



**UNIVERSITI PUTRA MALAYSIA**

**MECHANICAL PROPERTIES OF ALKALI-TREATED SUGAR PALM  
(*ARENGA PINNATA*) FIBER REINFORCED EPOXY COMPOSITES**

**DANDI BACHTIAR**

**FK 2008 11**

**MECHANICAL PROPERTIES OF ALKALI-TREATED SUGAR PALM  
(*ARENCA PINNATA*) FIBER-REINFORCED EPOXY COMPOSITES**

**DANDI BACHTIAR**

**MASTER OF SCIENCE**

**UNIVERSITI PUTRA MALAYSIA**

**2008**



**MECHANICAL PROPERTIES OF ALKALI-TREATED SUGAR PALM  
(*ARENCA PINNATA*) FIBER REINFORCED EPOXY COMPOSITES**

**DANDI BACHTIAR**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirement for the Degree of Master of Science**

**May 2008**



## DEDICATION

*My Father, Bachtiar Amin*

*My Mother, Alima*

*My Wife, Cut Helida*

*And*

*My Children, Muhammad Hadid Ghifary*

*Muhammad Salman Alfarisi*

*Siti Maghfira Azzahra*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

**MECHANICAL PROPERTIES OF ALKALI-TREATED SUGAR PALM  
(*ARENGA PINNATA*) FIBER REINFORCED EPOXY COMPOSITES**

By

**DANDI BACHTIAR**

**May 2008**

**Chairman : Professor Ir. Mohd. Sapuan b. Salit, PhD**

**Faculty : Engineering**

The aims of this study is to determine the mechanical properties (tensile, flexural and impact properties) of *Arenga pinnata* fiber reinforced epoxy polymer composite after introduce the alkali treatment to the *Arenga pinnata* fiber. The fiber was treated by alkali solution with 0.25 M and 0.5 M NaOH solution for 1 hr, 4 hrs, and 8 hrs soaking time. The fiber was mixed with with epoxy and hardener at 10% of volume with long random type of fiber arrangement. Hand lay up process in this experiments were to produce specimen test.

The mechanical properties of those fibers are 466.07 MPa for the tensile strength and 3.9 GPa for the modulus, the tensile strength of the pure epoxy is 69.39 MPa and 2.3 GPa for the modulus.

Results from the tests show that the improving mechanical properties of *Arenga pinnata* fiber reinforced epoxy polymer were proven by using the alkali treatment.



The ultimate tensile strength took place at 0.25 M NaOH solution with 1-hour soaking time, i.e. 49.875 MPa, an improvement of 16.4% from untreated composite. The tensile modulus at this condition gave the improvement of 13.6% from untreated fiber composite. The ultimate flexural strength also occurred at 0.25 M NaOH solution with 1 hour of soaking time, i.e. 96.71 MPa, an improvement of 24.42% from untreated fiber composite. However, the ultimate flexural modulus happened at 0.5 M NaOH solution with 4 hours soaking time, i.e. 6948 MPa; on improvement of 148% from untreated composite. The ultimate impact strength of treated *Arenga pinnata* fiber reinforced epoxy composite took place at 0.5 M NaOH solution with 8 hours soaking time, i.e. 60 J/m with improving of 9.8% from untreated composite. The SEM analysis has been conducted to provide the analysis on interface adhesion between the surfaces of fiber with the matrix.

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

**SIFAT MEKANIKAL KEPADA KOMPOSIT EPOKSI BERTELULANG  
GENTIAN ARENGA PINNATA YANG MENDAPAT RAWATAN ALKALI**

Oleh

**DANDI BACHTIAR**

**Mei 2008**

**Pengerusi : Profesor Ir. Mohd. Sapuan Salit, PhD**

**Fakulti : Kejuruteraan**

Matlamat dalam kajian ini adalah untuk menentukan sifat mekanikal (tegangan, lentur dan impak) bagi gentian *Arenga pinnata* bertetulang komposit epoksi setelah mendapat rawatan alkali kepada gentian *Arenga pinnata*. Gentian mendapat rawatan 0.25 M dan 0.5 M larutan dengan masa perendaman 1 jam, 4 jam dan 8 jam. Gentian dicampurkan dengan komposit epoksi pada 10% daripada jumlah kandungan gentian *Arenga pinnata*. Eksperimen untuk membuat spesimen dikendalikan secara manual.

Tegangan yang terjadi pada gentian *Arenga pinnata* tanpa rawatan adalah 466.07 MPa manakala tegangan modulusnya 3.9 GPa. Sedangkan tegangan pada epoksi sahaja adalah 69.39 MPa manakala tegangan modulus 2.3 GPa.

Keputusan daripada ujian yang menunjukkan kenaikan sifat-sifat mekanikal daripada gentian *Arenga pinnata* bertetulang komposit epoksi telah dibuktikan dengan

pemakaian rawatan alkali. Tegangan tertinggi terjadi pada rawatan 0.25 M alkali dengan waktu perendaman selama 1 jam, yaitu 49.875 MPa, dengan kenaikan sejumlah 16.4% dibandingkan dengan komposit tanpa rawatan gentian. Tegangan modulus memberikan kenaikan 13.6% dibandingkan dengan komposit tanpa rawatan. Lenturan tertinggi juga terjadi pada 0.25 M dan 1 jam perendaman, yaitu 96.71 MPa, dengan kenaikan 24.42% dibandingkan dengan komposit tanpa rawatan. Akan tetapi, lenturan modulus terjadi pada 0.5 M rawatan alkali dan 4 jam masa perendaman, yaitu 6948 MPa, dengan kenaikan sebesar 148% daripada komposit tanpa rawatan. Kekuatan impak tertinggi terjadi pada 0.5 M rawatan alkali dan 8 jam masa perendaman, yaitu 60 J/m dengan kenaikan 9.8% daripada komposit tanpa rawatan. Alat pengimbas mikro elektron telah digunakan untuk pemerhatian di antara permukaan gentian dan susunan matrik.



## ACKNOWLEDGEMENTS

*In the Name of Allah, Most Gracious, Most Merciful*

Most of all, Praise be to Almighty Allah SWT who makes this work approaches to its final stage. I would not have been able to make it without His help.

I would like to express my deepest gratitude and appreciation to the supervisory committee: Chairman, Professor Ir. Dr. Mohd. Sapuan b. Salit and co-supervisor, Associate Professor Dr. Megat Mohamad Hamdan b. Megat Ahmad, for their supervision and guidance of this research, and their continuous support through out my study in Universiti Putra Malaysia (UPM). Special thanks are also due to Dr. Hasan Yudie Sastra and Dr. Paridah Md. Tahir for guiding and providing the facilities in my earlier works.

Besides, I would like to express my deep gratitude and sincere thanks to Mr. Meor, Mr. Shaifuddin, Mr. Wildan, Mr. Shah and Mr. Faizal as technicians of the lab and workshop at Faculty of Engineering for their valuable assistance.

Last but not least, thanks to mother, brothers, sisters and my wife and children for their continous inspiration and encouragement to complete my project thesis.

I convey my thanks to all of my colleagues, friends, housemate and UPM support staff.

I certify that an Examination Committee has met on 30 October 2007 to conduct the final examination of Dandi Bachtiar on his Master of Science thesis entitled “Mechanical Properties Of Alkali-Treated Sugar Palm (*Arenga Pinnata*) Fiber Reinforced Epoxy Composites” In accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The Committee recommends that the candidate be awarded the relevant degree.

Members of the Examination Committee are as follows:

**Napsiah Ismail, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Ir. Barkawi Sahari, PhD**

Professor  
Institute of Advanced Technology (ITMA)  
Universiti Putra Malaysia  
(Internal Examiner)

**Luqman Chuah Abdullah, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Luay Bakir Hussain, PhD**

Associate Professor  
School of Material & Mineral Resource Engineering  
Universiti Sains Malaysia  
(External Examiner)

---

**HASANAH MOHD. GHAZALI, PhD**

Professor/Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia.

Date: 28 April 2008



This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

**Ir. Mohd. Sapuan Salit, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Megat Mohamad Hamdan B. Megat Ahmad, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**AINI IDERIS, PhD**  
Professor and Dean  
School Of Graduate Studies  
Universiti Putra Malaysia

Date: 8 May 2008



## **DECLARATION**

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

---

**DANDI BACHTIAR**

Date: 16 March 2008

## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	ii
<b>ABSTRACT</b>	iii
<b>ABSTRAK</b>	v
<b>ACKNOWLEDGEMENTS</b>	vii
<b>APPROVAL</b>	viii
<b>DECLARATION</b>	x
<b>LIST OF TABLES</b>	xiii
<b>LIST OF FIGURES</b>	xiv
<b>LIST OF ABBREVIATIONS</b>	xvii
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	1.1
1.1 Background	1.1
1.2 Problem Statement	1.3
1.3 Objectives of the Study	1.3
1.4 Scope of the Study	1.4
1.5 Structure of the Thesis	1.4
<b>2 LITERATURE REVIEW</b>	2.1
2.1 Introduction	2.1
2.2 Polymer Composite Material	2.2
2.3 Epoxy Resin	2.4
2.4 Natural Fiber	2.6
2.4.1 Chemical Composition of Natural Fibers	2.10
2.4.2 <i>Arenga pinnata</i> Fiber and <i>Arenga pinnata</i> Fiber Composite	2.12
2.5 Mechanical Properties of Natural Fiber Reinforced Composites	2.14
2.5.1 Tensile Properties	2.16
2.5.2 Flexural Properties	2.18
2.5.3 Impact Properties	2.20
2.6 Alkali Treatment	2.21
2.6.1 Influence of the Alkali Treatment on a Natural Fiber	2.22
2.6.2 Influence of the Alkali Treatment on the Mechanical Properties of Composites	2.24
2.7 The Manufacturing of Composites	2.29
2.7.1 Hand Lay-up Process	2.29
2.7.2 Constitutive Equation of Stress-Strain Behaviour of Composite	2.31
2.7.3 Rule of Mixture (ROM)	2.34
2.8 Failure Mechanism for Composites	2.32



2.9	Summary	2.33
<b>3</b>	<b>METHODOLOGY</b>	<b>3.1</b>
3.1	Introduction	3.1
3.2	Preparation of Materials	3.2
3.2.1	<i>Arenga pinnata</i> Fiber	3.3
3.2.2	Epoxy Resin	3.4
3.2.3	Sodium Hydroxide Solution	3.5
3.3	Preparation of Preliminary Testing	3.6
3.3.1	Procedure for Determining Lignin Content	3.6
3.3.2	Procedure for Determining Holocellulose Content	3.7
3.3.3	Procedure for Determining $\alpha$ -cellulose Content	3.8
3.3.4	Determination of Tensile Strength of Single fiber	3.10
3.4	Treatment Parameters	3.11
3.5	Fabrication of Composites	3.12
3.6	Testing Methods	3.14
3.6.1	Tensile Test	3.15
3.6.2	Flexural Test	3.16
3.6.3	Impact Test	3.17
3.6.4	Morphology Study of Fracture Surface	3.19
<b>4</b>	<b>RESULTS AND DISCUSSION</b>	<b>4.1</b>
4.1	Introduction	4.1
4.2	Composition of <i>Arenga pinnata</i> Fiber	4.2
4.3	Morphological Analysis of <i>Arenga pinnata</i> Fiber	4.3
4.4	Tensile Strength of <i>Arenga pinnata</i> Fiber	4.6
4.4	Tensile Testing for the Composites	4.7
4.4.1	Tensile Strength	4.9
4.4.2	Tensile Modulus	4.12
4.5	Flexural Testing	4.14
4.5.1	Flexural Strength	4.16
4.5.2	Flexural Modulus	4.17
4.6	Impact Testing	4.19
4.7	SEM Analysis for Fracture of Composite after Tensile Testing	4.23
<b>5</b>	<b>CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS</b>	<b>5.1</b>
5.1	Conclusions	5.1
5.2	Recommendations for Future Works	5.2
	<b>REFERENCES</b>	<b>R.1</b>
	<b>APPENDICES</b>	<b>A.1</b>
	<b>BIODATA OF THE STUDENT</b>	<b>D.1</b>
	<b>LIST OF PUBLICATIONS</b>	<b>E.1</b>

## LIST OF TABLES

Table		Page
2.1	Influence of flexibilisers on epoxy resins	2.6
2.2	Mechanical properties of natural fibres compared to conventional composite reinforcing fibres (Bledzki and Gassan, 1999)	2.8
2.3	Chemical composition of natural fibers	2.11
3.1	Properties of epoxy resin	3.4
4.1	Chemical composition of <i>Arenga pinnata</i> fiber	4.2
4.2	The experimental result of tensile properties of <i>Arenga pinnata</i> fiber	4.7
4.3	The tensile properties of <i>Arenga pinnata</i> fiber reinforced epoxy composites	4.8
4.4	The flexural properties of <i>Arenga pinnata</i> fiber reinforced epoxy composite	4.15
4.5	The average impact properties of <i>Arenga pinnata</i> epoxy composite	4.19

## LIST OF FIGURES

Figure		Page
2.1	Structure of unmodified epoxy prepolymer (Wikipedia, 2007)	2.5
2.2	Stress-strain curve of natural fibers (Satyanarayana <i>et al.</i> , 1999)	2.8
2.3	Structural constitution of natural fiber cell (Rong <i>et al.</i> , 2001)	2.11
2.4	<i>Arenga pinnata</i> tree	2.13
2.5	The three point bending flexural test	2.19
2.6	SEM micrographs of grass fibers (Liu <i>et al.</i> , 2004-a)	2.24
2.7	Lamina with unidirectional fibers (Cristescu <i>et al.</i> , 2004)	2.31
3.1	The flow chart for the experimental procedure	3.2
3.2	The bundles of <i>Arenga pinnata</i> fiber	3.3
3.3	Epoxy resin with hardener	3.4
3.4	The sodium hydroxide solution with concentration 1 M	3.5
3.5	The tensile test on single <i>Arenga pinnata</i> fiber	3.11
3.6	The mold of making specimen	3.12
3.7	The composite as a plate before cutting for the specimen testing	3.13
3.8	Schematic diagram of a tensile test	3.16
3.9	Instron 5566 machine for tensile and flexural testing	3.16
3.10	Schematic diagram of flexural test (ASTM D790-99)	3.17
3.11	Izod Impact Tester	3.18
3.12	Three type of testing specimen after loading	3.18
3.13	Scanning Electron Microscopy (SEM) PHILIPS XL30	3.19



4.1	The SEM micrograph of (a) untreated <i>Arenga pinnata</i> fiber and (b) treated <i>Arenga pinnata</i> fiber in 0.25 M NaOH with 1 hr soaking time	4.4
4.2	The SEM micrograph of (a) treated <i>Arenga pinnata</i> fiber in 0.25 M NaOH with 4 hrs. soaking time and (b) treated <i>Arenga pinnata</i> fiber in 0.25 M NaOH with 8 hrs. soaking time.	4.5
4.3	The SEM micrograph of (a) treated <i>Arenga pinnata</i> fiber in 0.5 M NaOH with 1 hr. soaking time and (b) treated <i>Arenga pinnata</i> fiber in 0.5 M NaOH with 8 hrs. soaking time.	4.6
4.4	Average tensile strength of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs alkali concentration	4.9
4.5	Average tensile strength of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs soaking time	4.10
4.6	Average tensile modulus of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs concentration of alkali	4.13
4.7	Average tensile modulus of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs soaking time	4.13
4.8	Average flexural strength of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs alkali concentration	4.16
4.9	Average flexural strength of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs soaking time	4.17
4.10	Average flexural modulus of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs alkali concentration	4.18
4.11	Average flexural modulus of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs soaking time	4.19
4.12	Average impact strength of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs alkali concentration	4.20
4.13	Average impact strength of <i>Arenga pinnata</i> fiber reinforced epoxy composite vs alkali concentration	4.20
4.14	SEM micrographs for untreated <i>Arenga pinnata</i> fiber reinforced epoxy composite fracture after tensile loading	4.23
4.15	SEM micrographs for treated 0.25 M NaOH <i>Arenga pinnata</i> fiber reinforced epoxy composite fracture after tensile loading	4.23

4.16	SEM micrographs for treated 0.5 M NaOH <i>Arenga pinnata</i> fiber reinforced epoxy composite fracture after tensile loading	4.24
------	--	------

## LIST OF ABBREVIATIONS

### ABBREVIATIONS

ASTM	American Society for Testing and Materials
CO <sub>2</sub>	Carbon Dioxide
ESEM	Environmental Scanning Electron Microscope
FTIR	Fourier Transfer Infra Red
NaOH	Natrium Hydroxide or Sodium Hydroxide
RTM	Resin Transfer Molding
SEM	Scanning Electron Microscope
UB	Unit Break
UD	Uni Directional
XPS	X-ray Photoelectron Spectroscopy

### NOMENCLATURE

<i>A</i>	Cross sectional area of test specimen (mm <sup>2</sup> )
<i>A</i>	Concentration of solution (M)
<i>D</i>	Distance between grip (mm)
<i>E</i>	Tensile modulus of test specimen (Pa)
<i>F</i>	Pulling force applied on test specimen (N)
<i>S<sub>τ</sub></i>	Tensile stress of specimen (Pa)
<i>L</i>	Support span (mm)



$P$	Load at yield (N)
$V$	Volume of concentration (litre)
$b$	Width (mm)
$d$	Thickness (mm)
$\varepsilon$	Strain of test specimen
$\sigma$	Stress applied on test specimen (Pa)
$\sigma_{\max}$	Flexural strength (Pa)

# CHAPTER 1

## INTRODUCTION

### 1.1 Background

Recently, growing environmental awareness has resulted in a renewed interest in the use of natural material for many applications. This paradigm has forced industries like automotive, packaging and construction to search for new materials to make the conventional composite materials be an environmentally friendly material. The composite materials mostly nowadays employed well-established fibers such as glass, carbon and aramid as the reinforcement. These inorganic fibers present disadvantages like their non-biodegradability, expensive, abrasive and non-renewable.

Compared to inorganic reinforcing fibers, natural fibers have a number of benefits, including low density and bio-degradability, less abrasiveness, lower cost and renewable. Natural fiber composites are likely to be environmentally superior to glass fiber composites in most cases (Joshi *et al.*, 2004). Several natural fibers like jute, pine, sisal, flax, hemp, kenaf, coir, and abaca have been used by researchers to replace the inorganic fibers (glass, aramid and carbon) in reinforced composites (Wambua *et al.*, 2003). So far, a good number of automotive components previously made by glass fiber composites are now being manufactured using natural fiber reinforced composites (Sapuan, 2007).



Unfortunately, several disadvantages of natural fibers such as thermal and mechanical degradation during processing can make them undesirable for certain applications. Natural fiber reinforced composites also have several drawbacks such as poor wettability, incompatibility with some polymeric matrices and high moisture absorption by the fibers. The main problem often encountered in its use is the fiber-matrix adhesion problem that is incompatibility between the hydrophilic natural fibers and the hydrophobic polymer matrix. This problem may be improved by fiber-surface chemically treatment. Alkali treatment is a common method to clean and modify the fiber surface to lower surface tension and enhance interfacial adhesion between a natural fiber and a polymeric matrix (Bledzki *et al.*, 1999). Several publications have discussed the effects of alkali treatment on structure and properties of natural fibers such as kenaf, hemp (Aziz and Ansell, 2004), flax (Weyenberg *et al.*, 2006), jute (Ray *et al.*, 2002), and sisal (Rong *et al.*, 2001).

In this research, natural fiber that is *ijuk* fiber (*Arenga pinnata* or *Arenga saccharifera*) is used as a suitable candidate to reinforce polymer matrix in composite. *Ijuk* fiber is a kind of natural fiber that comes from *Arenga pinnata* plant, a forest plant that can be found enormously in Southeast Asia like Indonesia and Malaysia. This fiber seems to have properties like other natural fibers, but the detail properties are not generally known yet. Generally, *ijuk* has desirable properties like strength and stiffness and its traditional applications include paint brush, septic tank base filter, clear water filter, door mat, carpet, rope, chair/sofa cushion, and for fish nest to hatch its eggs (Suwartapraja, 2003). In this study an attempt is made to highlight the potential use of this natural fiber in reinforcing polymer composites.

Previous study (Siregar, 2005) on the tensile and flexural properties of *ijuk* epoxy composites is concerned with the woven roving, long random and chopped random *ijuk* epoxy composites and it is found that the woven roving *ijuk* epoxy composites gave better properties compared to long random and chopped random fiber composites. However, all the samples showed inferior properties compared with the glass fiber epoxy composites (Deng *et al.*, 1999). Hence, the treatment of fiber is needed to improve the materials.

## 1.2 Problem Statement

The *Arenga pinnata* fiber composites still show inferior properties compared with the glass fiber epoxy composites. Therefore, extended work is needed to improve the performance of composites. One of the improvement steps is the treatment of *Arenga pinnata* fiber. In this work, the alkali treatment is used for the improvement of the properties of composites.

## 1.3 Objectives of the Study

The objectives of this study are as follows:

1. To investigate the mechanical properties and chemical content of *Arenga pinnata* fiber.
2. To investigate the influence of alkali treatment on the morphological characteristics of *ijuk* fiber.
3. To investigate the influence of alkali treatment on tensile, flexural and impact properties of *ijuk* fiber reinforced epoxy composites.

## 1.4 Scope of the Study

Improvement of the mechanical properties of *ijuk* fiber reinforced epoxy composites is investigated. Research is conducted for the fiber treatment i.e. alkalization and examination of the effect of fiber treatment on the mechanical properties i.e. tensile, flexural and impact strength of the composites and the results are compared with those untreated fiber composites.

## 1.5 Structure of the Thesis

Chapter 1 gives the background of studies, and also presents the objectives of the study. A literature survey of research work in various areas relevant to this research is presented in Chapter 2. The survey started with a comprehensive literature survey on the manufacturing and properties of composite products made out of natural fiber and plastic. A review of the physical and mechanical properties of *Arenga pinnata* fiber is also included in this chapter.

The methodology of the study is described in Chapter 3. This chapter presents techniques to determine the chemical content of *Arenga pinnata* fiber, technique to determine the mechanical (tensile strength) properties of *Arenga pinnata* fiber, techniques of the preparation of composites and the determination of mechanical properties of composites. This chapter also presents the techniques of the alkali treatment and the techniques of the morphological properties of the broken composites.



Chapter 4 described the results and discussion of the study. This chapter discussed the mechanical properties of the composites such as tensile, flexural, and impact tests. The results from Scanning Electron Microscopy (SEM) were also included in this chapter. Finally, the conclusions and recommendations for further works are presented in Chapter 5.

