FAILURE ANALYSIS OF NOTCHED COMPOSITE PLATES WITH BUSHINGS

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I dedicate this project to my wife and family, who offered me unconditional love and support throughout the course of this thesis

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ABSTRACT

Fiber reinforced composite structures are widely used in the aerospace, aircraft, civil and automotive applications due to their high specific modulus and high specific strength. These applications require the joining of the composite structures. In mechanically fastened joints holes should be drilled, and the stress concentration around the holes leads to significant reduction in the strength of composite laminates. Bushings are installed to improve the strength of the laminates. Based on finite element calculations, the effect of bushing installation on the failure characteristics of laminates was investigated in this thesis. The Tsai-Wu failure criterion was used for failure calculations. A carbon epoxy laminate subjected to 0.4 mm pin displacement was simulated through different models with and without bushing. Also, the established samples had different orientations which were $[0\ 45\ {-45}\ 90]_s$ and $[90\ 45\ {-45}\ 0]_s$ in order to study the influence of stacking sequence of layers on the laminate strength. The results showed a great improvement in load carrying capacity of samples with bushing due to the introduced bushing compressive load which postponed the failure. Moreover, the laminate with bushing and $[90\ 45\ {-45}\ 0]_s$ orientation showed higher strength compared to the $[0\ 45\ {-45}\ 90]_s$ laminate. The obtained results of the laminate orientation effect were matched with experimental test results.

ABSTRAK

Sturuktur diperkukuhkan gentian adalah digunakan secara meluas di dalam industry aero angkasa, penerbangan, kejuruteraan awam dan automotif disebabkan nilai spesifik modulus dan kekuatan spesifik yang tinggi. Di dalam sambungan yang disambung secara mekanikal tebukan lubang adalah diperlukan, dan penumpuan tekanan pada lubang akan mengakibatkan pengurangan yang signifikan terhadap kekuatan laminar komposit. Sesendal digunakan untuk menambahkan kekuatan lamina.Berdasarkan pengiraan elemen terhingga, kesan penggunaan sesendal terhadap kegagalan lamina dikaji di dalam tesis sini.Kriteria kegagalan Tsai-Wu digunakan untuk pengiraan kegagalan bahan.Satu lamina epoksi karbon dikenakan anjakan pin 0.4mm dan kemudiannya disimulasikan dengan model yang berbeza; dengan dan tanpa sesendal. Sampel juga mempunyai dua orientasi yang berbeza iaitu $[0\ 45\ -45\ 90]_s$ dan $[90\ 45\ -45\ 0]_s$ bagi mengkaji kesan susunan lapisan kepada kekuatan lamina. Keputusan menunjukkan peningkatan yang ketara terhadap kapasiti membawa bebanan pada sampel dengan sesendal disebabkan adanya kemuatan daya tekanan pada sesendal; yang menambahkan tempoh sebelum kegagalan bahan. Tambahan lagi, lamina dengan sesendal dan mempunyai orientasi $[90\ 45\ -45\ 0]_s$ menunjukkan kekuatan yang lebih tinggi berbanding orientasi lamina dengan susunan $[0\ 45\ -45\ 90]_s$. Keputusan kesan orientasi lamina yang diperolehi dibandingkan dengan keputusan ujian eksperimen.

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LIST OF SYMBOLS AND ABBREVIATIONS

CFRP	Carbon fiber reinforced polymer
GFRP	Glass fiber reinforced polymer
UDC	Unidirectional composite
FEM	Finite element method
XFEM	Extend finite element method
SMC	Sheet molding compound
BMC	Bulk molding compound
et al.	And others
SL	Single layer
DL	Duplex layer
e.g.	For example
etc.	And so on

CHAPTER 1

INTRODUCTION

1.1 Introduction

The advent of the composites as a distinct classification of materials began during the mid-20th century with the manufacturing of deliberately designed and engineered multiphase composites such as carbon or glass fiber reinforced polymers. Fiber reinforced composite materials have been widely used in aircraft and space structures because of their high specific modulus and high specific strength. As the use of composites has become popular in recent years, the design of the composite joints has become a very important research area. Also, improper design may lead to overweight of defective structures. These joints transfer loads between composite components and other composite or metallic parts.

There are three main methods for joining composite structures namely, bonding, mechanically fastened or a combination of the two. Among the different techniques for joining structural members, mechanical fastening through a pin or bolt is a common preference owing to low cost, simplicity, and facilitation of disassembly for fix. Opposing many metallic structural parts, for which the strength

of the joints is mainly governed by the shear and tensile strengths of the pins or bolts, composite joints present specific failure modes because of their heterogeneity and anisotropy.

Despite of aforementioned advantages, mechanical joining of composite structures requires holes to be drilled. These holes cause complicated stress concentration in the vicinity of the boundary of the holes, and thus significant reduction of load carrying capacity of the composite structure.

Thus, to improve mechanical behaviour of notched composite plates bushings can be used. The bushing is an interference fit in that the bushing outside diameter is larger than the hole diameter. This can be done by shrink fitting - a liquid nitrogen bath for the bushings - followed by quick and careful installation. The other method is to swage them in with a tapered mandrel.

Reliable analysis methods are required to predict accurately the behaviour and strength of bolted joints in composite structures without systematic use of experimental data. Pinned joints represent a particular case of bolted joint when there is no clamping force. With using the finite element (FE) analysis, the progressive damage models can be developed and simulated to achieve greater predictive capabilities. The aim of this work is to present an up-to-date refined FE model for fastened composite pinned joints including bushings. The model is based on a 3D progressive failure approach.

1.2 Problem statement

Based on literature review and importance of higher joint efficiency in composite structures, there are some significant reasons to carry out this project. Holes often occur in aircraft structures. After taking holes, the stress concentration is produced around the hole region, and it has a significant effect on the strength of the

composite laminates. The stress concentration depends on the geometric shape, size of the open hole and the size of round corner in the changed section [1].

Bearing and delamination which is a separation of fiber and matrix can happen as a result of high stress concentration at the vicinity of a pinned hole which weakens the strength of the composite laminates.

Although other investigations were done by many researches about failure analysis of fiber reinforced composites, there are not enough available results about composite plates with bushings.

1.3 Objective of the study

This project focuses on evaluation and prediction of failure state in composite plates due to the finite element method. Damage of composite laminates containing holes will be calculated with the Tsai-Wu failure criterion. The effect of load increments and stacking sequence on the failure of the composite structure will be discussed in this thesis.

1.4 Scope of the Study

The scope of study for this research is described in the following lines. Generation of appropriate finite element models based on MSC Marc was the first step. Then, the application of appropriate failure criteria was the next important step. The next step was the evaluation of the damage field in composites with and without bushings. Moreover, the effect of stacking sequence on strength, and damage zone was investigated. After all the prediction of the failure in different samples, this documentation was done.

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