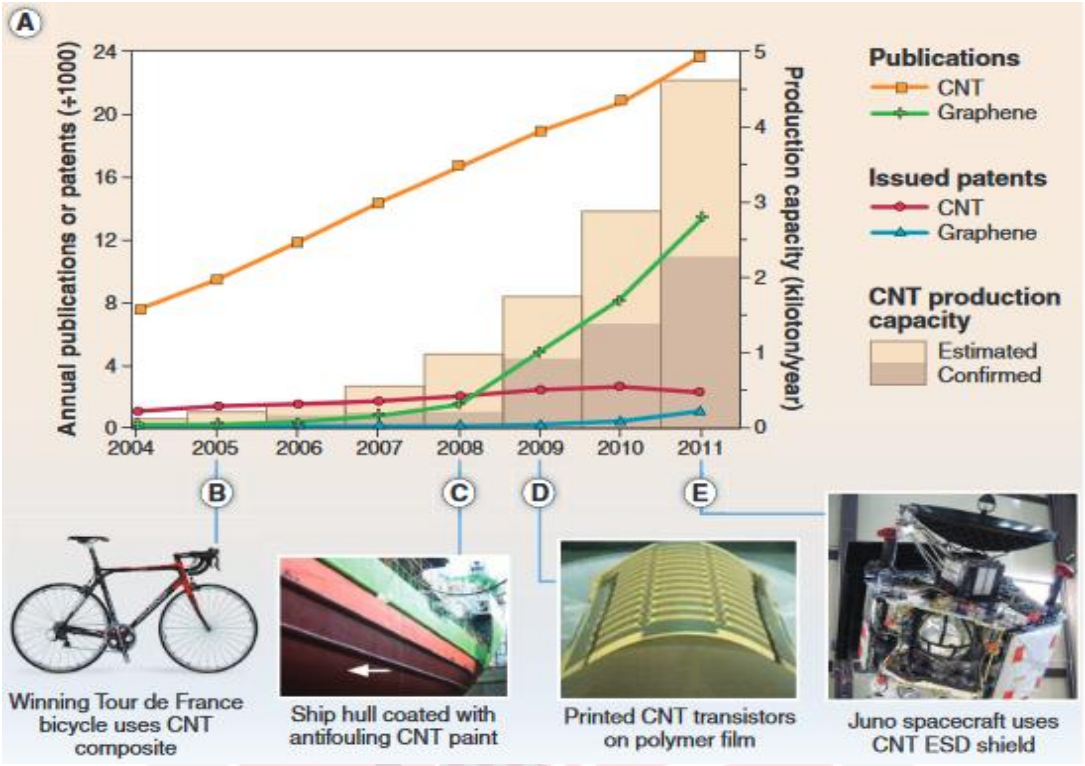

Figure 1.1 : Development of CNT and graphene in industry
(Source:Volder, Tawfick, Baughman, & Hart, 2013)

At present, carbon nanotubes are widely utilised in nano-engineering fields, with various physical, chemical and mechanical applications, so that many research studies on the dynamic behaviours of CNT have been published and presented. Since CNT was discovered, the studies on physical and mechanical behaviour of CNT has greatly increased. Although the applications of CNT in engineering fileds have been potentially impacted, there is still lack on detailed pact of the characteristics of CNT, thus the best design for devices and mechanical application has still not been greatly explored.

1.6 Thesis organisation

This book is organised into five different chapters that describe the whole study of a hybrid biocomposite modified with MWCNT. The descriptions of each chapter are given as follows:

i. Chapter 1; The introduction to the whole research work suggesting natural fibres as reinstatement for synthetic fibres in aerospace industrial applications. This chapter also explained the objectives, problem statements and scope in this research work.
ii. Chapter 2; Gives literature studies of the common synthetic fibres used in the aerospace industry and previous research on polymer nano-composites. Besides this, the benefits of natural fibres and nano-materials in polymer composites have also been identified.
iii. Chapter 3; The whole process involved in fabricating a hybrid bio-composite and a polymer nano-composite has been described in this chapter. It also includes all the quasi-static, impact and thermal loading laboratory work for this research work.
iv. Chapter 4; This depicts the results and discussion of the findings from the experimental analysis. Figures and tables are presented in this chapter to highlight the findings clearly.
v. Chapter 5; Draws the conclusion from the results and summarizes the findings from the whole project. In this last chapter, potential improvements and future work has also been suggested.

REFERENCES

Ahmad, F., Choi, H. S., & Park, M. K. (2015). A review: Natural fiber composites selection in view of mechanical, light weight, and economic properties. *Macromolecular Materials and Engineering*, *300*(1), 10–24. https://doi.org/10.1002/mame.201400089

Ajayan, P. M., Stephan, O., Colliex, C., & Trauth, D. (1994). Aligned Carbon Nanotube Arrays Formed by Cutting a Polymer Resin--Nanotube Composite. *Science*, *265*(5176), 1212–1214. https://doi.org/10.1126/science.265.5176.1212

Al-Saleh, M. H. (2015). Effect of processing conditions on the dispersion, electrical, and mechanical properties of carbon nanotube/polypropylene nanocomposites. *Journal of Reinforced Plastics and Composites*, *34*(9), 742–749. https://doi.org/10.1177/0731684415579214

Atas, C., & Liu, D. (2008). Impact response of woven composites with small weaving angles. *International Journal of Impact Engineering*, *35*(2), 80–97. https://doi.org/10.1016/j.ijimpeng.2006.12.004

Atas, C., & Sayman, O. (2008). An overall view on impact response of woven fabric composite plates. *Composite Structures*, *82*(3), 336–345. https://doi.org/10.1016/j.compstruct.2007.01.014

Ayatollahi, M. R., Shadlou, S., & Shokrieh, M. M. (2011). Mixed mode brittle fracture in epoxy/multi-walled carbon nanotube nanocomposites. *Engineering Fracture Mechanics*, *78*(14), 2620–2632. https://doi.org/10.1016/j.engfracmech.2011.06.021

Bandaru, P. R. (2007). Electrical Properties and Applications of Carbon Nanotube Structures. *Journal of Nanoscience and Nanotechnology*, *7*(4), 1239–1267. https://doi.org/10.1166/jnn.2007.307

Bauer, F., Gläsel, H. J., Hartmann, E., Langguth, H., & Hinterwaldner, R. (2004). Functionalized inorganic/organic nanocomposites as new basic raw materials for adhesives and sealants. *International Journal of Adhesion and Adhesives*, *24*(6), 519–522. https://doi.org/10.1016/j.ijadhadh.2004.02.001

Baur, J., & Silverman, E. (2007). C hallenges and Structures for Aerospace, *32*(April), 328–334.

Belingardi, G., & Vadori, R. (2002). Low velocity impact tests of laminate glass-fiber-epoxy matrix composite material plates. *International Journal of Impact Engineering*, *27*(2), 213–229. https://doi.org/10.1016/S0734-743X(01)00040-9

Bilyeu, B., Brostow, W., & Menard, K. P. (2000). Epoxy Thermosets and Their Applications . II . Thermal Analysis. *Journal of Materials Education*, *22*, 107–129.

Blumstein, A. (1965). Polymerization of Adsorbed Monolayeres . II. Thermal Degradation of the Inserted Polymer. *Journal of Polymer Science Part A*, *3*(7), 2665–2672. https://doi.org/10.1002/pol.1965.100030721

Chandrasekaran, V. C. S., Advani, S. G., & Santare, M. H. (2011). Influence of resin properties on interlaminar shear strength of glass/epoxy/MWNT hybrid composites. *Composites Part A: Applied Science and Manufacturing*, *42*(8), 1007–1016. https://doi.org/10.1016/j.compositesa.2011.04.004

Chang, M. S. (2010). An investigation on the dynamic behavior and thermal properties of MWCNTs / FRP laminate composites, (2). https://doi.org/10.1177/0731684410379510

Chang, M. S., Volder, M. F. L. De, Tawfick, S. H., Baughman, R. H., Hart, A. J., Behabtu, N., … Bose, S. (2005). Carbon Nanotube Based Composites- A Review. *Journal of Minerals & Materials Characterization & Engineering*, *4*(1), 31–46. https://doi.org/Vol. 4, No.1

Charlet, K., & Béakou, A. (2011). Mechanical characterization and modeling of interfacial lamella within a flax bundle. *Procedia Engineering*, *10*, 906–911. https://doi.org/10.1016/j.proeng.2011.04.149

Cheeseman, B. A., & Bogetti, T. A. (2003). Ballistic impact into fabric and compliant composite laminates. *Composite Structures*, *61*(1–2), 161–173. https://doi.org/10.1016/S0263-8223(03)00029-1

Chikhi, N., Fellahi, S., & Bakar, M. (2002). Modification of epoxy resin using reactive liquid (ATBN) rubber. *European Polymer Journal*, *38*(2), 251–264. https://doi.org/10.1016/S0014-3057(01)00194-X

Collectors, S., Load, P. U., Sensors, D., Materials, C., Polish, E. F., & Constructions, S. (2013). Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event 1, *i*, 1–16. https://doi.org/10.1520/D7136

Cui, L. J., Wang, Y. Bin, Xiu, W. J., Wang, W. Y., Xu, L. H., Xu, X. B., … Geng, H. Z. (2013). Effect of functionalization of multi-walled carbon nanotube on the curing behavior and mechanical property of multi-walled carbon nanotube/epoxy composites. *Materials and Design*, *49*, 279–284. https://doi.org/10.1016/j.matdes.2013.01.050

Davis, D. C., & Whelan, B. D. (2011). An experimental study of interlaminar shear fracture toughness of a nanotube reinforced composite. *Composites Part B: Engineering*, *42*(1), 105–116. https://doi.org/10.1016/j.compositesb.2010.06.001

Dicker, M. P. M., Duckworth, P. F., Baker, A. B., Francois, G., Hazzard, M. K., & Weaver, P. M. (2014). Green composites: A review of material attributes and complementary applications. *Composites Part A: Applied Science and Manufacturing*. https://doi.org/10.1016/j.compositesa.2013.10.014

Díez-Pascual, A. M., Ashrafi, B., Naffakh, M., González-Domínguez, J. M., Johnston, A., Simard, B., … Gómez-Fatou, M. A. (2011). Influence of carbon nanotubes on the thermal, electrical and mechanical properties of poly(ether ether ketone)/glass fiber laminates. *Carbon*, *49*(8), 2817–2833. https://doi.org/10.1016/j.carbon.2011.03.011

Esposito, L. H., Ramos, J. A., & Kortaberria, G. (2014). Dispersion of carbon nanotubes in nanostructured epoxy systems for coating application. *Progress in Organic Coatings*, *77*(9), 1452–1458. https://doi.org/10.1016/j.porgcoat.2014.05.001

Fang, C., Wang, J., & Zhang, T. (2014). Interlaminar improvement of carbon fiber/epoxy composites via depositing mixture of carbon nanotubes and sizing agent. *Applied Surface Science*, *321*, 1–9. https://doi.org/10.1016/j.apsusc.2014.09.170

Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000-2010. *Progress in Polymer Science*, *37*(11), 1552–1596. https://doi.org/10.1016/j.progpolymsci.2012.04.003

Gojny, F. H., Wichmann, M. H. G., Fiedler, B., & Schulte, K. (2005). Influence of different carbon nanotubes on the mechanical properties of epoxy matrix composites - A comparative study. *Composites Science and Technology*, *65*(15–16 SPEC. ISS.), 2300–2313. https://doi.org/10.1016/j.compscitech.2005.04.021

Gojny, F. H., Wichmann, M. H. G., Köpke, U., Fiedler, B., & Schulte, K. (2004). Carbon nanotube-reinforced epoxy-composites: Enhanced stiffness and fracture toughness at low nanotube content. *Composites Science and Technology*, *64*(15 SPEC. ISS.), 2363–2371. https://doi.org/10.1016/j.compscitech.2004.04.002

Guldi, D. M., Rahman, G. M. A., Zerbetto, F., & Prato, M. (2005). Carbon Nanotubes in Electron Donor−Acceptor Nanocomposites. *Accounts of Chemical Research*, *38*(11), 871–878. https://doi.org/10.1021/ar040238i

Gururaja, M. N., & Rao, H. (2012). A Review on Recent Applications and Future Prospectus of Hybrid Composites. *International Journal of Soft Computing and Engineering*, (16), 2231–2307.

Heimbs, S., Heller, S., Middendorf, P., Hähnel, F., & Weiße, J. (2009). Low velocity impact on CFRP plates with compressive preload: Test and modelling. *International Journal of Impact Engineering*, *36*(10–11), 1182–1193. https://doi.org/10.1016/j.ijimpeng.2009.04.006

Hosur, M. V., Chowdhury, F., & Jeelani, S. (2007). Low-velocity impact response and ultrasonic NDE of woven carbon/epoxy-nanoclay nanocomposites. *Journal of Composite Materials*, *41*(18), 2195–2212. https://doi.org/10.1177/0021998307074146

Icten, B. M. (2015). Low temperature effect on single and repeated impact behavior of woven glass-epoxy composite plates. *Journal of Composite Materials*, *49*(10), 1171–1178. https://doi.org/10.1177/0021998314531309

Imielińska, K., & Guillaumat, L. (2004). The effect of water immersion ageing on low-velocity impact behaviour of woven aramid-glass fibre/epoxy composites. *Composites Science and Technology*, *64*(13–14), 2271–2278. https://doi.org/10.1016/j.compscitech.2004.03.002

Inam, F., Wong, D. W. Y., Kuwata, M., & Peijs, T. (2010). Multiscale Hybrid Micro-Nanocomposites Based on Carbon Nanotubes and Carbon Fibers. *Journal of Nanomaterials*, *2010*, 1–12. https://doi.org/10.1155/2010/453420

Iqbal, K., Khan, S. U., Munir, A., & Kim, J. K. (2009). Impact damage resistance of CFRP with nanoclay-filled epoxy matrix. *Composites Science and Technology*, *69*(11–12), 1949–1957. https://doi.org/10.1016/j.compscitech.2009.04.016

Ismail, K. I., Sultan, M. T. H., Shah, A. U. M., Mazlan, N., & Ariffin, A. H. (2018). Tensile Properties of Hybrid Biocomposite Reinforced Epoxy Modified with Carbon Nanotube (CNT). *BioResources*, *13*(1), 1787–1800. https://doi.org/10.15376/biores.13.1.1787-1800

Jarukumjorn, K., & Suppakarn, N. (2009). Effect of glass fiber hybridization on properties of sisal fiber-polypropylene composites. *Composites Part B: Engineering*, *40*(7), 623–627. https://doi.org/10.1016/j.compositesb.2009.04.007

Jhala, A. J., & Hall, L. M. (2010). Flax (Linum usitatissimum L .): Current Uses and Future Applications, *4*(9), 4304–4312.

Karapappas, P., Vavouliotis, A., Tsotra, P., Kostopoulos, V., & Paipetis, A. (2009). Enhanced Fracture Properties of Carbon Reinforced Composites by the Addition of Multi-Wall Carbon Nanotubes. *Journal of Composite Materials*, *43*(9), 977–985. https://doi.org/10.1177/0021998308097735

Khan, S. U., & Kim, J. K. (2011). Impact and delamination failure of multiscale carbon nanotube-fiber reinforced polymer composites: A review. *International Journal of Aeronautical and Space Sciences*, *12*(2), 115–133. https://doi.org/10.5139/IJASS.2011.12.2.115

Kim, M. S., Lee, S. E., Lee, W. J., & Kim, C. G. (2009). Mechanical properties of MWNT-loaded plain-weave glass/epoxy composites. *Advanced Composite Materials*, *18*(3), 209–219. https://doi.org/10.1163/156855109X428826

Kim, S., Pechar, T. W., & Marand, E. (2006). Poly(imide siloxane) and carbon nanotube mixed matrix membranes for gas separation. *Desalination*, *192*(1–3), 330–339. https://doi.org/10.1016/j.desal.2005.03.098

Kim, W. J., Kang, S. O., Ah, C. S., Lee, Y. W., Ha, D. H., Choi, I. S., & Yun, W. S. (2004). Functionalization of shortened SWCNTs using esterification. *Bulletin of the Korean Chemical Society*, *25*(9), 1301–1302. https://doi.org/10.5012/bkcs.2004.25.9.1301

Kostopoulos, V., Baltopoulos, A., Karapappas, P., Vavouliotis, A., & Paipetis, A. (2010). Impact and after-impact properties of carbon fibre reinforced composites enhanced with multi-wall carbon nanotubes. *Composites Science and Technology*, *70*(4), 553–563. https://doi.org/10.1016/j.compscitech.2009.11.023

Kvavadze, E., Bar-Yoset, O., Belfer-Cohen, A., Boaretto, E., Jakeli, N., Matskevich, Z., & Meshveliani, T. (2010). Response to comment on “30,000-year-old wild flax fibers.” *Science*, *328*(5986), 0–1. https://doi.org/10.1126/science.1187161

LAU, K., LU, M., CHEUNG, H., SHENG, F., & LI, H. (2005). Thermal and mechanical properties of single-walled carbon nanotube bundle-reinforced epoxy nanocomposites: the role of solvent for nanotube dispersion. *Composites Science and Technology*, *65*(5), 719–725. https://doi.org/10.1016/j.compscitech.2004.10.005

Li, M., Gu, Y., Liu, Y., Li, Y., & Zhang, Z. (2013). Interfacial improvement of carbon fiber/epoxy composites using a simple process for depositing commercially functionalized carbon nanotubes on the fibers. *Carbon*, *52*, 109–121. https://doi.org/10.1016/j.carbon.2012.09.011

Lubineau, G., & Rahaman, A. (2012). A review of strategies for improving the degradation properties of laminated continuous-fiber/epoxy composites with carbon-based nanoreinforcements. *Carbon*, *50*(7), 2377–2395. https://doi.org/10.1016/j.carbon.2012.01.059

Ma, P. C., Kim, J. K., & Tang, B. Z. (2007). Effects of silane functionalization on the properties of carbon nanotube/epoxy nanocomposites. *Composites Science and Technology*, *67*(14), 2965–2972. https://doi.org/10.1016/j.compscitech.2007.05.006

Ma, P. C., Siddiqui, N. A., Marom, G., & Kim, J. K. (2010a). Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: A review. *Composites Part A: Applied Science and Manufacturing*, *41*(10), 1345–1367. https://doi.org/10.1016/j.compositesa.2010.07.003

Ma, P. C., Siddiqui, N. A., Marom, G., & Kim, J. K. (2010b). Dispersion and functionalization of carbon nanotubes for polymer-based nanocomposites: A review. *Composites Part A: Applied Science and Manufacturing*, *41*(10), 1345–1367. https://doi.org/10.1016/j.compositesa.2010.07.003

Malkapuram, R., Kumar, V., Negi, Y. S., & Yuvraj Singh Negi. (2008). Recent Development in Natural Fiber Reinforced Polypropylene Composites. *Journal of Reinforced Plastics and Composites*, *28*(10), 1169–1189. https://doi.org/10.1177/0731684407087759

Mittal, G., Dhand, V., Rhee, K. Y., Park, S.-J., & Lee, W. R. (2015). A review on carbon nanotubes and graphene as fillers in reinforced polymer nanocomposites. *Journal of Industrial and Engineering Chemistry*, *21*, 11–25. https://doi.org/10.1016/j.jiec.2014.03.022

Moniruzzaman, M., & Winey, K. I. (2006). Polymer nanocomposites containing carbon nanotubes. *Macromolecules*, *39*(16), 5194–5205. https://doi.org/10.1021/ma060733p

Montazeri, A., Javadpour, J., Khavandi, A., Tcharkhtchi, A., & Mohajeri, A. (2010). Mechanical properties of multi-walled carbon nanotube/epoxy composites. *Materials and Design*, *31*(9), 4202–4208. https://doi.org/10.1016/j.matdes.2010.04.018

Monteiro, S. N., Calado, V., Rodriguez, R. J. S., & Margem, F. M. (2012). Thermogravimetric behavior of natural fibers reinforced polymer composites-An overview. *Materials Science and Engineering A*, *557*, 17–28. https://doi.org/10.1016/j.msea.2012.05.109

Monthioux, M., & Kuznetsov, V. L. (2006). Who should be given the credit for the discovery of carbon nanotubes? *Carbon*, *44*(9), 1621–1623. https://doi.org/10.1016/j.carbon.2006.03.019

Muruganandhan, R., & Division, E. D. (2011). Experimental And Finite Element Analysis Of Mechanical Response On Unidirectional Glass Fibre Epoxy Laminate, (1), 100–104.

Naik, N. K., Chandra Sekher, Y., & Meduri, S. (2000). Damage in woven-fabric composites subjected to low-velocity impact. *Composites Science and Technology*, *60*(5), 731–744. https://doi.org/10.1016/S0266-3538(99)00183-9

Naik, N. K., Shrirao, P., & Reddy, B. C. K. (2005). Ballistic impact behaviour of woven fabric composites: Parametric studies. *Materials Science and Engineering: A*, *412*(1–2), 104–116. https://doi.org/http://dx.doi.org/10.1016/j.msea.2005.08.019

Nayak, S. K., Mohanty, S., & Samal, S. K. (2009). Influence of short bamboo/glass fiber on the thermal, dynamic mechanical and rheological properties of polypropylene hybrid composites. *Materials Science and Engineering A*, *523*(1–2), 32–38. https://doi.org/10.1016/j.msea.2009.06.020

Park, J. M., Kim, D. S., Lee, J. R., & Kim, T. W. (2003). Nondestructive damage sensitivity and reinforcing effect of carbon nanotube/epoxy composites using electro-micromechanical technique. *Materials Science and Engineering C*, *23*(6–8), 971–975. https://doi.org/10.1016/j.msec.2003.09.131

Qin, H., Su, Q., Zhang, S., Zhao, B., & Yang, M. (2003). Thermal stability and flammability of polyamide 66/montmorillonite nanocomposites. *Polymer*, *44*(24), 7533–7538. https://doi.org/10.1016/j.polymer.2003.09.014

Ramesh, M., Palanikumar, K., & Reddy, K. H. (2013). Comparative Evaluation on Properties of Hybrid Glass Fiber- Sisal/Jute Reinforced Epoxy Composites. *Procedia Engineering*, *51*(NUiCONE 2012), 745–750. https://doi.org/10.1016/j.proeng.2013.01.106

Ramesh, M., Palanikumar, K., & Reddy, K. H. (2017). Plant fibre based bio-composites: Sustainable and renewable green materials. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2017.05.094

Rathore, D. K., Prusty, R. K., Kumar, D. S., & Ray, B. C. (2016). Mechanical performance of CNT-filled glass fiber/epoxy composite in in-situ elevated temperature environments emphasizing the role of CNT content. *Composites Part A: Applied Science and Manufacturing*, *84*, 364–376. https://doi.org/10.1016/j.compositesa.2016.02.020

Richardson, M. O. W., & Wisheart, M. J. (1996). Review of low-velocity impact properties of composite materials. *Composites Part A: Applied Science and Manufacturing*, *27*(12), 1123–1131. https://doi.org/10.1016/1359-835X(96)00074-7

Safri, S. N. A., Chan, T. Y., & Sultan, M. T. H. (2014). An Experimental Study of Low Velocity Impact (LVI) On Fibre Glass Reinforced Polymer (FGRP). *The International Journal Of Engineering And Science*, *3*(8), 1–10.

Safri, S. N. A., Sultan, M. T. H., Yidris, N., & Mustapha, F. (2014). Low velocity and high velocity impact test on composite materials – A review. *The International Journal of Engineering and Science (IJES)*, *3*(9), 50–60. https://doi.org/10.1177/1464420711409985

Salit, M. S., Jawaid, M., Bin, N., & Hoque, E. (n.d.). *Manufacturing of Natural Fibre Reinforced Polymer Composites*.

Sanchez-Saez, S., Barbero, E., Zaera, R., & Navarro, C. (2005). Compression after impact of thin composite laminates. *Composites Science and Technology*, *65*(13), 1911–1919. https://doi.org/10.1016/j.compscitech.2005.04.009

Sanjay, M. R., Arpitha, G. R., & Yogesha, B. (2015). Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review. *Materials Today: Proceedings*, *2*(4–5), 2959–2967. https://doi.org/10.1016/j.matpr.2015.07.264

Schadler, L. S., Giannaris, S. C., & Ajayan, P. M. (1998). Load transfer in carbon nanotube epoxy composites. *Applied Physics Letters*, *73*(26), 3842–3844. https://doi.org/10.1063/1.122911

Shah, D. U. (2014). Natural fibre composites: Comprehensive Ashby-type materials selection charts. *Materials and Design*, *62*(May), 21–31. https://doi.org/10.1016/j.matdes.2014.05.002

Sharma, K., & Shukla, M. (2014). Three-phase carbon fiber amine functionalized carbon nanotubes epoxy composite: Processing, characterisation, and multiscale modeling. *Journal of Nanomaterials*, *2014*. https://doi.org/10.1155/2014/837492

Shim, V. P. W., & Yang, L. M. (2005). Characterization of the residual mechanical properties of woven fabric reinforced composites after low-velocity impact. *International Journal of Mechanical Sciences*, *47*(4–5 SPEC. ISS.), 647–665. https://doi.org/10.1016/j.ijmecsci.2005.01.014

Shyr, T. W., & Pan, Y. H. (2003). Impact resistance and damage characteristics of composite laminates. *Composite Structures*, *62*(2), 193–203. https://doi.org/10.1016/S0263-8223(03)00114-4

Soliman, E. M., Sheyka, M. P., & Taha, M. R. (2012). Low-velocity impact of thin woven carbon fabric composites incorporating multi-walled carbon nanotubes. *International Journal of Impact Engineering*, *47*, 39–47. https://doi.org/10.1016/j.ijimpeng.2012.03.002

Suhr, J., & Koratkar, N. A. (2008). Energy dissipation in carbon nanotube composites: A review. *Journal of Materials Science*, *43*(13), 4370–4382. https://doi.org/10.1007/s10853-007-2440-x

Tan, K. T., Yoshimura, A., Watanabe, N., Iwahori, Y., & Ishikawa, T. (2013). Effect of stitch density and stitch thread thickness on damage progression and failure characteristics of stitched composites under out-of-plane loading. *Composites Science and Technology*, *74*(12), 194–204. https://doi.org/10.1016/j.compscitech.2012.11.001

Tang, L. cheng, Zhang, H., Han, J. hua, Wu, X. ping, & Zhang, Z. (2011). Fracture mechanisms of epoxy filled with ozone functionalized multi-wall carbon nanotubes. *Composites Science and Technology*, *72*(1), 7–13. https://doi.org/10.1016/j.compscitech.2011.07.016

Thostenson, E. T., Ren, Z., & Chou, T.-W. (2001). Advances in the science and technology of carbon nanotubes and their composites: a review. *Composites Science and Technology*, *61*(13), 1899–1912. https://doi.org/10.1016/S0266-3538(01)00094-X

Tita, V., de Carvalho, J., & Vandepitte, D. (2008). Failure analysis of low velocity impact on thin composite laminates: Experimental and numerical approaches. *Composite Structures*, *83*(4), 413–428. https://doi.org/10.1016/j.compstruct.2007.06.003

Tseng, C. H., Wang, C. C., & Chen, C. Y. (2007). Functionalizing carbon nanotubes by plasma modification for the preparation of covalent-integrated epoxy composites. *Chemistry of Materials*, *19*(2), 308–315. https://doi.org/10.1021/cm062277p

Tugrul Seyhan, A., Tanoglu, M., & Schulte, K. (2008). Mode I and mode II fracture toughness of E-glass non-crimp fabric/carbon nanotube (CNT) modified polymer based composites. *Engineering Fracture Mechanics*, *75*(18), 5151–5162. https://doi.org/10.1016/j.engfracmech.2008.08.003

Vaidya, U. K. (2011). Impact Response of Laminated and Sandwich Composites, *5*, 97–191. https://doi.org/10.1007/978-3-7091-0523-8_4

Velasco-Santos, C., Mart´ınez-Hern´andez, A. L., Fisher, F., Ruoff, R., & Castano, V. M. (2003). Dynamical – mechanical and thermal analysis of carbon nanotube – methyl-ethyl methacrylate nanocomposites. *Journal of Physics D: Applied Physics*, *36*, 1423–1428. https://doi.org/10.1088/0022-3727/36/12/311

Volder, M. F. L. De, Tawfick, S. H., Baughman, R. H., & Hart, A. J. (2013). Carbon Nanotubes : Present and Future Commercial Applications, *339*(February), 535–540.

Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: Can they replace glass in fibre reinforced plastics? *Composites Science and Technology*, *63*(9), 1259–1264. https://doi.org/10.1016/S0266-3538(03)00096-4

Wang, P., Zhang, X., Lim, G., Neo, H., Malcolm, A. A., Xiang, Y., … Yang, J. (2015). Improvement of impact-resistant property of glass fiber-reinforced composites by carbon nanotube-modified epoxy and pre-stretched fiber fabrics. *Journal of Materials Science*, *50*(18), 5978–5992. https://doi.org/10.1007/s10853-015-9145-3

Wang, X., Hu, B., Feng, Y., Liang, F., Mo, J., Xiong, J., & Qiu, Y. (2008). Low velocity impact properties of 3D woven basalt/aramid hybrid composites. *Composites Science and Technology*, *68*(2), 444–450. https://doi.org/10.1016/j.compscitech.2007.06.016

Yahaya, R., Sapuan, S. M., Jawaid, M., Leman, Z., & Zainudin, E. S. (2014). Mechanical performance of woven kenaf-Kevlar hybrid composites. *Journal of Reinforced Plastics and Composites*, *33*(24), 2242–2254. https://doi.org/10.1177/0731684414559864

Yakobson, B. I., & Avouris, P. (2001). Mechanical Properties of Carbon Nanotubes. *Carbon Nanotubes*, *327*(2001), 287–327. https://doi.org/10.1007/3-540-39947-X

Yan, L., Chouw, N., & Jayaraman, K. (2014). Composites : Part B Flax fibre and its composites – A review. *Composites Part B*, *56*, 296–317. https://doi.org/10.1016/j.compositesb.2013.08.014

Yu, M.-F., Files, B. S., Arepalli, S., & Ruoff, R. S. (2000). Tensile Loading of Ropes of Single Wall Carbon Nanotubes and their Mechanical Properties. *Physical Review Letters*, *84*(24), 5552–5555. https://doi.org/10.1103/PhysRevLett.84.5552

Zanetti, M., Camino, G., Reichert, P., & Mülhaupt, R. (2001). Thermal behaviour of poly(propylene) layered silicate nanocomposites. *Macromolecular Rapid Communications*, *22*(3), 176–180. https://doi.org/10.1002/1521-3927(200102)22:3<176::AID-MARC176>3.0.CO;2-C

Zhang, X., Wang, P., Neo, H., Lim, G., Malcolm, A. A., Yang, E. H., & Yang, J. (2016). Design of glass fiber reinforced plastics modified with CNT and pre-stretching fabric for potential sports instruments. *Materials and Design*, *92*, 621–631. https://doi.org/10.1016/j.matdes.2015.12.051

Zhang, Y., Li, Y., Ma, H., & Yu, T. (2013). Tensile and interfacial properties of unidirectional flax/glass fiber reinforced hybrid composites. *Composites Science and Technology*, *88*, 172–177. https://doi.org/10.1016/j.compscitech.2013.08.037

Zhou, H. W., Mishnaevsky, L., Yi, H. Y., Liu, Y. Q., Hu, X., Warrier, A., & Dai, G. M. (2016). Carbon fiber/carbon nanotube reinforced hierarchical composites: Effect of CNT distribution on shearing strength. *Composites Part B: Engineering*, *88*, 201–211. https://doi.org/10.1016/j.compositesb.2015.10.035

Zhou, Y., Pervin, F., Lewis, L., & Jeelani, S. (2007). Experimental study on the thermal and mechanical properties of multi-walled carbon nanotube-reinforced epoxy. *Materials Science and Engineering A*, *452–453*, 657–664. https://doi.org/10.1016/j.msea.2006.11.066

Zhou, Y., Pervin, F., Lewis, L., & Jeelani, S. (2008). Fabrication and characterization of carbon/epoxy composites mixed with multi-walled carbon nanotubes. *Materials Science and Engineering A*, *475*(1–2), 157–165. https://doi.org/10.1016/j.msea.2007.04.043

Zhou, Y. X., Wu, P. X., Cheng, Z. Y., Ingram, J., & Jeelani, S. (2008). Improvement in electrical, thermal and mechanical properties of epoxy by filling carbon nanotube. *Express Polymer Letters*, *2*(1), 40–48. https://doi.org/10.3144/expresspolymlett.2008.6

Zhu, J., Kim, J. D., Peng, H., Margrave, J. L., Khabashesku, V. N., & Barrera, E. V. (2003). Improving the dispersion and integration of single-walled carbon nanotubes in epoxy composites through functionalization. *Nano Letters*, *3*(8), 1107–1113. https://doi.org/10.1021/nl0342489

Zulfli, N. M., Bakar, A. A., & Chow, W. S. (2013). Mechanical and water absorption behaviors of carbon nanotube reinforced epoxy/glass fiber laminates. *Journal of Reinforced Plastics and Composites*, *32*(22), 1715–1721. https://doi.org/10.1177/0731684413501926

BIODATA OF STUDENT

Khairul Izwan Ismail was born in Hospital KL, W. Persekutuan in February 1993 - successfully finishing primary school at the Methodist Boys Primary School (MBPS) and Sek. Keb. Bandar Baru Sentul (SKBBS). The eldest child of En. Ismail Harun and Pn. Rafeah Abd Rahman continued their successful journey in one of the boarding schools in Gombak. After five years in Gombak Integrated Boarding School (INTEGOMB), he pursued his study at Perak Matriculation College in Gopeng for one year. Then, he continued his Bachelor Degree in Aerospace Engineering and Masters of Science at Unversiti Putra Malaysia (UPM). Progressing well in his research studies on polymer nano-composites and hybrid composites, under the supervision of dedicated supervisors, Khairul is now completing his Master of Science in his fourth semester.

LIST OF PUBLICATIONS

Journals

Ismail, K. I., Sultan, M. T. H., Shah, A. U. M., Mazlan, Norkhairunnisa., Hamdan, A. (2018). Tensile Properties of Hybrid Biocomposite Reinforced Epoxy Modified with Carbon Nanotube (CNT). *Bioresources, 13*(1), 1787-1800. DOI: 10.15376/biores.13.1.1787-1800. ISMAIL – Published

Ismail, K. I.., Sultan, M. T. H., Shah, A. U. M. (2018), Impact and After-impact Properties of Hybrid Biocomposite Modified with Multi-walled Carbon Nanotube. Journal of Composite Part B – Submitted

Ismail, K. I., Sultan, M. T. H., Shah, A. U. M. (2018), Thermogravimetric Analysis of Hybrid Biocomposite Modified with Multi-walled Cabon Nanotube. Journal of Material Research and Technology - Submitted

Book chapters

Ain U, M. S., Azmi, A. M. R., Safri, S. N. A., **Ismail, K. I.**, A. F. M., Razali, N., Sultan, M. T. H., (2017). Numerical and Experimental Analysis of Delamination in Fibre Reinforced Polymer Composites Failure Analysis in Biocomposites, Fibre Reinforced Composites and Hybrid Composites - Accepted

Conference

Ismail, K. I., Sultan, M. T. H., Shah, A. U. M., Nor, A. F. M., Azmi, A. M. R., Hamdan, A., (2018). Effect of Carbon Nanotube (CNT) Concentration on Flexural Properties of Flax Hybrid Biocomposite. 6th International Conference on Advanced Material Engineering and Technology – Published

Nor, A. F. M., Sultan, M. T. H., Shah, A. U. M., Azmi, A. M. R., & **Ismail, K. I.** (2018). Effects of Carbon Nanotube (CNT) as the Nanofillers into Bamboo/Glass Hybrid Composites on Tensile, Flexural and Impact Properties. 6th International Conference on Advanced Material Engineering and Technology – Published

Azmi, A. M. R., Sultan, M. T. H., Shah, A. U. M., Nor, A. F. M., & Ismail, K. I. (2018). Tensile Properties of a Kenaf/X-Ray Film Hybrid Composites. 6th International Conference on Advanced Material Engineering and Technology – Published

Workshops and Seminars

1. 3rd Malaysia Super Satellite Campus (MSSC) International Workshop on Engineering and Health Science 2017: Collaboration for Bioengineering, Mechanics and Nano-materials, Aerospace Manufacturing Research Centre, UPM, 31 January 2017 – Participant

2. Global Aerospace Industry Outlook and Insight into Malaysia's Aerospace Initiatives Talk, Aerospace Manufacturing Centre, UPM, 2 March 2017 – Participant

3. Composite Technology - Current and Future Trends Talk, Aerospace Manufacturing Research Centre, UPM, 16 March 2017 – Participant

4. International Workshop on Advanced Composites and its Manufacturing, Aerospace Manufacturing Research Centre, UPM, 10 April 2017 – Participant

5. Sharing Session on Student – Supervisor Relationship, Aerospace Manufacturing Research Centre, UPM, 2 May 2017 - Participant

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : _____

TITLE OF THESIS / PROJECT REPORT :

CHARACTERIZATION OF HYBRID BIOCOMPOSITE SYNTHESISED WITH MULTI-WALLED CARBON NANOTUBE FOR FINITE STRAIN APPLICATION OF AEROSPACE STRUCTURES

NAME OF STUDENT: KHAIRUL IZWAN BIN ISMAIL

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐ **PATENT** Embargo from _____ (date) until _____ (date)

Approved by:

_____
(Signature of Student)
New IC No/ Passport No.:

Date :

_____
(Signature of Chairman of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]