UNIVERSITI PUTRA MALAYSIA

EXPERIMENTAL MODAL ANALYSIS OF COMPOSITE PLATES WITH LOW VELOCITY IMPACT DAMAGE

ELLYNA CHOK YEE LING

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By

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January 2018

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This research studies the dynamic characteristics change of kenaf/glass fiber hybrid composite under low velocity impact damage which can be used as an alternative for aircraft radome following the studies conducted by Haris (2014) and Jamal (2016) that proves the composite offers good dielectric and impact properties. The impact suffered by a composite will bring changes in dynamic characteristics. These changes can be used to assess the structural integrity, hence preventing catastrophic failure. Three materials (kenaf, glass and kenaf/glass fiber hybrid composites) were impacted beforehand with three impact levels (3, 6 and 9 Joules). The dynamic characteristics (natural frequency, damping and mode shapes) under vertically clamped and cantilevered boundary conditions for the materials are studied and compared. Experimental modal analysis is carried out with a roving hammer for 20 points on a $9.5 \times 11.5\,cm$ specimen and frequency response function (FRF) graphs are obtained to analyze the dynamic characteristics after curve fitting. In general, natural frequency decreases while damping increases with increasing damage level. Besides, cantilevered condition induced lower modes due to gravitational pull. Prior to damage, kenaf composite has highest damping due to its cellular structure that acts as a vibration absorber. To eliminate mass and geometrical effects on the materials, normalized modes are computed. It is found that glass fiber composite has highest frequency which corresponds to its high stiffness. Its frequency also decreases the most to a maximum of 35% when damage is induced, while kenaf suffered the least decrement at about 1 – 18%. It can be said that kenaf is useful in stalling damage progression; reducing effect of damage. This is proven when the percentage decrement of hybrid composite lies between the other two composites. The damping of glass fiber composite on the other hand increased significantly to a maximum of 38% upon impact. Using the threshold of 0.8 (ranging 0 to 1), modal assurance criterion (MAC) presented high correlation between two investigated modes; corresponds to the similar mode shapes obtained pre and post impact for all materials. This means that up to 9J impact damage, the structures can

maintain dynamic characteristics within 20% tolerance. This knowledge is vital for damage tolerance evaluation (DTE) which is normally conducted for aircraft parts. Hence, the hybrid composite can be utilized as radome due to its good dielectric, impact and dynamic characteristics.

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

ANALISIS MODAL EKSPERIMENTAL PLAT KOMPOSIT DENGAN IMPAK HALAJU RENDAH

Oleh

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Kajian ini mengkaji perubahan ciri dinamik komposit hibrid kenaf / gentian kaca di bawah impak halaju rendah yang boleh digunakan sebagai alternatif radome pesawat berikutan kajian yang dilakukan oleh Haris (2014) dan Jamal (2016) yang membuktikan komposit ini menawarkan sifat dielektrik dan impak yang baik. Kesan yang dialami oleh sesuatu komposit disertai perubahan pada ciri dinamik. Perubahan ini boleh digunakan untuk menilai integriti struktur, dengan itu mencegah kerosakan serius. Tiga bahan (komposit kenaf, kaca dan hybrid kenaf/kaca) telah diimpak dengan tiga tahap (3, 6 dan 9 Joule). Ciri-ciri dinamik (frekuensi semulajadi, redaman dan bentuk mod) di bawah kondisi menegak dan menjulur untuk ketiga-tiga jenis bahan telah dikaji dan dibandingkan. Analisis modal eksperimen dilakukan dengan tukul beralih untuk 20 posisi di atas spesimen berukuran $9.5 \times 11.5\ cm$ dan graf fungsi respon frekuensi (FRF) diperoleh untuk menganalisis ciri-ciri dinamik setelah proses penyesuaian lengkungan graf. Secara umumnya, frekuensi semulajadi menurun dan redaman meningkat dengan peningkatan tahap impak. Selain itu, kondisi menegak menghasilkan mod lebih rendah disebabkan tarikan graviti. Sebelum kerosakan, komposit kenaf mempunyai redaman tertinggi kerana struktur selularnya yang bertindak sebagai penyerap getaran. Untuk menghapuskan kesan jisim dan geometri, mod normal telah dikira. Komposit serat kaca mempunyai frekuensi tertinggi dan ia sepadan dengan kelenturan yang rendah. Frekuensinya juga berkurang paling banyak sehingga maksimum 35% apabila diimpak, sementara kenaf mengalami penurunan paling sedikit sekitar 1 - 18%. Ia boleh dikatakan bahawa kenaf berguna dalam melambatkan proses kerosakan. Ini terbukti apabila peratusan penurunan komposit hibrid terletak di antara dua komposit yang lain. Redaman komposit serat kaca meningkat dengan ketara sebanyak 38% apabila impak dikenakan. Dengan menggunakan ambang 0.8 (antara 0 hingga 1), kriteria jaminan modal (MAC) memberikan korelasi yang tinggi antara dua mod yang disiasat; sesuai dengan bentuk mod yang serupa yang diperolehi sebelum dan selepas impak untuk semua bahan. Ini bermakna sehingga kerosakan kesan 9J, struktur dapat

mengekalkan ciri dinamik dalam toleransi 20%. Pengetahuan ini penting untuk penilaian kerosakan toleransi (DTE) yang biasanya dilakukan untuk bahagian pesawat. Oleh itu, komposit hibrid boleh digunakan sebagai radome kerana ciri-ciri dielektrik, impak dan dinamiknya yang baik.

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TABLE OF CONTENTS

		Page
ABSTRACT		i
ABSTRAK		iii
ACKNOWLEDGEMENT		v
APPROVAL		vi
DECLARATION		viii
LIST OF TABLES		xii
LIST OF FIGURES		xiii
LIST OF ABBREVIATIONS		xvi

CHAPTER

1	**INTRODUCTION**	1
	1.1 Background	1
	1.2 Problem Statement	3
	1.3 Objectives of Research	3
	1.4 Scope of Research	4
	1.5 Thesis Outline	4
2	**LITERATURE REVIEW**	5
	2.1 Aircraft Radome	5
	2.2 Fiber Reinforced Composites	6
	2.2.1 Kenaf Fibers	8
	2.2.2 Glass Fibers	11
	2.2.3 Hybrid Composite	12
	2.3 Low Velocity Impact Studies	14
	2.3.1 Effect of Damage on a Structure	18
	2.4 Reviews on Preceding Studies	20
	2.5 Experimental Modal Analysis (EMA)	21
	2.5.1 Basics of Vibration	21
	2.5.2 Principles of Modal Testing	26
	2.5.3 Modal Testing Studies	28
	2.6 Dynamic Behaviors of Impact Damaged Materials	29
	2.6.1 Damping Properties of Fiber Reinforced Composite	31
	2.7 Modal Assurance Criterion (MAC)	32
	2.8 Failure Modes	35

3	**RESEARCH METHODOLOGY**		38
	3.1	Experimental Setup	38
	3.2	Materials	38
	3.3	Data Acquisition System	41
	3.4	Modal Testing Setup	44
	3.5	Clamping Condition	46
	3.6	Modal Parameters Extraction Procedure	47
	3.7	Test Sample Description	51
	3.8	Modal Assurance Criterion (MAC)	52
4	**RESULTS AND DISCUSSION**		55
	4.1	Frequency Response Function (FRF) and Coherence	55
	4.2	Dynamic Properties of Undamaged Specimens	59
		4.2.1 Natural Frequency	59
		4.2.2 Damping Ratio	63
		4.2.3 Mode Shapes	64
	4.3	Effect of Damage on Natural Frequency	65
	4.4	Effect of Damage on Damping Ratio	75
	4.5	Effect of Damage on Mode Shape	79
	4.6	Modal Assurance Criterion (MAC)	81
	4.7	Microstructural Analysis	84
		4.7.1 Kenaf fiber composites	86
		4.7.2 Glass fiber composites	88
		4.7.3 Kenaf/glass fiber composites	90
5	**CONCLUSIONS AND RECOMMENDATIONS**		93
	5.1	Conclusions	93
		5.1.1 Modal Properties of Undamaged Kenaf, Glass fiber and Kenaf/Glass fiber composites	93
		5.1.2 Effect of Damage on Modal Properties of a Material	93
		5.1.3 Failure Modes	94
	5.2	Recommendations for Future Work	95
REFERENCES			96
APPENDICES			107
BIODATA OF STUDENT			110
LIST OF PUBLICATIONS			111

LIST OF TABLES

Table		Page
2.1	Properties of selected of selected natural fibres (Akil et al 2011, Dayakar 2015)	8
2.2	Impact damage sources and location affected on an aircraft (Kim et al. 2012)	15
2.3	Material characterization (Haris, 2014)	20
2.4	Average peak force for all materials at 3 impact levels	21
2.5	Selected fiber reinforced composite and their respective damping ratios	32
2.6	Description of damage mode (Kim and Kedward, 2000; Kim et al., 2003)	35
3.1	Specimen impacted at different levels (Jamal, 2016)	40
3.2	Components used for EMA	41
3.3	Selected specifications for impact hammer and accelerometer	43
4.1	Mechanical and physical properties of all three materials (Jamal, 2016)	59
4.2	Natural frequency for all three undamaged materials under two boundary conditions	60
4.3	Damping ratio for all three undamaged materials under two boundary conditions	63
4.4	Natural frequency for Kenaf composite	70
4.5	Natural frequency for Glass fiber composite	70
4.6	Natural frequency for Kenaf/Glass fiber composite	70
4.7	Slopes of curves obtained through normalized frequency	74
4.8	Averaged damping ratio for all composites under two different boundary conditions	75
4.9	Typical mode shapes obtained for Kenaf composite	79
4.10	Typical mode shapes obtained for Glass fiber composite	80
4.11	Typical mode shapes obtained for Kenaf/ Glass fiber composite	80
4.12	MAC values categorization (Cherif et al., 2011)	81

LIST OF FIGURES

Figure		Page
2.1	(a) sandwich with honeycomb core (b) A-type sandwich with foam core	6
2.2	Simplified structures of kenaf plant	8
2.3	(a) transverse section of core fiber (b) transverse section of bark fiber (c) longitudinal section of core fiber (d) longitudinal section of bark fiber (Adapted from Khalil et al. 2010)	9
2.4	Cross sectional view of an untreated kenaf fiber filament (Adapted from Kim et al. 2011)	9
2.5	Classification of glass fibers	11
2.6	Examples of hybrid composites (a) sandwich (b) interlayer (c) intralayer (d) uniformly mixed	13
2.7	Examples of (a) matrix cracking (Guedes and Moua, 2012) (b) fiber breakage (Periasamy and Hariharasubramanian, 2012) (c) delamination	16
2.8	Tension and compression strength reduction after impact damage	17
2.9	Simplified diagram for (a) spring mass and (b)spring mass with damper system	22
2.10	Four categories of damping (Adapted from Clay,2017)	24
2.11	Simplified 2 DoF system	24
2.12	FRF flow representation	26
2.13	Typical FRF plot	26
2.14	Summation of resonance curves	27
2.15	Simplified impact hammer setup (Adapted from Schwarz & Richardson, 1999)	27
2.16	3D MAC plot (Adapted from Vancher et al. 2010)	34
2.17	Representation of orthogonal modes (Adapted from Aspencore, 2017)	34
2.18	Phase shift representation (Adapted from Sengpiel, 2017)	34
2.19	Damage mode progression model	35
2.20	Fracture modes for carbon fiber aluminium laminates (Yu et al. 2015)	36
3.1	Flowchart of experimental work	39
3.2	Fiber lay-up of hybrid kenaf/glass fiber composite	40
3.3	Accelerometer	42
3.4	Miniature impact hammer	42
3.5	6-Channels FFT Analyser	43
3.6	Calibration exciter used to calibrate accelerometer	44
3.7	Setup for modal testing	44
3.8	Actual setup for EMA	45
3.9	Example of (a) an accepted FRF graph and (b) a rejected FRF graph	45

3.10	(a) Clamping jig for cantilevered structure (b) Clamping jig for vertically clamped structure	46
3.11	Testing procedure of experimental work	47
3.12	Configuration setup of Pulse Labshop MTC Hammer Modal Testing	48
3.13	Interface of Pulse Labshop MTC Hammer Modal Testing	48
3.14	Typical FRF plot of response measurement	49
3.15	Typical curve fitted FRF plot of response measurement	49
3.16	Typical coherence function of response measurement	50
3.17	Interface of ME'Scope VES software	50
3.18	Geometry of specimen tested	51
3.19	Meshing of specimen	52
3.20	Points are assigned to impact hammer and one point is assigned to accelerometer	52
3.21	Example of 2D MAC plot	53
3.22	CrossMAC calculation using post processing software	54
4.1	Typical FRF plot with peak which indicate modes can be obtained through sample of kenaf composite	55
4.2	(a) Typical FRF graph and (b) Coherence graph for Kenaf fiber composite	56
4.3	(a) Typical FRF graph and (b) Coherence graph for Glass fiber composite	57
4.4	(a) Typical FRF graph and (b) Coherence graph for hybrid Kenaf/Glass Fiber composite	58
4.5	FRF overlay of undamaged materials for vertical clamping	60
4.6	FRF overlay of undamaged materials for cantilevered	61
4.7	FRF overlay of cantilevered and vertical clamping for undamaged kenaf composite	61
4.8	FRF overlay of cantilevered and vertical clamping for glass fiber undamaged composite	62
4.9	FRF overlay of cantilevered and vertical clamping for undamaged kenaf/glass fiber composite	62
4.10	Typical mode shapes for undamaged composites	64
4.11	Effect of impact damage to natural frequency for vertically clamped and cantilevered conditions	65
4.12	FRF overlay of kenaf composite for vertically clamped condition with different impact damage level	66
4.13	FRF overlay of glass fiber composite for vertically clamped condition with different impact damage level	67
4.14	FRF overlay of kenaf/glass fiber composite for vertically clamped condition with different impact damage level	67
4.15	FRF overlay of kenaf composite for cantilevered condition with different impact damage level	68
4.16	FRF overlay of glass fiber composite for cantilevered condition with different impact damage level	68
4.17	FRF overlay of kenaf/glass fiber composite for cantilevered condition with different impact damage level	69
4.18	Percentage decrements of natural frequency from undamaged state to damaged states for cantilever condition	71

4.19	Percentage decrements of natural frequency from undamaged state to damaged states for vertical condition	72
4.20	Normalized frequency for the three materials under cantilevered and vertically clamped boundary condition	73
4.21	Damping ratio of all composites at two different boundary conditions	76
4.22	Percentage increment of damping ratio for all materials after impact damage under cantilevered condition	77
4.23	Percentage increment of damping ratio for all materials after impact damage under vertically clamped condition	78
4.24	CrossMAC value for (a) Kenaf composite (b) Glass fiber composite (c) Kenaf/Glass fiber composites	82
4.25	Residual strength curve (Adapted from Fawcett, 2006)	84
4.26	Typical SEM observation of impact damaged kenaf composite (surface/top view)	84
4.27	Typical SEM observation of impact damaged glass fiber composite (surface/top view)	85
4.28	Typical SEM observation of impact damaged kenaf/glass fiber composite (surface/top view)	85
4.29	Failure modes for 3J impact damaged kenaf fiber composite (cross section)	86
4.30	Failure modes for 6J impact damaged kenaf fiber composite (cross section)	87
4.31	Failure modes for 9J impact damaged kenaf fiber composite (cross section)	88
4.32	Failure modes of 3J impact damaged glass fiber composites (cross section)	89
4.33	Failure modes of 6J impact damaged glass fiber composites (cross section)	89
4.34	Failure modes of 9J impact damaged glass fiber composites (cross section)	89
4.35	Failure modes of 3J impact damaged kenaf/glass fiber composites(cross section)	90
4.36	Failure modes of 6J impact damaged kenaf/glass fiber composites (cross section)	91
4.37	Failure modes of 9J impact damaged kenaf/glass fiber composites (cross section)	91

LIST OF ABBREVIATIONS

1B	1^{st} Bending
1T	1^{st} Torsion
2B	2^{nd} Bending
2T	2^{nd} Torsion
AR	Aspect Ratio
BVID	Barely Visible Impact Damage
CL	Cantilevered Boundary Condition
DoF	Degree of Freedom
EMA	Experimental Modal Analysis
FFT	Fast Fourier Transform
FRF	Frequency Response Function
GF	Glass Fiber Composites
KF	Kenaf Fiber Composites
KGF	Kenaf/Glass Fiber Composites
MAC	Modal Assurance Criterion
VC	Vertically Clamped Boundary Condition

CHAPTER 1

INTRODUCTION

1.1 Background

Owning to their comparable high mechanical properties, natural fibers, especially kenaf fibers had been suggested to replace highly hazardous synthetic fibers like glass fibers in used for structural loads. However, it is studied that the kenaf fibers are unable to fully replaced glass fibers as the mechanical properties difference between the two fibers are very high. This is why a lot of research works nowadays focused more on the hybridization of natural and synthetic fibers (Jawaid et al, 2011; Berhan et al, 2015; Ghani et al, 2012; Sharba et al, 2015). Hybridization is initiated from the purpose of maintaining the advantages of the two fibers and alleviates some of the disadvantages. Hence, the idea of hybridizing kenaf fiber with glass fiber is believed to be helpful in reducing the hazard issued brought from glass fiber, and also enhancing the mechanical properties of kenaf fibers through the aid of glass fiber. Since then, a lot of researches were carried out to investigate the mechanical properties of the hybrid material. According to these studies, while non-hybrid composites exhibit highest or lowest mechanical properties, the hybrid composites lies in between, depending on the reinforcement fibers ratio (Faruk et al. 2012). This is generally referred as the rule of mixture. Even though hybrid composite is less likely to exhibit the highest material properties, it is always considered in order to tailor the material to the exact needs of the structure under design. These needs revolve around the cost and weight factors, and also the biodegradability of material.

However, impact damage can act as a limitation to the composites' widespread application in the field. Unlike metal structures that are able to absorb large amount of energy, composites can fail in a wide variety of modes and the structural integrity of the component would be reduced severely (Richardson and Wisheart, 1996). Aircraft for instance may be exposed to a number of events that can cause impact damage with majority of the events involve low velocity impact damage. Being the most fore part of an aircraft, the radome is then expected to suffer most of the impact damages in service.

In general, radomes are made of materials with low dielectric constant (Crone et al. 1981), this is to ensure that the electromagnetic wave can travel through it. Haris (2011) had explored the potential of implementing natural fibers as a radome structure as the material is found to be possessing good dielectric properties. According to Lang (1994), the radome is susceptible to impact that come in various forms: high velocity rain, lightning strikes, rain erosion, static electricity or freeze/thaw cycle. Military Standard (MIL-STD-7705B) had also declared that the radome needs to be able to withstand fracture, delamination and degradation when subjected to the impact damages. This had driven the study conducted by Jamal (2016) where the author conducted a study on the impact damage analysis of a composite structure. The main findings of the study will be featured in Chapter 2. The studies conducted by Haris (2011) and Jamal (2016) had encouraged this study to be carried out in order to examine the feasibility of natural fibers to be implemented into aircraft radome. It is important to note that this study is the continuation work of the two mentioned studies.

Radome can also suffer damage from the dropped tools during maintenance routine and in service impacts by foreign objects or debris that can introduce out of plane impact on it. These induced damages existed through the mixture of matrix cracking, fiber breakage and delamination. Among these failure modes, delamination is said to be the most severe as it may reduce the stiffness and strength of the composites significantly (Perez et al., 2013). Kreculj and Rasuo (2013) had also mentioned that the compressive strength of a material will decrease significantly as a response to impact damage. Sharing the same conclusion are: Davies et al. (1996) who studied the residual strength of woven fabric glass polyester laminates and Ortega and Robles (2016) who tested on the residual life of concrete structures post corroded.

There are a few studies that analyzed the dynamic behavior of materials tested after being low velocity impact damaged. For instance, Shahdin et al (2009a), Perez et al (2011) and Nossol et al (2013) utilized carbon fiber to be the reinforcement of a composite. In these studies, it is concluded that the natural frequency tends to decrease with increasing impact level, while the damping increases with it. It is hence crucial to assess the changes in dynamic characteristics at early stage through accurate, time and cost effective tool so that the service life of the structure can be extended and the coincidence of resonant frequencies can be avoided. Vibration testing is one of the tools to investigate the damage without the need of knowing the exact location of damage. The concept of the test circulates on the physical and mechanical properties of a structure; namely the mass, stiffness and damping. The changes in these properties can be detected through the testing; hence indication of structural integrity can be obtained. The current work is a continuation study from previous works (Haris, 2011 and Jamal, 2016) in researching the low velocity impact damage properties of kenaf fiber to replace synthetic fiber in aircraft radome applications.

1.2 Problem Statement

It is apparent that the assessment of dynamic characteristics with impact damage is widely researched for synthetic fibers and the impact induced varied from low velocity, medium velocity and in ballistic form. However, most of the research works do not deliver comprehensive studies with all the modal parameters changes reported. The problem of illiteracy on the subject then surfaced.

Besides, there is also an absence in the post impact dynamic characteristics studies that involves natural fibers. Since the structural build of natural fibers can be helpful in vibration absorption characteristics, the dynamic behavior of the material should be explored in order to analyze its feasibility in various fields especially in aerospace sector. There are also no studies found on the effect of hybridizing natural fiber with synthetic fibers to the modal properties after being low velocity impact damaged.

Hence, this study is dedicated to study the effect of low velocity impact damage on the modal properties of a natural fiber, synthetic fiber and hybrid natural/synthetic fiber composites and investigate the difference in dynamic response between the materials. Besides, the modal parameters comparison of these materials without the effect of damage is also an interest. Last but not least, the correlation of undamaged and damaged structures from these composites is also to be investigated.

1.3 Objective of Research

The main objectives of the study conducted are as follows:

a.) To evaluate the modal properties of undamaged Kenaf, Glass, and hybrid Kenaf/Glass Fiber composites.

b.) To determine the effect of damage on material and to compare the dynamic characteristics of Kenaf, Glass and hybrid Kenaf/Glass fiber composites at energy level of 3, 6 and 9 J for cantilevered and vertically clamped boundary conditions.

c.) To correlate the effect of damage on modal properties to a material through Modal Assurance Criterion (MAC).

1.4 Scope of Research

The scope of work to achieve the objectives stated above is summarized as follows:

1. Frequency range to conduct EMA is set within the range of 0 – 800 Hz. The range is set to a maximum of 800Hz as the range is sufficient to be used to capture the required mode shapes.
2. Application of experimental modal analysis on cantilevered and vertical clamping conditions. Vertical clamping is normally applied when studying the dynamic characteristics of a structure. However, cantilevered condition is also tested in this study in order to imitate the real situation of a structure. For instance, the wing of an aircraft is of cantilevered condition. Hence, the boundary condition is essential to be studied in order to assess the damage of a structure realistically.
3. The dimensions for all specimens are controlled to the flat plate geometry of $10\ cm \times 15\ cm$ (width × length). The geometry and the usage of flat plate to represent the curved structure of radome are done so to comply with the ASTM standard used (D7136) to assess impact damage on a composite structure. Since the structure is to be tested for impact damage, the flat plate should be used as recommended by the mentioned standard.
4. All three materials are of aspect ratio of 1.2. This is determined from setting $2.5\ cm$ from the specimen length to be clamped to a clamping jig.
5. Data collected are to be processed through post processing software and the comparison with respect to materials and impact level can then be established. This allows the comparison of materials to be done.
6. The differences in all modal properties pre and post impact damage are also to be determined so that the effect of impact damage on a structure can be analyzed.

1.5 Thesis Outline

This thesis comprises of a total of five chapters. Chapter 2 highlights the previous studies done and also the background of modal testing alongside some discussion on fiber reinforced composites. The next chapter features the methodology which will describe the experimental setup and method of extracting data to be analyzed. Chapter 4 will present the results for the modal testing and the outputs are then discussed alongside some justifications and reasoning. Finally, conclusions will be drawn in Chapter 5 alongside the possible future works.

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