FINITE ELEMENT MODELLING STUDY ON DELAMINATION BEHAVIOR OF COMPOSITE MATERIAL

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**A thesis submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declare that this project entitled " Finite Element Modelling Study on Delamination Behavior of Composite Material" is the result of my own research except as cited in the references. The project has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : *Mohamad Afiq Danial Bin Mat Nasir*

Date : *11/1/2023*

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical Engineering Technology with Honours.

Signature	:	
Supervisor Name	:	*Febrian Bin Idral*
Date	:	*11/1/2023*

DEDICATION

To my beloved parents,

Mat Nasir Bin Ab Latif, Natrah Binti Mohamed, Noor Sharliana Binti Mat Nasir, Mohd Amir Rafie Bin Mat Nasir.

Thank you for all support, motivation, patient and all willingness to share with me.

To my honoured supervisor and co-supervisor,

En Febrian Bin Idral, Ts. Dr. Ahmad Fuad Bin Ab Ghani, and all the UteM lecturers.

Thank you for always giving me the guidance and persistent help to finish the project thesis.

ABSTRACT

In recent years, the usage of composite materials has become more prominent in a number of industries, including automotive and aerospace. However, because of their high prices, distinctive qualities, and heterogeneity-related implications, they provide difficult research gaps. As a result, composite materials exposed to the most unusual circumstances have been studied using the finite element approach. In order to simulate composite materials, this study focuses on material attributes, failure criteria, element kinds, and benchmark between FEM simulation and theoretical data. From the modelling point of view, it is to model and simulate three-bending flexural testing by using ANSYS Composite PrepPost on the balanced-symmetry layup, quasi-isotropic layup, and unidirectional layup by changing its fibre orientation layers. When it comes to their properties, various mechanical traits, theories, and constitutive relationships used to model these materials are discussed which is the Epoxy Carbon Woven (230 GPa) Prepreg. The text also discusses the types of data gathering which is total deformation, equivalent Von-Misses stress and equivalent elastic strain. In addition, to evaluate the benchmark of equivalent elastic strain between the FEM simulation and the theoretical data of the specimens.

ABSTRAK

Dalam beberapa tahun kebelakangan ini, penggunaan bahan komposit telah menjadi lebih menonjol dalam beberapa industri, termasuk automotif dan aeroangkasa. Walau bagaimanapun, kerana harga yang tinggi, kualiti tersendiri dan implikasi berkaitan heterogeniti, ia memberikan jurang penyelidikan yang sukar. Hasilnya, bahan komposit yang terdedah kepada keadaan yang paling luar biasa telah dikaji menggunakan pendekatan unsur terhingga. Untuk mensimulasikan bahan komposit, kajian ini memfokuskan pada atribut bahan, kriteria kegagalan, jenis elemen, dan penanda aras antara simulasi FEM dan data teori. Dari sudut pandangan pemodelan, ia adalah untuk memodelkan dan mensimulasikan ujian lentur tiga lentur dengan menggunakan ANSYS Composite PrepPost pada susun atur simetri seimbang, susun kuasi-isotropik dan susun atur satu arah dengan menukar lapisan orientasi gentiannya. Mengenai sifatnya, pelbagai sifat mekanikal, teori, dan hubungan konstitutif yang digunakan untuk memodelkan bahan-bahan ini dibincangkan iaitu Epoxy Carbon Woven (230 GPa) Prepreg. Teks ini juga membincangkan jenis pengumpulan data iaitu ubah bentuk total, tegasan Von-Misses setara dan regangan elastik setara. Di samping itu, untuk menilai penanda aras regangan elastik setara antara simulasi FEM dan data teori spesimen.

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CHAPTER 1

INTRODUCTION

1.1 Background

Composite materials are now widely employed in a wide range of industrial goods, bringing up new markets and applications. Over the last few decades, the utilisation of laminated composite materials in spacecraft and different machine components have expanded dramatically. The term composite refers to something that is made up of several pieces. In practise, the word composite material or composites refers to a substance that is made up of two or more materials with different natures and complimentary qualities, resulting in a material with better properties to its original constituents. Composites are popular for various reasons: they mix two or more components on a macroscopic scale to create a very useful material. Composites with reinforcing fibres have great toughness and rigidity, which leads to good accomplishment. In addition, as a comparison to steel and concrete, fibre/resin combinations have a lower density of weight. This translates to excellent strength and stiffness-to-weight ratios. However, because most composites contain thermoset matrices that cannot be moulded, one of the key issues when composites are damaged, they become difficult to repair. Internal faults can dramatically affect the stiffness and strength of composites once they have been damaged. As a result, non-destructive testing (NDT) processes for this type of material are becoming more suitable comparable with a destructive one.

Composite materials, particularly carbon fibre-reinforced polymers (CFRP), because of their higher specific toughness and rigidity, they have a variety of applications in aerospace, automobile, healthcare, and components and structures of a construction. Woven-fabric composite laminates feature reduce manufacturing costs, increase drapability, strong resilience to longitudinal rupture and crack due very high impact toughness and resilience to threading when compared to their unidirectional-tape equivalent. Because of these properties, woven CFRP laminates have begun to be used in the manufacture of athletic equipment in the sports industry. While in service, such products might well be exposed to large bending and frequent collisions. Due to the heterogeneity and asymmetry of composite laminates, these quasi-static and dynamic forces cause substantial local stresses and strains, resulting in complicated damage patterns. In research from Kishore et al. a laminate is subjected to transverse shear and normal stresses during flexural test because to its low through-thickness stiffness and strength, resulting in interlaminar delamination damage. Damage develops over time, resulting in a significant loss of in-service mechanical properties and structural integrity in composite sports equipment.

Delamination are one of the most prevalent problems in multilayer composite materials. They can be caused by manufacturing flaws or by operating impacts such as heat loading, impact loads, fatigue, and among others. Once started, they gradually expand within the material with continued loading, eventually leading to component failure. Because the ultrasound is diffused, deflected, or transmitted by the defect, linear ultrasonic methods that have been around for a long time may discover delamination if they are existed. At repose, however, early-stage delamination tends to close. The adhesion between two sections of the material is damaged in a closed defect, but the two delamination interfaces remain in touch. The contact can be opened or closed by using a limited excitation amplitude that can surpass the delamination specific activation threshold. Clapping is a local contact phenomenon that results in a non-linear stress-strain relationship at the defect location (a violation of Hooke's law).

Damage caused by computation during analysis, the capacity to predict the beginning and evolution of damage is required for delamination modelling. Delamination initiation in composite laminates is often measured using strength-based criteria; for example, the maximum nominal stress and quadratic strength criteria have proven to be effective. The J-integral, the method for extending simulated cracks, and the method for closing simulated cracks are among the fracture-mechanics-based approaches used in the finite element method (FEM) to model delamination growth (VCCT). In this regard, fracture mechanics analysis is constrained because it ignores material nonlinearity and demands that the positioning of the delamination fracture be decided in advance. Furthermore, a small mesh surrounding the fracture front is usually required, making three-dimensional composite structure analysis more computationally costly. As a result, computational forecasting the impact of interlaminar effect on composite laminate behaviour necessitates a finite-element technique capable of modelling both strength and toughness of the inter-ply layers.

1.2 Problem Statement

In this modern era, a composite material is widely used in many industries on any kind of device and have their own purposes. However, the strength of the composite material can be increase in what way the material laminates was plied. Epoxy Carbon Woven (230 GPa) Prepreg laminates been put under flexural test because of the complexity brought on by homogeneity and asymmetry and the mechanical characteristics of composite materials is still an origin of uncertainty. The difficulty of failure prediction rises when additional essential elements, such as stacking sequence and fibre orientation angle, are introduced to multi-layered composites. Research to better understand composite behaviour make it is a requirement to predict and modify damage cycles in multi-layered composites, as an example, intralaminar and interlaminar failure modes. When in-plane forces are calculated to a composites laminate, intralaminar failure modes such as matrix crushing, matrix cracking, and fibre rupture or breaking can occur.

1.3 Research Objective

The main aim of this research is to study by using finite element modelling on delamination behaviour of composite material. Specifically, the objectives are as follows:

a) To model and simulate three-bending flexural testing by using ANSYS Composite PrepPost on the balanced-symmetry layup, quasi-isotropic layup and unidirectional layup of Epoxy Carbon Woven (230 GPa) Prepreg.

b) To identify the total deformation, equivalent Von-Misses stress and equivalent elastic strain of balanced-symmetry layup, quasi-isotropic layup and unidirectional layup of Epoxy Carbon Woven (230 GPa) Prepreg.

c) To evaluate the benchmark of equivalent elastic strain between the FEM simulation and the theoretical data of balanced-symmetry layup, quasi-isotropic layup and unidirectional layup of Epoxy Carbon Woven (230 GPa) Prepreg.

1.4 Scope of Research

The scope of this research are as follows:

- The simulation will be run using ANSYS Composite PrepPost software.
- Epoxy Carbon Woven (230 GPa) Prepreg is the chosen composite material for this project.
- The laminates each will be tested for three-point flexural / bending test on 100 N, 200 N, 300 N, 400 N, 500 N, 600 N, 700 N and 800 N.
- Three different forms of symmetric orthotropic composite laminates are investigated which is balanced laminate, quasi-isotropic laminate and unidirectional laminate.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In our today's modern society, because of its excellent strength/stiffness-to-weight ratios, carbon fiber reinforced composites have become more popular in aerospace and aviation. The failure mechanisms of layered composites, on the other hand, make it difficult to design and deploy composites. Delamination is often regarded as a significant failure mechanism that has a major impact of composite structures on its stiffness and strength. Furthermore, when composites are used to stiffen panels of aeroplane structures, they are frequently subjected to compressive pressures, which can result in complex interactions between buckling, post buckling, and delamination development. It is critical to develop reliable numerical methods for predicting composite buckling and post buckling behaviours, as well as delamination mechanisms.

2.2 Composite Material

Composites existed long before they were technically discovered. Long cellulose fibres are bound together by the presence of lignin in a block of plywood turns it into a composite. A composite is a substance that is made up of two or more constituents. Reinforcement, matrix, and interface are the three essential parts of a composite, where the interface would be the surface of contact between both the matrix and the reinforcement, and reinforcement is used to bear load. A hardener/accelerator is frequently used to facilitate component binding. Composites are classified into four groups based on their respective matrix medium: carbon/carbon composites, ceramic matrix composites, metal matrix composites, and polymer matrix composites (PMCs). In the meantime, interest for PMCs is increasing, especially for those with superior mechanical properties. Due to its wavy fibres, PMCs, on the other hand, lack compression strength. Epoxy resin/epoxy carbon bonded with carbon fibre has displayed exceptional mechanical properties in aerospace and automotive applications (Kishore et al., 2021).

Pre-impregnated with an epoxy resin, a series of high-performance woven prepregs is available in carbon fiber and fiberglass. Woven prepregs, unlike unidirectional prepregs, provide strength in various directions and are available in plain weave, satin weave, and twill weave patterns. Prepregs are frequently stored in the freezer, but if that isn't an option, you may pick from one of our Room-Temperature Storage Prepregs. In addition, there is now a comprehensive line of prepreg production technologies on the market, including autoclave, compression, and oven curing capabilities. The word "prepreg" refers to a reinforcing fabric that has been pre-impregnated with a resin system employing catalysed resin under pressure, temperature, or solvents with various weave patterns, fibre kinds, and other factors. The required curing agent is already included in this resin system (usually epoxy). The hardening agent for the resin system, which is added to the carrier material in a predetermined concentration, is calibrated such that the materials may be maintained at room temperature for several days or months without reacting, but they must often be kept cold to ensure processing quality. As a consequence, the prepreg is ready to be inserted into the mould without the need for any more resin. It is required to apply a mixture of pressure and heat in order for the laminate to cure. Furthermore, the applications for carbon fibre prepreg are as diverse as the product itself. It can be processed in a variety of ways, or it can be customised for each job. High-quality optical applications and structural or flame-retardant composite components are among the uses for our prepreg.

In research from Ramesh et al., the propeller's deformation can also be used to determine the appropriate material. In order to extend the scope of the FSI analysis to all carbon fiber-based composite materials, the low deformed perspective was also examined. In this perspective, carbon UD-Prepreg is responded with minimal deformation in comparison to other materials. Table 2.1 presents an analysis and listing of all structural data. Figures 2.1 show the bi-directional carbon fiber-based composite structural results. The related parameters are deformation, equivalent stress, and normal stress, respectively (2021).

Table 2. 1 Comparitive structural output of CFRP materials

SI. No	Material Name	Total Deformation (µm)	Equivalent Stress (Pa)	Normal Stress (Pa)
1	Epoxy Carbon UD – 230 GPa – Wet	4.8002	56119	30515
2	Epoxy Carbon UD – 230 GPa – Prepreg	4.3864	56410	28658
3	Epoxy Carbon Woven – 230 GPa – Wet	5.0932	55960	25512
4	Epoxy Carbon Woven – 230 GPa – Prepreg	5.4908	55590	26458

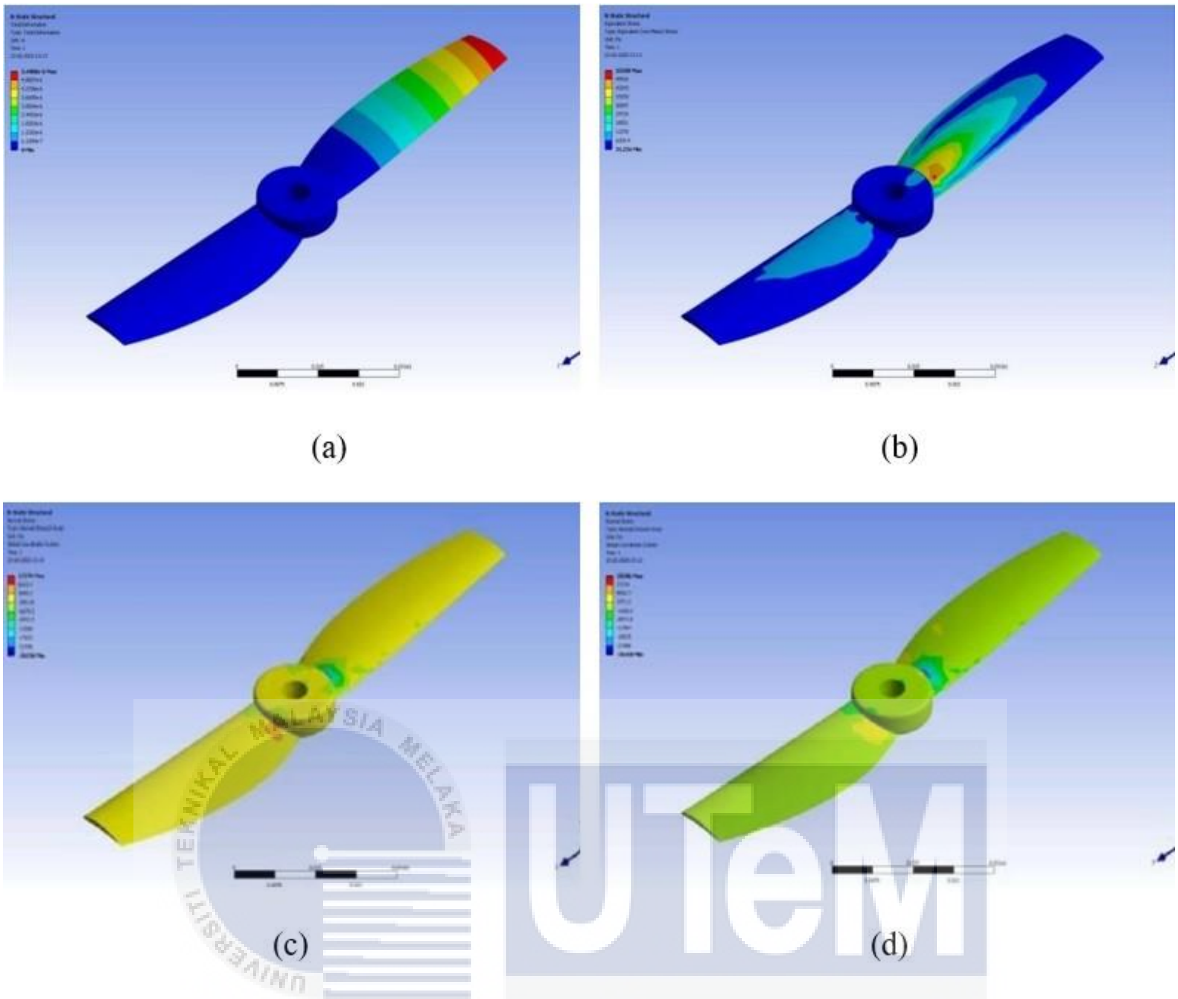

Figure 2. 1 (a) Variations of deformation of Epoxy Carbon UD – 230 GPa – Prepreg's Propeller, (b) Variations of equivalent stress of Epoxy Carbon UD – 230 GPa – Prepreg, (c) Normal Stress variations of Epoxy S-glass UD's Propeller & (d) Variations of normal stress of Epoxy Carbon Woven – 230 GPa – Prepreg

2.3 Composite Laminates

Due to the obvious complexity brought on by anisotropy and heterogeneity in the composite material where heterogeneity refers to the variation in the values of several factors such as permeability and porosity from one location to the next while anisotropy describes how a parameter's value changes with directions like a permeability has distinct values in the X, Y, and Z directions, the mechanical properties of composite materials still are a work in progress is cause for concern. Whenever more key elements such as stacking sequence and