I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor Engineering Mechanical Engineering (Structure & Material)

Signature : ....

Name of Supervisor : Mohd Juzaila Bin Abdul Latif

Date : May 7, 2007

INVESTIGATION OF MAXIMUM STRESS ON CARBON FIBER LAMINATE COMPOSITE WITH HOLE USING FINITE ELEMENT ANALYSIS (FEA)

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Thesis submitted to the Faculty of Mechanical Engineering
In partial fulfillment of requirements for the degree of
Bachelor Engineering Mechanical Engineering (Structure & Material)

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May, 2007

I declare that this thesis entitled "Investigation of Maximum Stress on Carbon Fibre Laminate Composite with Hole using Finite Element Analysis (FEA)" is the result of my own research except as cited in the references.

Signature : ....

Name : Nurul Fateen Binti Shukarnu

Date : May 04 , 2007

Dedicated to my loving parents

ACKNOWLEDGEMENT

In the name of Allah, the most gracious and the most merciful.

Thank to Allah swt for I had finished my final year project which I have put much effort in it. First of all, I am taking this chance to acknowledge my supervisor, En. Mohd Juzaila bin Abdul Latif for all his guidance, support and for helping me in doing my project as perfect as it has become. All his advice and knowledge he had teach me during this while is very precious to me in continuing this life journey. Not forgetting, thanks to Pn. Zuraidah binti Salleh from UiTM Shah Alam for her contribution in making this project a reality.

From my deepest heart, I wanted to thank my parents and family who have support me with their love and care when I feel like I am loosing my strength. Their never ending encouragement has brought me this far and keep me standing. Thank you for believing in me, accept me the way I am and inspired me to keep moving on in this challenging life.

Lastly, I wanted to thank all friends who have been very nice to me ever since we have known each other, along with this knowledge journey, being with me and taught me a lot of things.

All these love has indeed motivated me in some way, to be strong. Thank you.

ABSTRACT

This project investigates on the maximum stress and the difference of results achieved between simulation method and experimental method. Several constitutive equations are to be determined to present the relation of stress and strain in terms of stiffness and compliance matrices. Then, analysis of deflection for a cantilever beam (single layer composite) anisotropic elastic material was developed to compare the difference between analytical results and simulation results.

The simulation and experimental tensile test is brought up to compare the results of maximum stress on a carbon fiber laminated composite with and without hole. The laminate involve multi layer of lamina, placed in unidirectional and with different type of configuration. In simulation, analysis of a structure using the finite element analysis includes steps of preprocessing, processing and processing.

Preprocessing begins with the construction of specimen where geometry dimension and element is created. The material was then arranged sheet by sheet to create the composite material. Processing is where boundary condition and load is applied on the specimen and post processing is the final stage where analysis is done and result is achieved. Results are compared with the experimental results to validate the simulation results.

ABSTRAK

Projek ini mengkaji nilai tegasan maksimum pada bahan rencam melalui simulasi ujian tegangan serta mengesan perbezaan di antara nilai tersebut dengan nilai tegasan maksimum yang diperolehi melalui eksperimen. Beberapa persamaan asas digunakan untuk menunjukkan hubungan antara tegasan dan terikan dalam bentuk matrik tegasan dan terikan dan seterusnya, analisis lenturan bagi rasuk julur bahan anisotropik dibangunkan untuk membandingkan keputusan analitikal dan simulasi.

Komposit gentian karbon berlaminat terdiri daripada 10 lapisan lamina dan disusun dengan empat konfigurasi yang berbeza. Kaedah unsur terhingga digunakan dalam simulasi di mana ia melibatkan tiga langkah iaitu *preprocessing*, *processing* dan *post processing*.

Preprocessing dimulakan dengan memodelkan specimen di mana dimensi geometri dan elemen dibentuk. Bahan (gentian karbon dan gentian) pula dihasilkan dan di susun lapisan demi lapisan untuk menghasilkan bahan komposit. *Processing* adalah peringkat di mana keadaan sempadan serta beban dikenakan pada specimen manakala *post processing* adalah peringkat terakhir iaitu dengan menganalisa masalah dan mendapatkan keputusan. Keputusan simulasi kemudian dibandingkan dengan keputusan eksperimen untuk disahkan.

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LIST OF SYMBOLS

SYMBOL	DESCRIPTION
L	Length of specimen
W	Width of specimen
d	Diameter of hole
t	Thickness of specimen
P	Load applied to specimen
σ	Stress
ε	Strain
θ	Degree
I	Moment of inertia
E_1	Modulus in axial fiber direction
E_2	Modulus in transverse fiber direction
E_3	Composite modulus in a fiber (z) direction
ν_{AT}	Poisson's ratio in axial direction
ν_{TT}	Poisson's ratio in transverse direction
G_A	Fiber axial shear modulus
Q_{ij}	Stiffness matrix
S_{ij}	Compliance matrix
Q_{ij}	Transformed stiffness matrix
S_{ij}	Transformed compliance matrix
T	Transformation matrix
K_{IC}	Fracture toughness
σ_n	Maximum stress for specimen with hole
σ_{un}	Maximum stress for specimen without hole

SUBSCRIPT	**DESCRIPTION**
FEA	Finite Element Analysis
PMC	Polymer Matrix Composites
FRP	Fiber Reinforced Polymer
CFRP	Carbon Fibre Reinforced Plastics
GFRP	Glass Fibre Reinforced Plastics
ASTM	American Standard Testing and Material
ISO	International Standard Organization
CF	Carbon fibre
GF	Glass Fibre
2D	Two dimension (Planar)
3D	Three dimension (Solid)
x	Direction for x-axis
y	Direction for y-axis
$_{max}$	Maximum
4-2-4	Specimen with configuration 4FG-2CF-4FG
1-8-1	Specimen with configuration 1CF-8FG-1CF
5-5	Specimen with configuration 5FG-5CF
Alt	Specimen with configuration Alternate
$_{EXP}$	Experiment
$_{SIM}$	Simulation
$_{FEM}$	Finite element method

CHAPTER 1

INTRODUCTION

1.1 Background Study

A composite material refers to materials which have strong fibres, either continuous or non-continuous and is surrounded by a weaker matrix material. Fibres act as the reinforcement while the matrix serves to distribute the fibres and also to transmit the load to the fibres. In getting the mechanical properties of a composite material, the principal characteristic properties must be studied first so that range of result from any engineering problem can be predicted. This result which is obtained through experiments will be precise if it follows the standard test method.

The characteristic of a composite material is also important to be understood in order to produce the computational modeling of any engineering problem with finite element analysis (FEA). FEA commercial software works as the solver for engineering work that needs recommendation on creating a new design or altering any present design. This software is employed to build a model of layered fibre with the known shape, geometry and properties of the material. In completing this project, simulation of carbon fibre tensile test will be performed to investigate the maximum stress. The FEA results will be validated with experiment result that has been conducted by *Rahman N.A*

1.2 Objectives

The main objective of this project is to find the maximum stress of a tensile test simulation for carbon fibre laminate composite material, with and without hole. In order to complete this project, modeling of single layer and multi layer composite using FEA commercial software has to be understood. Next, the result from simulation using FEA will be compared with maximum stress that is obtained from experiment conducted in UiTM

Other objectives in this project are:

i) To understand the properties and characteristic of composite material
ii) To model different type of configuration for laminated composites which consist of carbon fibre and fibre glass
iii) To model a hole in laminate composite material and to model the tensile test for laminate composite material using FEA commercial software
iv) To study the effect of notch in tensile test for a composite material.

1.3 Research Scope

This project will focus on modeling a carbon fibre laminate composite material by using finite element commercial software. The finite element commercial software called MSC Patran and Nastran will be used in this project where the model of composite material will consists of carbon fibre and glass fibre. The model will be laminated with ten sheet of lamina where the laminate will be arranged sheet by sheet and with different type of configuration.

The laminate composite material will be model with and without hole and the simulation tensile test will be perform by using the FEA commercial software. Static analysis will be performed in this test where the result is assumed to be in elastic condition.

Maximum stress will be determined for the model which is subjected to tensile load at different hole size and laminate configuration. The result of simulation for tensile test of these laminate composite materials will be compared with the result from the experimental results that has been conducted by by *Rahman N.A*. The effect of notch and different type of configuration in tensile test will also be studied. FEA software should give the same result with the experimental result if it follows the standard test method.

CHAPTER 2

COMPOSITE MATERIAL

2.1 Introduction

Composite material have become important over the past 50 years, and are now the first choice for fabricating structures where low weight in combination with high strength and stiffness are required. Egyptians are credited for the earliest records with the introduction of straw in mud to strengthening bricks and in medieval time, swords and armor were plated to add strength [Swanson. S.R]. Unlike metals, the material is made at the same time as the component where analyst must pay close attention to the fabrication of the structure. There are numerous different manufacturing techniques for composites including the hand lay-up, spray lay-up, pressure moulding, pultrusion and others more which can be found in *Barbero* and *Daniel G.*

Composite materials were constructed from two or more elements to provide a material that has different properties to the individual elements. Composite is considered to be one that contains two or more distinct constituents with significantly different macroscopic behavior and a distinct interface between each constituent. The constituent parts of a composite are the *matrix* and the *reinforcement*.

The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions, transfer load between reinforcement and also protects the reinforcement from the environment, abrasion and impact.

Reinforcement in the other hand, provides the strength and stiffness properties of a composite. This reinforcement is usually described as being either fibrous or particulate. A combination of reinforcing materials is useful to provide a multitude of composite properties, where the material characteristics are aligned with the required performance properties. **Figure 2.1** represents a commonly employed classifications scheme for composite materials which utilizes the designation for the reinforcement.

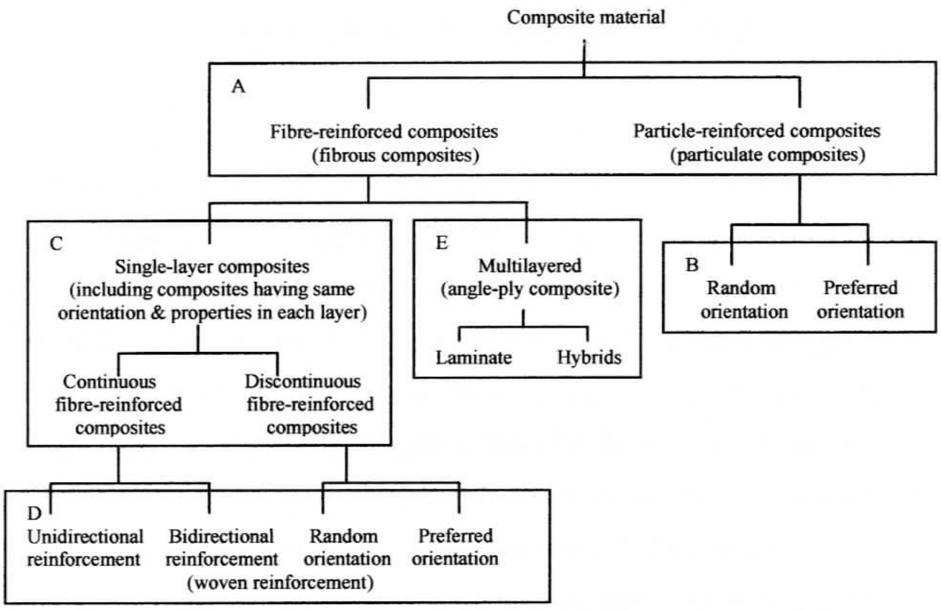

Figure 2.1 : Classification of composite materials.

The arrangement of the fibres can be as short strands of randomly orientated whiskers, a bundle of fibres, a unidirectional fabric, a woven fabric, a braid (tubular) fabric or a multi-axial fabric. **Figure 2.2** shows several sample of reinforcement fibre in a composite material where the texture is different from each other.

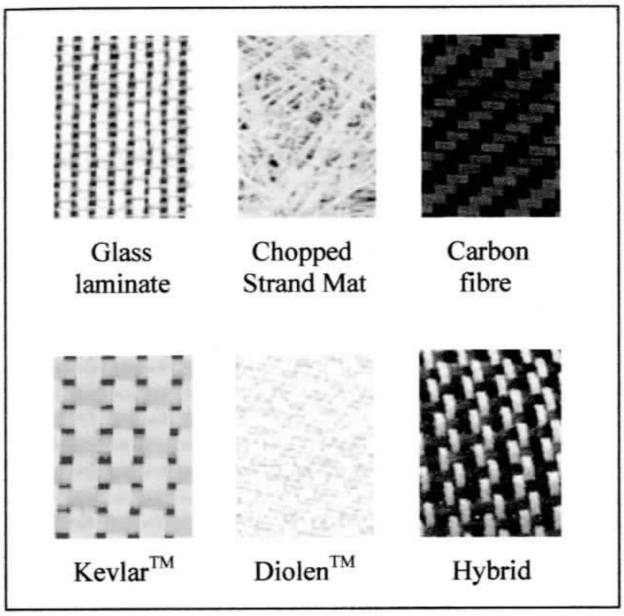

Figure 2.2 : Example of Reinforcement fibre

There are three types of composite materials; Polymer Matrix Composites (PMC's), Metal Matrix Composites (MMC's) and Ceramic Matrix Composites (CMC's). The widely used composite are PMC's, also known as FRP – Fibre Reinforced Polymers (or Plastics) use a polymer-based resin and variety of fibres as constituent and is mainly used in ambient temperature applications. MMCs are commonly used to increase the strength of low-density metals, increasingly found in automotive industry which use metal as the matrix and reinforced with fibres. CMCs use ceramic as the matrix and reinforced with short fibre or whiskers, for very high temperature applications which require high strength and toughness characteristics.

This project will concentrate on PMC where it uses a polymer-based resin as the matrix and fibre as the reinforcement. The matrix chosen is epoxy and the reinforcement of this laminate will consists of two types, carbon fibre and fibre glass.

2.2 Polymer Matrix Composites

Polymer Matrix composite which is sometimes called reinforced plastic composite consists of fibre reinforcements embedded in a resin matrix and is also known as Fibre Reinforced Polymers (FRP). These materials use a polymer-based resin as the matrix and fibre as the reinforcement.

Resin systems such as epoxies and polyesters have limited use since their mechanical properties are not very high. However, their ability to be easily formed into complex shapes is one of its desirable properties. Materials such as glass, carbon and boron have high tensile and compressive strength but these properties are not readily apparent in solid form. Producing it in fibre form (and in a bundle) will reflect the optimum performance of the material. However, fibre alone can only exhibit tensile properties along its length, in the same way as rope.

Combining a resin system and reinforcing fibres to made PMC's will change the properties of the resulting composite material where it combines properties of the resin on its own with that of the fibres on their own. Resultant composite are superior to metals for many applications for its high strengths and stiffness, high environmental resistance and ease of moulding complex shapes.

Composite parts can also be built to withstand stresses in a particular direction by aligning the fibre reinforcements along that direction, and by adding extra fibres only in high stress areas. This saves additional weight by removing unnecessary material from areas with little stress.

2.2.1 Matrix

Resin can be classified in thermoplastic and thermosetting type. This study use thermosetting type, which is a plastic that cures from a liquid to a solid through a chemical reaction of its two components. In matrix-impregnated fibre bundles, matrix acts to bridge around individual fibre breaks, so that the fibre quickly picks up load-carrying ability. Here, fibres only have to carry an increased load over a small axial distance.

Common types used to provide the composite matrix are polymers such as Polyester, Vinyl ester, starch and Epoxy. Polyester resins are the most widely used due to the fact that they can be used to construct composites without the need to introduce pressure. Vinyl ester resins are similar to polyesters but provide better resistance to chemical and water attack and also display improved toughness. Epoxy resins exhibit higher levels of mechanical strength and they can also be tougher to environmental attack.

The most interesting aspects of fibre composites are the role of the matrix in determining tensile strength. As mentioned before, the load-carrying ability of fibre composites with relatively weak matrices is determined by the fibres. This means that the design for composites of this type must used fibres which they can carry the primary load. The matrix in other hand play a vital role in determining the tensile strength, as indicated by the experimental observation that the strength of matrix-impregnated fibre bundles can be in the order of a factor of two or higher than the measured tensile strength of dry fibre bundles without matrix impregnation. This can be found in the synergistic effect between fibre and matrix by *Swanson S.R*

2.2.2 Reinforcement

Reinforcing materials that are widely used for PMCs are glass, carbon, aramid and boron. This material, usually fibre is manufactured by deciding on the architecture, classified into four categories which are the discrete, continuous, planar interlaced (2-D) and fully integrated (3-D) structure. They can be aligned unidirectional, multidirectional or as various fibre weaves such as braided yarns, orthogonal fabrics or multidirectional weaves. **Figure 2.3** shows the architecture of reinforcing material.

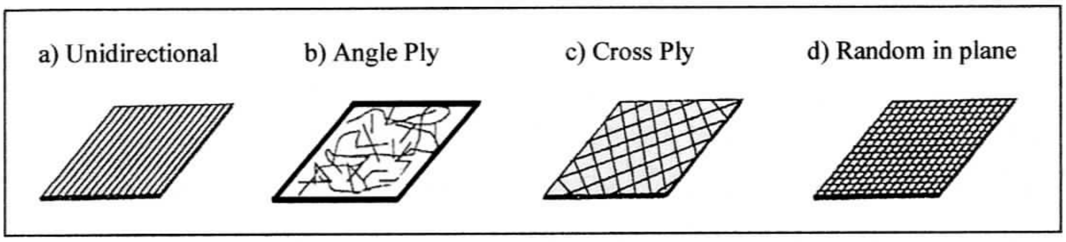

Figure 2.3 : Example arrangement of reinforcement fibre

Fibres are brittle and sensitive to surface imperfections that are randomly distributed over the length of the fibre. The strength of individual fibres varies widely and can show reductions in strength with increasing length. This characteristic is modified with the addition of the matrix where it surprisingly has increased the strength of a fibre bundle by as much as a factor of two. [*Swanson S.R*]

The composite material used in thist project consists of carbon fibre and glass fibre as the reinforcement which they are aligned in unidirectional. Continuous filament or unidirectional system is used in this project because it have several quality such as :

- Highest level of fibre continuity and linearity
- Highest level of property translation efficiency
- Suitable for filament-wound and angle-ply-tape layup structure.

i.Carbon Fibre

Carbon fibre, also called graphite fibres is a modern reinforcement that is extremely light weight, strong, and stiff with excellent chemical resistance. The properties of carbon fibres depend on the raw material and the process used for its manufacture. The base materials used for producing the fibre are polyacrylonitrile (PAN) and pitch or cellulose. Pitch fibres are less expensive but have lower strength than PAN fibres. Modifying the fibre production processes produces different classes of fibre which is classified with high strength or standard modulus (HS), intermediate modulus (IM), high modulus (HM), and ultra high modulus (UHM).

Carbon Fibre Reinforced Plastic (CFRP) can be the most expensive of the reinforcing fibres and the used often limits to parts needing selective reinforcement or high stiffness with the least weight. CFRP is expensive since it used carbon fibre which is extremely strong in resisting load. Parts made with carbon fibre as the only reinforcement fibre can be brittle, and susceptible to impact damage. **Figure 2.4** shows sample of carbon fibre in a unidirectional arrangement which is used to make laminate composite material in this project.

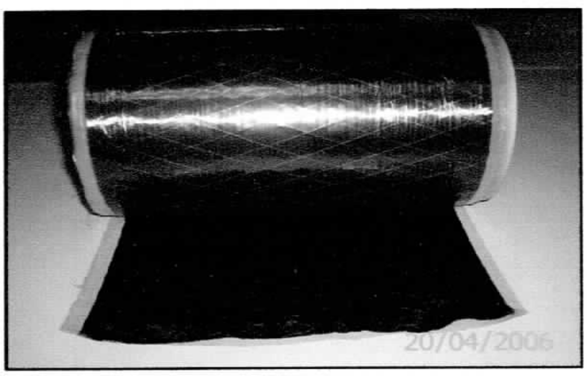

Figure 2.4 : Unidirectional Carbon Fibre before laminate