UNIVERSITI PUTRA MALAYSIA

VALIDATION OF LOW VELOCITY IMPACT ON A BIOCOMPOSITE FLAT PLATE LAMINATES

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By

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

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Chair: Dayang Laila Binti Abang Abdul Majid, PhD
Faculty: Engineering

Impact analysis under low velocity was carried out on flat plate structure at normal and oblique impact with energy level of 3J to 9J with interval of 3J. Utilization of natural fiber reinforced with polymer and hybridizing it with synthetic fiber were introduced. The aim of the study was to assess the effects of low velocity impact on biocomposite structure composed of chopped strand mat (CSM) glass fiber, kenaf fiber and hybrid of both materials and epoxy as resin material. Drop weight impact test of flat plate structure and determination of mechanical characterization were carried out with samples prepared under vacuum infusion method for glass/epoxy, kenaf/epoxy and hybrid composites composed of those two material. Glass/epoxy composites exhibit better mechanical properties as compared to kenaf/epoxy composites. From the experimental work, it was found that the impact energy level influenced the impact peak force proportionately. Hybrid composites generates damage propagation with combination of damage propagation from individual fiber of glass and kenaf reinforced polymer. The severity of damage was high at higher impact energy although significant damage at impact energy of 3J was detected under drop weight impact test where internal damage on all three configurations had occurred which further suggested reduction in residual strength. Finite element analysis was then carried out for flat plate model of all three configurations and validated against the experimental work. It was found that validation on all configurations meet the agreement with experimental results. Further finite element analysis considered all configuration based on the validation results for flat plate on oblique impact. The influence of impact angle was found to affect the maximum impact force of the impacted material where at higher impact energy the respond of maximum impact force was significant. However, there is slightly impact damage detected at lower impact energies under oblique impact.

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

KAJIAN ANALISIS MENGENAI PENGESAHAN IMPAK BERKELAJUAN RENDAH TERHADAP STRUKTUR PLAT RATA BIOKOMPOSIT

Oleh

QISTINA BINTI MOHD JAMAL

Disember 2016

Pengerusi: Dayang Laila Binti Abang Abdul Majid, PhD
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Satu kajian telah dijalanlan terhadap struktur plat rata terhadap analisis impak dalam kelajuan minima secara menegak dan serong berbekalkan tenaga impak antara 3J hingga 9J. Penggunaan campuran antara serat gentian asli dan serat sintetik diperkenalkan dalam penyelidikan ini. Tujuan kajian ini dijalankan bagi mengenalpasti kesan penggunaan gentian asli yang terdiri daripada serat kenaf dan serat sintektik terdiri daripada gentian kaca dengan bahan pengukuhan epoksi terhadap analisis impak berkadar kelajuan minima. Eksperimen impak dan eksperimen perincian terhadap sifat mekanikal bahan telah dijalankan dengan penyedian sampel seperti gentian kaca , serat kenaf dan epoksi melalui proses infusi vacuum. Komposit gentian kaca menunjukkan kelebihan melalui eksperimen perincian terhadap sifat mekanikal bahan berbanding komposit yang terdiri daripada serat kenaf. Kepentingan perincian terhadap sifat mekanikal bahan diketengahkan oleh kerana penggunaan hasil dapatan digunakan untuk analisis berangka. Melalui eksperimen impak, hubungan antara tahap tenaga impak berkadar terus dengan daya maksimum impak. Hibrid komposit menunjukkan tahap kerosakan terhadap sampel merangkumi gabungan gentian kaca dan gentian serat kenaf berikutan hybrid komposit terdiri daripada gabungan dua bahan tersebut. Tahap kerosakan paling tinggi adalah pada sampel yang memiliki jumlah impak tenaga yang tinggi walaubagaimanapun pada sampel yang di impak pada jumlah tenaga yang paling rendah, kerosakan dapat dilihat telah terhasil melalui kerosakan di dalam sampel tersebut.

Kajian terhadap analisis impak berkelajuan rendah telah dijalankan melalui kaedah analisis berangka terhadap plat rata untuk ketiga-tiga konfigurasi komposit dan pengesahan dijalankan berdasarkan keputusan daripada hasil eksperimen. Hasil menunjukkan kesemua sampel memiliki keputusan yang hampir dengan hasil eksperimen. Kesan hasil analisis berangka dipengaruhi oleh ciri kerosakan yang terhasil daripada eksperimen pengenalpastian ciri bahan komposite yang digunakan. Evolusi kerosakan terhadap sampel

mengambil kira tenaga kerosakan yang diperolehi daripada hubungan antara ketegasan dengan sesaran dimana nilai tersebut diambik kira melalui luas bawah lengkung. Kajian terhadap analisis impak secara menegak dan serong dijalankan bagi struktur plat rata dengan impak tenaga 3J, 6J dan 9J. Sumber impak serong yang berdarjah mempengaruhi nilai daya impak maksimum terhadap sampel. Hasil kajian mendapati, impak serong memberikan nilai daya impak yang rendah berbanding impak menegak terhadap sampel.

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I certify that a Thesis Examination Committee has met on 20 December 2016 to conduct the final examination of Qistina binti Mohd Jamal on her thesis entitled "Validation of Low Velocity Impact on Biocomposite Flat Plate Laminates" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of 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:

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CHAPTER 1

INTRODUCTION

1.1 Background

Composite materials are well established in the application of aerospace, automotive and marine industry. Composite materials compromise of two or more dissimilar components either chemical or physical properties reinforced with plastics and results in greater properties than the individual component. They provide high specific strength and stiffness properties with the direction of fiber can be tailored into desired design for specific application compared to metallic material. Recently, attention has been focusing on utilizing biodegradable material for commercial purposes. The advantages of using natural fiber composite are low density, low cost, less harmful than conventional material and possess comparable specific strength and stiffness.

In aerospace, composite materials are prone to impact loading or damage due to low transverse and interlaminar shear strength, which may be subjected by dropping tools during the maintenance process or hit by the debris from a runaway. The low energy impact can be barely visible with naked eyes and potentially threatening that can induce structure failure when further loading applied. The damage that may be induce throughout the impact are matrix cracking, fibre fracture and delamination. Application of composite in aviation industry are widely used since 1970 based on evolution composite application at Airbus(Faivre & Morteau, 2011) and described forecast on annual aircraft composites structures requirement from 2011 till 2020(Red, 2012). An increase in the usage of composite in the commercial aircraft is due to high specific stiffness that can reduce in terms of weight of the aircraft hence saving in fuel consumption. An example in increase usage of composite materials in aircraft is the Boeing's 787 Dreamliner that uses up to 50% composite by total weight, as shown in Figure1.2

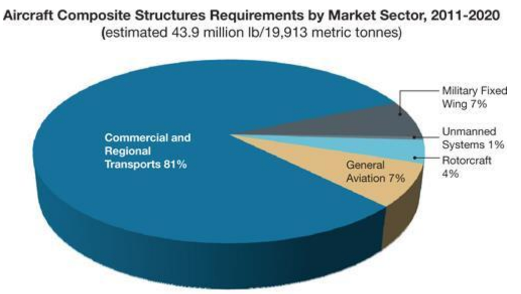

Figure 1.1: Average aircraft composite structures requirements by market sector from 2011-2020.
[Adapted from:(Red, 2012)]

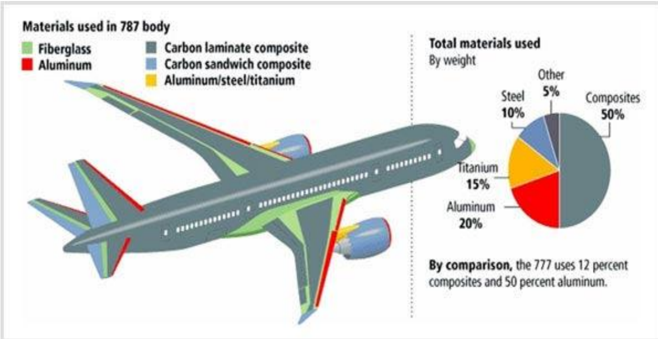

Figure 1.2: Composite materials in Boeing 787.
[Adapted from (Red, 2012)]

1.2 Natural fibers

Natural fiber composite can be defined as a component consisting either natural fiber as reinforcement or the usage of natural polymer or combination of both results in better properties than the individual material. Natural fibers can be classified as wood and non-wood (leaf, seed/fruits, stalk,stem and grass) fibers as in Table 1.1(John & Thomas, 2008; Mohanty, Misra, & Drzal, 2002)

Table 1.1 : Classification of natural fibers.
[Adapted from(John & Thomas, 2008; Mohanty et al., 2002)]

Non-wood	• Leaf -Abaca -Mauritius hemp -Sisal • Grass -Bagasse -Bamboo	• Bast/Stem -Jute -Hemp -Kenaf -Nettle -Roselle -Ramie	• Stalk -Straw(Cereal) • Seed/Fruits -Coir -Kapok -Sponge gourd -Oil palm
Wood	Soft and hardwood		

The structure of a natural fiber consists of cellulose, hemicellulose, lignin, pectin and waxes. Each different type of plants has its own cellulose content. The cellulose content for the plant determines the stiffness and tensile strength of the fibres(John & Thomas, 2008). (Biopolymers such as polysaccharides (starch,cellulose) proteins (collagen), polyesters (polyhydroxyalkanoates), liginin, and natural fibers are also highlighted in research as they provide as an alternative towards petroleum based matrix polymers. Natural fibres offer good thermal insulation, better electrical resistance and improved acoustic insulation(John & Thomas, 2008).

Attention towards the eco-friendly materials are due to the awareness on environmental problem and depletion of petroleum-based products. The utilization of natural resources may reduce the emission of carbon dioxide as the decomposition of natural fiber composite can curb greenhouse effects(Avella 2007; Holbery & Houston, 2006; Mohanty, Misra, & Drzal et al., 2002; Mohanty, Misra, & Drzal, 2012). There will be no presence of excess carbon dioxide in the atmosphere cause by combustion or decomposition(John & Thomas, 2008). A.K. Mohanty et al (2002) revised that around 10-11 million of vehicle which 96% are cars being scrapped in the United States. From this action, about 25% of the materials are from plastics waste that could not be decompose hence contribute to the environmental problems. The decrease of reliance on petroleum based products has created a demand and need for development of bio based composite. European legislation is enforcing law on employing biodegradable material to the manufacturers to reduce the dependency towards petroleum based products. Table 1.2 showed an example of implementation of natural fibers composite in the automotive applications(Holbery & Houston, 2006).

Table 1.2: Application of natural fiber in automotive.
[Adapted from(Holbery & Houston, 2006)]

Manufacturers	**Parts**	**Material**
Honda	Floor area of Pilot SUV	Wood fiber
General Motors	Door panel	Mixture of kenaf and flax fiber
	Package tray	
	Seat backs	Wood fiber
	Floor cargo area	
Ford	Sliding door	
Findlay Industries	Headliners	Hemp,flax,kenaf and sisal mixture
	Body panels	Soy-resin

1.3 Airborne radome

Radomes are defined as a structure that is transparent to electromagnetic waves and at the same time serve to protect the antenna from damage and environmental conditions(Cary, 1983). Radomes are being utilize for certain application such as weather radar, air traffic control, satellite communications, and telemetry which can be construct into several shapes according to Figure 1.3and Figure 1.4(Croatia, 2015; “Ground Radome,” 2014)

Figure 1.3: The caribou radome.
[Adapted from:(“Ground Radome,” 2014)]

Figure 1.4: The shipboard radome installation.
[Adapted from:(Croatia, 2015)]

The airborne radomes are usually constructed in a hemispherical shape. For the selection type of the radome, under reliability section in MIL-R-7705B the radome may provide a service life of at least 500 flight hours specific for disposable radome or the radome require to function at its maximum service life with least of maintenance. The radomes may encounter impacts from high velocity rain, rain erosion,freeze-thaw cycle, single/multiple impacts, lightning strikes and static electricity(Lang, 1994). Based on MIL-STD-7705B, under sub chapter ‘requirement in considering performance of the radome by the environment requirement’ state that the radome need to withstand delamination, fracture and degradation when subjected to rain impact, rain erosion, hail impact and atmospheric electricity as in Figure 1.6and Figure 1.5(Alves, 2015).

Figure 1.6: Rain erosion testing.
[Adapted from:(Alves, 2015)]

Figure 1.5: Hail impact.
[Adapted from:(Alves, 2015)]

Generally, radomes are made of dielectric material and the existing material that made up the aircraft radome is fiberglass type-E which is classified under electrical insulation that is suitable for the radome application. Due to its concern in maintaining the electrical performance to be function efficiently, natural fibers show an improvement in low dielectric constant than the existing material. The polarizability of a material determines its dielectric constant especially in hydrophilic material. Upon the increase in the polarizability of a material, the dielectric constant will increase(Pathania & Singh, 2009). The importance in having a low dielectric constant is due to minimize the reflection so that to reduce insertion loss and the impact of radiation pattern.

Potential of implementing natural fibers as a radome structure due to its low dielectric strength found by Mohd Haris(2014) encourage this research to be carried out in determining its sustainability to withstand impact. Hence, in current study, low velocity impact of biocomposite flat plate specimens will be carried out since considering the implementation of the material towards radome rather than focusing on the impact of the geometrical structure. Kenaf fiber will be used as the reinforcement material with combination of glass fiber E-type. Throughout this research, numerical analysis will be utilized in considering normal impact validated with experimental drop weight impact test

1.4 Problem Statement

Composite structures are susceptible to impact damage due to its low transverse strength. The factors that affecting impact resistance or impact damage are due to types of fibre, types of matrix, types of impactor, stacking sequence, fiber orientation, temperature, volume of fibre/matrix loading and geometry of specimen impacted(Abrate, 2005; Cantwell & Morton, 1989; Dhakal, Zhang, Bennett, & Reis, 2012; Gupta & Velmurugany, 2002; Reid & Zhou, 2000; Richardson & Wisheart, 1996). Impacted structure under low velocity impact may cause a reduction on the impact strength. The importance of determining low velocity impact was due to detect the damage tolerance of the composite structure. The internal damage that is barely visible will induce the structure to fail with constant applied load. Implementation of natural fiber composite as an alternative to synthetic fibers is widely researched upon. The current research work is a continuation from Mohd Haris (2014) whereby the results showed a potential in utilizing hybrid of kenaf fiber and glass fiber reinforced with epoxy for aitrcraft radome considered determination its material characterization and impact strength under quasi static analysis. Meanwhile in this research, the importance of low velocity impact was considered due to determination on the sustainability of the materials in resisting low velocity impact damage. A lot of studies have been carried out on low velocity impact of composite with natural fiber or conventional fiber but there is little attention investigating low velocity impact of natural fiber composites and hybrid with synthetic fiber, which is a potential material for aircraft radome. Most of the studies have been carried out on flat plat structures with synthetic fibers(Dhakal, Skrifvars, Adekunle, & Zhang, 2014; Dhakal et al., 2012; Dhakal, Zhang, Richardson, & Errajhi, 2006; Ismail & Hassan, 2014; Srinivasa & Bharath, 2011). In this research, impact energy of 3J to 9J with interval of 3J which are in the range of low velocity impact will be applied and kenaf fiber is an alternative in replacing Nomex honeycomb core which is the existing core material of the radome. Even though sandwich structure give good performance in improving stability and lightweight material but solid laminate provides better resistance to damage and damage tolerance(Abrate, 2005). Although solid laminate is heavier but then with the advantage of kenaf fiber which is low density may be one of the solution in providing a greener radome material.

1.5 Aims and Objectives of the Study

The objectives of the study are as follows:

1. To investigate low velocity impact under drop weight impact tester with energy levels of 3J, 6J and 9J for glass/epoxy, kenaf/epoxy and hybrid kenaf-glass/epoxy laminates.
2. To carry out low velocity impact simulation under Abaqus/Explicit with validation of experimental results with energy levels of 3J, 6J and 9J for glass/epoxy, kenaf/epoxy and hybrid kenaf-glass/epoxy laminates.

3. To carry out low velocity oblique impact simulation with oblique angles of 15°, 30° and 45° with energy levels of 3J, 6J and 9J for glass/epoxy, kenaf/epoxy and hybrid kenaf-glass/epoxy laminates.

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BIODATA OF STUDENT

Qistina Mohd Jamal is currently a postgraduate students under Master of Science in aerospace engineering. Previously in undergraduates was receiving Bachelor of Engineering(Aerospace) at Universiti Putra Malaysia. The final year project handled before was quasi static analysis of a biocomposites aircraft radome was continued in this study in impact under low velocity determining for selected composites materials utilized in the aircraft radome both in experimental and numerical analysis.

During the undergrad studies, soft skills were built by joining student organization community such as Aeros Club which comes under department of aerospace engineering Universiti Putra Malaysia. It is an opportunity in gaining leadership and communication skills throughout the participation. During receiving intership under Malaysia Airlines Berhad, it helped gained insight in the technical and administrative programmes throughout the courses given for about 10 weeks in exploring works under engineering sector.

Throughout this postgraduate programme, participation under university programme helps to improve the soft skills especially joining the conference and seminars. Patience and resilient in working under research were acknowledge throughout the semester and its and opportunity gaining knowledge in this field of study.

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