UNIVERSITI PUTRA MALAYSIA

DESIGN AND FABRICATE FILAMENT WINDING MACHINE AND ANALYSIS OF COTTON/EPOXY AND PANDANUS/EPOXY

ELSADIG MAHDI AHMED SAAD

DESIGN AND FABRICATE FILAMENT WINDING MACHINE AND ANALYSIS OF COTTON/EPOXY AND PANDANUS/EPOXY

ELSADIG MAHDI AHMED SAAD

MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA
1997

DESIGN AND FABRICATE FILAMENT WINDING MACHINE AND ANALYSIS OF COTTON/EPOXY AND PANDANUS/EPOXY

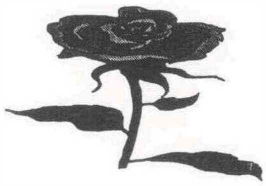
By

Elsadig Mahdi Ahmed Saad

Thesis Submitted in Partial Fulfilment of the Requirements for the Degree Of Master of Science in the Faculty of Engineering, Universiti Putra Malaysia

September 1997

To My Great Parents



Mahdi Ahmed Saad

Elsaida Elshiekh Abd Elmahmoud

ACKNOWLEDGEMENTS

My deep thanks go to my Supervisor Associate Prof. Dr. Barkawi Bin Sahari to his support, guidance and encouragement throughout this work.

It is very generous of Dr. Yousif Khalid to his indeed helps through out this work. I acknowledge the help from the Head Department of Mechanical and Manufacturing Engineering, Dr. Shamsuddin Sulaiman, whose support is also appreciated. I am very grateful to, Puan Mahyon, Tajularifin, Mohammed Rashid, Sharani, Ahmed Shaifuldeen and Zulkifli for their serving as technicians.

I would like to thank my great family members for their kinds and full support in my study.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS...iii
LIST OF TABLES...vii
LIST OF FIGURES...viii
LIST OF PLATES...xii
NOMENCLATURES...xiii
ABSTRACT...xvi
ABSTRAK...xviii

CHAPTER

I **INTRODUCTION**...1

Pandanus...3
Cotton...4
Objectives...4

II **LITERATURE REVIEW**...6
Composites Material Constituents...6
Fibre Reinforcement...6
Natural Fibres...7
Natural Fibres Production...7
Chemical Structure of Cotton Fibre...8
Mechanical Properties of Natural Fibres...9
Matrix...11
Types of Matrix...12
Selection of Matrix...12
Polymeric Matrix...12
Mechanics of Fibre-Reinforced Composites...15
Properties of Orthotropic Materials...16
Determination of Longitudinal Modulus...16
Determination of Transverse Young's Modulus...19
Determination of Major Poisson's Ratio...19
Determination of In-Plane Shear Modulus...20
Determination of E_{33}, G_{13}, ν_{13}, G_{23} and ν_{23}...20
Stress-Strain Relationship...21
Structural Behaviour...25
Plane Stress...25
Laminated Structure...27
Lamination Theory...28
Prediction Methods...29

Fabrication Process 32
Automation of Manufacturing Polymer Composites..........32
Filament Winding Process (FWP)..........................33
Conventional Filament Winding 33
Classification of Filament Winding Process..........34
Bag Moulding Process (BMP)..........................36
Compression Moulding Process (CMP)..........................36
Pultrusion Process (PP)..........................37
Resin Transfer Molding (RTM)..........................37
Structural Reaction Injection Molding (SRIM)..........................38
Structural Applications 38
Conclusion 39

III **MONOFILAMENT WINDING MACHINE** 40
Design Analysis and Fabrication of Mono-Filament Winding Machine Components 40
Design Analysis of Components 40
Setting of Monofilament Winding Machine 43
Winding Process 45
Types of Winding Patterns 45
Machine Components Analysis and Calculation 46
Tension Device 48
Left Guide Pulley 50
Guide Pulley Shaft 51
Guide Pulley Stand 52
Rectangular Weld 53
Right Guide Pulley 56
Machine Performance 57
Testing Procedure 58
Results on Machine Testing 59
Circularity of the Fabricated Tubes 60
Discussion 64
Conclusion 65

IV **EXPERIMENTAL WORK** 68
Testing Criteria 68
General Requirements and Shape of Test Specimens 69
Material Description 70
Preparation of Specimen 71
Flat Specimens for Tensile Test..........................71
Tubes for Internal Pressure Test 71
Tubes for Compression Test 72
Preliminary Results 72
Failure Prediction Under Uniaxial Loading 74
Maximum Stress Theory 74
Maximum Strain Theory 75

Experimental Techniques 77
Experimental Testing Results 78
Internal Pressure Test Results 78
Compression Test Results 80
Tensile Test Results 90
Discussion 95

V **FINITE ELEMENT ANALYSIS TECHNIQUES** 96
PAFEC Modules for Composites 96
Material Properties 97
Mesh and Boundary Conditions 98
Case 1: $\theta=90^0$ 99
Case 2: $\theta=80^0$ 100
Discussion 103

VI **DISCUSSION** 105

VII **CONCLUSION** 109

VIII **RECOMENDATION FOR FURTHER STUDY** 111

REFERENCES 112

APPENDICES 115

VITA 131

LIST OF TABLES

Table		Page
1	Annual Fibre Production / Availability of some of the Natural Fibres (Tones)	10
2	Mechanical Properties of Some Natural Fibres	10
3	The Contracted Suffix	23
4	Relationship between the Parameters and the Carriage Speed	62
5	Machine Performance	62
6	Material Properties	70
7	Maximum Stress and Maximum Strain Theory for cotton /epoxy	76
8	Internal Pressure Test Results	78
9	Results for cotton/epoxy Tube with fibre Diameter 0.333mm of Uniaxial Compression Test Results	80
10	Results for cotton/epoxy Tube with fibre Diameter 1mm and Pandanus/epoxy of Uniaxial Compression Test Results	81
11	Results for Uniaxial Tensile Test	90
12	Results for Axial Displacement of Cotton/epoxy Composites Cylinders	100
13	Results for Axial Stresses of Cotton/epoxy Composites Cylinders	100

LIST OF FIGURES

Figure		Page
1	Chemical Structure of Cellulose	9
2	Relationship between the Strength of Natural Fibres and their Cellulose Contents and Microfibril Angle	11
3	Principal in Preparation of an Epoxy Matrix	14
4	Tensile Loading of Continuous Parallel Fibres Lamina	18
5	Orthotropic Lamina with Principal co-ordinate System	22
6	Three- Dimensional State of Stress	23
7	Compliance Coefficient s_{ij}	24
8	Definition of Principal Material axes and Loading Axes for Lamina	26
9	Unidirectional Laminate	27
10	Angle-Ply Lamina	27
11	Cross-Ply Lamina	28
12	Laminate Geometry	29
13	The Present Monofilament Winding Machine	41
14	Reduction of Winding Speed through a Set of Pulleys	44
15	Schematic of Helical Winding Pattern	47
16	Resin Pot	48
17	Scissors Bar Controlling Fibre Tension	49
18	Minimum Tension	49
19	Maximum Tension	50

20	Guide Pulley	50
21	Guide Pulley Shaft	51
22	Guide Pulley Stand	53
23	Side Elevation of the Rectangular Weld	54
24	Plan View of a rectangular Weld	55
25	Theoretical and Actual Winding Phase for Tube with Diameter 5.08 cm	63
26	Theoretical and Actual Winding Phase for Tube with Diameter 7.62 cm	63
27	Theoretical and Actual Winding Phase for Tube with Diameter 12.7 cm	64
28	Flat Tensile Test Specimen	71
29	Loading Scheme of Tubes with Internal Pressure Test	72
30	Composite Tube Specimen Dimension	72
31	Stress-Strain Curve of Maximum Stress Theory with Uni-axial Strength data of Cotton/Epoxy	76
32	Stress-Strain Curve of Maximum Strain Theory with Uni-axial Strength data of Cotton/Epoxy	77
33	Hoop stress of Cotton fibre composites Tubes	79
34	Load-Displacement Curve of 50.8mm Diameter Cotton/Epoxy hoop (90^0) Laminated Tube	83
35	Load-Displacement Curve of 50.8mm Diameter Cotton/Epoxy 80^0 Laminated Tube	83
36	Load-Displacement Curve of 76.2mm Diameter Cotton/Epoxy hoop (90^0) Laminated Tube	84
37	Load-Displacement Curve of 76.2mm Diameter Cotton/Epoxy 80^0 Laminated Tube	84
38	Load-Displacement Curve of 127mm Diameter Cotton/Epoxy hoop (90^0) Laminated Tube	85

39 Load-Displacement Curve of 127mm Diameter Cotton/Epoxy 80^0 Laminated Tube 85

40 Load-Displacement Curve of 127mm Diameter Largest Fibre Diameter Cotton/Epoxy hoop (90^0) Laminated Tube 86

41 Load-Displacement Curve of 50.8mm Diameter Pandanus/Epoxy hoop (90^0) Laminated Tube 86

42 Load-Displacement Curve of 90^0 Laminated Flat Tensile Specimen.....92

43 Load-Displacement Curve of 80^0 Laminated Flat Tensile Specimen.....92

44 The Mesh of the Structure 98

45 The Deformed Structure of Hoop Tube 99

46 The Deformed Structure of 80^0 Laminated Tube 100

47 Displacement-Load Curves Laminated Tube1 102

48 Displacement-Load Curves of Laminated Tube2 102

49 Load-Displacement Curves of Laminated Tube3 103

LIST OF PLATES

Plate		Page
1	Machine Setup	66
2	Reduction of Winding Speed through a Set of Pulleys	66
3	Machine Products in Different Sizes	67
4	Computerised Minstral Machine used For measuring The Circularity of the Fabricated Tubes	67
5	Computerised Instron Machine	87
6	The Undeformed Stucture of Tube with Helix Angle 90^0	87
7	The Undeformed Structure of Tube with Helix Angle 80^0	88
8	The Deformed Structure of Cotton/Epoxy Laminated Tubes with Fibre Diameter =0333mm	88
9	The Deformed Structure of Cotton/Epoxy Laminated Tubes with Diameter =127mm	89
10	The Deformed Structure of Largest Fibre Diameter Cotton/Epoxy laminated Tubes with Diameter 127mm	89
11	The Deformed Structure of Pandanus /Epoxy laminated Tubes with Diameter 50.8mm	90
12	The Undeformed Structure of Flat Tensile Test Specimen with 90^0	93
13	Deformed structure of Flat Tensile Test Specimen with 90^0	93
14	Undeformed Structure of Flat Tensile Test Specimen with 80^0	94
15	Deformed Structure of Flat Tensile Test Specimen with 80^0	94

LIST OF ABBREVIATIONS

σ_{fu}	Fiber tensile strength
σ'_m	Matrix stress at the fiber failure strain
G_m	Matrix shear modulus
σ_y	Yield strength of mild steel bar
τ	Shear strength of mild steel bar
Y	Centroid of mild steel bar
A	Area of mild steel bar
I	Moment of inertia
J	Polar moment of inertia
J_u	Unit polar moment of inertia
T_1, T_2	Tension in fiber
c_1, c_2	Torsion constants for rectangular sections
μ	Factor of fiber friction
M	Moments
[Q]	Reduce stiffness matrix
$[\varepsilon(z)]$	Strain at any thickness coordinate z
$[\varepsilon^0]$	In-plane strain
ε_1, ε_2, ε_3	Normal strain in the 1, 2 and 3 direction
ε_4, ε_5, ε_6	Shear strain in the 2-3, 1-3 and 1-2 plane
A_{66}	Shear stiffness
E_{11}	Longitudinal modulus

E_{22}	Transverse modulus
E_{33}	Transverse Young modulus in the direction of laminate thickness
G_{12}	In-plane shear modulus
G_{13}	Transverse shear modulus
G_{23}	Transverse shear modulus in 2-3 plane
ν_{12}	Major Poison's ratio
ν_{21}	Minor Poisson's ratio
ν_{23}	Transverse poisson's ratio in 2-3 plane
$\sigma_1, \sigma_2, \sigma_3$	Normal stresses in 1, 2 and 3 directions
$\sigma_4, \sigma_5, \sigma_6$	Shear stresses in 2-3, 1-3 and 1-2 plane
d	Mandrel diameter
θ	Winding angle
N_6	Mandrel rotation speed
V	Carriage speed
E_f	Fiber Young's modulus
E_m	Matrix Young's modulus
ν_f	Fiber Poisson's ratio
ν_m	Matrix Poisson's ratio
V_f	Fiber volume fraction
V_m	Matrix volume fraction
d_f	Fiber diameter
s	Fiber spacing
G_m	Matrix shear modulus

k_σ	Stress concentration
S_{ij}	Compliance matrix
n	Number of layers
h	Thickness of layer
S_{Lt}	Longitudinal tensile strength
S_{Tt}	Transverse tensile strength
S_{Tc}	Transverse compressive strength
S_{LTs}	In-plane (intralaminar) shear strength
S_{Lc}	Longitudinal compressive strength
F	Force to move one surface over another
N	Normal force pressing the surface together

Abstract of Thesis Presented to the Senate of Universiti Putra Malaysia in Partial fulfilment of the Requirements for the degree of Master of Science.

DESIGN, FABRICATE FILAMENT WINDING MACHINE AND ANALYSIS OF COTTON/EPOXY AND PANDANUS/EPOXY COMPOSITES

By

ELSADIG MAHDI

September 1997

Chairman: Associate Professor Barkawi Bin Sahari, Ph.D.

Faculty: Engineering

This project concerned with filament wound cotton/epoxy and pandanus/epoxy composite tubes. Monofilament winding machine has been designed and fabricated. It is later used in fabricating the composite tubes. The performance of this machine was measured. The results revealed that the winding angle depended primarily on the carriage speed traversing at speed synchronised with mandrel rotation. Also, the efficiency of the machine showed that winding at high angles relative to rotational axis was very high (i.e. at 90^0 the efficiency is 100%). Winding at low angles (parallel to rotational axis) was difficult. The surface

finish depended on the fibre tension, the wiping process and band formation (i.e. smooth surface finish at 4.4 kN).

The behaviour of filament wound cotton/epoxy and pandanus/epoxy composite tubes was studied experimentally. Circular cylindrical of cotton/epoxy and pandanus/epoxy were loaded in uni-axial compression. The test results show that cotton/epoxy hoop tubes the maximum strength was found to be 13kN and for the 80^0 cotton/epoxy tubes was found to be 10.6kN. For the pandanus/epoxy hoop tube the maximum strength was found to be 0.3kN. Flat specimens were also prepared from wound tubes and loaded in uni-axial tension. The cotton/epoxy composite tubes were tested under internal pressure. The results show that the maximum pressure that the tube can be withstand was found to be 5 bar. Maximum stress and maximum strain theories are used to predict the failure of these tubes. Finite element method also used in the analysis of cotton/epoxy composite tubes. The uni-axial tensile test results show that the mean modulus was found to be 3867.6 MPa for the 80^0 laminated tensile test specimens and 1067.0 MPa for hoop (90^0) laminated tensile test specimens. The maximum strain mean in 80^0 and 90^0 laminated tensile specimens are essentially the same (0.1). The uni-axial compression test results show that in the condition of hoop (90^0) laminated tubes and 80^0 laminated tubes the load-displacement curve is linearly up to initial failure.

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

MEMBUAT, MEREKABENTUK FILAMEN MESIN PEMBALUT DAN PENGANALISAAN UNTUK KAPAS/EPOXY DAN PANDAN/EPOXY KOMPOSIT

Oleh

ELSADIG MAHDI

September 1997

Pengerusi: **Profesor Madya Barkawi Bin Sahari, Ph.D.**

Fakulti: **Kejuruteraan**

Kajian ini adalah berkaitan tentang filamen kapas pembalut luka/epoxy dan tiub komposit pandanus/epoxy. Mesin pemutar monofilamen yang telah direkacipta digunakan untuk membentuk tiub komposit. Prestasi alat tersebut telah disukat dan di dapati sudut putaran di pengaruhi oleh kelajuan pembawa yang bergerak pada halaju sama dengan halaju putaran mandrel. Selain itu, kecekapan mesin bertambah apabila sudut putaran relatif kepada paksi putaran adalah tinggi. (cth. pada sudut 90^{o}, kecekapan adalah 100%) Apabila sudut putaran adalah rendah (selari dengan paksi putaran), mesin sukar berputar.

Sifat permukaan bergatung kepada ketegangan gentian, proses mengelap dan formasi jalur. (cth. keadaan permukaan rata pada 4.4 kN)

Sifat filamen kapas pembalut luka/epoxy dan tiub komposit pandanus/epoxy telah dikaji secara percubaan dan teori. Silinder bulat bagi kapas/epoxy dan tiub pandanus/epoxy telah dikenakan beban dalam mampatan uniaxial. Spesimen yang mendatar di sediakan daripada tiub pembalut luka yang di kenakan beban dalam ketegangan uniaxial. Tiub komposit kapas/epoxy diuji di bawah tekanan dalaman. Teori ketegangan maksimum dan keterikan maksimum di gunakan untuk menentukan kegagalan tiub-tiub tersebut. Keadah elemen finite juga dicuba dalam analisis tiub komposit kapas/epoxy.

CHAPTER I

INTRODUCTION

Composite materials or advanced materials are a synergetic combination of two constituents, one called the matrix, and the other called the reinforcement. The matrix is the principal phase in which another constituents (e.g. reinforcement, particles, or fillers) are embedded or surrounded. The reinforcement is a material used to reinforce, strengthen or give dimensional stability to the matrix. For the purpose of differentiation between advanced materials and composite materials, advanced materials are classified as those materials made from higher modulus fibres (e.g. graphite, silicon carbide, aramid polymer, etc.). Composite materials are classified as those materials made from a relatively low modulus fibres (e.g. glass, cotton, sisal, jute, etc.).

There are many types of composite and advanced materials. Glass fibre is the most widely used reinforcement for composites. Glass/epoxy and glass/polyester are used in light applications. Graphite or carbon fibres are the most widely used advanced fibres and graphite/epoxy or carbon/carbon are now used routinely in aerospace structure. Boron/epoxy and boron/aluminium composites are also widely used in aerospace structures. Natural/epoxy composites such as sisal/epoxy, jute/epoxy and cotton/epoxy have a great potential in light applications requiring high toughness and sound absorption (Chen, 1996). Rigby (1996) reported that natural fibres can be used in medical or healthcare requirements because of their highly flexible and versatile. Natural fibres have attracted the attention of scientists and technologist in view of their advantages such as, low density with high specific strengths, abundantly available renewable resources and non-toxic.

The selection of composite fabrication process depends on the type of matrix be used (e.g. the process for polymer matrix, metal matrix and ceramic matrix) are quite different. Filament winding is a manufacturing process suited for fabrication of closed shape composite structures, such as cylinders and various tubular elements. Filament winding is comparatively simple operation in which continuous reinforcements in the form of roving or monofilament are wound over a rotating mandrel. The open mold process has two types, hand lay-up of woven fibre mat or chopped strand mat and spray-up. Prepreg tape is a tape consisting of fibres precoated with the polymer resin. Autoclave molding is simply a heated pressure vessel into which the mold is placed and subjected to the required temperature and pressure for curing. Sheet molding compound is an important innovation in composite manufacturing which is used extensively in automobile industry.

Pandanus

Pandanus are found in tropical areas and belong to PANDANANCEAE family. The roots are airy. The leaves are arranged radially outward, of 5 meters long and with spikes at the side and in the middle. In Malaysia, there are 37 types of pandanus, which grow every where, near the seaside, villages, riverbanks, forests, swampy areas and hills. 'Mengkuang' is *Pandanus* pectoris and this is the most widely used type for making grass-mats in Malaysia. In certain places mengkuang plants are grown. 'Pandan banor', 'pandan wangi' are *Pandanus odourus*. This *pandanus* has two types; big and small. Small types are normally grown and are between one and two meters high. The leaves are about 75 cm long and 4cm wide. Bigger types are between 4 and 5 m in height and its leaves are 225 cm in length and 8 cm in width. They are widely used for aromatic purposes. It is used as a flavour in bakeries and is one of the most important ingredient materials for flower. Other types are called 'Pandan batu' has no spikes like 'Mengkuang'. 'Pandan tetongkat' is the family name for all big type of pandanus with the supporting roots. Among all the 37 types of pandan in Malaysia not all are well researched and given the suitable scientific names. Some of the well known of pandanus are 'Mengkuang air', *'Pandonus immersus', 'Pandanus ornatus', 'Pandanus parvus' and 'Pandanus ridleyi'*. We can say that almost all parts of pandan plant are usable. Its leaves surely can be used as materials for decorations and some others. The long leaf of the pandan renders it suitable for making composite materials using filament winding.

Cotton

Cotton is chiefly cellulose with various other substances at or near the surface. Cotton grows in many countries such as U.S.A., Sudan, Egypt, Bangladesh, India, etc. The helix angle in cotton is 20 to 30 degrees (Stevan, 1995). Cotton fibres are on average 33mm long. The flat fibre twist, giving cotton fibre a natural texture. Cotton grade before melt when heated, because cotton has hydrogen bonds. To avoid this defect cotton is treated chemically. Chemically treated of cotton by NaOH, improved its tensile properties. Crystallinity in cotton is thought to range from 60-100%. The high crystallinity in cotton attracted the scientist to use cotton in many applications of composite and advanced materials (Pernard, 1983).

Objectives

The present study is focused on the cotton/epoxy and pandanus/epoxy, in this respect the aims of the current project are:

1. to design and fabricate helical monofilament winding machine.
2. to measure the performance of the helical mono-filament winding machine
3. to measure the mechanical properties of the natural fibre-reinforced polymer composites fabricated by the monofilament winding machine.
4. to determine the mechanical properties of pandanus fibre and its composite.
5. to predict the behaviour of composite tube using finite element method.

6. to measure the deformation and strength of natural composite tube, when subjected to an internal pressure.

The thesis is divided into eight chapters. A review of literature is presented in Chapter 2. Chapter 3 describes design, fabrication and performance of the helical monofilament winding machine, from the machine design concept to the performance testing results. The experimental work and preliminary test results of material fabricated are presented in Chapter 4. Chapter 5 is concerned with the results obtained for finite element analysis using the PAFEC software. The experimental results and theoretical results are presented and discussed in Chapter 6. The conclusion of the research is presented in Chapter 7. Recommendations for further work, based on findings from research program, are presented in Chapter 8.