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APPLICABILITY OF KENAF-BASED HYBRID COMPOSITE FOR AIRCRAFT RADOME

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By

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APPLICABILITY OF KENAF-BASED HYBRID COMPOSITE FOR AIRCRAFT RADOME

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November 2014

Chair: **Dayang Laila Binti Abg Abdul Majid, PhD**
Faculty: **Engineering**

In this research, the potential of natural fibre is explored for use in aircraft radome application. An aircraft radome usually refer to radar transparent, dome-shape structure which protects radar antennas on aircraft from aerodynamic loading, weather, as well as impacts from bird strikes. Materials that are used for small aircraft radome usually have low dielectric constant and high toughness. However, the need for biodegradable materials has prompted the usage of natural fibres. Natural fibres have comparable mechanical properties such as low weight, low cost, and are renewable and biodegradable. Based on previous research conducted, kenaf fibre has been used for car bumper due to impact property and antenna due to low dielectric property. To date, there are no applications of hybrid kenaf composite in aircraft parts, where it is approved according to the airworthiness standard by Federal Aviation Regulation has been reported. Therefore, this research will provide a motivation to explore a new potential application and particular on the aerospace industry. To assess the potential of natural fibre composite for aircraft radome application, a solid laminate hybrid composite radome design composed of kenaf fibre and fibreglass with epoxy resin is proposed. To fabricate the radome structure, a closed mould vacuum infusion manufacturing process is developed and optimized in order to produce radome structure with consistent wall thickness. Current fabrication technique employed the more traditional hand lay-up technique. Radome structure based on a Duke 60 Beechcraft is fabricated using hybrid of kenaf/fibreglass with epoxy as solid laminates. Current aircraft radome used fibreglass epoxy laminates is also fabricated as the control configuration. Effect of silane chemical treatment on the kenaf fibre was also investigated and denoted as hybrid composite treated kenaf. The physical, mechanical and microstructure of all configurations were later assessed and comparisons are made. Experimental investigations were also carried out to assess the energy absorption capability and load carrying capacity of all configurations subjected to quasi-static axial compressive load. Six test are conducted to analysed performance of hybrid composite for aircraft radome which is i) water absorption test, ii) density test, iii) dielectric constant test, iv) tensile

test, v) quasi static test and vi) scanning electron microscope (SEM). The summary of result for each type of result is stated below. For water absorption, hybrid composite untreated kenaf is 5.73%, hybrid composite treated kenaf is 4.53% and fibreglass composite is 0.86%. For density test, hybrid composite untreated kenaf is 1383 kg/m^3, hybrid composite treated kenaf is 1440 kg/m^3 and fibreglass composite is 1877 kg/m^3. For dielectric constant test, hybrid composite untreated kenaf is 2.97, hybrid composite treated kenaf is 1.28 and fibreglass composite is 3.52. For ultimate tensile test, hybrid composite untreated kenaf is 32.54 MPa, hybrid composite treated kenaf is 38.25 MPa and fibreglass composite is 89.92 MPa. For quasi static test, energy absorb by hybrid composite untreated kenaf is 1534Nm, hybrid composite treated kenaf is 1708 Nm and fibreglass composite is 3910Nm. By using this result and additional two more criteria added which is cost and renewable, the technique for order preference by similarity to ideal solution or TOPSIS is used to determine best alternative material as closed as ideal possible to ideal solution based on three types of composite configuration. Fabrication the aircraft radome part by using closed mould system via vacuum infusion process is successful given a consistency thickness. From TOPSIS analysis on rank alternative material, hybrid composite treated kenaf is near to ideal solution comparing to hybrid composite untreated kenaf and fibreglass composite.

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

KEBOLEHGUNAAN HIBRID BERASASKAN KENAF UNTUK PESAWAT RADOM

Oleh

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Dalam kajian ini, potensi gentian asli diteroka untuk digunakan dalam aplikasi pesawat radom. Pesawat radom biasanya merujuk kepada struktur berbentuk kubah, telus radar dan melindungi antena radar pada pesawat daripada beban aerodinamik, cuaca dan impak perlanggaran burung. Bahan yang digunakan untuk pesawat radom bersaiz kecil biasanya mempunyai pemalar dielectrik yang rendah dan kekuatan yang tinggi. Walau bagaimanapun, keperluan untuk bahan-bahan mesra alam telah mendorong penggunaan gentian asli. Gentian asli mempunyai sifat mekanikal yang setanding dari segi berat yang rendah, kos rendah, boleh diperbaharui dan mesra alam. Berdasarkan kajian yang dijalankan sebelum ini, gentian kenaf telah digunakan untuk bumper kerana keupayaan menyerap hentakan dan antena kerana keupayaan dielectik yang rendah. Sehingga kini, tiada aplikasi daripada komposit hibrid kenaf di bahagian pesawat, dimana ia diluluskan mengikut standard kelayakan penerbangan mengikut Federal Aviation Regulation telah dilaporkan. Oleh itu, kajian ini akan memberi motivasi untuk meneroka aplikasi baru yang berpotensi dan khusus kepada industri aeroangkasa. Untuk menilai potensi komposit daripada gentian asli di dalam aplikasi pesawat radom, reka bentuk lapisan padu komposit hibrid radom terdiri daripada gentian kenaf dan gentian kaca bersama epoksi dicadangkan. Manakala untuk fabrikasi struktur radom, satu system acuan tertutup bersama proses vakum infusi dibangun dan dioptimumkan bagi menghasilkan struktur radom dengan ketebalan dinding yang konsisten. Pada masa kini, teknik fabrikasi pesawat radom menggunakan kaedah tradisional iaitu teknik 'hand lay-up'. Struktur radom dibina berdasarkan bentuk radom pesawat Duke 60 Beechcraft yang menggunakan hibrid gentian kenaf dan gentian kaca bersama epoksi sebagai lapisan padu. Bahan semasa untuk pesawat radom iaitu gentian kaca bersama epoksi digunakan sebagai konfigurasi kawalan. Kesan rawatan kimia menggunakan silane ke atas gentian kenaf juga disiasat dan ditandakan sebagai hibrid komposit kenaf dirawat. Sifat fizikal, mekanikal dan mikrostruktur bagi semua konfigurasi kemudiannya dinilai dan perbandingan dibuat. Ujikaji untuk menilai keupayaan penyerapan tenaga dan kapasiti menahan beban mampatan kuasi-statik juga dijalankan. Enam ujian telah dijalankan untuk

menganalisa prestasi komposit hibrid untuk pesawat radom iaitu: i) ujian penyerapan air, ii) ujian ketumpatan, iii) ujian pemalar dielectric, iv) ujian tegangan, v) ujian kuasi-statik dan vi) pengimbasan mikroskop electron (SEM). Ringkasan hasil untuk setiap ujian dinyatakan di bawah. Untuk ujian penyerapan air, komposit hibrid kenaf yang tidak dirawat adalah 5.73%, komposit hibrid kenaf dirawat adalah 4.53% dan komposit gentian kaca adalah 0.86%. Untuk ujian ketumpatan, komposit hibrid kenaf yang tidak dirawat adalah 1383 kg/m^3, komposit hibrid kenaf dirawat adalah 1440 kg/m^3 dan komposit gentian kaca adalah 1877 kg/m^3. Untuk ujian pemalar dielectrik, komposit hibrid kenaf yang tidak dirawat adalah 2.97, komposit hibrid kenaf dirawat adalah 1.28 dan komposit gentian kaca adalah 3.52. Untuk ujian tegangan, komposit hibrid kenaf yang tidak dirawat adalah 32.54 MPa, komposit hibrid kenaf dirawat adalah 38.25 MPa dan komposit gentian kaca adalah 89.92 MPa. Untuk ujian kuasi-statik, komposit hibrid kenaf yang tidak dirawat adalah 1534 Nm, komposit hibrid kenaf dirawat adalah 1708 Nm dan komposit gentian kaca adalah 3910 Nm. Dengan menggunakan keputusan ini dan penambahan dua kriteria iaitu kos dan boleh diperbaharui, teknik untuk keutamaan persamaan berdasar keputusan ideal atau TOPSIS digunakan untuk menentukan bahan alternatif terbaik yang hampir kepada penyelesaian ideal berdasarkan tiga jenis konfigurasi komposit yang dihasilkan. Fabrikasi bahagian pesawat radom dengan menggunakan sistem acuan tertutup melalui proses vakum infusi telah berjaya memberi ketebalan produk yang konsisten. Daripada analisis TOPSIS ke atas keutamaan bahan alternatif, komposit hibrid kenaf yang dirawat mempunyai nilai yang hampir kepada penyelesaian yang ideal berbanding kepada komposit hibrid kenaf yang tidak dirawat dan komposit gentian kaca.

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I certify that a Thesis Examination Committee has met on (**the date of viva voce**) to conduct the final examination of Mohd Yusoff Bin Mohd Haris on his thesis entitle "**An Investigation of Kenaf Based HYBRID COMPOSITE FOR AIRCRAFT RADOME APPLICABILITY**" in accordance with the Universities and Universities Collages Act 1971 and Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master Science.

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LIST OF ABBREVIATIONS

FRP	Fibre reinforced polymer
CO_2	Carbon dioxide
FAR	Federal Aviation Regulation
CSIR	South Africa Council for Scientific and Industrial Research
RF	Radio frequency
RTM	Resin transfer moulding
OPEFB	Oil palm empty fruit bunch
PALF	Pineapple leaf fibre
PP	Polypropylene
PE	Polyethylene
HDPE	High density polyethylene
PLA	Poly lactic acid
PVC	Polyvinyl chloride
PF	Phenol formaldehyde
NaoH	Sodium hydroxide
ICAO	International Civil Aviation Organization
CAEP	Council Committee on Aviation Environmental Protection
IATA	International Air Transport Association
BMI	Bismaleimides
FAA	Federal Aviation Administration
CSM	Chopped strands mat
ASTM	American Society for Testing and Materials
VNA	Vector Network Analyser
MSDS	Material Safety Data sheet
SEM	Scanning Electron Microscope
FERA	Food and Environment Research Agency
EASA	European Aviation Safety Agency
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution

CHAPTER 1

INTRODUCTION

Fibre reinforced polymer (FRP) composites are lightweight, noncorrosive, demonstrate high specific strength and specific stiffness, are easily constructed, and can be tailored to satisfy performance requirements. Due to these advantageous characteristics, FRP composites have been included in new constructions and the rehabilitation of structures as a reinforcement in concrete, bridge decks, modular structures, formwork, and in external reinforcements for strengthening and seismic upgrade. While the mechanical advantages of using FRP composites were widely reported in the literature, uncertainty remains with regards to the feasibility of FRP composites within the framework of a sustainable-built environment [1]. The usage of an alternative composite material will be explored in this research.

A composite material is a combination of two or more distinct materials with the intent of suppressing the undesirable properties of the constituent materials in favour of the desirable properties [2]. Over the past several decades, the uses of composite materials have increased in infrastructure applications. For structural applications, FRP composites are typically fabricated using a polymer matrix, such as epoxy, vinyl ester or polyester and reinforced with various grades of carbon, glass, and/or aramid fibres. The fabrication of constituent materials for FRP composites, namely matrix and fibre, are areas of concern especially when considering that the primary resource from which polymers (excluding biopolymers) are derived is crude oil. Depending on primary resource polymer is a limitation and researchers need to seek alternative resources.

In the case of FRP composites, environmental concerns appear to be a barrier to their feasibility as a sustainable material, especially when considering fossil fuel depletion, and the air pollution, smog, and acidification associated with their production. In addition, the ability to recycle FRP composites are is limited; unlike with steel and timber, the structural components cannot be reused to perform a similar function in another structure. However, evaluating the environmental impact of FRP composites in infrastructure applications, specifically through life cycle analysis, may reveal direct and indirect benefits that are more competitive than conventional materials [1]. Global environmental issues are often discussed at international conferences.

Due to global environmental awareness concerning issues such as global warming, decreasing natural resources and high price fossil fuels in the market, many researchers are focusing on green technology to overcome current problems. Global warming is the rise in the average temperature of the Earth's ocean and atmosphere and its projected continuation if no action is taken. Global warming can be explained as the effect of greenhouse gases emitted as a result of human activities. The gas responsible for the most warming is carbon dioxide, also called CO_2. This gas comes from the combustion fossil fuels in cars, factories and electricity production. The loss of forests has caused an imbalance in the natural cycle and has also contributed to the increase of CO_2. The continuing trend of CO_2 emission has urged most countries to an increasing awareness of the greenhouse effect.

The fossil fuel price has become higher due to a high demand from consumers and the limited supply of oil-producing companies. According to the United States' Energy Information Administration, in the last 10 years, oil has jumped in price because of several factors [3]. Another impact factor was the war in Iraq, which is one of the highest oil-producing countries. Another key factor was the economic crisis in the United States, also known as the subprime crisis, which caused the dollar to weaken against other currencies.

In general, natural fibres are obtained from plants, animals or mineral resources. Plant fibre comes from the plant's seed, leaf, bast, fruit and stalk. The basic component of natural plant fibre is cellulose, hemicellulose and lignin. The basic components collectively function as a matrix and adhesive, helping to hold together the cellulosic framework structure of the natural composite fibre. The natural fibres from plants will be discussed in the following chapters. Table 1.1 shows a list of vegetable and cellulose fibres according to their classification.

Table 1.1: A list of vegetable and cellulose fibre classifications [4]

Bast	Leaf	Seed	Fruit	Stalk
Flax	Sisal	Cotton	Coconut	Bamboo
Hemp	Manila	Kapok	Coir	Wheat
Jute	Curaua			Rice
Ramie	Banana			Grass
Banana	Palm			Corn
Rattan				

The current awareness of critical global environmental issues and escalating oil prices due to high demand and oil depletion, has urged the need to minimise dependence on synthetic fibres as reinforcement, and natural fibre has shown the potential to overcome this issue. The advantages of natural fibres are their low density, low cost, low energy consumption to produce and the fact that they are renewable. Several research studies on natural fibre reinforced polymers have been carried out in Malaysia due to the abundant source of fibres which can be obtained at a low cost. This low cost natural fibre can be used as the reinforcing fibre in biocomposite application.

Increasing the use of biocomposites has significant potential for positive environmental outcomes, but achieving this will require addressing major challenges, as well as choosing the right applications in the short term [3]. The application of natural fibres can be found as a panel with low mechanical properties and protected from moisture. There are various applications of biocomposites in several industries. Figure 1.1 shows an application of natural fibres in the automotive industry whereby flax, hemp, sisal and other natural fibres have been used for Mercedes Benz components [5]. In figure 1.2, the case of the cell phone is made from kenaf/PLA developed by NEC [6] and in figure 1.3 the surfboard is made from hemp and epoxy [7].

Figure 1.1: Application of natural fibre in the automotive industry. [5]

Figure 1.2: Application of natural fibre in a mobile phone. [6]

Figure 1.3: Surfboard made from hemp and epoxy. [7]

One of the objectives set by the European 2000/53 Directive is to be recycling 85% and reusing 95% of an automotive by 2015 [8]. Japan requires 88% of a vehicle to be recovered (which includes incineration of some components) by 2005, rising to 95% by 2015. As a result, today most automakers are evaluating the environmental impact of a vehicle's entire life cycle, from raw materials to manufacturing to reuse or disposal of the materials. One of the initiatives is to use biocomposites in current composite applications.

To date, no application of biocomposites in aircraft parts, where it is approved according to the airworthiness standard by the Federal Aviation Regulation (FAR), has been reported. However, the international commercial airline manufacturer Airbus has shown interest in natural fibre. In 2008, Airbus and the South African Council for Scientific and Industrial Research (CSIR) collaborated in research for a new generation of eco-friendly aircraft based on natural fibre material [9]. Also, through the Fly Your Ideas competition organized by Airbus, a project to apply a natural fibre composite made from castor plants in aircraft cabins and Kapok tree fibre in the thermal and acoustic insulation blankets used in aircraft cabins is amongst the top five projects and has attracted their attention [10].

A radome is a compound word formed from the words radar and dome meaning a cover or structure placed over an antenna which protects the antenna from its physical environment. Ideally, the radome is radio frequency (RF) transparent so that it does not degrade the electrical performance of the enclosed antenna in any way [11]. Today, the radome is used in wider applications in ground, maritime, terrestrial (ground), vehicular, aircraft, and missile electronic systems. For example, a radome-enclosed air traffic control radar antenna is shown in figure 1.4, and a radome-enclosed SATCOM antenna is shown in figure 1.5.

Figure 1.4: Radome-enclosed air traffic control radar antenna. [11]

Figure 1.5: Radome-enclosed SATCOM antennas. [11]

An aircraft radome usually refers to the dome-shaped structure encapsulating the antenna and protects radar antennas on aircraft from wind or aerodynamic load, bird strike impacts and lightning strikes. The structural integrity of the aircraft nose radome has constantly been a major concern as it is forward-facing on an aircraft and is therefore exposed to incoming impacts from aerodynamic loads, rain, lightning and bird strikes. The first reported aircraft radomes used simple, thin-wall designs. In 1941, the first in-flight radome was a hemispherical nose radome fabricated using Plexiglas in a B-18A aircraft [11]. Figure 1.6 shows an example radome used for the Boeing 737-400 and the Bell 429 helicopter.

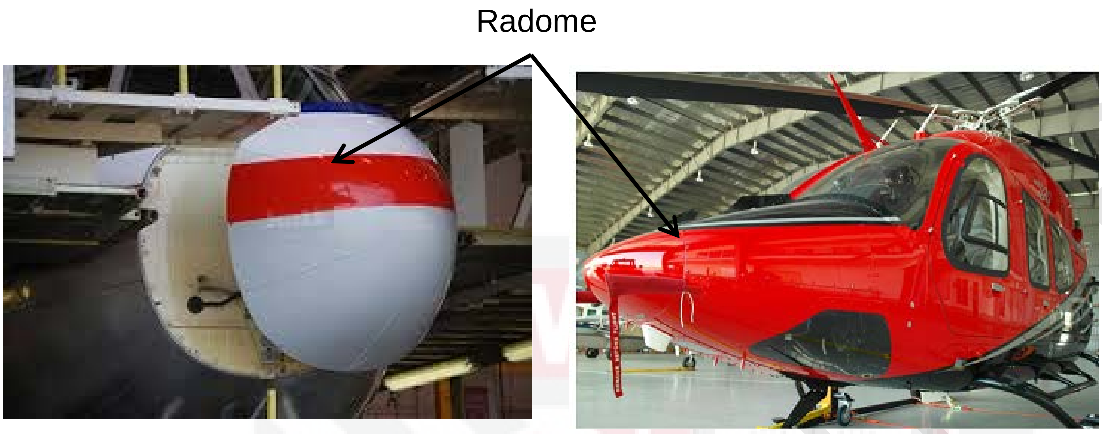

Figure 1.6: Examples of aircraft radome. [12,13]

The materials that are used for the aircraft radome must be radar transparent, and usually have a low dielectric constant and possess high toughness. Usually fibreglass type E and an aramid honeycomb are used as the radome material. The typical radome wall construction is a solid wall for a small size radome, and a sandwich wall with a honeycomb as a core for the large area radome. The most common methods used in radome fabrication are vacuum bag and autoclave moulding. Natural fibre shows a capability for having a specific toughness and a low dielectric constant. Therefore the suitability of natural fibre for use in radome applications will be explored in this research.

The fundamental on energy absorption and failure mode of composite radome is needed. In the energy absorption of composite material, most of the experimental work has been carried out using quasi-static test on axis symmetric cylindrical tubes mainly because they are easy to fabricate and has proven to be one of most favourable shapes for energy absorption. Quasi-static test is a fundamental method to determine energy absorption of material. Also, most of the energy characteristics are obtained from crushing investigations of shell structures with circular, rectangular and square cross section or known as a primitive shape.

Kenaf fibre is selected in this research based on previous research done by Prof. Ir. Dr. Mohd Sapuan Salit at Universiti Putra Malaysia on car bumper made from kenaf fibre, where kenaf fibre shown a good energy absorption property [53]. Also research on antenna made from kenaf fibre done by Assoc. Prof. Dr. Alyani at a same university, kenaf fibre shown a low dielectric property [81] and at present, there are still few research has been done on natural fibre as an aircraft component especially in radome part. Therefore, due to this research data and material requirement for aircraft radome, the capabilities of natural fibre as a radome part will be investigated and in contrast, this study also can investigate further of development a green technology in other applications.

1.2 Research Objective

The main objective of this work is to assess the potential of a biocomposite for use in aircraft radome applications. The following are the aims of this study:

- To investigate the manufacturing process for a hybrid composite radome.
- To evaluate the physical characteristic and mechanical properties of a hybrid composite radome design.
- To assess the energy storage capability of kenaf based hybrid composite radome subjected to quasi-static loading.

1.3 Significance of the study

This research will provide the impetus for more research on the creation of new potential applications for biocomposites and in particular for the aerospace industry. In addition, this research can promote further development of biocomposites for the electronic industry whereby their dielectric properties as well as their impact characteristics are required. As a result, there will be a higher demand for natural fibres from a variety of sources such as pineapple leaf, oil palm, empty fruit bunch, kenaf, banana, wood, coir and other plants which are abundant in Malaysia.

1.4 Thesis Organization

The thesis is divided into five chapters. Following this introduction, the literature review will be covered in the next chapter. Chapter three will describe the experimental programme whereby the preparation of the flat specimen and the biocomposite radome part is explained. The material characterisation programme will also be covered here. Chapter four presents the results of the experimental work and an overall discussion of the research. Finally, in chapter five, the conclusions from this work are drawn and future studies are listed.

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