UNIVERSITI TEKNOLOGI MARA

NUMERICAL SIMULATION OF FAILURE PREDICTION ON COMPOSITE LAMINATES WITH VARIOUS CUTOUT SHAPES UNDER UNIAXIAL TENSION AND COMPRESSION

NURDALILAH BINTI NOORDIN

Thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
(Mechanical Engineering)

College of Engineering

November 2022

ABSTRACT

In the era of modern structures, composite laminates are widely used and have become progressively trending due to its tailorable of material properties. Nevertheless, due to the complex fibre-matrix interaction added by the existing cutouts, it is complicated to figure out the failure mechanism and deformation behaviour of composite laminates. In reality, the application of cutout shapes is found practical for many composite structures. Practically, the failure behaviour of composite laminates with and without cutouts involves a lot of data; therefore, it is crucial to be predicted thoroughly and accurately. Based on literature review, the studies on the failure prediction of various cutout shapes to the composite laminates are limited. This study aims to predict the failure behaviour of Graphite/Epoxy and Kevlar/Epoxy with various cutout shapes under uniaxial tension and compression due to the variations of fibre orientations. The two main stages of this study involved the prediction of laminate failure using finite element simulation software (ANSYS); and then the prediction of laminate failure using Artificial Neural Network (ANN) from the simulated data. Prior to that, mesh convergence analysis and numerical validation were carried out. The studied composite laminates consisted of 24 layers with the symmetric angle-ply lamination scheme of $[\theta_4/0_4/-\theta_4]_s$, where θ ranges from 0^o to 90^o. Maximum Stress Theory and Tsai-Wu criterion were employed to determine the failure load. These data of failure loads were then input into ANN tools in MATLAB software for training, validating and again predicting the failure loads similar to the case studies developed earlier using ANSYS. Comparing the predicted loads from both approaches (ANSYS and ANN) for the same case studies, the results show that the difference is found to be less than 5%. In analysing the effect of fibre orientation on the laminate without cutout, increasing the angle will reduce the strength of the composite laminates. In terms of analysing the effect of cutouts and materials, results showed a noticeable strength difference between composite plates with and without cutout. The results show that the determined failure load for Graphite/Epoxy, UD Kevlar/Epoxy and Woven/Epoxy laminates range from 210 MPa to 1700 MPa, 101 MPa to 1380 MPa, 88.7 MPa to 420 MPa respectively for the cases of laminates without cutout. For the cases of laminates with circular cutouts, the determined failure load for Graphite/Epoxy, UD Kevlar/Epoxy and Woven Kevlar/Epoxy laminates ranges from 10 MPa to 57.9 MPa, 6.08 to 101 MPa, 19.8 to 64.9 MPa respectively. For the cases of laminates with diamond cutouts, the determined failure load for Graphite/Epoxy, UD Kevlar/Epoxy and Woven Kevlar/Epoxy laminates ranges from 7.2 MPa to 45.8 MPa, 4.5 MPa to 75 MPa, 16.2 MPa to 54 MPa respectively. It is interesting to observe that the strength of Graphite/Epoxy, UD Kevlar/Epoxy and Woven Kevlar/Epoxy composite laminates has reduced up to 99.5%, 99.6% and 89.0% respectively due to the existence of the cutouts. In general, this information is important in designing practical composite structure where cutouts often exist. In conclusion, the close agreement between simulation and ANN prediction proves that both approaches could complement each other. The main idea of simulation is to reduce tedious and costly physical tests, especially on composite materials. The main idea of predicting using ANN is to further reduced the number of physical tests and simulation. This proves that the present study is useful and has significantly contributed new fundamental knowledge in predicting the failure behaviour of composite laminates with cutouts using simulation and its alternative solution using ANN.

ACKNOWLEDGEMENT

First and foremost, praise be to ALLAH S.W.T., the Almighty, the Beneficent, on whom we ultimately rely for nourishment and guidance. I would want to express my gratitude to Almighty Allah for providing me with the opportunity, determination, and strength to complete my research. Throughout my life, and especially during the course of my studies, His constant love and mercy were with me.

Now, I would like to offer my heartfelt gratitude to my supervisor, Prof. Ir. Dr. Jamaluddin Mahmud and co-supervisor, Dr. Abdul Malek Abdul Wahab for their good advice and support. I am so grateful that they have shown great patience in guiding me and have put lots of effort. It is an honour for me because without their guidance, I would not be able to write and complete the thesis.

I would like to thank my wonderful friends and every person who were involved in helping me to complete the thesis. Some of them shared their thoughts and suggested valuable ideas that gave a large impact on my study. I really appreciate their willingness to help me. Without all their support, it would not have been possible to achieve the goals and become successful in completing the thesis.

Lastly, I would like to give special thanks to my beloved family for keep supporting me throughout this journey. Even though there were a lot of obstacles, they never forget or left me behind. This work would never have been possible without their motivation. I owe everything to my family, who have supported and encouraged me throughout my personal and academic lives and have a strong desire to see this achievement come true. This work is dedicated to my lovely mother and my sincere and generous father. Every breath I take and every drop of blood I shed is for my family.

TABLE OF CONTENTS

		Page
CONFIRMATION BY PANEL OF EXAMINERS		**ii**
AUTHOR'S DECLARATION		**iii**
ABSTRACT		**iv**
ACKNOWLEDGEMENT		**v**
TABLE OF CONTENTS		**vi**
LIST OF TABLES		**ix**
LIST OF FIGURES		**x**
LIST OF SYMBOLS		**xiii**
LIST OF ABBREVIATIONS		**xv**
CHAPTER ONE INTRODUCTION		**1**
1.1	Research Background	1
1.2	Problem Statement	3
1.3	Objectives	5
1.4	Scope and Limitation of Study	5
1.5	Significance of Study	6
CHAPTER TWO LITERATURE REVIEW		**8**
2.1	Overview	8
2.2	Composite Materials	9
2.3	Composite Laminates	11
2.4	Lamination Theory of Composite Materials	12
2.5	Composite Plates with Cutouts	15
2.6	Failure Analysis of Composite Laminates	16
2.7	Failure Criteria of Composite Laminates	18
	2.7.1 Maximum Stress Theory	18
	2.7.2 Tsai Wu Criterion	19
2.8	Mechanical Tests	19
2.9	Finite Element Analysis	21

2.10 Artificial Neural Network (ANN) 27
2.11 Research Gap 30

CHAPTER THREE RESEARCH METHODOLOGY 32
3.1 Overview 32
3.2 Stage 1: Mesh Convergence Analysis and Numerical Validation 34
3.2.1 Defining the Materials 36
3.2.2 Meshing and Boundary Conditions 37
3.2.3 Mesh Convergence Analysis 37
3.2.4 Numerical Validation 38
3.3 Stage 2: Failure Analysis 41
3.3.1 Finite Element Analysis (FEA) procedure using ANSYS APDL 45
3.4 Stage 3: Data Prediction using Artificial Neural Network (ANN) 47
3.5 Analysis of Error (Difference Percentage) 50

CHAPTER FOUR RESULTS AND DISCUSSION 51
4.1 Introduction 51
4.2 Results of Mesh Convergence Analysis 52
4.2.1 Composite Laminates with No Cutout 52
4.2.2 Composite Laminates with Circular Cutout 53
4.3 Results of Numerical Validation 54
4.4 Failure Analysis using ANSYS 57
4.4.1 Failure Behaviour of T300/5208 Graphite/Epoxy 57
4.4.2 Failure Behaviour of UD Kevlar/Epoxy 63
4.4.3 Failure Behaviour of Woven Kevlar/Epoxy 69
4.5 Predicted Data based on Artificial Neural Network (ANN) 76
4.6 Results for Percentage Difference Analysis 81

CHAPTER FIVE CONCLUSION AND FUTURE WORK 84
5.1 Overview 84
5.2 Conclusion 84
5.3 Recommendations for Future Works 86