# MOISTURE ABSORPTION CAPACITY OF KENAF FIBER-REINFORCED UNSATURATED POLYMER COMPOSITES AND ITS EFFECT ON THEIR MECHANICAL PROPERTIES

**By**

**ABDALLA A. AB. RASHDI**



**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the requirement for the degree of Doctor of Philosophy

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**Chairman: Professor Mohd Sapuan Salit, PhD, PEng**

**Faculty : Engineering**

Conventional fiber reinforced composites are composed of carbon and glass fibers, which are incorporated into unsaturated polyester or epoxy resin. These composites show high mechanical and thermal properties, so they are widely used in various applications from aerospace to sports. However, these advantages, on the other hand, cause environmental problems in disposal by incineration. Thus, in order to overcome these problems, environmentally friendly composites such as kenaf are today keenly required by utilizing natural fibers as reinforcements combined with unsaturated polyester as matrices.

There are numerous advantages of using Kenaf. Kenaf exhibits low density, non-abrasiveness during processing, high specific mechanical properties, and biodegradability.

But natural composites are susceptible moisture when operating in changing environmental conditions. Moisture absorption can result in swelling of the fiber

resulting in dimensional stability problems in the lignocellulosic fiber composite. This leads to changes in mechanical properties of the thermoset are known to occur as a result of water absorption. The absorption of moisture by the fibers is minimized in the composites due to encapsulation by the polymer and good fiber-matrix bonding. Most of the moisture studies that have been conducted have focused on water immersion. Fewer studies have examined the effects of relative humidity related to weathering conditions and soil buried.

This study concentrate in evaluating the amount of moisture absorption of kenaf unsaturated polyester composites exposed to three different environmental conditions for a certain period of time, and to provide which condition that would be better for kenaf unsaturated polyester engineering applications. Thus moisture absorption due to soil buried, moisture absorption due to water immersion and moisture absorption due to natural weathering were studied, as well as the effect of fibers contents in moisture absorption rate was studied where 10%, 20%, and 30% fiber contents where used. Also the study discuss if the unsaturated polyester can reduce the amount of moisture pick up of the fibers and gives good adhesion to decrease the rate and amount of water absorbed in the interphase region of the composites. Therefore the study will explain the behavior of moisture up-take due to these three conditions and its effects in the mechanical properties of the kenaf unsaturated composites the properties of interest was tensile strength.

KFRUPC samples tensile strength and modulus of kenaf fiber reinforced unsaturated polyester composite were carried out using the Instron 5569 Universal Electromechanical Testing System with 50 KN loading capacity. This work

employed long kenaf fiber (modified by alkali surface treatment on the fiber with a 6% NaOH solution to improve the adhesion and make them more polar) as reinforcement of the composite. For the matrix resin, unsaturated polyester resin of type Reservol P9509 was used. In this study, kenaf fiber reinforced unsaturated polyester composite (KFRUPC) was made, and their mechanical performances were investigated. This combination of environmental conditions provides a broad overview for most any condition that would be typically seen in an infrastructure application ranging from underwater applications to natural weather environments. The availability of comparable data for the various humidity conditions also provides data that can be used to design test environments to simulate long-term exposure conditions.

Finally we can conclude that high fiber content leads to increase in moisture absorption for all environmental conditions. Although with high fiber content slightly better tensile strength were obtained with all environmental conditions. This increase in tensile strength may be due to better mechanical interlocking between fiber and matrix due to the limited swelling of the fiber by low water absorption. Form another point of view the effect of moisture absorption in tensile strength was high in case of water immersion test compare to soil buried and natural weathering tests, where the tensile stress of the KFRUPC drop to 84 MPa, 122 MPa and 134 MPa respectively for the 30%wt fiber content. Natural weathering test case showed that the KFRUPC absorb less moisture and gives high tensile strength compare to soil buried and water immersion tests, which indicate that KFRUPC could be good candidate for outdoor applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENYERAPAN KELEMBAPAN SERAT KENAF BERTETULANG KOMPOSIT POLIMER TAK TEPU DAN PENGARUHNYA TERHADAP SIFAT MEKANIK**

Oleh

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Komposit diperkuat gentian konvensional terdiri daripada gentian karbon dan kaca yang digabungkan dalam damar poliester tak tepu dan epoksi.Komposit ini menunjukkan sifat mekanikal dan termal yang tinggi, jadi bahan ini digunakan secara meluas dalam pelbagai aplikasi daripada aero angkasa hingga sukan. Walau bagaimana pun, di sebalik kebaikan ini, ia menyebabkan masalah persekitaran dalam pembuangan menggunakan insinerasi. Jadi, bagi menyelesaikan masalah ini, komposit mesra alam pada hari ini amat diperlukan dengan menggunakan gentian asli sebagai penguat digabungkan dengan poliester tak tepu sebagai matriks.

Terdapat pelbagai kebaikan dalam penggunaan kenaf.Kenaf menunjukkan ketumpatan yang rendah, ketaklelasan semasa pemprosesan, sifat mekanikal spesifik yang tinggi, dan keboleh biorosotan.

Tetapi komposit gentian asli mudah dipengaruhi lembapan bila beroperasi dalam keadaan persekitaran yang berubah-ubah.Penyerapan lembapan boleh menghasilkan

gelembungan gentian yang menyebabkan masalah kestabilan dimensi dalam komposit gentian lignoselulosik.Ini mengakibatkan perubahan dalam sifat mekanikal bagi termoset yang diketahui berlaku disebabkan penyerapan air. Penyerapan lembapan gentian diminimumkan dalam komposit disebabkan enkapsulasi oleh polimer dan ikatan gentian-matriks. Kebanyakan kajian mengenai lembapan yang telah dijalankan member fokus terhadap rendaman air.Sedikit kajian telah dijalankan berkaitan kesan kelembapan relatif ke atas keadaan cuaca dan penanaman dalam tanah.

Kajian ini member tumpuan terhadap jumlah penyerapan lembapan komposit poliester tak tepu kenaf yang didedahkan kepada tiga keadaan persekitaran berbeza untuk satu jangka masa tertentu, dan member maklumat tentang keadaan yang lebih baik bagi poliester tak tepu kenaf untuk aplikasi kejuruteraan. Jadi penyerapan lembapan disebabkan penanaman dalam tanah, penyerapan lembapan disebabkan rendaman dalam air dan penyerapan lembapan disebabkan cuaca persekitaran semula jadi telah dikaji, di samping kesan kandungan gentian dalam kadar juga telah dikaji di mana kandungan gentian 10%, 20%, dan 30% telah digunakan. Kajian ini juga membincangkan sama ada poliester tak tepu boleh mengurangkan kandungan pengambilan lembapan bagi gentian dan memberikan lekatan bagi mengurangkan kadar air yang terserap dalam kawasan antara fasa bagi komposit. Oleh itu, kajian ini menerangkan kelakuan pengambilan lembapan disebabkan tiga keadaan tersebut dan kesannya ke atas sifat mekanikal komposit poliester tak tepu kenaf.Sifat mekanikal yang dikaji ialah kekuatan tegangan.

Ujian kekuatan dan modulus tegangan bagi komposit polyester taktepu diperkuat gentian kenaf telah dijalankan menggunakan mesin Instron 5569 *Universal Electromechanical Testing System* dengan keupayaan bebanan 50 kN. Kajian ini menggunakan gentian kenaf panjang sebagai penguat bagi komposit (diubah suai dengan rawatan permukaan alkali dengan 6 % larutan NaOH untuk memperbaiki lekatan dan menjadikan mereka lebih bersifat polar). Untuk damar matriks, damar polyester tak tepu jenis Reservol P9509 telah digunakan. Dalam kajian ini, komposit poliester tak tepu diperkuat gentian kenaf telah dibangunkan dan prestasi mekanikalnya telah dikaji.Gabungan keadaan persekitaran ini telah memberikan gambaran umum mengenai apa juga keadaan yang biasa dilihat dalam aplikasi infrastruktur daripada aplikasi dalam air kepada persekitaran cuaca semula jadi. Dengan wujudnya data yang setara bagi pelbagai keadaan kelembapan ini memberikan data yang boleh digunakan bagi mereka bentuk persekitaran pengujian yang boleh menyelaku keadaan pendedahan jangka panjang.

Akhirnya kita boleh membuat kesimpulan bahawa kandungan serat yang tinggi menyebabkan peningkatan penyerapan air untuk semua keadaan persekitaran. Walaubagaimanapun, dengan kandungan serat yang tinggi kekuatan tarik yang lebih baik diperoleh untuk semua keadaan persekitaran. Peningkatan kekuatan tarik mungkin kerana ikatan mekanik yang lebih baik antara serat dan matriks kerana terbatasnya pembengkakan serat dengan penyerapan air yang rendah. Dari sudut pandangan yang lain, pengaruh penyerapan air di dalam kekuatan tarik adalah tinggi dalam kes ujian air rendaman berbanding dengan tanah ditanam dan ujian pelapukan semulajadi, di mana tegasan tarik KFRUPC jatuh ke 84 MPa, 122 MPa dan 134 MPa masing-masing untuk 30%wt kandungan serat. Ujian pelapukan semulajadi

menunjukkan bahawa KFRUCP kurang menyerap kelembapan dan mempunyai kekuatan tarik yang tinggi berbanding dengan tanah ditanam dan ujian perendaman air, yang menunjukkan bahawa KFRUCP adalah calon yang baik untuk aplikasi luar bilik.

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I certify that an Examination Committee met on 10-2-2009 to conduct the final examination of **Abdalla A, Ab. Rashdi** on his Doctor of Philosophy thesis entitled "Moisture Absorption Capacity of Kenaf Fiber-Reinforced Unsaturated Polymer Composites and Its Effect on Their Mechanical Properties" in accordance with Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the Doctor of Philosophy.

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## 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 or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

**ABDALLA A. AB. RASHDI**

Date: 2 November 2010

## TABLE OF CONTENTS


**Page**

**ABSTRACT** ii
**ABSTRAK** v
**ACKNOWLEDGEMENTS** ix
**DECLARATION** xiii

**CHAPTER**

1 **INTRODUCTION** 1
1.1 Overview 1
1.2 Background and Significance of the study 2
1.3 Problem Statement and Importance of Study 3
1.4 Objectives 5
1.5 Thesis Layout 6

2 **LITERATURE REVIEW** **Error! Bookmark not defined.**
2.1 Introduction **Error! Bookmark not defined.**
2.2 Natural Fiber Reinforced Composites **Error! Bookmark not defined.**
2.3 Introduction of Kenaf **Error! Bookmark not defined.**
2.4 Kenaf Fiber **Error! Bookmark not defined.**
2.4.1 General Properties of Kenaf Fibers **Error! Bookmark not defined.**
2.4.2 Mechanical Properties of Kenaf fibers **Error! Bookmark not defined.**
2.5 Uses of Kenaf **Error! Bookmark not defined.**
2.5.1 Traditional Use of Kenaf **Error! Bookmark not defined.**
2.6 Polyester Resins **Error! Bookmark not defined.**
2.6.1 Introduction **Error! Bookmark not defined.**
2.6.2 Unsaturated polyesters (UPE) **Error! Bookmark not defined.**
2.6.3 Polyester Resin Chemistry **Error! Bookmark not defined.**
2.6.4 Mechanical Properties of P9509 and P9728P resin **Error! Bookmark not defined.**
2.7 Environmental Effects, Moisture and Composite Materials **Error! Bookmark not defined.**
2.7.1 Elevated Temperature **Error! Bookmark not defined.**
2.7.2 Moisture **Error! Bookmark not defined.**
2.7.3 Moisture Concentration **Error! Bookmark not defined.**
2.7.4 Physical Effects of Moisture Absorption **Error! Bookmark not defined.**
2.7.5 Changes in performance due to moisture and temperature **Error! Bookmark not defined.**
2.8 Soil burial **Error! Bookmark not defined.**
2.9 Natural weathering **Error! Bookmark not defined.**
2.10 Scanning Electron Microscopy (SEM) **Error! Bookmark not defined.**
2.11 Advantages and Limitations of Composites Containing Natural Fibers **Error! Bookmark not defined.**
2.11.1 Advantages of Composites Containing Natural Fibers **Error! Bookmark not defined.**

2.11.2 Limitations of Fiber Application to Composites **Error! Bookmark not defined.**
2.12 Conclusions **Error! Bookmark not defined.**

3 **MATERIALS AND METHODS** 58
3.1 Introduction 58
3.2 Materials 58
3.3 Specimen's design and preparation 60
3.4 Experimental Procedure 61
3.4.1 Soil buried Test 62
3.4.2 Water absorption test 64
3.4.3 Natural weather test 66
3.4.4 Moisture absorption test 68
3.4.5 Tensile test 69
3.5 Glossary used in the following chapters 70

4 **Water absorption and tensile properties of soil buried kenaf fiber reinforced unsaturated polyester composites (KFRUPC)** 72
4.1 Article 1 73
4.2 Copyright permission/Acceptance letter 89

5 **WEATHER EFFECTS IN THE MECHANICAL PROPERTY OF KENAF UNSATURATED POLYESTER COMPOSITES (KFUPC)** 91
5.1 Article 2 92
5.2 Copyright permission/Acceptance letter 109

6 **WATER ABSORPTION BEHAVIOUR OF KENAF REINFORCED UNSATURATED POLYESTER COMPOSITES AND ITS INFLUENCE ON THEIR MECHANICAL PROPERTIES** 112
6.1 Article 3 113
6.2 Copyright permission/Acceptance letter 127

7 **COMBINED EFFECTS OF WATER ABSORPTION DUE TO WATER IMMERSION, SOIL BURIED AND NATURAL WEATHER ON MECHANICAL PROPERTIES OF KENAF FIBER UNSATURATED POLYESTER COMPOSITES (KFUPC)** 130
7.1 Article 4 131
7.2 Copyright permission/Acceptance letter 150

8 **DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS** 153
8.1 Introduction 153
8.2 Conclusions 153
8.2.1 KFRUPC Fabrication Process 154
8.2.2 Testing Procedure 154
8.2.3 Moisture absorption and tensile test 155
8.3 Comparison with previous work 157
8.4 Recommendations 158

**REFERENCES** 160
**APPENDICES** 169
**BIODATA OF STUDENT** 175

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

In the recent years, there is a rapid growth in the study and the use of composite materials. The major thrust in the area of composite material has been directed towards the development and study of high performance reinforcing materials like nylon, polyester, Kevlar, glass, and carbon fibers in appropriate polymer composites. Nevertheless, these materials are expensive and non-renewable resources. The growing global environmental concern, high rate of depletion of petroleum resources, as well as new environmental regulations have forced the search for new fiber reinforced composite materials that are compatible with the environment. The recent trend in environment awareness has contributed to a great interest in the development, improvement and use of natural fibers such as kenaf, flax, jute, hemp, sisal, banana, palm, bamboo, coir, henequen, cotton, coconut (coir), kapok, and Pineapple as reinforcing materials in polymeric composites. The attractive features of natural fibers are their low cost, lightweight, high specific modulus, renewability and biodegradability. Composite reinforced with such natural fibers have been the subject of intense study for low cost application in contrast to the synthetic fiber-reinforced composites.

This research examines the effects of moisture absorption levels, at three different environmental conditions (soil buried, water immersion and natural weather) for a time period of four months, on the mechanical properties of kenaffiber reinforced

unsaturated polyester composites (KFRUPC). KFRUPCwith (10%, 20% and 30%) weight percentage of fiber contents were used. The properties of interest are tensile strength. Unsaturated polyester resin of type Reservol P9509 supplied by Revertex (Malaysia) Shd. Bhd. Company was used as matrix.

Experimental tensile tests were conducted for long kenaf fibers reinforced unsaturated polyester composite. This combination of environmental conditions provides a broad overview for most any condition that would be typically seen in an infrastructure application ranging from underwater applications to dry environments. The availability of comparable data for the various humidity and temperature conditions also provides data that can be used to design test environments to simulate long-term exposure conditions.

## 1.2 Background and Significance of the study

Over the last decade, composites of polymers reinforced with natural fibers have received ever-increasing attention, both from the academic world and from various industries. There is a wide variety of different natural fibers which can be applied as reinforces or fillers. All these natural fibers consist of long cells with relatively thick cell walls, which make them stiff and strong. In most of the fiber plants, the cells are glued together into long thin fibers, the length of which is dependent on the length of the plant. The fibers may differ in coarseness, in the length of the cells and in the strength and stiffness of the cell walls. The most important of the natural fibers used in composite materials are flax, hemp, jute, kenaf and sisal, due to their properties and availability(Satyanarayana et al., 1990). Flax, hemp, jute and kenaf are bast fibers, fibers that develop in the bast of the plant. Kenaf fibers have been selected as

reinforced composite in this work because of their characteristics: stress at break 350-600 MPa, strain at break 2.5-3.5 %, modulus 40-45 GPa, density 1500 kg m−3, cellulose content 75-90(Bogoeva et al., 2006).

Kenaf is more lustrous, has greater tensile strength, and has greater resistance to rot than jute. The price for kenaf fibers became reasonable with the latest improvements in the growing, harvesting, environment on the mechanical properties of the KFRUPC. Kenaf fibers have been investigated and great mechanical properties have been reported. The specific stiffness is comparable to the glass fibers, and the price is 3 to 2 times lower than the glass fibers.

## 1.3 Problem Statement and Importance of Study

Conventional and traditional fiber reinforced composites are composed of carbon fibers, glass fibers, which are incorporated into unsaturated polyester or epoxy resin. These composites show high mechanical and thermal properties, so they are widely used in various applications. However, these advantages, on the other hand, cause environmental problems in disposal by incineration. Thus, in order to overcome these problems, environmentally friendly composites are today keenly required by utilizing natural fibers as reinforcements. Natural fiber composites are used in many industries such as automotive, sporting goods, marine, electrical, construction, and household appliances (Wallenberger and Weston, 2004). Kenaf, sisal, coir, banana, jute flax, pulp, wood flour, oil palm, pineapple leaf and coir are the main natural fibers used as reinforcement(Rowell et al., 1997).

Kenaf fibers provide high stiffness and strength values. They also have higher aspect ratios making them suitable to be used as reinforcement in polymer composite(Sanadi et al., 1995). Kenaf (*Hibiscus cannabinus, L*. family *Malvaceae*) is an herbaceous annual plant. Kenaf is a warm-season annual row crop. The attractive features of kenaf fibers are the low cost, lightweight, renewability, biodegradability and high specific mechanical properties. Kenaf has a bast fiber which contains 75% cellulose and 15% lignin and offers the advantages of being biodegradable and environmentally safe(Mansur and Aziz, 1983). Kenaf fiber has superior flexural strength and excellent tensile strength which make kenaf a good candidate for many applications(Aji et al., 2009). However, it has some disadvantages, including high absorption of moisture, which negatively affects the mechanical(Coutinho et al., 1997; Rowell et al., 1997).The incompatibility between the hydrophilic fibers and hydrophobic thermoplastic and thermoset matrices requires appropriate treatments to enhance the adhesion between fiber and the matrix(Dhakal et al., 2007; Gassan and Cutowski, 2000). The effect of absorption of moisture leads to the degradation of fiber-matrix interface region creating poor stress transfer efficiencies resulting in a reduction of mechanical properties(Yang et al., 1996). One of the main concerns in the use of natural fiber reinforced composite materials is their susceptibility to moisture absorption and the effect on physical and mechanical properties(Thwe and Kin, 2002). Therefore, it is important that this problem be investigated in order that natural fiber may be considered as a viable reinforcement in composite materials.

The purpose of the present research is to discuss these effects of absorption of moisture on kenaf fiber reinforced unsaturated polyester composites (KFRUPC). Most of the moisture studies that have been conducted have focused on water

immersion. And no studies have examined and investigated the effects of relative humidity on kenaf fiber reinforced unsaturated polymer composite and its effect on mechanical engineering due to natural weather or soil buried till date.

## 1.4 Objectives

Research main objective as natural composites are utilized in more engineering applications, the need to better understand the effects of relative humidity on the properties of these composites. Moreover, how fiber reinforced materials react when exposed to moisture, and since many applications are in contact with water (at least some of the time), the effect of moisture on the composite needs to be examined before it is put into place. The designer needs to evaluate each application to determine if the moisture absorption of the composite will be a problem in that specific situation. The main objective of this the current works are:

1. To study the moisture absorption capacity of kenaf fiber reinforced unsaturated polymer composites under three different environmental conditions.
    a. Buried under the soil
    b. Open atmosphere
    c. Immersed in water

2. To Study the effect of absorbed moisture of kenaf fiber reinforced unsaturated polymer composites (under the above three conditions) on the mechanical properties.

## 1.5 Thesis Layout

The thesis is divided into seven chapters. Following this chapter, chapter 2 presents a review of literature that related to the natural composite materials, reinforcement, composite forms, mechanism of composites shell under different loading modes. Particular attention is given to the carrying capacity of cylindrical made from fiber reinforced composite materials. Chapter 3 presents a thorough description of the materials and methods used in this study frompreparing and fabrication of the composite samples of the materials, testing procedure and data collecting of the study, to evaluate the effects of moisture absorption on the KFRUPC. Chapter 4 present the water absorption behavior and tensile properties results of soil buried samples, extracted from publishedpaper in Journals indexed in 'Science CitationIndex Expended impact with factor 0.282'(proof of is in the appendix A); A.A.A. Rashdi, S.M. Sapuan, M.M.H.M. Ahmad and A. Khalina, Waterabsorption and tensile properties of soil buried kenaf fiber reinforced unsaturated polyesters (KFRUPC). Chapter 5 reported the effects of water absorption due to natural weathering in the mechanical properties of kenaf, extracted from accepted paper indexed in 'Journal indexed in Materials Science Citation Index with impact factor 0.355', A.A.A. Rashdi, S.M. Sapuan, M.M.H.M. Ahmad and A. Khalina, Weather effects in the mechanical property of kenaf unsaturated polyester composites (KFUPC). Chapter 6 presents the effects ofwater immersed in the tensile strength of (KFRUPC) extracted from published paper indexed in EBSCO,A.A.A. Rashdi, S.M. Sapuan, M.M.H.M. Ahmad and A. Khalina, Water absorption behavior of kenaf reinforced unsaturated polyester composites and its influence on their mechanical properties. Chapter 7 presents comparison of the results of moisture absorption

effects from different environmental condition in the mechanical properties of (KFRUPC), results extracted from published paper indexed in Scopus', A.A.A. Rashdi, S.M. Sapuan, M.M.H.M. Ahmad and A. Khalina, Combined effects of water absorption due to water immersion, soil buried and natural weather on mechanical properties of kenaf fiber unsaturated polyester composites (KFUPC). General conclusion and recommendations for further work, based on the present research are suggested in chapter 8.

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