UNIVERSITI PUTRA MALAYSIA

***MOULD DESIGN AND CHARACTERIZATION OF KENAF FIBER HONEYCOMB CORE- REINFORCED EPOXY COMPOSITES FOR AEROSPACE APPLICATIONS***

NOR HAFIZAH BINTI MANAN

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By

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

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**December 2017**

**Chairman : Dayang Laila Binti Abang Haji Abdul Majid, PhD**
**Faculty : Engineering**

Sandwich structures with honeycomb core are known to significantly improve stiffness at lower weight and possess high flexural rigidity. These structures are found wide applications in aerospace as part of the primary structures as well as the interior paneling and flooring. High performance aluminum and aramid are typical material used for the purpose of honeycomb core whereas in addition to other industries, other materials such as fiber glass, carbon fiber, Nomex, and also Kevlar reinforced with polymer are used. Recently, growing interest in developing composite structures with natural fiber reinforcement has also spurred research in natural fiber honeycomb material. The performances of honeycomb cores are dictated by cell size, wall thickness and core thickness. In term of research purposes, it has been reported that the honeycomb core are fabricated using single core mould however, the mould is not specifically for aerospace application. In this work, a single core mould for honeycomb core is designed and fabricated as per aerospace standard. In terms of fiber direction, the majority of the previous works have generally emphasized on the usage of random chopped fiber and few are reported on development of honeycomb structure using unidirectional fiber as the reinforcement. This is mainly due to its processing difficulties which usually involve several stages to account for the arrangement of fibers and curing. In this work, honeycomb cores of neat epoxy, random chopped strand kenaf/epoxy and unidirectional kenaf/epoxy are introduced and their mechanical properties are compared in term of tensile test, edgewise compression test, flatwise compression test, and flexural test. In order to compare the performances of honeycomb in term of fiber orientations, the density and volume fraction are ensured to be the same for all samples.

From the result, the coupon specimen of unidirectional kenaf/epoxy has high tensile strength which is 43.18% more than random kenaf/epoxy. In comparing between honeycomb core biocomposites, the honeycomb core of random kenaf/epoxy is

superior to unidirectional kenaf/fiber in term of edgewise compressive strength, flatwise compressive strength and flexural strength which is 21%, 17.7%, and 88.67% respectively. Failure modes analysis shows that unidirectional kenaf fiber suffer fiber breakage, fiber pulled out, obvious stress lines, matrix cracking, cohesion failure and fiber buckling. However, in random kenaf fiber the fracture modes are defined only by fiber breakage, fiber splitting, obvious stress lines, fiber pulled out and compaction.

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

**REKABENTUK ACUAN DAN PERCIRIAN TERAS SARANG LEBAH DARI SERAT KENAF YANG DIPERKUAT DENGAN EPOKSI UNTUK APLIKASI AEROANGKASA**

Oleh

**NOR HAFIZAH BINTI MANAN**

**Disember 2017**

**Pengerusi : Dayang Laila Binti Abang Haji Abdul Majid, PhD**
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Struktur sandwic dengan teras sarang lebah sangat dikenali dengan keupayaannya untuk mengukuhkan sesuatu benda dengan berat yang ringan dan mempunyai ketegaran lenturan yang tinggi. Struktur ini juga diaplikasikan secara meluas dalam aeroangkasa sebagai sebahagian daripada struktur utama serta panel dalaman dan lantai. Aluminium dan aramid adalah bahan yang biasa digunakan untuk membuat teras sarang lebah dalam industri aeroangkasa manakala tambahan kepada industri-industri lain, bahan seperti gentian kaca, gentian karbon, Nomex dan Kevlar yang diperkuat dengan polimer juga digunakan. Kebelakangan ini, kemajuan penyelidikan struktur komposit yang diperkuatkan dengan serat semula jadi telah mendorong kepada penyelidikan dalam membina teras sarang lebah dari komposit serat semula jadi. Prestasi teras sarang lebah ditentukan oleh saiz sel, ketebalan dinding dan ketebalan teras. Dari segi penyelidikan, telah dilaporkan bahawa inti sarang lebah direka dengan menggunakan acuan teras tunggal namun tidak khusus untuk aplikasi aeroangkasa. Dalam tugasan ini, acuan teras tunggal untuk teras sarang lebah telah direka dan dibuat mengikut piawaian aeroangkasa. Dari segi arah gentian, majoriti karya-karya terdahulu secara amnya menekankan penggunaan gentian secara rawak dan kurang laporan mengenai pembangunan struktur sarang lebah dengan menggunakan gentian satu arah sebagai tetulang. Hal ini kerana kesukaran membuat struktur tersebut yang kebiasaannya melibatkan beberapa peringkat proses yang melibatkan penyusunan dan penyembuhan gentian. Dalam kajian ini, teras sarang lebah daripada epoxy, gentian kenaf satu arah dan juga gentian kenaf secara rawak diperkenalkan dan sifat mekanikal kesemua teras ini dibandingkan dari segi mampatan dari atas, mampatan dari sisi dan juga lenturan. Untuk membandingkan prestasi sarang lebah dari segi orientasi serat, ketumpatan dan pecahan isipadu dipastikan sama untuk semua sampel.

Dari keputusan yang diperolehi, spesimen kupon dari kenaf/epoksi satu arah mempunyai kekuatan tegangan yang 43.18% lebih daripada kenaf/epoksi rawak. Dalam membandingkan antara sarang lebah biokomposit, teras sarang lebah kenaf rawak/epoksi adalah lebih tinggi dengan kenaf satu arah/epoksi dalam kekuatan mampatan sisi, kekuatan mampatan rata dan kekuatan lentur yang masing-masing adalah 21%, 17.7% dan 88.67%. Analisa mod kegagalan menunjukkan bahawa serat kenaf satu arah mengalami kerosakan serat, serat yang ditarik keluar, garis tekanan yang jelas, retakan matriks, kegagalan perpaduan dan tangkapan serat. Walaubagaimanapun, mod kegagalan dalam gentian kenaf secara rawak adalah kerosakan serat, pepecahan serat, garis tekanan yang jelas, serat ditarik keluar dan juga mampatan.

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I certify that a Thesis Examination Committee has met on 28 December 2017 to conduct the final examination of Nor Hafizah binti Manan on her thesis entitled "Mould Design and Characterization of Kenaf Fiber Honeycomb Core-Reinforced Epoxy Composites for Aerospace Applications" 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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| | |
|---|---|
| $t$ | Thickness |
| $P$ | Pressure |
| $L$ | Load |
| $A$ | Area |
| $\sigma$ | Stress |
| $\epsilon$ | Strain |
| $\Delta L$ | Change of length |
| $L_o$ | Initial length |
| $L$ | Support span |
| $b$ | Width of beam |
| $d$ | Depth of beam |
| $\epsilon_f$ | Flexural strain |
| $D$ | Maximum deflection |
| $d$ | Diameter |
| $\rho$ | Density |
| $M_a$ | Mass in air |
| $M_s$ | Mass in solvent |
| $W_f$ | Weight ratio of fiber |
| $W_m$ | Weight ratio of matrix |
| $w_f$ | Weight of fiber |
| $w_m$ | Weight of composite |
| $V_f$ | Volume fraction of fiber |
| $V_m$ | Volume fraction of matrix |
| $\rho_c$ | Density of composite |
| $\rho_f$ | Density of water |

# CHAPTER 1

# INTRODUCTION

## 1.1 Project background

In recent times, there is a wide exploitation of composite materials in aerospace industries and there is a wide exploitation of composite materials in aerospace industries, and the application of fiber reinforced polymer composites has been a focus. Aircraft original equipment manufacturers (OEMs) are continuously striving to make their products more fuel-efficient with enhanced engines and ever-increasing utilization of composite materials, including interiors such as seats, floor boards, bulkheads and cabin dividers, lavatories, galleys, wall and ceiling panels and stowage bins. Composites have long had a role in cabin finishes because of their strength to weight ratio and thus contribution to higher aircraft fuel efficiency. According to Shishoo (Shishoo & Consulting, 1998), carbon, glass, aramid, high modulus polyethylene and boron fibers are very common for composite reinforcement and they already gained a reputation due to their excellent properties such as lightweight, high strength to weight ratio and high thermal stability. In addition, they are also known as high-performance reinforcement besides they dominate the aerospace, leisure, automotive, construction and sporting industries. However, despite having excellent mechanical properties, the aforementioned composite reinforcement material also possess some drawbacks such as high cost, non-recyclable, non-biodegradable, high health risk when inhaled, high energy consumption and high density (Iqbal, Islam, Ananda, & Lau, 2014).

Therefore, the search for new high performance materials at affordable costs has been extended which is driven from the development of environmental awareness. Over the years, a large amount of research has been conducted on green and eco-friendly material. However, the fundamental research in regards to natural fiber composites has deepened only in recent years due to the increasing demand for the purpose of greater environmental protection. The natural fiber reinforced composites recently become high valuable materials because of their low cost as well as satisfactory mechanical properties, which makes them attractive due to the availability and renewability of raw materials. The uses of natural fibers as reinforcement in aircraft are no longer foreign to the current industry. Normally, natural fibers are used as reinforcing material or known as fillers for polymer based matrices (Al-oqla & Sapuan, 2014). They are renewable, cheap, completely or partially recyclable and biodegradable. Natural fibers are known to have the advantages of low density, high strength to weight ratio and most importantly, they are abundantly available and low cost as compared to synthetic fibers.

One of the basic interior materials used in aircraft which apply the usage of natural fibers is honeycomb cores. Honeycomb cores are man-made structure that resembles beehives structure. The main function of using this structure is to downplay the sum of material used and to reach minimum weight and minimum material cost in its manufacturing processes. In addition to have greater weight to volume ratio which contributes to higher cost saving, the honeycomb structure also has high strength characteristic that normally made by various metal and non-metal based materials. Honeycomb structure made up of Nomex and aluminum is no doubt has been widely used in aerospace industries. Normally, the most common materials used in manufacturing the honeycomb core are aluminum, fiberglass, carbon fiber, Nomex, and also Kevlar reinforced with polymer. Honeycomb core with reinforced polymer composites offer greater specific stiffness and strength properties in flexure compared to their monolithic counterparts (Stocchi, Colabella, Cisilino, & Álvarez, 2014). Taking into consideration the tremendous need and awareness of environmental impact, the interest to substitute synthetic material with biocomposites for honeycomb core has recently given higher priority in aircraft industry and for example, LSG Sky Chefs and Norduyn have invented the lightest in-flight trolleys and other extrusion profiles using polymer composites.

However, in order to manufacture biocomposites materials a lot of criteria need to be considered. For example, it is not easy to maintain the excellent fiber/matrix bonding in biocomposites, thus suitable treatment for natural fibers is different according to their types. Furthermore, it is important to keep natural fibers in proper storage so that it will not be degrade. Because of that, never ending research about biocomposites has been widely spread where researchers are racing to find outstanding outcomes involving materials from biocomposites.

Several methods to develop honeycomb core from natural fibers or known as honeycomb biocomposites were proposed when recent researches explored their potential applications in current industries. These methods are including corrugation method and one-step process using single core method. In both methods, the type of resin dictates the design of the mould. In order to use thermosetting resin, the mould used should ensure has no leaking so that it will be able to prevent the resin from flowing out while thermoplastics resin needs mould made up of material that can withstand their higher processing temperature. Natural fiber becomes potential application for honeycomb structures in current industries because their usage is endlessly increasing in applications such as aerospace, automotive, naval, packaging and construction industries (Rejab & Cantwell, 2013; Riedel & Nickel, 2005; Stocchi et al., 2014; Q. Zhang, Yang, Li, & Huang, 2015).

By producing a honeycomb core using a single core mould, the process can be reduced compared to when producing honeycomb using corrugation method, therefore contribute in greater manufacturing cost saving. Besides that, when producing corrugated panel, special care need to be taken to replicate the manufacturing conditions of honeycomb in order to obtain samples with same thickness and fiber content (Stocchi et al., 2014). Based on the literature review, a few types of natural fiber has been used as the reinforcement in honeycomb structure such as jute fabric reinforced with vinylester matrix (Stocchi et al., 2014) and flax fiber reinforced with polyethylene (Petrone et al., 2013). The natural fibers used are normally in the form of chopped strand. The usage of continuous unidirectional fiber are very rare because of the difficulties to extract natural fiber as long bundle without any twisted fibers due to nature of plant (Mahjoub, Mohamad, Rahman, Sam, & Raftari, 2014).

**Figure 1.1 : Kenaf fiber**

One of the examples of continuous unidirectional fiber is kenaf as shown in Figure 1.1. Kenaf fiber is getting attention of researchers and industries to utilize it in different polymer composites due to environmental awareness of consumers and government regulations. In many research studies, kenaf fibers are reinforced with polymer matrix to form fiber reinforced polymeric composites which perfectly improve the features of polymer.

In aerospace application, the core performance is determined by cell size, wall thickness and core thickness. The commercial honeycomb cores for aerospace application are normally produced using fibers in the form of composites sheet bonded together. In term of research purposes, it has been reported that Stocchi et al., (2014) has produced honeycomb core using single core mould but the mould is not designed to the aerospace standards. The honeycomb cores needs to be tested in term of compressive strength and flexural strength. The standards test method for honeycomb structures are usually based on military standard MIL-STD-401.

In this study, honeycomb core of kenaf reinforced with epoxy is fabricated using one step process with single stage mould through compression method with adherence to aerospace standard. Three types of honeycomb core are produced, which consist of neat epoxy, random chopped strand kenaf fiber, and also unidirectional (longitudinal) kenaf fiber. The epoxy is chosen as a matrix because it is more suitable to be used in single stage mould compared to thermoplastic polymer. Furthermore, as compared to other resins, epoxy composites exhibit higher strength values thus contribute a higher ultimate tensile strain in the structure (Mahjoub et al., 2014). The mould is designed to support the use of continuous unidirectional kenaf fiber and random chopped strand in honeycomb structures. All the dimensions of the mould are referred to the standard size of honeycomb structure used in aircraft.

## 1.2 Problem statement

The performance of honeycomb core is dictated by the cell configuration which is the cell size, wall thickness and core thickness. In aerospace application, there is a certain range of cell configuration used with accordance to regulations of Federal Aviation Administration (FAA), European Aviation Safety Agency (EASA), and military standards. The commercial production of honeycomb core by established aerospace manufacturer such as Hexcel uses expansion and corrugation process to produce honeycomb cores. However, there are a lot of processes and precautions involved using these method. Moreover, there is no work has been reported on using single core mould that meets the specification by FAA and EASA such as cell configuration of honeycomb core. For the use of natural fiber, no work has been done to produce single core mould for honeycomb core as per aerospace standard.

In addition, it is known that natural fibers can be used as reinforcement in honeycomb structure, however, there are very uncommon studies of fiber orientation in honeycomb core, including continuous unidirectional fiber as it is hard to extract natural fiber as long bundle due to nature of plant and the method of fiber retting as well. Furthermore, there is also no work reported on producing honeycomb core with unidirectional fiber orientation with single core mould.

To minimize the gap in current research, single core mould with cell configurations with accordance to aerospace standard is designed and fabricated. Besides that, the usage of random chopped kenaf fiber and unidirectional kenaf fiber reinforced with epoxy will be compared in this study and the neat epoxy honeycomb core will be fabricated as a control specimen.

## 1.3 Objective of Research

The main objective of this research is to develop honeycomb core of kenaf/epoxy composites with unidirectional and random fiber orientation using single core mould. In order to achieve main objective, a few objectives need to be achieved first. They are:

- To design and fabricate mould for honeycomb of kenaf/epoxy that supports random chopped fiber and unidirectional fiber arrangement with core specifications that fulfill aerospace standards.

- To evaluate mechanical properties between honeycomb of kenaf/epoxy and honeycomb of neat epoxy in term of flatwise compression, edgewise compression flexural test and tensile test.

- To analyze the fracture modes of honeycomb with various fiber direction.

## 1.4 Scope of Research

1. The mould is designed according to aircraft core specification which emphasized on cell size and wall thickness.
2. The mould is designed to facilitate the flow of resin so that it will spread evenly in the mould either operated manually or using vacuum infusion.
3. The honeycomb core is to be evaluated in terms of compression and flexural as per Federal Aviation Administration (FAA) and European Aviation Safety Agency (EASA) regulations and policies. The important testing for honeycomb core in aerospace application are edgewise compression test, flatwise compression test and also flexural test.
4. Geometry of mould should be large enough to produce enough samples for all tests. All cores that will be tested should be fabricated at once to avoid difference in handling procedure during fabrication and also the difference of average fiber distribution.

## 1.5 Contribution to new knowledge

1. The usage of single core mould that supports different fiber orientation which are random chopped fiber and also unidirectional fiber.
2. The mould is designed as per aerospace standard. This includes the cell size, wall thickness, and core thickness.

## 1.6 Thesis Organization

This report has been organised into five chapters including this chapter which briefly explained the introduction of the project. Chapter 1 is about the general knowledge of the honeycomb core structure and direction of fiber. It also pointed out the problem statements, project objectives and scopes which are important to ensure that this project is completed successfully.

Chapter 2 briefly discussed about literature review works. The study includes all the details about honeycomb core structure, the dimension used in aircraft applications, type of mould used to fabricate core, the testing and standard involved and the strength of various fiber arrangements.

Chapter 3 explained the methodology. The work flow chart has been made to highlight the work progress. All the details about mould design consideration and fabrication process has been pointed out.

Result and discussion are presented in fourth chapter. The result obtained from the testing are collected and compared with theoretical data, and discussed.

The final chapter includes some recommendations for future works around this project and conclusion.

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