UNIVERSITI PUTRA MALAYSIA

ANALYSIS OF COIR BASED FIBRE/EPOXY COMPOSITES PLATE SUBJECT TO AEROELASTIC INSTABILITY

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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 Master of Science

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This thesis specially dedicated to my beloved parents, brothers and sister.

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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Chairman : Azmin Shakrine Mohd Rafie, PhD

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The effects of aspect ratio and fiber-epoxy weight ratio of coir fibre/epoxy composite wing idealized as flat plate on flutter speed were preliminary studied in the current research to investigate the aeroelastic instability on natural fiber composite material. Among the main concerns of composite materials application for aircraft are weight saving and cost reduction factor while the design of structures should be made stiffer to avoid aeroelastic instability problems. In connection between aeroelasticity and environmental issue, the usage of natural material like coir fiber reinforce composite might turn up as potential solutions for the problem of increasing aircraft weight & cost in making airframe more rigid with the purpose of reducing aeroelastic instability in addition of utilization of eco-friendly factor material. The coir fiber reinforces offer low in weight and cost reduction, and is more environmentally friendly compared to metallic materials. For the current work, the analysis of the coir fiber on the aeroelastic problem will be preliminary investigated to establish related data to be served especially in the aerospace research areas. Several previous researches that introduced the natural fibres to optimize the performance of structure have been done generally in other mechanical and civil research areas while conventional glass or carbon fibre reinforced composites has been traditionally used in the aeroelastic research.

The research began with the existing raw untreated coir fibre which in the form of pressed mat and originally in random oriented fibre form are used in the composite preparation process by simple hand-lay-up and compression moulding method under room temperature and controlled pressure conditions. Then, the fabricated panels underwent material mechanical tests; tensile, flexural, and torsion test to obtain material mechanical properties. The 25% wt fiber composite has been selected as the highest performance specimen among others. The specimen with different aspect ratios (AR5, AR6, and AR7) with 25% wt fiber reinforcement composite underwent modal testing to get the mode shapes, natural frequencies, and damping ratios. The result shows that the plates with higher aspect ratio seem to have higher natural frequency and damping ratio. Then, the specimens of different aspect ratio (6 and 7) were installed in the wind tunnel for subsonic experimental aeroelastic test. The result shows that the plates with lower aspect ratio seem to have higher flutter speed. In terms of aeroelastic point of view, the results shows that there is a potential in the use coir fibers for secondary aircraft structures due to low density and vibration damping characteristics, in addition to low cost and green technology considerations. The preliminary data established potentially serve as a reference for future studies.

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

KAJIAN KEATAS KOMPOSIT SABUT KELAPA DENGAN EPOKSI TERHADAP KETIDAKSTABILAN AEROELASTIK

Oleh

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Penyelidikan awal terhadap kesan-kesan nisbah aspek dan nisbah berat fiber-epoksi sabut kelapa komposit panel rata seperti perumpamaan sayap kapal terbang ke atas ramalan kelajuan fluter untuk menyiasat ketidakstabilan aeroelastik ke atas bahan komposit fiber semulajadi telah dijalankan. Salah satu tumpuan utama dalam aplikasi bahan komposit untuk pesawat ialah pengurangan berat and pengurangan kos disamping menambah ketegaran untuk mengelakkan masalah fenomena aeroelastik. Dalam kaitan aeroelastik dan isu alam sekitar, pengunaan bahan-bahan semulajadi seperti komposit sabut kelapa berpotensi dijadikan sebagai penyelesaian masalah peningkatan berat pesawat dan kos dengan tujuan menambah ketegaran kerangka pesawat udara untuk mengurangkan risiko fenomena aeroelastik dan faktor penggunaan bahan mesra alam. Komposit sabut kelapa menawarkan faktor ketumpatan bahan yang rendah, harga yang murah, dan pemeliharaan alam sekitar jika dibandingkan dengan bahan digunapakai pada masa kini. Analisis awal keatas sabut kelapa terhadap masalah aeroelastik telah dijalankan untuk menghasilkan data yang berkaitan seterusnya dijadikan panduan untuk kajian dalam bidang aeroangkasa pada masa depan. Terdapat kajian-kajian lepas yang memperkenalkan pengunaan fiber semulajadi untuk mengoptimumkan sifat-sifat struktur. Kajian-kajian sebelum ini kebanyakannya telah dilakukan di dalam bidang-bidang mekanikal dan pembinaan. Pengunaan komposit gentian kaca dan karbon pula secara tradisionalnya telah banyak digunakan dalam bidang kajian aeroelastik.

Kajian ini dimulakan dengan menggunakan sabut kelapa mentah yang tidak dirawat di dalam bentuk sedia mampat dan mempunyai susunan fiber yang rawak sebagai bahan utama di dalam pembuatan komposit. Komposit ini

dibuat secara kaedah manual “hand-lay-up” dan kaedah pemampatan acuan dibawah suhu bilik dan tekanan yang terkawal. Panel komposit yang telah siap dibuat seterusnya melalui proses ujian sifat-sifat mekanikal bahan iaitu ujian tegangan, ujian lentur, dan ujian pulasan . Komposit dengan komposisi fiber sebanyak 25% telah dipilih sebagai hasil yang paling optimum berbanding nisbah komposisi lain dan akan nisbah itu digunakan untuk penghasilan komposit untuk kajian berikutnya. Seterusnya sampel komposit panel yang mempunyai nisbah aspek 5, 6, dan 7 telah melalui proses ujian getaran untuk mendapatkan bentuk mod, frekuensi semulajadi, dan nisbah pelembap. Keputusan daripada ujian tersebut menunjukkan panel dengan nisbah aspek yang tinggi mencatatkan peningkatan frekuensi semulajadi dan nisbah kelembapan. Seterusnya, sampel panel dengan nisbah aspek 6 dan 7 telah dipasang didalam terowong angin untuk eksperimen sub-sonik aeroelastik. Hasil dari ujian menunjukkan panel dengan nisbah aspek yang rendah mempunyai kelajuan fluter yang tinggi. Dari sudut aeroelastik, data yang diperolehi menunjukkan bahan tersebut berpotensi digunakan untuk bahagian yang bukan struktur utama struktur pesawat kerana sifatnya yang berketumpatan rendah dan penebat getaran disamping kos bahan yang rendah dan aplikasi teknologi hijau. Data awalan yang dihasilkan berpotensi dijadikan rujukan dalam kajian masa akan datang.

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I certify that an Examination Committee has met on 5th August 2014 to conduct the final examination of Mohd Amirul Bin Abdul Rahman on his thesis entitled "Analysis of Coir Based Fibre/Epoxy Composites Plate Subject to Aeroelastic Instability" in accordance with the Universities and University College 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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LIST OF ABBREVIATIONS AND NOTATIONS

LCO	Limit Cycle Oscillations
EMA	Experimental Modal Analysis
wt	Weightage
AR	Aspect Ratio
DOF	Degree of Freedom
CFD	Computational Fluid Dynamics
PP	Polypropylene
HDPE	high density polyethylene
ASTM	American Society for Testing and Materials
GFRP	Glass Fibre Reinforced Plastic
LDPE	Low Density Polyethylene
FFT	Fast Fourier Transformation
UPM	Universiti Putra Malaysia
DAQ	Data Acquisition System

Nomenclature

M'	Moment per unit length
ac	Aerodynamic center
N	Normal load factor
mg	Weight per unit length
GJ	Effective torsional stiffness

T	Torque
q	Dynamic pressure
c_l	Lift coefficient
q_D	Divergence dynamic pressure
τ_d	Damped period
δ	Logarithmic decrement
Z	Damping Ratio
σ	Engineering stress
ϵ	Engineering strain
σ_{fs}	Flexural strength
F_f	Load at fracture
γ	Shear strain
ϕ	Angle of twist
τ	Shear stress
G	Shear modulus
λ	St. Venant Constant
f_n	Frequency of nth mode
C	Damping constant
m	Mass
ω_n	Natural frequency

CHAPTER 1

INTRODUCTION

1.1 Introduction

In general, aeroelastic phenomena can be defined as the study of the effect of aerodynamic forces on elastic structures. It can be broken down into two major branches which are static aeroelasticity and dynamic aeroelasticity. The static aeroelasticity is concerned with the system in equilibrium and independent of time instabilities. The structure (i.e. aircraft wing) will deform once an aerodynamic load is placed on the structure. This phenomenon is caused by aerodynamic and elastic forces. Some examples of aeroelastic phenomena are load distribution, divergence and control surface effectiveness. The case of dynamic aeroelasticity is concerned with the time dependent instabilities and caused by interaction of aerodynamic, elastic and inertial forces. The examples of aeroelastic phenomena are dynamic response, limit cycle oscillation (LCO), buffet and flutter.

The most prominent case is flutter which is unstable self-excited vibration in which the structure extracts the energy from the air stream and often results in catastrophic structure failure. It occurs when the aerodynamic forces combined with motion in two modes of vibration and lead to modes coupling in an unfavourable manner. This phenomenon happened at the flutter speed when the structure starts to experience both coupling modes following some initial disturbances. Flutter encountered in flexible structures subjected to aerodynamic forces including aircraft, buildings, telegraph wires and bridges. In the case of aircraft, flutter can take various forms involving different pairs of interacting modes, e.g. wing bending and torsion, wing torsion and control surface, wing and engine, etc.

The continuous improvement remained in the aerospace industries where they start considerably to put their attention on the natural fibres as one of the possible materials to be introduced in aircraft manufacturing process. Furthermore, the increment in consumptions of coconut fruit for food processing and other industrial usages in present day lead to increase in the production of non-recyclable coconut trash in the form of coconut husks. Therefore, any recommended utilization of this waste coir fibre might be seen as a good response to make use of this abundantly available raw material. In an aircraft, as the speed of the wind increases, there may be a point at which the structural damping is insufficient to damp out the motions which are increasing due to aerodynamic energy being added to structure. This vibration can catastrophically cause structural failure and therefore considering flutter characteristic which is obvious on the aircraft lifting surfaces as an essential part of designing an aircraft.

1.2 Problem Statement

One way to reduce the risk of aeroelastic phenomena is to make airframe more rigid but it normally results another setback of aircraft gross weight increase. In fact, one of the main objectives in the aircraft design process is to reduce the overall weight of the structure. In the past few decades, several efforts have been carried out to counter the problem including reduction of weight by using the conventional composites and metallic materials. In the connection between aeroelasticity and environmental issues, the introduction of natural material like coir fibre reinforced composite might contribute as a potential solution where it offers low in weight criteria, cost reduction, and preservation of the environmental factors compared to conventional materials.

1.3 Objectives and Scope of Works

The objectives of the research are:

1. to investigate the aeroelastic response of the aircraft lifting surface visualize as a flat plate made by coir fibre/epoxy composite through experimental method by varying aspect ratio and fibre-epoxy weight ratio of the plate.
2. To establish related data including material mechanical test data, experimental modal analysis (EMA) data and experimental aeroelastic test data for untreated coir fibre/epoxy pressed mat composite. These data then might be used especially in the future aerospace research areas.

Several scopes of work have been set up for the studies which are:

1. All the tests including material mechanical test, ground vibration test and wind tunnel flutter test for the current work had done only for experimental investigation.
2. The data obtained for the current works are tensile modulus, flexural strength, shear modulus, natural frequencies, damping ratio, mode shapes and flutter speed.
3. The parametric study undergone on fibre-epoxy weight ratio and aspect ratio of the plate.
4. The wind tunnel flutter test undergone under incompressible flight regime.
5. The specimens used are assumed to be an isotropic

material.

For the current research, aircraft wing idealized as a coir fibre/epoxy composite flat plate which represents different aspect ratio wings that will be experimentally analysed in term of their aeroelasticity response to establish preliminary related data that could be served in future aerospace research areas. The research process begins with the parametric study including variation of fibre-epoxy weight ratio and plate aspect ratio in order to highlight the significance of these design variables towards the effects of aeroelasticity. This study will be carried out in the range of incompressible flight regime.

1.4 Thesis Layout

This thesis comprises of six chapters. Chapter 1 introduce a fundamental theory to the aeroelastic phenomena with more brief discussion on flutter phenomenon, the significant of its analysis and problem statement. This chapter also state the purpose and scope of the research. The previous research including natural fiber and experimental aeroelasticity is reviewed in the chapter 2. The fundamental theory of aeroelasticity and mechanical properties of the material are presented in the last section of chapter 2. The brief of research methodology is described in chapter 3 including the model development and experimental test encountered. Chapter 4 presents the results obtained from the tests and analyses with discussion in the comprehensive way while on chapter 5 the conclusion and recommendations for the related future research were drawn.

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