UNIVERSITI PUTRA MALAYSIA

LOW VELOCITY IMPACT CHARACTERISATIONS OF FLAX/KENAF/GLASS FIBRE HYBRID COMPOSITES

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

July 2020

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: Mohamed Thariq bin Hameed Sultan, PhD, PEng, CEng, PTech
Faculty: Engineering

Kenaf is widely used in Malaysia. Flax was hybridized with kenaf to improve the kenaf composites properties. Glass fibre has been chosen to hybrid with flax/kenaf composites to study their impact damage behaviour. All specimens were fabricated using hand lay-up technique. Flax/kenaf specimens were used for physical, mechanical and thermal test. The result shows that the mechanical properties are improve when the hybrid specimen was used as test specimens. From the entire test, hybrid composites of flax BL150 fibre and kenaf fibre show the highest tensile and flexural properties for each test. The thermal properties will be increased when the hybrid specimen was used as test specimens. From the results achieved, the best kenaf/flax composites were selected to hybrid with glass fibre for low velocity impact test. The motivation for this work is to identify the low velocity impact damage by changes in the type of materials and impact energy level. Different energy levels used were 15J, 30J, 45J, 60J, 75J and 90J. The impact energy absorption, penetration behaviour, composites failure and impact force were discussed. The specimen was attached to acoustic emission sensor while doing the impact test. The correlation between the impacted specimens and types of materials was discussed. A general trend was observed which indicates that as height increase, the energy absorbed also increases. Impact damage was found to be in the form of fibre cracking, fibre breakage and matrix cracking. Results from this research can be used as a reference in designing the structure of aircraft applications and in developing a better understanding of the test methods used to characterise impact behaviour. The research later was end up with the result from post impact.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KESAN IMPAK HALAJU RENDAH KOMPOSIT HIBRID FLAKS/KENAF/GENTIAN KACA

Oleh

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Kenaf digunakan secara meluas di Malaysia. Flaks telah digabungkan dengan kenaf untuk meningkatkan keupayaan komposit kenaf. Gentian kaca telah dipilih untuk digabungkan dengan komposit flaks / kenaf untuk mengkaji kesan hentaman ke atasnya. Semua spesimen telah dihasilkan dengan menggunakan teknik hamparan tangan secara helai demi helai. Komposit gabungan flaks dan kenaf telah digunakan untuk ujian fizikal, mekanikal dan haba. Keputusan daripada ujian mekanikal menunjukkan peningkatan terhadap keupayaannya apabila spesimen gabungan telah digunakan sebagai spesimen ujian. Daripada keseluruhan ujian, komposit gabungan serat flaks BL150 dan serat kenaf menunjukkan tegangan yang paling tinggi dan sifat-sifat lenturan bagi setiap ujian. Hasil ujian haba menunjukkan bahawa sifat haba akan meningkat apabila spesimen gabungan telah digunakan sebagai spesimen ujian. Daripada keputusan yang telah dicapai, gabungan kenaf / flaks terbaik telah dipilih untuk digabungkan dengan gentian kaca untuk menjalani ujian halaju rendah. Motivasi untuk kerja-kerja ini adalah untuk mengenal pasti kerosakan kesan halaju rendah dengan perubahan jenis bahan dan tahap tenaga hentaman. Tahap tenaga yang berbeza telah digunakan untuk setiap jenis spesimen iaitu 15J, 30J, 45J, 60J, 75J dan 90J. Penyerapan tenaga hentaman, tingkah laku penembusan, kegagalan komposit dan kesan daya telah dibincangkan. Spesimen juga telah dilekatkan pada sensor pelepasan akustik ketika melakukan ujian hentaman. Hubungan antara spesimen hentaman dan jenis bahan yang digunakan untuk ujian dibincangkan. Satu bentuk graf umum menunjukkan bahawa semakin meningkat ketinggian, tenaga yang diserap juga semakin bertambah. Kerosakan itu terus meningkat kerana halaju pemberat bertambah. Kerosakan yang didapati adalah dalam bentuk retakan serat, kerosakan serat, keretakan matriks dan serat sisipan. Hasil daripada kajian ini boleh digunakan sebagai rujukan dalam mereka bentuk struktur aplikasi pesawat dan dalam meningkatkan pemahaman yang lebih baik kepada kaedah ujian yang digunakan untuk tingkah laku hentaman yang dicirikan. Kajian ini

kemudiannya berakhir dengan hasil ujian yang dijalankan ke atas spesimen selepas hentaman.

ACKNOWLEDGEMENTS

First and foremost, all praises go to Allah S.W.T, The Almighty, for His continuous blessings and mercy throughout my journey of completing this research successfully. I would like to express my gratitude to my supportive supervisor, Prof. Ir. Ts. Dr. Mohamed Thariq bin Hameed Sultan for guidance and support throughout my research study. Thank you for giving me an opportunity to pursue my studies and provides anything that needed in my research. He always not gives up helping me and always encourages me to finish my study. Without his guidance, I may not being able to finish my research and writing this thesis. I also want to thanks my supervisory committee; Dr Mohamed Jawaid and Prof. Ir. Ts. Dr. Abdul Rahim bin Abu Talib for their support and help.

To my mother and my late father, Zaimah and Allahyarham Razali, thank you for your support and pray throughout my period of study. Their encouragement, sacrifices, and prayers make me strong and never give up finishing my study. They have taught me how to face the reality of life. To my lovely husband, Captain Ibrahim, thank you for your love, understanding, support and helping during my research work. I would not being able to finish my study without your support and permission. To my son, Iyad Imad, you made me really strong mother with your clingy and love. I am very grateful to have you as my son. Thinking of your future made me strong, finish up my study and I want to be a role model to you.

To my fellow colleagues, Dr. Syafiqah, Dr. Ain Umaira, Dr. Madiha, Ariff, Izwan, Mustafa, Hasfa, Faizzudin, Tabrej and all members of Aerospace Manufacturing Research Centre (AMRC) and Institute of Tropical Forestry and Forest Product (INTROP) for helping and discussing the problem throughout my research work. Thanks you for always be there to support and assist me on data collection, journal publication, and preparing thesis. They always give me motivation and encourage me whenever I need them and feel down.

Lastly, a big thank to Ministry of Higher Education Malaysia for giving me financial support throughout the MyBrain scholarship. Without this scholarship, I might not being able to pursue my study to a higher stage.

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

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TABLE OF CONTENTS

				Page
ABSTRACT				i
ABSTRAK				ii
ACKNOWLEDGEMENT				iv
APPROVAL				v
DECLARATION				vii
LIST OF TABLES				xii
LIST OF FIGURES				xiii
LIST OF ABBREVIATIONS				xv
CHAPTER				
1	**INTRODUCTION**			1
	1.1	Overview		1
	1.2	Problem Statements		2
	1.3	Objectives Of Study		3
	1.4	Scope and Limitation of the Study		3
	1.5	Thesis Organization		4
2	**LITERATURE REVIEW**			6
	2.1	Introduction		6
	2.2	Natural Fibres		6
		2.2.1	Kenaf Fibres	7
		2.2.2	Flax Fibres	8
	2.3	Synthetic Fibres		9
		2.3.1	Classification of Synthetic Fibres	10
		2.3.2	Glass Fibres	10
	2.4	Hybrid Composites		12
	2.5	Mechanical Properties		13
	2.6	Thermal Properties		15
	2.7	Impact Test		19
	2.8	Non-Destructive Testing		21
		2.8.1	Acoutic Emission	24
		2.8.2	Ultrasonic C-Scan	24
	2.9	Summary		25
3	**MATERIAL AND METHODOLOGY**			27
	3.1	Introduction		27
	3.2	Material Selection		29
		3.2.1	Flax	30
		3.2.2	Kenaf	30
		3.2.3	Glass Fibre	30
		3.2.4	Epoxy resin	31
	3.3	Fabrication of Composites		32
	3.4	Physical Tests		34

3.4.1 Density 34
3.4.2 Water Absorption 34
3.5 Mechanical Tests 35
3.5.1 Tensile 35
3.5.2 Flexural 36
3.5.3 Compression 37
3.5.4 Scanning electron microscopy 38
3.6 Thermal Tests 38
3.6.1 Dynamic Mechanical analysis 38
3.6.2 Thermogalvanic analysis 38
3.7 Low Velocity Impact 39
3.8 Acoustic Emission 40
3.9 Post-Impact Test 42
3.9.1 Ultrasonic C-Scan 42
3.9.2 Compression After Impact 44
3.10 Summary 44

4 RESULTS AND DISCUSSIONS 46
4.1 Introduction 46
4.2 Physical Properties of Hybrid Composites 46
4.2.1 Density 46
4.2.2 Water Absorption 47
4.3 Mechanical Properties of Hybrid Composites 49
4.3.1 Tensile 49
4.3.2 Flexural 52
4.3.3 Compression 54
4.3.4 Scanning electron microscopy 56
4.4 Thermal Properties of Hybrid Composites 58
4.4.1 Dynamic Mechanical Analysis (DMA) 58
4.4.2 Thermogravimetric analysis (TGA) 62
4.5 Impact Properties of Hybrid Composites 66
4.5.1 Low-Velocity Impact 66
4.5.2 Acoustic Emission 72
4.6 Post-impact Properties of Hybrid Composites 74
4.6.1 Ultrasonic C-Scan 74
4.6.2 Compression After Impact 80
4.7 Summary 82

5 CONCLUSION AND RECOMMENDATION FOR FUTURE WORK 83
5.1 Conclusion 83
5.1.1 Physical Properties 83
5.1.2 Mechanical Properties 83
5.1.3 Thermal Properties 84
5.1.4 Low Velocity Impact Properties 84
5.1.5 Post-Impact Properties 85
5.1.6 Overall Conclusion 86
5.2 Future Recommendations 86
88

REFERENCES
BIODATA OF STUDENT 97
LIST OF PUBLICATIONS 98

LIST OF TABLES

Table		Page
2.1	Typical values of E-glass and some natural fibers	9
2.2	Major types of glass fibre	11
2.3	Reported researches on tensile and flexure testing for hybrid composites	14
2.4	Reported studies on thermal analysis of composites	16
2.5	Commonly used NDT method and their limitations	21
2.6	Summary of problems and the proposes of solution	25
3.1	Physical properties of the epoxy resin and hardener	31
3.2	Formulation of kenaf, flax and hybrid composites	33
3.3	Data of span length	37
3.4	Height of drop weight impactor release for certain impact energy	40
4.1	Density of all composite specimens	47
4.2	Glass Transition Temperature (T_g) values obtained from loss modulus curves	60
4.3	The initial degradation temperature, weight loss, and residue of the composites tested	63
4.4	Chemical composition of the specimens tested and other fibers from previous research	65
4.5	Lowest and highest frequencies obtained from acoustic emission testing for all the tested specimens	73
4.6	Comparison between the visual and ultrasonic C-scan views of the tested specimens	75
4.7	Average area of damage (mm^2) from upper and bottom surfaces of the specimens using ultrasonic C-scan	79

LIST OF FIGURES

Figure		Page
3.1	Flow chart of research work	28
3.2	Flax (a) BL150 and (b) BL200	30
3.3	Kenaf woven mat	30
3.4	Glass fibre woven roving	31
3.5	Stacking sequence of the flax/kenaf hybrid biocomposites	32
3.6	Stacking sequence of the glass/flax/kenaf hybrid composites	34
3.7	Specimens soaked into distilled water in a water bath	35
3.8	Specimen on two point of the support span and load at the centre	36
3.9	Specimens for compression testing	37
3.10	IM10 Drop weight impact tester	39
3.11	Hemispherical cap impactor	39
3.12	Acoustic emission machine	41
3.13	Specimen covered with plasticine around the edge clamped on the drop weight impactor clamp unit	42
3.14	Ultrasonic C-Scan setup	43
3.15	Movement of the sound wave	43
4.1	Water absorption behaviour of all the specimens	48
4.2	Tensile stress – strain graph of all specimens tested	49
4.3	Tensile properties of all specimens tested	51
4.4	Flexure stress - strain graph of all specimens tested	52
4.5	Flexure properties of all specimens tested	53
4.6	Compression properties of all specimens tested	55
4.7	Compressive stress – strain graph of all specimens tested	56

4.8 The type of failure after mechanical testing on the composites 57

4.9 Storage modulus - temperature graph for all the tested composites 58

4.10 Loss modulus - temperature graph for all the tested composites 59

4.11 Tan delta - temperature graph for all the tested composites 61

4.12 Percentage of weight loss of the specimens as a function of temperature 62

4.13 DTG curves of all the tested specimens 64

4.14 Force-Time curves of the flax-kenaf fibre composite hybridised with glass fibre: (a) E200; (b) E400; (c) E600; and (d) E800 67

4.15 Energy-Time curves of the flax-kenaf fibre composite hybridised with glass fibre: (a) E200; (b) E400; (c) E600; and (d) E800 69

4.16 Force-Displacement curves of flax-kenaf fibre composite hybridised with glass fibre: (a) E200; (b) E400; (c) E600; (d) E800 71

4.17 Absorbed energy of the hybrid composites 72

4.18 Compressive stress – compressive strain curves: (a) E200; (b) E400; (c) E600; and (d) E800 81

LIST OF ABBREVIATIONS

°C	Degree Celsius
°F	Degree fahrenheit
ρ	Density
A_0	Cross sectional area
AE	Acoustic emission
ASTM	American Society for Testing Materials
BVID	Barely visible impact damage
C	Compression
CAI	Compression after impact
CFRP	Carbon fibre reinforced plastic
CMC	Ceramic matrix composites
CNC	Computer numerical control machine
DMA	Dynamic mechanical analysis
DSC	Differential scanning calorimetry
DTG	Derivative thermogravimetric
E’	Storage modulus
E”	Loss modulus
E200	Glass Fibre 200 g/m^2
E400	Glass Fibre 400 g/m^2
E600	Glass Fibre 600 g/m^2
E800	Glass Fibre 800 g/m^2
EFB	Empty fruit bunch
E_i	Impact energy

ET	Electromagnetic testing
F	Flexural
F_{150}	Flax BL150
F_{200}	Flax BL200
FESEM	Field emission scanning electron microscope
FFT	Fast fourier transform
FRP	Fibre reinforced polymer
FTIR	Fourier transform infrared spectroscopy
F_u	Ultimate force
g	Gravitational force
GFRP	Glass fibre reinforced polymer
GPR	Ground penetrating radar
GW	Guided wave testing
h	Impactor height
HIPS	High impact polystyrene
Hr	Hours
IR	Infrared testing
J	Joule
K	Kenaf
kg	Kilogram
kN	Kilo newton
L_0	Gauge length distance
LM	Laser testing method
LVI	Low velocity impact
m	mass

MFL	Magnetic flux leakage
min	Minute
mm	milimeter
MMC	Metal matrix composites
MPa	Mega pascal
MT	Magnetic particle testing
N	Newton
NDE	Non-destructive evaluation
NDT	Non-destructive testing
NFRP	Natural fibre reinforced polymer
NR	Neutron radiographic testing
PLA	Polylactic acid
PMC	Polymer matrix composites
PP	Polypropylene
PS	Polystyrene
PT	Liquid penetrant testing
PVC	Polyvinyl chloride
RS_{uc}	Ultimate compressive residual strength
SEM	Scanning electron microscopy
T	Thickness of the specimens
T_g	Glass transition temperature
TGA	Thermogravimetric analysis
TS	Thickness swelling
UP	Unsaturated polyester
UT	Ultrasonic testing

v	Volume
VA	Vibration analysis
VT	Visual testing
W	Width of the specimens
WA	Water absorption

CHAPTER 1

INTRODUCTION

1.1 Overview

For a several years, natural fibres have become outstanding materials which offer an alternative replacement for more expensive synthetic materials. The ability of natural fibres to be hybridised with synthetic fibres will reduce the cost of production, which will be beneficial for economic growth and the implementation of green applications. These natural fibres have been cultivated for many of years, and have now become raw materials for many industries which include aerospace, marine, automotive industries, and other military applications within the defence industry. Thus, they play an important role in developing towards greener industry. Economic and environmental factors have led to a new trend towards greater utilisation of renewable sources of composite materials. The challenges faced by developers are to create the technologies needed to turn this renewable sources revolution into a reality.

In the aerospace industries, most commercial aircraft are now moving towards the application of hybrid composites. This is because a hybrid composite offers a low cost material with specific properties to meet the demands of high stress on power, and safety (Gururaja et. al, 2012). This advanced technology used glass as its synthetic fibre and carbon as its natural fibre to make reinforced hybrid composites. However, it is only suitable for usage in low temperatures, which has limits its application. To operate well in higher temperature situation, for example in an engine parts, fibre epoxy composites were used to ensure the best performance in operations. The purpose of carbon fibre hybridised with synthetic fibre is to reduce the amount of existing Kevlar in certain aircraft parts and components.

Fibre-reinforced composite materials are generally utilized in airplane, present day vehicles and lightweight structures. Composite structures have a high strength to-weight and stiffness to-weight ratio, be that as it may, on the grounds that they are laminar frameworks with feeble interfaces, they are vulnerable to impact. This may make imperceptible splits and delaminations happen in the material, which are frequently hard to foresee and recognize. The impact damage of composite structures from impact occasions is one of the most significant parts of conduct that represses more far reaching utilization of composite materials. Understanding the deformation and damage systems associated with the impact of composite targets is significant in the powerful plan of a composite structure. An essential for expanding the utilization of composite materials is the need to foresee damage from low velocity impacts.

There are a many research studies being conducted to characterize the impact damage of composite materials. Impact damage can be categorised into a few velocity ranges which are low, high, ballistics and hypervelocity. A low velocity impact may be in situation such as dropped maintenance equipment (< 31 m/s), while a high velocity impact may be in situation such as a bird crashed on an airplane (31 m/s – 240 m/s). Ballistic impacts are condition such as a bullet fired from a gun at velocity exceeding 240 m/s and lastly orbital debris that travels in outer-space at speed up to 15,240 m/s are well known as hypervelocity impact damage situation.

1.2 Problem Statements

Usually, a designer chooses their material based on its cost and performance. The most efficient decision relies upon the expense of the material, the creation cost, the existence cycle cost and the material's properties. Weight sparing and execution normally play a central point in the selection of materials. For aviation structures, obviously carbon fiber is better than glass fiber from a presentation/cost angle since unnecessary weight is exorbitant (Gururaja et. al, 2012). The most commonly used composites commonly known as the Polymer Matrix Composites or Fibre Reinforced Polymers (FRP). This material has proven to be a highly favourable material for the aerospace applications. At the point when composites were presented in airplane segments and aviation ventures, unforeseen impact happened. These may have been because of impact during flight tasks, for example, runway debris while taking a flight, bird strike during flight activities and dropping of hand instruments during maintenance work. For this research, the impact velocity is set to be less than 31 m/s which indicates low velocity testing. For high velocity testing, the impact velocity is in the range of 31 m/s - 240 m/s.

When composites materials are impacted by high and low-velocity impacts events, the structural integrity, stiffness and the toughness of the composites will be reduced, which may cause a catastrophic failure to the structure in worse case situations. Matrix cracking, fibre fracture, fibre pullout and delamination are major undetected hidden damages faced by composite materials after the event of an impact. Therefore, there is important to study the behaviour under impact damage of composite materials since impacts usually occur mainly during maintenance and work manufacturing. An essential for expanding the use of composite materials is the need to anticipate damage during impact occasions. Numerous scientists have utilized a test way to deal with assess impact damage to composite materials. A Drop Weight Impact Tester is used to perform the low velocity impact test.

However, to save the environment, biocomposites had been proposed. Biocomposites itself is not safe to use in structural application as the composites can be degradable in a short time as compared to synthetic fibre. Therefore, the research of hybridisation between synthetic and natural composites needs to be conducted.

In this research, low velocity impact test has been chosen to conduct a test on hybrid of Kenaf fibre, flax fibre and GFRP since this material has been used widely in many applications. Previous researchers have conducted studies on the comparison between different types of composite. Moreover, the studies of low velocity on natural and synthetic fibre such as kenaf, flax and GFRP have not been done before. Therefore, this study needs to be done in order to analyse and to study the impact behaviour of those natural and synthetic hybrid composites.

Kenaf fibre is well known in Malaysia and easy to get here. To improve the properties of the kenaf, flax has been chosen to hybridise with kenaf as flax is well known that has good properties as biocomposites. Glass fibre has been chosen as the synthetic material that will hybridise with the flax/kenaf composites. Glass fibre is less expensive than carbon fibre and Kevlar. Due to the cost of production nowadays, this material is chosen to test its strength and its impact behaviour in low velocity impact. The main interest in this research is to compare the four different type of glass fibre in terms of stiffness, toughness and impact resistance subjected to changes of impact energy level. Finally, at the end of this research, conclusions can be drawn about the type of these materials which are safe to be implemented in inner structural applications as a replacement for existing materials (such as type S-glass and Kevlar) due to their high cost, materials availability and not environmental friendly.

1.3 Objectives of Study

The aim of the research is

1. To analyze the physical and mechanical properties of Kenaf/Flax B200 and Kenaf/Flax B150 epoxy hybrid composites.
2. To evaluate the thermal and dynamic mechanical properties of Kenaf/Flax B200 and Kenaf/Flax B150 epoxy hybrid composites.
3. To determine the low velocity impact properties and acoustic emission of Kenaf/Flax/Glass Fibre epoxy hybrid composites.
4. To analyse the post-impact properties of Kenaf/Flax/Glass Fibre epoxy hybrid composites using ultrasonic C-scan and compression after impact testing.

1.4 Scope and Limitation of the Study

The scope of this research is limited to the following:

1. The composites were fabricated using woven ply of kenaf, flax and glass fibre as reinforcement, and epoxy resin as the matrix.
2. The hybrid composites were prepared by conventional hand lay-up method with the ratio of 40% of fibre and 60% of matrix. Flax and kenaf fibres were laid up in the weight ratio 30:70, while glass fibre were

added after that in the weight ratio between the natural fibres is 50:50 for low velocity impact test.

3. This study focussed on the mechanical, thermal and physical properties of the biocomposites material which is the hybrid of kenaf and two types of flax fibres.
4. The research is continue deeper to determine the low velocity impact properties of hybridization between the synthetic fibre (glass fibre) and natural fibre (kenaf/flax); and the acoustic emission respond from the impact test.
5. The investigation on the post-impact properties of the impacted specimens is continued by using ultrasonic C-scan testing and compression after impact (CAI) testing. This material only limited to C-Scan observation method as the other non-destructive testing is not suitable to detect the damage on the specimens.

1.5 Thesis organization

This thesis is basically divided into 5 chapters. The first chapter has been discussed here thoroughly. The outlines of the following chapters are as follows:

Chapter 1: Background information on natural fibre and synthethic fibre, the problem statement, the objectives of the research, the scope and significants of the study and the organization of the thesis are presented.

Chapter 2: A literature review has been carried out in order to study the previous experimental and research studies on flax, kenaf and glass fibre. This chapter discussed about the materials and the previous mechanical, thermal and physical properties finding of kenaf/flax composites. This chapter also discussed on the low velocity impact properties and acoustic emission responds on impacted composites studies. Further explanation and finding of post impact study were discussed. Once the literature review is done, the appropriate methodology for the current research can be decided.

Chapter 3: The methodology of this research is discussed in detailed in this chapter. The first section provides the detailed of the material and matrix used in this research. The second section explains the preparation of the specimens, step by step from the fabrication to specimens cutting. The following section shows in detailed the specimens testing starting from mechanical test, physical test, thermal test, impact test, acoustic emission setting, ultrasonic C-scan specimens examination and compression after impact (CAI) testing.

Chapter 4: All of testing results obtained from the experimental are presented in this chapter which are results from mechanical test, thermal test, physical test, low velocity impact test, acoustic emission respond and the post impact properties of each tested specimens.

Chapter 5: The study is concluded and summarize in Chapter 5. Future recommendations are also proposed in this chapter.

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BIODATA OF STUDENT

The student was born at Tampin, Negeri Sembilan in September 1989. She obtained her secondary education in Sekolah Menengah Kebangsaan Tampin, Negeri Sembilan which is now known as Sekolah Menengah Tuanku Syed Idrus, Tampin, Negeri Sembilan. She sat for her SPM examination in 2006 which qualified her to pursue her higher education in the Matriculation College of Pahang (KMPh). In 2008, she got a certificate for the physical science programme from the college. After finishing her study in KMPh, she got an offer to further her study at the University Putra Malaysia (UPM) in the Aerospace Engineering programme. She obtained a Bachelor Degree in Aerospace Engineering in April 2012.

The student pursued her postgraduate studies in Master of Science (Aerospace Engineering) at UPM in September 2012. Throughout her master's programme, the author took several courses that would help her while doing her research. All the courses attended were to broaden her knowledge in the field. While doing her research, she also works as a part time tutor at UPM, and as a Mathematics and Sciences tuition teacher for secondary school students. During her Master's Programme, she submitted three papers to a conference and three papers to a journal. She obtained a Master of Science (Aerospace Engineering in January 2015. The student further continues her postgraduate studies in Degree of Doctor of Philosophy (Material Engineering) at UPM in February 2015. She obtained a Cumulative Grade Point Average (CGPA) of 4.00. During her PhD's Programme, she submitted several papers to conference and journal and also writes a book chapter. The detailed were listed on the following pages.

LIST OF PUBLICATIONS

Published

Razali, N., Sultan, M.T.H., Cardona, F. An Experimental Study of Non-Destructive Testing On Glass Fibre Reinforce Polymer after High Velocity Impact Event. IOP Conf. Series: Materials Science and Engineering 152 (2016) 012045, doi:10.1088/1757-899X/152/1/012045.

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Razali, N., Sultan, M.T.H., Jawaid, M., Shah, A.U.M., Safri, S.N.A. Mechanical Properties of Flax/Kenaf Hybrid Composites. Structural Health Monitoring System for Synthetic, Hybrid and Natural Fiber Composites pp 177-194, 2021.

Submitted

Razali, N., Sultan, M.T.H., Jawaid, M., Talib, A.R.A., Lee, S.H., Shah, A.U.M., Safri, **S.N.A.** “Thermogravimetric Analysis (TGA) and Dynamic Mechanical Analysis (DMA) of Flax/Kenaf Woven Reinforced Epoxy Hybrid Composites”

Workshop and Seminars

1. 2-Days Workshop On A Guide to Technical Computing With Matlab : Building Standalone Graphical User Interfaces Software Packages for Research with the Introduction to Simulink and Academics Publishing, *Main Computer Lab 3, Level 12, Wisma R & D Universiti Malaya,*17-18 January 2015 – Participant

2. Training on Research in Statistics, *Al- Farabi Seminar Room 2nd Floor, INSPEM,* 26 January 2015 – Participant.

3. Important of X-Ray Diffraction XRD, *Seminar Hall, Faculty of Engineering UPM,* 27 January 2015 – Participant.

4. Half Day Seminar on Fatigue & Durability Assessment, *Main Meeting Room, Level 4, Admin Building, Faculty of Engineering and Built Environment UKM,* 29 January 2015 –Participant.

5. Workshop on Dynamic Mechanical Analysis (DMA), *Meeting Room Institute Tropical Forestry and Forest Product (INTROP),* 11 March 2015 – Participant.

6. Two Days High Impact Journal Writing and Publishing Workshop, *Gallery Room, Faculty of Engineering UPM,* 3rd-4th June 2015 – Participant.

7. Global Aerospace Industry Outlook and Insight into Malaysia's Aerospace Initiative Talk, *Galleria 2, Faculty of Engineering UPM,* 2 March 2017 - Participant.

8. Composite Technology – Current and Future Trends, *Seminar Room Level 2 Faculty of Engineering UPM,* 16 March 2017 – Participant.

9. Time Management, *Auditorium Faculty of Engineering UPM*, 22 March 2017 – Participant.

10. International Workshop on Advanced Composites and Its Manufacturing, 10-13 April 2017 – Participant.

11. Free LabVIEW – Hands on Training, *Computer Laboratory H2.4 Faculty of Engineering UPM*, 7 September 2017.