STUDIES ON THE PROPERTIES OF SHORT OKRA-GLASS FIBERS REINFORCED EPOXY HYBRID COMPOSITES

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By

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DEPARTMENT OF CHEMICAL ENGINEERING,
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OCTOBER 2014

Declaration

I declare that the work in this thesis entitled **"Studies on the Properties of Short Okra-Glass Fibers Reinforced Epoxy Hybrid Composites"** has been carried out by me in the Department of Chemical Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree at this or any other Institution.

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Name of Student	Signature	Date

Certification

This thesis entitled **"STUDIES ON THE PROPERTIES OF SHORT OKRA-GLASS FIBERS REINFORCED EPOXY HYBRID COMPOSITES"** by Usman, SULE with registration number MSc/ENG/10937/2011-2012 meets the regulations governing the award of the degree of Master of Science (M.Sc) in Chemical Engineering of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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Dedication

This project work is dedicated to the loving Memory of my beloved mum, Hajia MARIAM S. MOMOH (May Allah grant her Aljanatul Firdaus).

Table of Contents

Title Page iii

Declaration iii

Certification ivii

Acknowledgements iv

Dedication vi

Table of Contents…….. vi

List of Tables…… xi

List of Figures……. xii

List of Appendices……... xiv

Abbreviations and Symbols……..... xvi

Abstract……..... xviii

CHAPTER ONE…….…... 1

1.0 INTRODUCTION……... 1

1.1 Problem Statement.……..... 4

1.2 Justification…….. 4

1.3 Aim and Objectives 4

1.4 Scope of Work 5

CHAPTER TWO…….. 6

2.0 LITERATURE SURVEY. 6

2.1 Composites……..... 6

2.2 Classification of Composites 6

2.2.1 Particulate reinforced composite 7

2.2.2Fibrous reinforced composites.....8

2.2.3Calculating the composites theoretical properties……..……12

2.2.4Factors affecting the mechanical behavior of hybrid composites…….……..15

2.3 Composite Structures……..17

2.3.1 Matrix phase.....18

2.3.2 Reinforcement Phase……...22

2.4 Natural (Cellulosic) Fibers…….……..……..23

2.4.1 Cellulosic fibers: Advantages and Disadvantages……...…….……..25

2.4.2 Surface properties 26

2.4.3 Methods of surface modification of natural fibers.....27

2.4.5 Okra fibers ……. ……..……..37

2.5 Synthetic Fibers ……. ……...……..…….……...39

2.5.1Glass fibers…… …….……..…….....40

2.6 Epoxy Resins…… …….……..……41

2.7 Curing Agents (Hardners)…… ……..……...43

2.8Curing Reactions…...…… ……..……45

CHAPTER THREE……...49

3.0 MATERIALS AND METHODOLOGY……..…..49

3.1 Materials and Equipment……..….49

3.1.1 Materials…….…….……....49

3.1.2 Equipment…….…….……....50

3.2 Experimental Methods……..…….……51

3.2.1 Mould preparation…….……..51

3.2.2 Virgin specimen preparation……...51

3.2.3Determination of Critical Fiber Length…..…….....51

3.2.4Determination of optimal hybridization ratio……..……52

3.2.5Determination of optimal treatment concentration……..……53

3.3 Materials Characterization 54

3.3.1 Tensile test 55

3.3.2 Flexural test.....55

3.3.3 Impact test.....55

3.3.4Hardness test 55

3.3.5Water absorption test 55

CHAPTER FOUR.....57

4.0 RESULTS AND DISCUSSION 57

4.1 Determination of Critical Fiber Length.....57

4.1.1 Effect of fiber length on the tensile strength.....57

4.1.2 Effect of fiber length on the modulus of elasticity (MoE).....58

4.1.3 Effect of fiber length on the Impact strength of the composite……..…60

4.1.4 Effect of fiber length on the flexural modulus of the composite…….61

4.1.5 Effect of fiber length on the hardness of the composite……..63

4.1.6 Effect of fiber length on the elongation at break of the composite.....64

4.1.7 Effect of fiber length on the energy at break of the composite.....65

4.1.8 Effect of fiber length on the water absorption of the composite.....66

4.2 Determination of Optimal Okra-Glass Hybridization Ratio……..…..67

4.2.1 Effect of okra-glass hybridization on the tensile strength of the composite.....67

4.2.2Effect of okra-glass hybridization on the modulus of elasticity(MoE) of the Composite…….……...…..69

4.2.3Effect of okra-glass hybridization on the elongation at break ofthe composite……..70

4.2.4Effect of okra-glass hybridization on the energy at break of the composite……..72

4.2.5 Effect of okra-glass hybridization on the impact strength of the composite……73

4.2.6 Effect of okra-glass hybridization on the flexural modulus (MoR) of the composite……...74

4.2.7 Effect of okra-glass hybridization on the hardness of the composite…...……...75

4.2.8 Effect of okra-glass hybridization on the water absorption capacity of the composite……...77

4.3 Determination of Optimal Fiber Treatment Concentration……78

4.3.1 Effect of fiber treatment on the tensile strength of hybridized composite……..……78

4.3.2 Effect of fiber treatment on the elongation at break of the hybridized composite……..……...80

4.3.3 Effect of fiber treatment on the impact strength of the hybridized composite……81

4.3.4 Effect of fiber treatment on the modulus of elasticity of hybridized composite…….83

4.3.5 Effect of fiber treatment on the modulus of rupture (MoR) of hybridized composite……...……...85

4.3.6 Effect of fiber treatment on the water absorption capacity of hybridized composite……...……...86

4.3.7 Effect of fiber treatment on the hardness of the hybridized composite…….…...88

4.3.8 Effect of fiber treatment on the energy at break of hybridized composite……89

CHAPTER FIVE…….……92

5.0 CONCLUSION AND RECOMMENDATION…….....92

5.1 Conclusion……..……92

5.2 Recommendation……....93

REFERENCES…….....94

APPENDICES……107

LIST OF TABLES

Table 2.1**:** Advantage and Disadvantages of Natural Fibers……..26

Table 2.2: Chemical Composition of Okra Bast Fiber……....38

Table 2.3: Advantages and Disadvantages of Synthetic Fibers……..40

Table 2.4: Glass Fiber types and their areas of application……..…41

Table 2.5: Chemical Structure of some Epoxy Resins…….43

Table 2.6: Curing Agents and Their Chemical Structures……...45

Table 3.1: Equipment used and their characteristics……....50

LIST OF FIGURES

Figure 2.1:Classification of Composites Materials……7

Figure 2.2: Activation of copolymer step 30

Figure 2.3: Esterification of cellulose step 30

Figure 4.1: The Effect of Fiber Length on the Tensile Strength of Short Okra Fiber Reinforced Epoxy Composite…….57

Figure 4.2: Effect of Fiber Length on the Modulus of Elasticity of Short Okra Fiber Reinforced Epoxy Composite…….59

Figure 4.3: Effect of Fiber Length on the Impact Strength of Short Okra Fiber Reinforced Epoxy Composite…….…….60

Figure 4.4: Effect of Fiber Length on the Flexural Modulus of the Composite……..62

Figure 4.5: Effect of Fiber Length on the Hardness of Short Okra Fiber ReinforcedEpoxy Composite…….……..63

Figure 4.6: Effect of Fiber Length on the Elongation at Break of the Short Okra FiberReinforced Epoxy Composite…….…….64

Figure 4.7: Effect of Fiber Length on Energy Absorbed of the short okra Reinforced Epoxy composite…….……...65

Figure 4.8: Effect of Fiber Length on Water Absorption Capacity of Short OkraFiber Reinforced Epoxy Composite…….……66

Figure 4.9: Effect of Glass Fiber Hybridization on the Tensile Strength of the Composite……..……...68

Figure 4.10:Effect of Glass Fiber Hybridization on the MOE of the Composite……..…69

Figure 4.11: Effect of Glass Fiber Hybridization on the Elongation at Break of

the Composite…….....71

Figure 4.12: Effect of Glass Fiber Hybridization on the energy at Break of the Composite…….72

Figure 4.13: Effect of Glass Fiber Hybridization on the Impact Strength of the Composite…...……..…..73

Figure 4.14: Effect of Glass Fiber Hybridization on the MOR of the Composite…….……74

Figure 4.15: Effect of hybridization ratio on the hardness of the Composite……..…....76

Figure 4.16: Effect of Glass Fiber Hybridization on Water Absorption of Composite…….…….....77

Figure 4.17: Effect of Fiber Treatment on the Tensile Strength of the Composite……...79

Figure 4.18: Effect of Fiber Treatment on the Elongation at Break of the Composite……...……....81

Figure 4.19: Variation of Fiber Treatment with Impact Strength of Composite……..……82

Figure 4.20: Effect of Fiber Treatment on the MOE of the Composite……...……...83

Figure 4.21: Effect of Fiber Treatment on the MOR of the Composite…….....85

Figure 4.22: Variation of Fiber Treatment on the Water Absorption propertyof the Composite……...87

Figure 4.23:Variation of Fiber Treatment on the Hardness of the Composite……...88

Figure 4.24: Effect of Fiber Treatment on the Energy at Break of the Composite ……..90

LIST OF APPENDICES

Appendix A-1: Mechanical Properties of Unreinforced Virgin Epoxy Composite……108

Appendix A-2: Mechanical Properties of 10mm Fiber Length Reinforced Epoxy Composite Material…….....112

Appendix A-3: Mechanical Properties of 20mm fiber length reinforced Epoxy Composite Material…….....116

Appendix A-4: Mechanical Properties of 30mm fiber length reinforced Epoxy Composite Material…….....120

Appendix A-5: Mechanical Properties of 40mm fiber length reinforced Epoxy Composite Material…….....124

Appendix A-6:Mechanical Properties of 50mm fiber length reinforced Epoxy Composite Material……...128

Appendix B-1:Mechanical Properties of 9:1 Okra:Glass hybridized reinforced Epoxy Composite Material……..132

Appendix B-2: Mechanical Properties of 8:2 Okra:Glass hybridized reinforced Epoxy Composite Material……..126

Appendix B-3: Mechanical Properties of 7:3 Okra:Glass hybridized reinforced Epoxy Composite Material……..140

Appendix B-4: Mechanical Properties of 5:5 Okra:Glass hybridized reinforced Epoxy Composite Material……..144

Appendix C-1: Mechanical Properties of 5%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material……..……..148

Appendix C-2: Mechanical Properties of 10%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material……...……...151

Appendix C-3: Mechanical Properties of 15%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material……...……...155

Appendix C-4: Mechanical Properties of 20%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material……...…...158

ABBREVIATIONS AND SYMBOLS

A: Einstein's Coefficient which measures reinforcement geometry

η: Dimensionless Constant

ψ: Dimensionless Constant

$\phi_{m:}$ Packing Fraction

$\sigma_{H:}$ Tensile Strength of Hybrid Composite (MPa)

σ_a: Tensile Strength of first fiber component (MPa)

σ_b: Tensile Strength of second fiber component (MPa)

σ_{le}: Tensile Strength of low elongation fiber component (MPa)

σ_{he}: Tensile Strength of high elongation fiber component (MPa)

ε_{le}: Strain in the low elongation fiber component

ρ_C: Density of composites (kg/m^3)

ρ_R: Density of resin (kg/m^3)

f: Fiber

M: Matrix

E_{he}: Modulus of Elasticity of high elongation fiber component (MPa)

E_{le}: Modulus of Elasticity of low elongation fiber component (MPa)

E_c: Modulus of Elasticity of the composite (MPa)

E_M: Modulus of Elasticity of the matrix (MPa)

E_f: Modulus of Elasticity of the fiber (MPa)

E_H: Modulus of Elasticity of the hybrid composite (MPa)

E_a: Modulus of Elasticity of the first fiber component (MPa)

E_b: Modulus of Elasticity of the second fiber component (MPa)

M_R: Mass of resin (kg)

M_c: Mass of composite (kg)

P_H: Property of the hybrid to be determined

P_1: Corresponding property of the first component in the hybrid to be determined

P_2: Corresponding property of the second component in the hybrid to be determined

V_{le}: Volume fraction of low elongation fiber component (m^3)

V_{he}: Volume fraction of high elongation fiber component (m^3)

V_{crit}: Critical volume (m^3)

V_1: Relative hybrid volume fraction of the first component in the hybrid system

V_2: Relative hybrid volume fraction of the second component in the hybrid system

V_R: Volume fraction of the resin in the hybrid system (m^3)

V_R: Volume fraction of the matrix in the hybrid system (m^3)

V_f: Volume fraction of the fiber in the hybrid system (m^3)

V_a: Volume fraction of the first fiber in the hybrid system (m^3)

V_b: Volume fraction of the second fiber in the hybrid system (m^3)

MoE: Modulus of Elasticity (MPa)

MoR: Modulus of Rupture (MPa)

W_f: The weight of the samples after immersion in water (g).

W_i: The weight of the samples before immersion in water (g).

ABSTRACT

In this work,theproperties of short okra-glass fibers reinforced epoxy hybrid composites were studied. Critical fiber length of the okra fiber was studied at different lengths (10mm, 20mm, 30mm, 40mm and 50mm). Fiber length of 20mm exhibited the best optimal property values. The properties obtained were Tensile strength value of 10.7MPa, MoE value of 698.8MPa, impact strength of 20kJ/m^2, hardness of 39.7HRF and the least water absorption capacity of 4.3%.Based on these results, 20mm was selected as the critical length of the okra fiber. Hybridization of okra fiber with the glass fiber was based on the established 20mm length of okra fiber. The best hybridization ratio of okra:glass was determined by varying the hybrid ratio (90:10, 80:20, 70:30, 60:40 and 50:50). The 50:50 okra:glass ratio was observed to have the best tensile strength value of 12.4MPa, MoE of 752MPa, elongation and energy at break values of 2.5mm and 4.6J, impact strength of 27.8kJ/m^2, hardness of 56.8HRF and the least percentage water absorption capacity of 2.6%. To improve on the properties of the composite, the okra fiber was treated with varying concentrations of NaOH solution (5%, 10%, 15% and 20%) to determine the best treatment concentration. The result showed that the 10% concentration treated fiber composite exhibited the best tensile strength, elongation at break, MoE, hardness and energy at break with values of 24.5MPa, 29mm, 786MPa, 68.6HRF and 5.8J respectively. The 5% concentration treated fiber composite exhibited the highest impact strength, flexural modulus (MoR) and the least water absorption with values of 64.3kJ/m^2, 50.4MPa and 1.9% respectively.

CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

Hybrid composites involve two or more types of fibers set in common matrix (Dixit and Verma, 2012). The particular combination of fiber is usually selected to balance strength and stiffness, provide dimensional stability, reduce cost, reduce weight or improve fatigue and fracture resistance (Moriteiro *et al., 2005*). The idea of hybrid fiber reinforced composite has been researched for a series of material combination. Hybridization ofcomposites made of natural fibers and synthetic fibers, can improve the properties of the natural fiber reinforced composite significantly (Mubarak *et al., 2009*).

The potential advantages of combining two kinds of fiber in a singlepolymer matrix have been described by many researchers. Jawaid and Abdul Khalil (2011)reported that the behaviour of hybrid composites appeared to be simply aweighted sum of the individual components in which there is a more favourable balance between the inherent advantages and disadvantages. While using a hybrid composite in which two or more types of fibers are employed, the advantages of one type of fiber could compliment what the other hybridized fiber lacks (Maya and Thomas 2008).

It is generally accepted that the properties of hybridcomposites are controlled by many factors such as the nature of matrix, nature of the fiber, hybriddesign,length and relative composition of the individual fibers, the fiber-matrix interface bonding, arrangement of both the fibers and also on the failure strain of individual fibers (Sreekala*et al.,* 2002). Hybrid composites reinforced with natural fibers, very often combined with synthetic fibers demonstrate good mechanical performance. The use of natural fibers in hybridization has also been reported (Maya and

Thomas 2008), but due to the fact that wholly natural fibers are deficient in many mechanical properties, their application as structural material is limited; they also offer low weight and are biodegradable which is an advantage on their part.

Srinivasababu *et al*., (2009) studied the tensile properties of okra, sisal and banana reinforced polyester composite. The results showed that the density of okra, sisal and banana fiber reinforced polyester composites decreased with increasing volume fraction of the fiber. The tensile strength of the untreated okra fiber composites increased linearly up to the volume fraction of 20.4% and was 2.34 times higher than that of the polyester matrix. Their results also show that chemically treated okra fiber composite showeda tensile strength of 6.43% higher than the untreated okra fiber composite and 154.17% higher than the matrix.

Koradiya *et al*., (2010) studied the mechanical and water absorption properties of jute/glass fiber reinforced epoxy composites and the results indicated that hybrid composites have intermediate properties than those of jute and glass composites. The effect of water absorption in different chemical environment and boiling water was also studied. It was observed that hybrid composites show improvement in water absorption behavior compared to jute and glass composites.

Raghavendra *et al.,* (2009) studied the flexural and compressive properties of bamboo/glass fiber reinforced epoxy hybrid composites and their results indicated that alkali treated bamboo hybrid composites show better properties compared to untreated bamboo fiber composites.

Pavithran *et al*., (1991) carried out a detailed investigation of sisal-glass hybrid fiber and coir-glass hybrid fiber reinforced polyester resin and showed that the addition of small amounts of glass fibers to the natural fibers not only enhanced the mechanical properties but also improved

the weathering characteristics of the composites. It is important to mention that the performance of hybrid fiber reinforced composites can be improved to a great extent by proper chemical modifications. The use of chemical modification such as mercerization has also been reported to enhance hybridization. MohdYussni *et al*., (2012) reported the various effects of mercerization on different types of fibers. Srinivasababu *et al.,* (2009) reported that Okra individual fiber reinforced composites after chemical treatment with NaOH is better choice than other composites studied because it shows highest tensile strength and tensile modulus and the specific tensile strength is also highest for chemically treated okra fiber reinforced polyester composites.

The development of such materials has not only been a great motivating factor for materials scientists, but also an important provider of opportunities to improve the standard of living of people around the world. The natural fibers are renewable materials and are agricultural based, and these could generate a non-food source of economic development for farming in rural areas in developing countries like Nigeria. This can provide a potential for economic improvement based on these materials even though major thrust for their use has been driven by the needs in industrialized countries. Natural fibers such as jute, sisal, pineapple, okra, banana etc., whose extraction is an important process that determines the properties of the fibers, can generate rural jobs. These fibers have established their potential as reinforcing fillers in many polymers and products, and hence have found increasing use on a commercial scale in recent years. All these natural fibers especially okrahave not been fully utilized in combination with synthetic fibers in hybrid composites development. Therefore there is need to consider their use and ways of improving their properties for hybrid composites development.

1.2 PROBLEM STATEMENT

Composite materials based wholly on synthetic fibers are not biodegradable and are also considered to be heavy. However, those from natural fibers are light but have low mechanical properties compared to wholly synthetic fiber composites making their structural applications limited. The use of okra fiber in composites materials is still very limited despite its potentials, hence the need to consider okra fiber in this research work and also contribute to knowledge on okra fiber composites.

1.3 AIM AND OBJECTIVES OF THIS RESEARCH

The aim of the research is to study the properties of short okra-glass fiber hybrid composite with the following objectives;

i. To determine the critical fiber length of okra
ii. To improve the mechanical and water absorption properties of okra fiber composites by hybridization with glass fibers.
iii. To study the degree of mechanical reinforcement that could be obtained by the hybridization of glass and okra fibers.
iv. To investigate the effect of varying concentration of NaOH treatment on fiber modification**.**

1.4 JUSTIFICATION

The research serves as a means of obtaining lightweight materials with improved mechanical properties and optimal performance. It will also encourage the development of more ecofriendly materials to address environmental challenges posed by wholly synthetic fiber composites and

the need to also contribute to existing data on properties of okra-glass fiber hybrid composites. It will also generate more income to the farmers.

1.5 SCOPE OF THE RESEARCH WORK

The scope of the research involves the production of okra and glass fibers reinforced epoxy based composite materials, evaluation of mechanical properties of the fabricated materials, to study the degree of mechanical reinforcement that could be obtained by the hybridization of glass and okra fibers to achieve the improved mechanical properties and to study the effect of varying NaOH concentration of okra fiber modification.

CHAPTER TWO

LITERATURE SURVEY

2.1 COMPOSITES

A composite is a structural material that consists of two or more constituents that are combined at a macroscopic level and are not soluble in each other (Al-Mosawi 2012). One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix (Patel *et al*., 2012). The composite material however, generally possesses characteristic properties, such as stiffness, strength, weight, high-temperature performance, corrosion resistance, hardness, and conductivity that is not possible with the individual components by themselves (Dubey *et al.*, 2012). The mechanical properties of composite materials have a great importancein the field where high mechanical properties values are required so thatthey can perform successfully. (Rao-Sathish and Rodrigues, 2012)

2.2 CLASSIFICATION OF COMPOSITES

Most composite materials developed thus far have been fabricated to improve the mechanical properties. It is naturally convenient to study together the composites that have the same strengthening mechanism, which in-turn depends on the geometry of the reinforcement. It is therefore convenient to classify composite materials on the geometry of a representative unit of reinforcement (Bhagwan and Lawrence, 2006). Figure 2.1 represents a commonly accepted classification scheme.

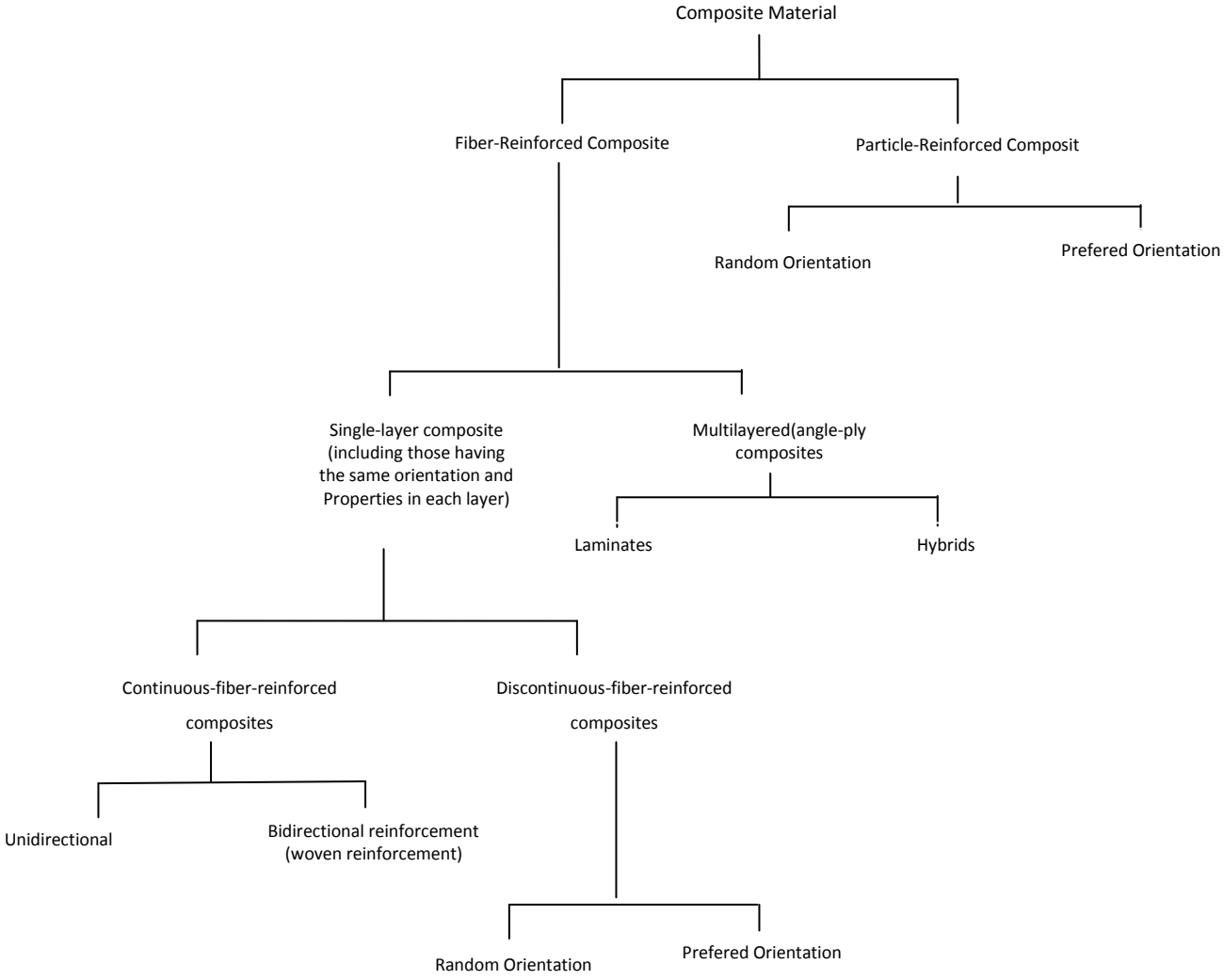


Figure 2.1: Classification of composite materials (Bhagwan and Lawrence, 2006)

2.2.1 Particulate Reinforced Composite

A composite whose reinforcement may be classified as particles is called a particulate composite (Bhagwan and Lawrence, 2006). A particle by its own definition is nonferrous and generally has no long dimension with the exception of the platelets (Bhagwan and Lawrence, 2006). Particulate fillers are employed to improve high temperature performance, reduce friction,

increase wear resistance and to reduce shrinkage (Richardson, 1987). The particles will also share the load with the matrix, but to a lesser extent than a fiber. A particulate reinforcement will therefore improve stiffness but will not generally strengthen.

2.2.2 Fibrous Reinforced Composite

Fiber reinforcement represents physical rather than a chemical means of modifying a material to suit various engineering applications (Warner, 1995).

Fibers, because of their small cross-sectional dimensions, do not have direct engineering application. They are therefore embedded in matrix materials to form fibrous composites (Bhagwan and Lawrence, 2006). Fibers incorporated in a polymer matrix increase the stiffness, strength, fatigue life, and other properties (Agarwal and Broutman, 1990; Schwartz, 1992). Fibers are mechanically more effective in achieving a stiff, strong composite than particles.

2.2.2.1 Hybrid composite

The incorporation of several different types of fibers into a single matrix has led to the development of hybrid composites. The behavior of hybrid composites is a weighed sum of the individual components in which there is a more favorable balance between the inherent advantages and disadvantages. Also, using a hybrid composite that contains two or more types of fibers, the advantages of one type of fiber could complement with what are lacking in the other. As a consequence, a balance in cost and performance could be achieved through proper material design (Thwe and Liao, 2003). The properties of a hybrid composite mainly depend upon the fiber content, length of individual fibers, orientation, extent of intermingling of fibers, fiber to matrix bonding and arrangement of both the fibers. The strength of the hybrid composite is also

dependent on the failure strain of individual fibers. Maximum hybrid results are obtained when the fibers are highly strain compatible (Sreekala *etal*., 2002).

A positive or negative hybrid effect is defined as a positive or negative deviation of a certain mechanical property from the rule of hybrid mixture. The term hybrid effect has been used to describe the phenomenon of an apparent synergistic improvement in the properties of a composite containing two or more types of fiber. The selection of the components that make up the hybrid composite is determined by the purpose of hybridization, requirements imposed on the material or the construction being designed. The problem of selecting the type of compatible fibers and the level of their properties is of prime importance when designing and producing hybrid composites. The successful use of hybrid composites is determined by the chemical, mechanical and physical stability of the fiber/matrix system. Hybrid biocomposites can be designed by the combination of a synthetic fiber and natural fiber (biofiber) in a matrix and a combination of two natural fiber/biofibers in a matrix. .

Hybridization with glass fiber provides a method to improve the mechanical properties of natural fiber composites and its effect in different modes of stress depends on the design and construction of the composites. The effect of hybridization of glass fiber in thermoset biocomposites has been discussed in detail (Ray *et al*., 2005). The tensile and impact behavior of oil palm fiber-glass fiber-reinforced epoxy resin was investigated by Bakar *et al*., (2005). The hybridization of oil palm fibers with glass fibers increased the tensile strength, Young's modulus, and elongation at break of the hybrid composites. A negative hybrid effect was observed for the tensile strength and Young's modulus while a positive hybrid effect was observed for the elongation at break of the hybrid composites. The impact strength of the hybrid composites increased with the addition of glass fibers.

Hybridization also has a profound effect on the water absorption property of composites. An attempt to study the moisture uptake characteristics of hybrid systems was performed by Mishra *et al.,* (2003). The composite systems chosen were sisal/glass and pineapple/glass fiber reinforced polyester composites. Composites were prepared by varying the concentration of glass fiber and by subjecting the bio-fibers to different chemical treatments. The authors observed that water uptake of hybrid composites were less than that of un-hybridized composites. Kasama and Suppakarn (2009) studied the effect of glass fiber hybridization on the properties of sisal fiber polypropylene composites and observed a decrease in water absorption of the sisal-polypropylene composites.

The flexural behaviour of hybrid laminated composites (LC) with a hemp fiber-polypropylene core and two glass fibers/polypropylene surface layers at each side of the specimen were investigated by Reis *etal.,* (2007). When compared with full glass fibers reinforced polypropylene laminates, the hybrid composites were found to have economical, ecological and recycling advantages and also specific fatigue strength benefits. Static and fatigue tests were performed in three point bending for both laminates to evaluate flexural strength properties and fatigue behaviour. The major findings were that laminated composites (LC) exhibited an ultimate strength about 4% higher than the hybrid laminated composites (HLC) associated to changes in failure mechanisms, while the stiffness' modulus was also about 3.8% higher. Fatigue strength of hybrid laminated composites was also about 20% lower than the laminated composites as consequence of the change of the failure mechanisms and of the different static strengths.

The mechanical, water absorption, and thermal properties of injection-moulded short hemp fiber/glass fiber-reinforced polypropylene hybrid composites were investigated by Panthapulakkal and Sain (2007). They observed that hybridization with glass fiber enhanced the

performance properties. A value of 101 MPa for flexural strength and 5.5 GPa for the flexural modulus was achieved from hybrid composite containing 25 wt% of hemp and 15 wt% of glass. Notched Izod impact strength of the hybrid composites exhibited great enhancement (34%) compared to un-hybridized samples. Thermal properties and resistance to water absorption properties of the hemp fiber composites were improved by hybridization with glass fibers.

Vemu *et al., (*2011) studied the chemical resistance and tensile properties of bamboo/glass fiber reinforced epoxy hybrid composite. It was observed that tensile properties of the hybrid composites increase with glass fiber content. These properties were found to be higher when alkali treated bamboo fibers was used in the hybrid composites. The hybrid fiber composites showed better resistance to chemicals like acetic acid, nitric acid, hydrochloric acid, sodium hydroxide, ammonium hydroxide, sodium carbonate, benzene, toluene and carbon tetrachloride which were used for the study. The elimination of amorphous hemi-cellulose with alkali treatment leading to higher crystallinity of the bamboo fibers with alkali treatment may be responsible for these observations.

2.2.2.2 Prediction of properties of hybrid system

The properties of the hybrid system consisting of two components can be predicted by the rule of mixtures as presented in Equations 2.1 to 2.4 (Thwe and Liao (2003), Sreekala *et al.*, 2002).

$$P_H = P_1V_1 + P_2V_2 \quad (2.1)$$

WhereP_H is the property to be investigated, P_1 the corresponding property of the first system and P_2 the corresponding property of the second system, V1 and V_2 are the relative hybrid volume fractions of the first and second system (Resin and the fiber).

$V_1 + V_2 = 1$ (Sreekala *et al*., 2002). (2.2)

The volume fractions of the resins and composites are calculated with the relationship (Srinivasababu *et al*., 2009):

$$V_R = \frac{M_R \times \rho_C}{M_C \times \rho_R} \quad (2.3)$$

Where ρ_R and ρ_C = density of resin and composites in kg/m^3

Then the fiber volume fraction is determined by the relation

$$V_f = 1 - V_R \quad (2.4)$$

$M_c$andM_R are the mass of composite and resin respectively.

2.2.3 Calculating the Composite Theoretical Properties

By the rule of mixtures, the modulus of a composite is defined as the combination of the modulus of the fiber and the modulus of the matrix that are related to the volume fractions of the constituent materials (Maya*et al*., 2009). If subscript f and m denotes fiber and matrix, then the rule of mixture equation will be given by Equation 2.5:

$$E_c = E_f V_f + E_m V_m = E_f V_f + E_m (1 - V_f). \quad (2.5)$$

E_c is the modulus of elasticity of the composite material. According to the rule of mixtures, the volume fraction of the fiber and the volume fraction of the matrix must be unity as in Equation2.6 (Yakubu*et al*., 2012):

$$V_f + V_m = 1 \quad (2.6)$$

In an aligned two fiber composite (hybrid composite), the rule of mixtures can be expanded as in Equation 2.7 where subscript a and b indicates each of the fiber species (Maya*et al*., 2009).

$$E_H = E_a V_a + E_b V_b + E_m (1 - V_a - V_b) \quad (2.7)$$

$$V_a + V_b + V_m = 1 \quad (2.8)$$

V_a and V_b are the volume fractions of each of the fiber species.

In practice, the contribution of the matrix to the overall strength of the composite is negligible and is ignored (Short and Summerscales, 1982).

$$E_H = E_a V_a + E_b V_b \quad (2.90$$

$$\sigma_H = \sigma_a V_a + \sigma_b V_b \quad (2.10)$$

If the volume fraction of the high elongation fiber is high in the composite and load is applied, the low elongation fibers will experience multiple failures before the failure of the high elongation fibers is reached. It is assumed that the low elongation fibers did not make any contribution in the composite. From the Rule of mixture, the hybrid composite strength ($\sigma_{H)}$ is therefore given by Equation 2.11 (Bryan 1999).

$$\sigma_H = \sigma_{he} V_{he} \quad (2.11)$$

When a high volume fraction of the low elongation fiber is added, the composite will still fail and the entire load will be carried by the high elongation fibers. The hybrid composite strength is given by Equation 2.12 (Bryan 1999).

$$\sigma_H = \sigma_{he} V_{he} + \sigma_{le} V_{le} \quad (2.12)$$

Where σ_{he} is the strength of the high elongation fiber, $\sigma_{le}$is the strength of the low elongation components V_{he} and V_{le} are the volume fractions of the high elongation and low elongation components respectively. Yakubu *et al*., (2012) studied the properties of woven kenaf-polyethylene terephthalate fiber reinforced polyoxymethylene hybrid composite and observed that the high elongation fiber contributes more in raising the composite strength while the low elongation fiber increases the composite modulus more in the longitudinal direction. The critical volume fraction (the volume fraction in which any strengthening effect of the fiber is observed) of the high elongation component is given by Equation 2.13 (Bryan 1999).

$$V_{crit} = \frac{\sigma_{le}}{\sigma_{le}+\sigma_{he}-\varepsilon_{le}E_{he}} \tag{2.13}$$

The hybrid composite strength at fiber fracture strain is given by:

$$\sigma_{min} = (1-V_{crit})\, E_{le}\, \varepsilon_{le} \tag{2.14}$$

Where

E_{le} is the modulus of elasticity in the low elongation component (MPa)

$\varepsilon_{le}$is the strain in the low elongation component.

The tensile modulus of the hybrid composite is calculated using the modified Halpin-Tsai equation.

$$\frac{E_H}{E_M} = \frac{1+A\eta V_F}{1-\eta\psi V_f} \tag{2.15}$$

where E_H and E_M, are the tensile modulus of the hybrid composite and matrix (MPa). In the case where two fibers are combined V_f is the total volume fraction of the two fibers. A is a constant

called Einstein's coefficient, for composites which is governed by the packing geometry and loading condition of the reinforcement. In this equation, Halpin and Tsai suggested that the value of Ais found to be 2.5 for fibers with circular or square cross section(Bhagwan and Lawrence, 2006)**.** It was reported that the Avalue for aggregates of spheres can have the same value as that of short fibers or rods. The values of η and ψ are given by the Equations 2.16 and 2.17.

$$\eta = \frac{\frac{E_f}{E_M} - 1}{\frac{E_f}{E_M} + A} \tag{2.16}$$

$$\psi = 1 + [(1 - \phi_m)/\phi^2_m]V_f \tag{2.17}$$

Where,ϕ_m in Equation 2.17 is the packing fraction of fibers.

The value of packing fraction for different fiber arrangement in the matrix has already been reported in the literature (Chawla, 1998)**.** The different arrangements of fibers in the matrix are square packing, hexagonal packing and random packing. For a randomly close packed in the matrix, the value of ϕm is 0.82, Square packing is 0.785 and hexagonal packing is 0.907 (Chawla, 1998).

2.2.4 Factors Affecting the Mechanical Behaviour of Hybrid Composite

Srinivas*et al.*, (2012) in their work listed some of the factors that affect the behavior of hybrid composites. The factors include;

1. Fiber volume or Weight fraction: It is the measure of the volume or weight proportion of fibers in a hybrid composite (Srinivas *et al.*, 2012). Positive and negative effects of varying

the volume/weightfractions of the fibers had been observed by many researchers. Pothan *et al.,* (1999) concluded that the impact strength of banana and glass hybrid composite increases when the glass volume fraction is increased up to 11%. A further increase in the glass volume fraction lowers the impact strength slightly.

Rajesh *et al*., (2011) studied the effect of volume fraction on the tensile strength of banana fiber reinforced vinyl ester resin composite and observed an improvement in the tensile properties of the banana-vinyl ester resin composite. The tensile strength and tensile modulus increased by 38.6% and 65% respectively at 35% fiber volume fraction. Prasad (2011) studied the tensile and flexural properties of hybrid jute and glass fibers reinforced polyester composite. He observed that the tensile strength of the hybrid composite increased with the increase in glass fiber volume fraction. The young modulus is greater for the hybrid composite with greater jute fiber volume fraction than the one with higher glass fiber volume fraction.

2. Stacking Sequence of the Fiber. Stacking sequence represents the pattern of arrangement of the fiber layers in the hybrid composite. (Srinivas*et al*., 2012).

   Sabeel and Vijayarangan, (2008) investigated the tensile, interlaminar shear and flexural properties of jute and glass fiber reinforced polyester hybrid composite by varying the stacking sequence of the layers. The result indicated that tensile strength of the specimens with glass fibers at the extreme showed higher values than the other specimen. This, they explained was as a result of the superior strength and stiffness of the glass fibers compared to the jute fibers. The flexural strength wasmore for the specimen with glass fibers at the extreme ends and the jute layer at the core. This wasbecause the flexural strength is mainly controlled by the stiffness of the extreme plies.

Gupta, (2009) experimentally evaluated the mechanical properties for flax fiber reinforced composite lamina, Glass fiber reinforced composite lamina, glass-flax-glass hybrid and flax-glass-flax hybrid. A change in properties due to variation in stacking was observed. The glass-flax-glass hybrid has the superior properties (tensile, compressive, flexural, impact and specific tensile strength) compared to the flax-glass-flax hybrid.

3. Treatment of Fibers: in composite materials, good interfacial bonding between the fiber and matrix is essential for optimum performance (Srinivas *et al*., 2012). Chemical treatment of the fibers is one of the ways adopted by researchers to achieve good bond strength between the fiber and matrix.

   Raghu *et al.,* (2010) examined the chemical resistance of the treated and untreated sisal, silk fiber reinforced polyester hybrid composite. The treated and untreated hybrid composites wereexposed to various acids, solvents and alkali. Exposure of the treated and untreated hybrid composite to carbon tetra chloride showed predominant weight loss due to damage to polyester cross-linking caused by chlorinated hydrocarbon. Venkata *et al.,* (2010) studied the effect of chemicals and alkali treatment on the mechanical behavior of glass and bamboo fiber reinforced polypropylene hybrid composites. The alkali treated composite showed positive effect on the tensile properties and chemical resistance due to removal of hemicellulose on the bamboo fibers.

2.3 COMPOSITE STRUCTURES

The individual materials that make up composites are called constituents. Most composites have two constituent materials: a binder or matrix, and reinforcement. The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its good properties. The

matrix holds the reinforcements in an orderly pattern. Because the reinforcements are usually discontinuous, the matrix also helps to transfer load among the reinforcements.

The fundamental design concept of composites is that the bulk phase accepts the load over a large surface area, and transfers it to the reinforcement material, which can carry a greater load. The significance here lies in that there are numerous matrix materials and as many fiber types, which can be combined in countless ways to produce just the desired properties.

Most commonly, composite materials have a bulk phase, which is continuous, called the matrix; and a dispersed, non-continuous, phase called the reinforcement.

2.3.1 Matrix Phase

The matrix phase is the bulk phase and it comprises of materials such as the polymer resins, ceramics and metals. A comparison in general terms, however, can identify some of the more obvious advantages and disadvantages of the different types of material, at a simplistic level.

2.3.1.1 Plastics

They have good short-term chemical resistance but they lack thermal stability and have only moderate resistance to environmental degradation (especially that caused by the photo-chemical effects of sunlight). They have poor mechanical properties, but are easily fabricated and joined and are of low density.

Typically, most common polymer-based composite materials, including fiberglass, carbon fiber, and Kevlar include at least two parts, the substrate and the resin. The two most common plastic matrices are epoxy resins and polyester resins.

Polyester resin tends to have yellowish tint, and is suitable for most backyard projects. Its weaknesses are that it is UV sensitive and can tend to degrade over time, and thus generally is also coated to help preserve it. It is often used in the making of surfboards and for marine applications. Its hardener is peroxide, often MEKP (methyl ethyl ketone peroxide). When the peroxide is mixed with the resin, it decomposes to generate free radicals, which initiate the curing reaction. Hardeners in these systems are commonly called catalysts, but since they do not re-appear unchanged at the end of the reaction, they do not fit the strictest chemical definition of a catalyst.

Vinylester resin tends to have a purplish to bluish to greenish tint. This resin has lower viscosity than polyester resin, and is more transparent. This resin is often billed as being fuel resistant, but will melt in contact with gasoline. This resin tends to be more resistant over time to degradation than polyester resin, and is more flexible. It uses the same hardeners as polyester resin (at a similar mix ratio) and the cost is approximately the same.

Epoxy resin is almost totally transparent when cured. In the aerospace industry, epoxy is used as a structural matrix material or as structural glue.

2.3.1.2 Ceramics

Ceramics may be of low density (although some are very dense). They have great thermal stability and are resistant to most forms of attack (abrasion, wear, corrosion). Although intrinsically very rigid and strong because of their chemical bonding, they are all brittle and can be formed and shaped only with difficulty.

2.3.1.3 Metals

Metals are mostly of medium to high density, which implies that only magnesium, aluminum and beryllium can compete with plastics in this respect. Many have good thermal stability and may be made corrosion-resistant by alloying. They have useful mechanical properties and high toughness, and they are moderately easy to shape and join. It is largely a consequence of their ductility and resistance to cracking that metals, as a class, became (and remain) the preferred engineering materials.

2.3.1.4Functions of the matrix

1. The matrix binds the fibers together, holding them aligned in the important stressed directions. Loads applied to the composite are then transferred into the fibers, the principal load-bearing component, through the matrix, enabling the composite to withstand compression, flexural and shear forces as well as tensile loads. The ability of composites reinforced with short fibers to support loads of any kind is dependent on the presence of the matrix as the load-transfer medium, and the efficiency of this load transfer is directly related to the quality of the fiber/matrix bond.

2. The matrix must also isolate the fibers from each other so that they can act as separate entities. Many reinforcing fibers are brittle solids with highly variable strengths. When such materials are used in the form of fine fibers, not only are the fibers stronger than the monolithic form of the same solid, but there is the additional benefit that the fiber aggregate does not fail catastrophically. Moreover, the fiber bundle strength is less variable than that of a monolithic rod of equivalent load-bearing ability. But these advantages of the fiber aggregate can only be realized if the matrix separates the fibers from each other so that cracks are unable to pass

unimpeded through sequences of fibers in contact, which would result in completely brittle composites.

3. The matrix should protect the reinforcing filaments from mechanical damage (*eg.* abrasion) and from environmental attack. Since many of the resins which are used as matrices for glass fibers permit diffusion of water, this function is often not fulfilled in many GRP (Glass Reinforced Products) materials and the environmental damage that results is aggravated by stress. In cement the alkaline nature of the matrix itself is damaging to ordinary glass fibers and alkali-resistant glasses containing zirconium have been developed (Proctor and Yale., 1980) in an effort to counter this. For composites like MMCs (Metal Matrix Composites) or CMCs (Ceramics Matrix Composites) operating at elevated temperature, the matrix would need to protect the fibers from oxidative attack.

4. A ductile matrix will provide a means of slowing down or stopping cracks that might have originated at broken fibers: conversely, a brittle matrix may depend upon the fibers to act as matrix crack stoppers.

5. Through the quality of its 'grip' on the fibers (the interfacial bond strength), the matrix can also be an important means of increasing the toughness of the composite.

6. By comparison with the common reinforcing filaments most matrix materials are weak and flexible and their strengths and moduli are often neglected in calculating composite properties. But metals are structural materials in their own right and in MMCs their inherent shear stiffness and compressional rigidity are important in determining the behaviour of the composite in shear and compression. (Bryan 1999).

2.3.2 Reinforcement Phase

Reinforcements basically come in three forms: particulate, discontinuous fibers, and continuous fibers. A particle has roughly equal dimensions in all directions, though it doesn't have to be spherical. Gravel and resin powder are examples of particulate reinforcements. Reinforcements become fibers when one dimension becomes long compared to others. Discontinuous reinforcements (chopped fibers, milled fibers, or whiskers) vary in length from a few millimeters to a few centimeters. Most fibers are only a few microns in diameter, so it doesn't take much length to make the transition from particle to fiber.

With either particles or short fibers, the matrix must transfer the load at very short intervals. Thus, the composite properties cannot come close to the reinforcement properties. With continous fibers, however, there are few if any breaks in the reinforcements. Composite properties are much higher, and continuous fibers are therefore used in most high performance components.

Reinforcement fibers usually employed are the natural and synthetic fibers. A fiber has a length that is much greater than its diameter. The length-to-diameter (l/d) ratio is known as the *aspect ratio* and can vary greatly. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratios. Continuous-fiber composites normally have a preferred orientation and examples of continuous reinforcements include unidirectional, woven cloth and helical winding while discontinuous fibers generally have a random orientation and examples of discontinuous reinforcements are chopped fibers and random mat (Campbell, 2010).

Fibers produce high-strength composites because of their small diameter; they contain far fewer defects (normally surface defects) compared to the material produced in bulk,as a general rule, the smaller the diameter of the fiber, the higher its strength. Smaller-diameter high-strength fibers have greater flexibility and are more amenable to fabrication processes such as weaving (Campbell, 2010).

2.4 NATURAL (CELLULOSIC) FIBERS

Natural fibers are subdivided based on their origins, coming from plants, animals or minerals. All plant fibers are composed of cellulose while animal fibers consist of proteins (hair, silk, and wool) (Maya and Thomas, 2008). Plant fibers include bast (or stem or soft sclerenchyma) fibers, leaf or hard fibers, seed, fruit, wood, cereal straw, and other grass fibers. Over the last few years, a number of researchers have been involved in investigating the exploitation of natural fibers as load bearing constituents in composite materials. The use of such materials in composites has increased due to their relative cheapness, their ability to recycle and for the fact that they can compete well in terms of strength per weight of material. Natural fibers can be considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix (Maya and Thomas, 2008). The cellulose fibrils are aligned along the length of the fiber, which render maximum tensile and flexural strengths, in addition to providing rigidity. The reinforcing efficiency of natural fiber is related to the nature of cellulose and its crystallinity. The main components of natural fibers are cellulose (a-cellulose), hemicellulose, lignin, pectins, and waxes (Kestur *et al*., 2009).

Cellulose is a natural polymer consisting of D-anhydroglucose ($C_6H_{11}O_5$) repeating units joined by 1,4-b-D-glycosidic linkages at C1 and C4 position (Nevell et al., 1985). The degree of polymerization (DP) is around 10,000. Each repeating unit contains three hydroxyl groups. These hydroxyl groups and their ability to hydrogen bond play a major role in directing the crystalline packing and also govern the physical properties of cellulose.

Solid cellulose forms a microcrystalline structure with regions of high order i.e. crystalline regions and regions of low order i.e. amorphous regions. Cellulose is also formed of slender rod like crystalline microfibrils. The crystal nature (monoclinic sphenodic) of naturally occurring cellulose is known as cellulose I. Cellulose is resistant to strong alkali (17.5 wt%) but is easily hydrolyzed by acid to water-soluble sugars. Cellulose is relatively resistant to oxidizing agents.

2.4.1 Cellulosic Fibers: Advantages and Disadvantages

The growing interest in lignocellulosic fibers is mainly due to their economical production with few requirements for equipment and low specific weight, which results in a higher specific strength and stiffness when compared to glass reinforced composites. They also present safer handling and working conditions compared to synthetic reinforcements (Maya and Thomas, 2008).

Biofibers are nonabrasive to mixing and moulding equipment, which can contribute to significant cost reductions. The most interesting aspect about natural fibers is their positive environmental impact. Biofibers are a renewable resource with production requiring little energy (Maya and Thomas, 2008).

They are carbon dioxide neutral i.e. they do not return excess carbon dioxide into the atmosphere when they are composted or combusted. The processing atmosphere is friendly with better

working conditions and therefore there will be reduced dermal and respiratory irritation. Biofibers possess high electrical resistance. Thermal recycling is also possible. The hollow cellular structure provides good acoustic insulating properties. The worldwide availability is an additional factor (Maya and Thomas, 2008). The inherent polar and hydrophilic nature of lignocellulosic fibers and the non-polar characteristics of most thermoplastics results in compounding difficulties leading to non-uniform dispersion of fibers within the matrix which impairs the efficiency of the composite. This is a major disadvantage of natural fiber reinforced composites. Another problem is that the processing temperature of composites is restricted to 200 ^{0}C as vegetable fibers undergo degradation at higher temperatures; this restricts the choice of matrix material. Another setback is the high moisture absorption of natural fibers leading to swelling and presence of voids at the interface, which results in poor mechanical properties and reduces dimensional stability of composites. Another restriction to the successful exploitation of biofibers for durable composite application is low microbial resistance and susceptibility to rotting. These properties pose serious problems during shipping, storage and composite processing (Maya and Thomas, 2008). The non-uniformity and variation of dimensions and of their mechanical properties (even between individual plants in the same cultivation) poses another serious problem.

It is quite clear that the advantages outweigh the disadvantages and most of the shortcomings have remedial measures in the form of chemical treatments. The lignocellulosic fibers have an advantage over synthetic ones since they buckle rather than break during processing and fabrication (Bledzki and Gassan, 1999). In addition, cellulose possesses a flattened oval cross section that enhances stress transfer by presenting an effectively higher aspect ratio. The advantages and disadvantages of natural fibers are summerised in Table 2.1.

Table 2.1**:** Advantage and Disadvantages of Natural Fibers

Advantages	Disadvantages
Low specific weight results in higher specific strength and stiffness than glass.	Lower strength especially impact strength.
Good tensile strength	Variable quality influenced by weather.
Renewable resources, production requires little energy and low CO_2 emission.	Poor moisture resistance which causes swelling of the fiber.
Friendly processing, no wear of tools and no skin irritation.	Restricted maximum processing temperature
High electrical resistance	Lower durability and poor fire resistant
Good thermal and acoustic insulating properties	Poor fiber/matrix adhesion
Biodegradable.	Poor microbial resistance.
	Anisotropic fiber properties.

(Source: Stamboulis *etal*., 2001.)

2.4.2 Surface Properties

A better understanding of natural fiber surface and adhesive bonding is necessary. The natural fiber surface is a complex heterogeneous polymer composed of cellulose, hemicellulose and lignin. The surface is influenced by polymer morphology, extractive chemicals and processing conditions.

Because of the physical difficulties combined with these chemical and morphological complexities, some investigators have reported to characterize surfaces of cast films of isolated natural fiber or wood polymers.

In spite of the limited applicability of these results to the real surface of the natural fibers, the use of the isolated polymers is necessary for estimating the individual wetting characteristics of the various natural fiber components.

2.4.3 Methods for Surface Modification of Natural Fibers

The quality of the fiber–matrix interface is significant for the application of natural fibers as reinforcement fibers. Physical and chemical methods can be used to optimize this interface. These modification methods are of different efficiency for the adhesion between matrix and fiber

2.4.3.1 Physical methods

Reinforcing fibers can be modified by physical and chemical methods. Physical methods, such as stretching, calandering, therms can be used to modify natural fibers.

Electric discharge (corona, cold plasma) is another way of physical treatment. Corona treatment is one of the most interesting techniques for surface oxidation activation. This process changes the surface energy of the cellulose fibers and in case of wood surface activation increases the amount of aldehyde groups

2.4.3.2 Chemical methods

Strongly polarized cellulose fibers are inherently incompatible with hydrophobic polymers. When two materials are incompatible, it is often possible to bring about compatibility by introducing a third material, which has properties intermediate between those of the other two. There are several mechanisms of coupling in materials:

1. Weak boundary layers – coupling agents eliminate weak boundary layers,
2. Deformable layers – coupling agents produce a tough, flexible layer,
3. Restrained layers – coupling agents develop a highly crosslinked interphase region, with a modulus intermediate between that of substrate and of the polymer,
4. Wettability – coupling agents improve the wetting between polymer and substrate (critical surface tension factor),
5. Chemical bonding – coupling agents form covalent bonds with both materials, and
6. Acid–base effect – coupling agents alter acidity of substrate surface.

The development of a definitive theory for the mechanism of bonding by coupling agents in composites is a complex problem. The main chemical bonding theory alone is not sufficient. So the consideration of other concepts appears to be necessary, which include the morphology of the interphase, the acid–base reactions at the interface, surface energy and the wetting phenomena.

Change of surface tension: The surface energy of fibers is closely related to the hydrophility of the fiber. Some investigations are concerned with methods to decrease hydrophility. The modification of wood-cellulose fibers with stearic acid hydrophobizes those fibers and improves their dispersion in polypropylene. As can be observed in jute reinforced unsaturated polyester resin composites, treatment with polyvinylacetate increases the mechanical properties (Semsarzadeh, 1986) and moisture repellence. Silane coupling agents may contribute hydrophilic properties to the interface. Especially when aminofunctional silanes, such as epoxies and

urethanes silanes, are used as primers for reactive polymers. The primer may supply much more amine functionality than can possibly react with the resin at the interphase.

Those amines which could not react are hydrophilic and therefore responsible for the poor water resistance of bonds. An effective way to use hydrophilic silanes is to blend them with hydrophobic silanes such as pheniltrimethoxysilane. Mixed siloxane primers also have an improved thermal stability, which is typical for aromatic silicones (Mittal, 1992).

Impregnation of fibers: A better combination of fiber and polymer is achieved by impregnation (Gebner 1989) of the reinforcing fabrics with polymer matrixes compatible to the polymer. For this purpose polymer solutions (Felix *et al*., 1991)or dispersions (Gatenholm *et al*., 1993) of low viscosity are used. For a number of interesting polymers the lack of solvents limits the use of the method of impregnation (Gebner, 1989). When cellulose fibers are impregnated with a butyl benzyl phthalate plastified polyvinylchloride (PVC) dispersion, excellent partitions can be achieved in polystyrene (PS). This significantly lowers the viscosity of the compound and of the plasticator and results in co-solvent action for both PS and PVC (Gatenholm *et al*., 1993).

Chemical coupling: An important chemical modification method is the chemical coupling method, which improves the interfacial adhesion. The fiber surface is treated with a compound, which forms a bridge of chemical bonds between fiber and matrix.

Graft copolymerization**:** An effective method of chemical modification of natural fibers is graft copolymerization (Sakata *et al*., 1993). This reaction is initiated by free radicals of the cellulose molecule. The cellulose is treated with an aqueous solution with selected ions and is exposed to a high energy radiation. Then the cellulose molecule cracks and radicals are formed. Afterwards the radical sites of the cellulose are treated with a suitable solution (compatible with the

polymer matrix), for example vinyl monomer (Kroschwitz 1990), acrylonitrile (Ugbolue 1990), methyl methacrylate (Ghosh *et al.,* 1989), polystyrene (Maldas *et al.,* 1989). The resulting co-polymer possesses properties characteristic of both, fibrous cellulose and grafted polymer.

For example, the treatment of cellulose fibers with hot polypropylene–maleic anhydride (MAH–PP) copolymers provides covalent bonds across the interface. The mechanism of reaction can bedivided into two steps:

a. activation of the copolymer by heating (*t* . 170^0C) (before fiber treatment) as in Figure. 2.2.

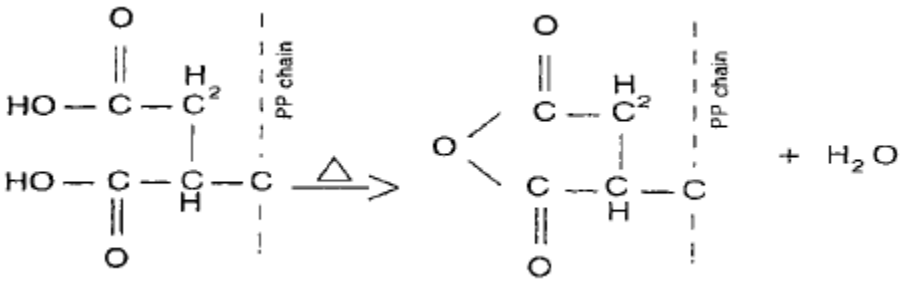


Figure 2.2: Activation of Copolymer Step.

and

b. esterification of cellulose as shown in Figure. 2.3

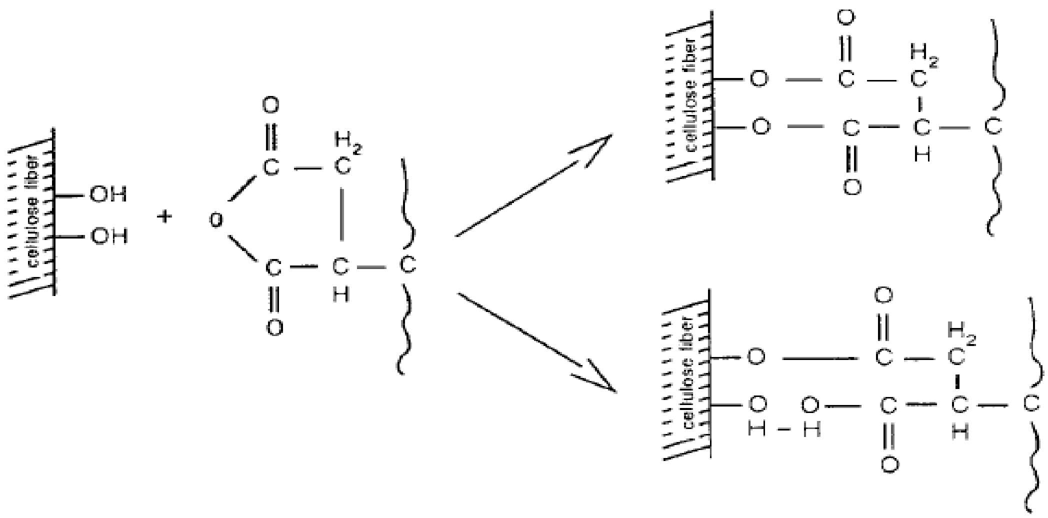


Figure 2.3: Esterification of Cellulose step.

After this treatment the surface energy of the fibers is increased to a level much closer to the surface energy of the matrix. Thus, a better wettability and a higher interfacial adhesion is obtained. The polypropylene (PP) chain permits segmental crystallization and cohesive coupling between the modified fiber and the PP matrix (Felix*et al*., 1991). The graft copolymerization method is effective, but complex.

Mercerization: An old method of cellulose fiber modification is mercerization. Mercerization is an alkali treatment of cellulose-fibers; it depends on the concentration of the alkaline solution, its temperature, time of treatment, tension of the material as well as on the additives. At present there is a tendency to use mercerization on natural fibers as well. Optimal conditions of mercerization ensure the improvement of the tensile properties and absorption characteristics, which are important in the composing process.

The effects of mercerization on the suitability to mechanical treatment, notable tensile strength, of cotton fibers have been extensively studied. The standard definition of mercerization proposed

by ASTMD 1965 is: the process of subjecting a vegetable fiber to an interaction with a fairly concentrated aqueous solution of a strong base, to produce great swelling with resultant changes in the fine structure, dimension, morphology and mechanical properties.

Cellulose forms the main structural component of vegetable natural fibers, the non-cellulosic components, e.g. lignin and hemicellulose, also play an important part in the characteristic properties of the fibers. Hemicellulose, which is thought to consist principally of xylan, polyuronide and hexosan, has shown to be very sensitive to the action of caustic soda, which exerts only a slight effect on lignin or a-cellulose. Later studies about the alkali treatment of jute-fibers, for instance, reports about the removal of lignin and hemicellulose which affects the tensile characteristics of the fibers. When the hemicelluloses are removed, the interfibrillar region is likely to be less dense and less rigid and thereby makes the fibrils more capable of rearranging themselves along the direction of tensile deformation. When natural fibers are stretched, such rearrangements amongst the fibrils would result in better load sharing by them and hence result in higher stress development in the fiber. In contrast, softening of the inter-fibrillar matrix adversely affects the stress transfer between the fibril and, thereby the overall stress development in the fiber under tensile deformation. As lignin is removed gradually, the middle lamella joining the ultimate cells is expected to be more plastic as well as homogeneous due to the gradual elimination of microvoids, while the ultimate cells themselves are affected only slightly.

Some authors reported about changes in the crystallinity through alkaline treatment on coir (Varma *etal*., 1989, Sreenivasan *etal*., 1996) and flax (Sharma et*al*., 1995) fibers. The increase in the percentage crystallinity index of alkali treated fibers occurs because of the removal of the cementing materials, which leads to a better packing of cellulose chains. Additionally, treatment

with NaOH leads to a decrease in the spiral angle, i.e. closer to fiber axis, and increase in molecular orientation. A fair amount of randomness is introduced in the orientation of the crystallites due to the removal of non-cellulosic matter (Sreenivasan *et al*., 1996). The elastic moduli of fibers, for instance, are expected to increase with increasing degree of molecular orientation.

Tests made by Prasad *et al*., (1983) on coir fibers and by Chand and Rohatgi (1986) on sisal fibers showed distinct index changes achieved by an alkalization process in an 8% NaOH solution. An increase of 25% in tensile strength was reached in leather fibers and of 100% in sisal fibersalso depending on the respective soaking time.

Retting: Retting involves the use of ammonium oxalate (15% solution) in the dissolution of binding materials. The boiling of cellulosic fibers with 15% solution of ammoniumoxalate for 30 min at 100°C which results in dissolution of non-cellulosic materials which originally binds the bundles together.

Bleaching: Hydrogen peroxide is useful for bleaching cellulose materials, because the oxidative damage to the material is usually minimal. In the investigation done by (Trotman, 1970), 5% concentration of hydrogen peroxide was used. It has been suggested that the bleaching action is as follows

$$H_2O_2 \xrightarrow{NaOH} H^+ + HO^{-2} \quad (2.18)$$

$$HO_2 \longrightarrow OH^- + [O] \quad (2.19)$$

$$[O] + I \longrightarrow IO \quad (2.20)$$

Where; I represent the impurities.

In an alkaline condition, the hydroxyl ions (OH-) produced by the perhydroxyl ion HO^{-2}, hydrolyses the hydrogen ions (H^+), thereby promoting the liberation of more perhydroxyl ions.

$$H^+(aq) + OH^- (aq) \longrightarrow H_2O (l) \quad (2.21)$$

Care must be taken in the production of perhydroxyl ions, since it may decompose into hydroxyl ions and atomic oxygen. The atomic oxygen is responsible for bleaching. If atomic oxygen is produced in excess, this may dissociate to molecular oxygen.

$$[O] + [O] \longrightarrow O_2(g) \quad (2.22)$$

Oxidation of cellulose as a result of this reaction may lead to depolarization of cellulose with a consequent reduction in tensile strength.

Scouring: Scouring is the process that removes all undesirable impurities;theseinclude pectins, waxes, gums fats and oils. During this treatment, natural impurities and adventitious dirt were removed by saponification. The scoured sample appeared soft, smooth, slightly thicker and brighter. It has been established (Sadov and Korchangin, 1978) that during alkali treatment, fatty acids are converted to soap which helps to emulsify other wax like substances. Caustic soda hydrolyses protein and the molecules are broken along peptide links with the formation of alkali soluble amino acids. Similarly, pectins are hydrolyzed, gradually destroyed or decomposed to form methyl alcohol and glacturonic acid (Sadov and Korchangin, 1978). Pentoses are hydrolysed to pentosans, which in turn contain aldehyde groups. This together with the size starch decomposition impacts a reducing property to the boiling liquor.

Treatment with compounds which contain methanol groups: Chemical compounds which contain methanol groups (–CH2OH) form stable, covalent bonds with cellulose fibers. Those compounds are well known and widely used in textile chemistry. Hydrogen bonds with cellulose can be formed in this reaction as well. The treatment of cellulose with methanolmelamine compounds before forming cellulose unsaturated polyesters (UP) composites, decreases the moisture pick up, and increases the wet strength of reinforced plastic (Hua *et al*., 1987).

Treatment with isocyanates: The mechanical properties of composites reinforced with wood fibers and PVC or PS as resin can be improved by an isocyanate treatment of those cellulose fibers or the polymer matrix (Maldas *et al*., 1989). Polymethylenepolyphenylisocyanate (PMPPIC) in pure state or solution in plasticizer can be used. PMPPIC is chemically linked to the cellulose matrix through strongcovalent bonds:

Organosilanes as coupling agents: Organosilanes are the main group of coupling agents for glass-fiber reinforced polymers. They have been developed to couple virtually any polymer to the minerals, which are used in reinforced composites (Plueddemann, 1974).

Most of the silane coupling agents can be represented by the following formula:

R – (CH2)*n* - Si(OR')3

Where*n* . 0–3, OR' is the hydrolyzable alkoxy group, and R the functional organic group.

The organo functional group (R) in the coupling agent causes the reaction with the polymer. This could be a co-polymerization, and/or the formation of an interpenetrating network. The curing reaction of a silane treated substrate enhances the wetting by the resin.

Alkoxysilanes undergo hydrolysis, condensation (catalysts for alkoxysilane hydrolysis are usually catalysts for condensation) and the bond formation stage, under base as well as under

acid catalyzed mechanisms. In addition to this reaction of silanols with hydroxyls of the fiber surface, the formation of polysiloxane structures can take place. The treatment of mercerized sisal-fiber with aminosilanes (Bisanda and Ansell., 1991) before forming sisal–epoxy composites, markedly improves moisture repellence of the composite. These examples show that theories used for the silane treatment of natural fibers are contradictory, therefore further studies are necessary.

2.4.4 Influence of Coupling Agents on the Mechanical Properties of Natural Fiber Reinforced Thermosets Composites.

The surface modifications due to coupling agent cause noticeable improvementsof the characteristic values of composites, depending on the fiber, matrix, and on the type ofsurface treatment used.

In the materials group of natural fiber-reinforced thermosetting plastics, especially in the group of natural fiber-reinforced epoxides, there is only a little knowledge about the influence of suitable coupling agents on the parameters of composites in comparison with natural fiber and reinforced thermoplastics.

Some of the most extensive examinations about the influence of silanes (g - aminopropyltriethoxy-silane) on natural-fiber–epoxy composites were carried out by Bisanda and Ansell, (1991) and Bledzki and Gassan, (1997).

Bisanda and Ansell, (1991) used alcoholic solutions of 5% with a catalyst as well as pure silane, whereby the duration of treatment was 24 h. The water absorption of sisal–epoxy composites could be remarkably reduced by a fiber treatment with pure silane. However, the silane treatment (with a solution of 5% and catalyst) did not result in any increase in parameters as flexural

strength and flexural stiffness. In contrast, the compression strength of the composites was clearly increased by the coupling agent.

Depending on the concentration of silane in the application solution as well as on the duration of treatment there was a noticeable increase in parameters, for example flexural modulus and flexural strength, (Bledzki and Gassan, 1997).

Gliesche and Mader, (1995) investigated flax–Epoxy composites and found out that there was a reduction in the flexural strength of composites, if a g -aminopropyltriethoxy-silane was used, the flexural modulus of the composite could be increased by approximately 20%, however. The g -aminopropyltriethoxy-silane did not result in any remarkable increase in flexural strength dealing with ramie–epoxy composites; the flexural modulus was also increased by approximately 20%. Also used was a water solution of 3% silane, the fiber treatment was carried out at 80^0C.

The fixing of the silanes on the surface of the natural fibers is carried out with the ligno-cellulose by chemical bonds (silanole-bonds) and hydrogen linkages, which result in an improvement of the fiber–matrix adhesion. Although, examinations about surface stresses of natural fibers as well as about the structural composition of natural fibers showed that the surface of natural fibers is essentially built of lignin and therefore the silane fixing has to be carried out with the (silanole-bonds) and hydrogen linkages.

2.4.5 Okra Fiber

Okra fibers are extracted from the stem of plant of Malvaceae family (*Abelmoschus esculentus*), which is originally from Egypt. (De Rosa *et al*., 2009). The plant is commonly called lady's finger, ila, kubewa, oro, okwuru in English, Yoruba, Hausa, Igala and Igbo languages respectively. The colour of okra fiber is quite variable from whitish to yellowish, depending on the action of UV radiation (De Rosa *et al*., 2009).

The difficulty common to most soft bast fibers, such as kenaf, okra, are in their extraction and retting, which results in fiber with very variable diameter, and whose effectiveness shows a strong dependence on agricultural factors such as stem age (Aire *et al*.,2009). This issue is particularly relevant when using okra fibers as a composite reinforcement, because of the inherent variability of the fiber geometry and mechanical properties (De Rosa et al., 2009).

2.4.5.1 Physio-chemical properties of okrafiber

The chemical composition as well as the morphological microstructure of vegetable fibers is extremely complex due to the hierarchical organization and the different compounds present at various concentrations (Mohanty *et al*., 2005).

De Rosa*et al*., (2009) in their study observed that the cross-sectional shape of okra fiber shows a polygonal shape that varies notably from irregular shape to reasonably circular. Their diameter considerably vary in the range of about 40-180µm. each ultimate cell is roughly polygonal in shape with a central hole, or lumen like other natural plant fibers. The cell wall thickness and lumen diameter vary typically between 1 to 10µm and 0.1 to 20 µm respectively. As a consequence, the considerable difference of the diameter values of the single fiber and lumen, and their rough shape strongly affects the mechanical and dimensional properties of okra fibers.

Okra bast, a multicellular was analysed for chemical composition by Md Shamsul *etal.,* (2007) and the following compostions as shown in Table 2.2was obtained.

Table 2.2: Chemical Composition of Okra Bast Fiber

Component	**Composition**
a-Cellolose	67.5%

Hemicellulose	15.4%
Lignin	7.1%
Pectic matter	3.4%
Fatty and waxy matter	3.9%
Aqeous extract	2.7%

(Source: Md Shamsul*et al*., (2007)).

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2.4.5.2 Thermal degradation of okra fiber

It is well known that one of the limiting factors in the use of natural fibers as reinforcement is their low thermal stability. De Rosa*et al*., (2009) investigated the thermal stability of okra fibers by thermogravimetric (TG) analysis. The results compared to the works of Saikia and Bora (2003) and Ganan *et al*., (2005), shows that the TG curve for okra fibers shows three weight loss steps, whilst their decomposition occurs in two main stages. The initial weight loss (about 8%) observed between 30 and 110^0C is attributed to the vapourization of the water from the fibers, whilst the onset degradation for the okra fiber occurs at a higher temperature of 220^0C. Degradation of the okra fibers was observed above this temperature. The first stage (220 – 310^0C) is associated to the thermal depolarization of hemicelluloses, pectin and cleavage of the glycosidic linkages of cellulose (16.1% weight loss) whilst, the second degradation occurs in the range of 310 – 390^0C, and it correspond to the degradation of the α-cellulose present in the fiber (60.6% weight loss).

De Rosa*et al*., (2009) concluded that the okra fibers are stable until around temperature of 220^0C, which is in agreement with many vegetable fibers reported in literatures.

2.5 SYNTHETIC FIBERS

Synthetic fibers are made from synthesized polymers or small molecules. The compounds that are used to make these fibers come from raw materials such as, petroleum based chemicals or petrochemicals. These materials are polymerized into a long, linear chemical that bond two adjacent carbon atoms. Differing chemical compounds will be used to produce different types of fibers. In the literature, it is often noted that there are three kinds of man-made fibers: those made by "transformation of natural polymers" (also called regenerated cellulosics), those made from synthetic polymers and those made from inorganic materials (These include the fibers made of glass, metal, ceramics and carbon.) But by far the largest groups of man-made synthetic fibers being produced today are made from synthetic polymers,

Although there are several different synthetic fibers, they generally have the same common properties. Generally, they are known for being Heat-sensitive, Resistant to most chemicals, Resistant to insects, fungi and rot but when damp and warm may attract them, Low moisture absorbency and Electrostatic. Synthetic fibers also have their advantages and disadvantages, which are summarized in Table 2.3

Table 2.3: Advantages and Disadvantages of Synthetic Fibers

Advantages	Disadvantages
Synthetic fibers do not depend either on an agricultural crop or on animal farming.	Synthetic fibers melt before burning

They are generally cheaper than natural fiber	Some electrical charge accumulates on the synthetic fibers. The electrical charge causes irritation of the skin.
Synthetic fibers possess unique characteristics which make them popular dress material.	Low melting temperature
They dry up quickly, are durable, readily available and easy to maintain.	Extremely hazardous to the environment.
	Can shrink rapidly and suffocate the user

(Source:NFPA (2004) pp262.)

2.5.1 Glass Fibers

Glass fiber is a material consisting of numerous extremely fine fibers of glass. Glass fiber is commonly used as an insulating material. It is also used as a reinforcing agent for many polymer products to form a very strong and light fiber-reinforced polymer (FRP) composite material called glass-reinforced plastic (GRP), popularly known as "fiberglass". Glass fiber has roughly comparable properties to other fibers such as polymers and carbon fiber. Although not as strong or as rigid as carbon fiber, it is much cheaper and significantly less brittle.

2.5.1.1 Types of glass fibers and areas of applications

The various types of glass fibers, their compositions andareas of application are summerized in Table 2.4;

Table 2.4: Types of Glass fibers and their areas of application

Glass Type	**Area of Application**
A GLASS	Soda lime silicate glasses used where the strength, durability, and good electrical resistivity of E Glass are not required.
C GLASS	Calcium borosilicate glasses used for their chemical stability in corrosive acid environments.
D GLASS	Borosilicate glasses with a low dielectric constant for electrical applications.
E GLASS	Alumina-calcium-borosilicate glasses with a maximum alkali content of 2 wt.% used as general purpose fibers where strength and high electrical resistivity are required.
ECRGLAS	Calcium aluminosilicate glasses with a maximum alkali content of 2 wt. % used where strength, electrical resistivity, and acid corrosion resistance are desired
AR GLASS	Alkali resistant glasses composed of alkali zirconium silicates used in cement substrates and concrete.

R GLASS	Calcium aluminosilicate glasses used for reinforcement where added strength and acid corrosion resistance are required.
S-2 GLASS	Magnesium aluminosilicate glasses used for textile substrates or reinforcement in composite structural applications which require high strength, modulus, and stability under extreme temperature and corrosive environments.

(Source:David *et al*., 1996)

2.6 EPOXY RESIN

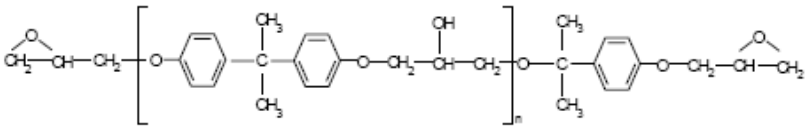
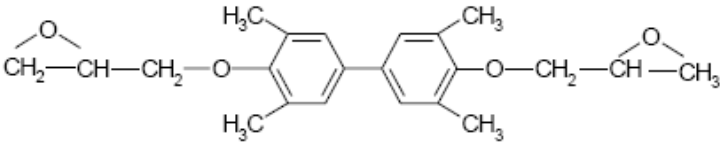
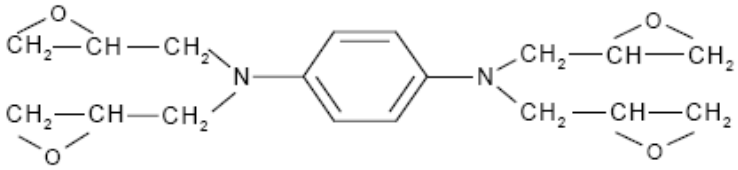
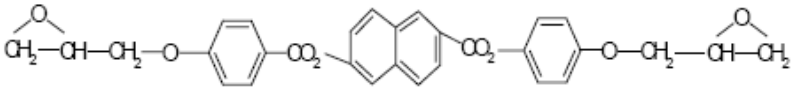
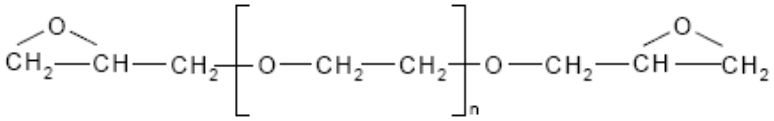
Epoxy resins are thermosetting polymers that, before curing, have one or more active epoxide or oxirane groups at the end(s) of the molecule and a few repeated units in the middle of the molecule (Lee and Neville 1975). Chemically, they can be any compounds that have one or more 1,2-epoxy groups and can convert to thermosetting materials. Their molecular weights can vary greatly. They exist either as liquids with lower viscosity or as solids. Through the ring opening reaction, the active epoxide groups in the uncured epoxy can react with many curing agents or hardeners that contain hydroxyl, carboxyl, amine, and amino groups (Saunders 1988).

Compared to other materials, epoxy resins have several unique chemical and physical properties. Epoxy resins can be produced to have excellent chemical resistance, excellent adhesion, good heat and electrical resistance, low shrinkage, and good mechanical properties, such as high strength and toughness. These desirable properties result in epoxy resins having wide markets in

industry, packaging, aerospace, construction, etc. They have found remarkable applications as bonding and adhesives, protective coatings, electrical laminates, apparel finishes, fiber-reinforced plastics, flooring and paving, and composite pipes.

Since the 1930's when the preparation of epoxy resins was patented, many types of new epoxy resins have been developed from epoxides. Tanaka and Bauer (1988) gave a complete list of epoxides and discussed their properties and preparation. Most conventional epoxy resins are prepared from bisphenol A and epichlorohydrin. For example, the most commonly used epoxy resins are produced from diglycidyl ethers of bisphenol A (DGEBA). Its properties and reaction mechanism with various curing agents have been reported extensively (Simpson *et al*., (1995), Barton*et al*., (1998)). Other types of epoxy resins are glycidyl ethers of novolac resins, phenoxy epoxy resins, and (cyclo) aliphatic epoxy resins. Glycidyl ethers of novolac resins and phenoxy epoxy resins usually have high viscosity and better high temperatures properties while (cyclo) aliphatic epoxy resins have low viscosity and low glass transition temperatures.

Table 2.5: Chemical Structure of some Epoxy Resins

COMPOSITION	CHEMICAL STRUCTURE
DGEBA	
4,4′-diglycidyloxy-3,3′, 5,5′-tetramethyl biphenyl	
TGDDM	
LCE	
POEDE	

(Source:Matsuoka, 1986).

2.7 CURING AGENTS (HARDNERS)

Curing agents play an important role in the curing process of epoxy resin because they relate to the curing kinetics, reaction rate, gel time, degree of cure, viscosity, curing cycle, and the final properties of the cured products.

Mika and Bauer (1988) gave an overview of the epoxy curing agents and modifiers. They discussed three main types of curing agents:

1. The first type of curing agents includes active hydrogen compounds and their derivatives. Compounds with amine, amides, hydroxyl, acid or acid anhydride groups belong to this type.

They usually react with epoxy resin by polyaddition to result in an amine, ether, or ester. Aliphatic and aromatic polyamines, polyamides, and their derivatives are the commonly used amine type curing agents. The aliphatic amines are very reactive and have a short lifetime. Their applications are limited because they are usually volatile, toxic or irritating to eyes and skin and thus cause health problems. Compared to aliphatic amine, aromatic amines are less reactive, less harmful to people, and need higher cure temperature and longer cure time. Hydroxyl and anhydride curing agents are usually less reactive than amines and require a higher cure temperature and more cure time. They have longer lifetimes. Polyphenols are the more frequently used hydroxyl type curing agents. Polybasic acids and acid anhydrides are the acid and anhydride type curing agents that are widely used in the coating field. Table 2-7 gives a list of commonly-used type 1 curing agents and their chemical structures.

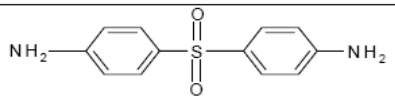
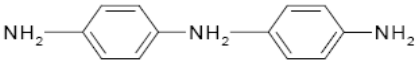
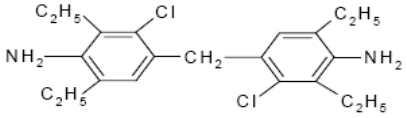
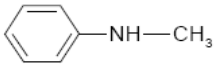
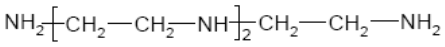
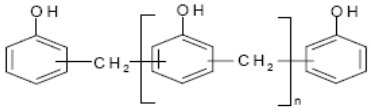
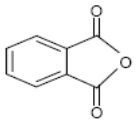
2. The second type of curing agents includes the anionic and cationic initiators. They are used to catalyze the homopolymerization of epoxy resins. Molecules, which can provide an anion such as tertiary amine, secondary amines and metal alkoxides are the effective anionic initiators for epoxy resins. Molecules that can provide a cation, such as the halides of tin, zinc, iron and the fluoroborates of these metals, are the effective cationic initiators**.** The most important types of cationic initiators are the complexes of BF3.

3. The third type of curing agents is called reactive cross linkers. They usually have higher equivalent weights and crosslink with the second hydroxyls of the epoxy resins or by self-condensation. Examples of this type of curing agents are melamine, phenol, and urea formaldehyde resins.

Among the three types of curing agents, compounds with active hydrogen are the most frequently used curing agents and have gained wide commercial success. Most anionic and

cationic initiators have not been used commercially because of their long curing cycles and other poor cured product properties. Crosslinkers are mainly used as surface coatings and usually are cured at high temperatures to produce films having good physical and chemical properties.

Table 2.6: Curing Agents and Their Chemical Structures

COMPOUNDS	CHEMICAL STRUCTURE
DDS	
DDM	
MCDEA	
Methylaniline	
TETA	
Phenol novolac	
Phthalic anhydride	

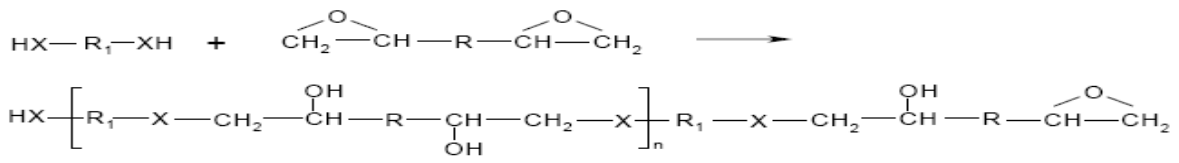
(Source: Mika and Bauer (1988)).

2.8 CURING REACTIONS

The curing reaction of epoxide is the process by which one or more kinds of reactants, i.e., an epoxide and one or more curing agents with or without the catalysts are transformed from low-molecular-weight to a highly crosslinked structure. As mentioned earlier, the epoxy resin contains one or more 1, 2-epoxide groups. Because an oxygen atom has a high electronegativity, the chemical bonds between oxygen and carbon atoms in the 1, 2-epoxide groups are the polar bonds, in which the oxygen atom becomes partially negative, whereas the carbon atoms become partially positive. Because the epoxide ring is strained (unstable), and polar groups (nucleophiles) can attack it, the epoxy group is easily broken. It can react with both nucleophilic curing reagents and electrophilic curing agents. The curing reaction is the repeated process of the ring opening reaction of epoxides, adding molecules and producing a higher molecular weight and finally resulting in a three-dimensional structure. The chemical structures of the epoxides have an important effect on the curing reactions. Tanaka and Bauer (1988) provide more details about the relative reactivity of the various epoxides with different curing agents and the orientation of the ring opening of epoxides. It was concluded that the electron-withdrawing groups in the epoxides would increase the rate of reaction when cured with nucleophilic reagents, but would decrease the rate of reaction of epoxides when cured with electrophilic curing agents.

Many curing agents may be used to react with epoxides; but for different curing agents, there exist different mechanisms of the curing reaction. Even for same epoxy resin systems, the cure mechanism may be different for the isothermal and dynamic cure processes.

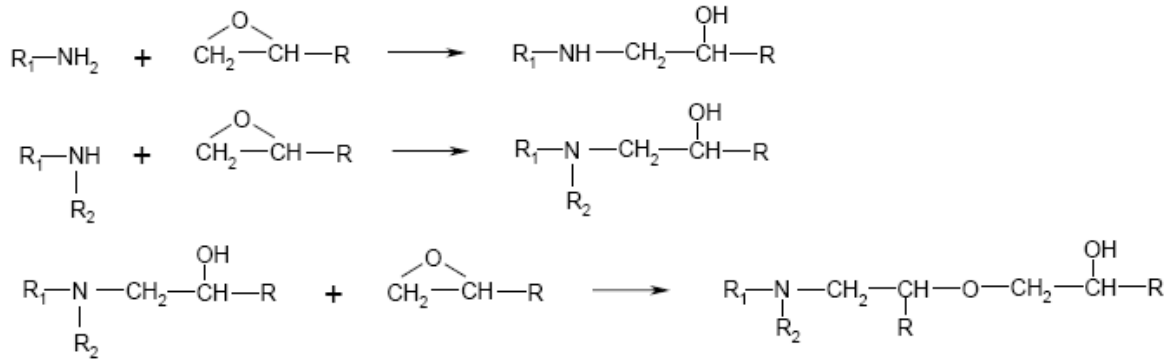
Many polyfunctional curing agents with active hydrogen atoms such as polyamines, polyamides and polyphenols perform nucleophilic addition reaction with epoxides. Tanaka and Bauer (1988) gave the following general cure reaction as shown in Equation 2.23:



(2.23)

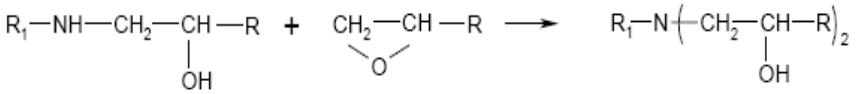
Where X represents NR2, O or S nucleophilic group or element and n is the degree of polymerization, having a value of 0, 1, 2 …

Tanaka and Bauer (1988) discussed in detail the curing mechanisms of epoxides with several types of curing agents. For epoxy-1-propyl phenyl ether/polyamines system they concluded that a primary amine would react with epoxy-1-propyl phenyl ether to produce a secondary amine, and the secondary amine would react with the same epoxide to produce a tertiary amine. No evidence of tertiary-catalyzed etherification between the epoxide and the derived hydroxyl was found as shown in Equation 2.24.



(2.24)

Xu and Schlup (1998) studied the curing mechanism of epoxy resin/amine system by near-infrared spectroscopy and derived the following equation of curing reaction:



(2.25)

They pointed out that the etherification during the epoxy resin cure was significant only at certain reaction conditions such as at a high curing temperature and for only some epoxy resin/amine systems. For the tetraglycidyl 4, 4-diaminodiphenylmethane and methylaniline system, they found that the etherification reaction during cure is more significant. The main curing reactions, similar to the above equations, were also used by Gonis *et al*., (1999) and Laza *et al*., (1998) in the different epoxy resin/amine systems.

Unlike mechanisms of polyaddition, the stepwise polymerization of epoxy resin is initiated by anionic and cationic reagents. Anionic polymerization of epoxides may be induced by initiators such as metal hydroxides and secondary and tertiary amines. Cationic polymerization may be induced by using Lewis acids as initiators. Many inorganic halides could be used as cationic initiators. Tanaka and Bauer (1988) also discussed the mechanisms of anionic and cationic polymerization of epoxy resin. They pointed out that the products from anionic and cationic polymerization with monoepoxides have relatively low molecular weights.

One important factor of polymerization is stoichiometry. It has effects on the viscosity and the gel time of the epoxy resin system (Hadad 1988).

CHAPTER THREE

MATERIALS AND METHODOLOGY

This chapter presents the equipment, materials and experimental procedure used in this work.

3.1 MATERIALS AND EQUIPMENT

3.1.1 Materials

The materials used in this research work include;

Okra fibers (obtained from Juneng Nig Ltd in Nssuke, Enugu State).

Woven Glass fibers (obtained from Juneng Nig Ltd in Nssuke, Enugu State).

Epoxy resins {Diglycidyl Ether of Bisphenol A (DGEBA)} Grade 3554A and the Hardener {Diethylene Triamine (DETA)} Grade 3554B.

Sodium Hydroxide (NaOH) Pellets

Acetic Acid (CH_3COOH).

Brushes (1.5 inch)

Plastic cups (150ml)

Wax

Pyrex Measuring cylinders (500ml and 50ml)

210 x 160 x 20mm steel mould.

3.1.2 Equipment

Table 3.1: Equipment used and their characteristics

Equipment	Description
Tensile Testing Machine	Instron Machine Model 3369, System Number 3369K1781, Capacity 50kN, Weight 141kg, Maximum speed 500mm/min, Power Requirement 100/120/220/240V, Maximum Vertical Test Space 1193mm Located at Center for Energy Research and Development (CERD) OAU Ile-Ife Osun State.
Flexural Testing Machine	Enerpac Universal Material Testing Machine located at the Strength of Material Lab of the Department of Mechanical Engineering Ahmadu Bello University Zaria.
Impact Testing Machine	Charpy Impact Testing Machine, Capacity 15J and 25J at the Department of Metallurgical and Materials Engineering, Ahmadu Bello University Zaria.
Hardness Testing Machine	Rockwell Indentec Universal Testing Machine, Type 8187.5 LKV Model B at the Department of Metallurgical and Materials Engineering, Ahmadu Bello University Zaria.

3.2 EXPERIMENTAL METHODS

3.2.1 Mould Preparation

A mould with dimensions 210mm x 160mm x 20mm mould cavity was used in the research. The mould cavity was cleaned to remove particles and then coated with layers of releasing agent (wax) for easy removal (demoulding) of the composite.

3.2.2 Virgin Specimen Preparation

The volume of the matrix (epoxy and hardener) required was calculated by multiplying the dimensions of the steel mould with the required thickness of the composite to be moulded. The required amount of the epoxy and hardener were calculated by weight in the ratio of 5:1.

4mm and 10mm thick samples were made respectively by mixing the required volume of epoxy and the hardener in a plastic cup and stirred thoroughly for 10 minutes before the mixture was poured into the prepared mould. It was left in the mould to cure at room temperature for 24 hours. The sample was demoulded and further post cured in an oven at 70^0C for 3 hours.

3.2.3 Step I:Determination of Critical Fiber Length

The critical fiber length of the okra fiber was determined by varying the lengths of the fiber from 10mm – 50mm. The result obtained was used in step II of the experiment.

3.2.3.1 Okra-Epoxy Composite Specimen Preparation

The okra fibers were cut to various lengths of 10mm, 20mm, 30mm, 40mm and 50mm. Preliminary loading of the short okra fiber in the pre-calculated matrix showed that the mean loading capacity was 15 wt %, compared to the 20.4 wt % reported by Srinivasababu *et al.*,(2009).

The matrix (epoxy and hardener) made up 85 wt % of the total composite weight and the ratio was calculated based on that weight while the fibers made up 15 wt % of the total composite weight. The various lengths of the fibers were then weighed based on the total volume of the matrix required for the 4mm and 10mm composite samples.

Similar procedure of preparing the virgin epoxy composite was employed in this okra-epoxy composite preparation. A portion of the mixture was poured into the prepared mould and some quantity of the weighed 10mm fiberwas loaded in random orientation using hand lay-up method. Brush was used to apply the matrix to ensure the fibers were properly coated with the matrix. The procedure was repeated until the remaining fiber and the matrix was exhausted (100% okra fiber). The procedure was repeated for the 20mm, 30mm, 40mm and 50mm fiberlengths.

3.2.4 Step II - Determination of Optimal Hybridization Ratio

The critical fiber length result obtained in step I of the experiment was used in step II and the result obtained in this stage wouldsubsequently be applied in stage III.

3.2.4.1 Okra-Glass-Epoxy Composite Specimen Preparation

The okra and glass fibers were cut to 20mm fiber lengths (the critical fiber length established in step I). Based on the 15 wt % fiber loading established, okra and glass fibers' weight were varied and calculated based on the following ratios (90:10, 80:20, 70:30, 60:40 and 50:50). The calculated amount of the various ratios were weighed and kept in a container and covered to avoid scattering prior to usage.

Similar sample preparation method explained earlier for the okra-epoxy composite was employed. The hybridized fiber (90:10 okra-glass fiber ratios) was loaded in random orientation using hand lay-up method. The procedure was repeated for the other hybridized okra:glass fibersratios of 80:20, 70:30, 60:40 and 50:50.

3.2.5 Step III -Determination of the Optimal Treatment Concentration

In this step, the result obtained in step II of the experiment was further worked upon.

3.2.4.1 Treated Okra/Glass-Epoxy Composite Specimen Preparation

5% w/v, 10% w/v, 15% w/v and 20% w/v Sodium hydroxide solutions were prepared in 500ml beaker by diluting 20g, 40g, 60g and 80g pellets respectively of sodium hydroxide in 400ml of distilled water.

5% v/v acetic acid solution was prepared in a 500ml beaker by mixing 20ml of acetic acid in 380ml of water.

The okra fibers were cut to 20mm fiber length and some quantity were soaked in the prepared 5% w/v sodium hydroxide (NaOH) solution to remove some of the lignin (delignification) and other materials like wax and pectin. The soaked fibers were kept in the refrigerator (about $5^{o}C$)

for 20 mins with occasional stirring. On expiration of the time, they were removed, washed with tap water and then soaked in the prepared 5% v/v acetic acid solution for 5 mins to neutralize the excess sodium hydroxide left on the fibers. The fibers were then washed with tap water and, finally, thoroughly with distilled water. They were letter dried in air for two weeks and finally in an oven at 70^{o}C until they attain constant weight. The procedure was repeated using the 10% w/v, 15% w/v and 20% w/v sodium hydroxide solutions.

Based on the 15 wt % fiber loading established earlier and the thickness of the composite to be moulded, okra treated with 5% w/v NaOH and the glass fiber were calculated and weighed on 50:50 ratios.

Similar sample preparation methods explained earlier in steps I and II was followed but in this step, the hybridized 50:50 (5% w/v treated okra:glass) fibers were loaded in random orientation using hand lay-up method. Brush was used to apply the matrix to ensure that the fibers were properly coated with the matrix. The procedure was repeated until the remaining fiber and the matrix was exhausted. The sample was cured at room temperature for 24 hours under load. It was then demoulded and further post-cured in an oven at 70^{0}C for 3 hours. The procedure was repeated using the 10% w/v, 15% w/v and 20% w/v treated okra fibers.

3.3 MATERIALS' CHARACTERIZATION

Three samples each were selectedfrom the composites made from the different fiber lengths, hybridized okra-glass fiber ratio composites and those made from hybridized treated okra –glass fiber composites. The respective mean values of the properties and standard deviation were calculated.

3.3.1 Tensile Test

The tensile test was conducted according to ASTM D638 using the Instron universal testing machine.

3.3.2 Flexural Test

The flexural test was conducted according to ASTM D790 using the Enerpac universal material testing machine. The flexural modulus (MOR), was calculated using

Equation (3.1)

$$\text{MOR} = \frac{3PS}{2bt^2} \tag{3.1}$$

Where, *S* is the span length of the sample (guage length). P is the load applied; b and tare the width and thickness of the specimen respectively.

3.3.3 Impact Test

The impact test was conducted according to ASTM D256-78 using the Charpy impact testing machine.

3.3.4 Hardness Test

The hardness test was conducted according to ASTM E18 using the Indentec universal hardness testing machine.

3.3.5 Water Absorption Test

The test samples were placed in an oven at temperature of 60^0C for 4 hours. The samples were removed and placed in desiccators for 4 hours so as to maintain a constant weight. They were removed, weighed and submerged in a 250ml plastic cups containing water for 24 hours. On

expiration of the 24 hours, the samples were taken out of the water, dried and weighed according to ASTM D570-98. The percentage water absorbed was calculated using Equation 3.2

$$\frac{W_f - W_i}{W_i} X\ 100 \qquad (3.2)$$

Where W_f is the weight of the samples after immersion in water (g).

$W_i$is the weight of the samples before immersion in water (g).

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CHAPTER FOUR

RESULTS AND DISCUSSION

In this section, the results obtained are presented and discussed. The analyses of the results were done to establish whether significant differences existed between the mechanical and water absorption properties of the various composites as a result of the variation in their compositions by the use of error bars.

4.1DETERMINATION OF CRITICAL FIBER LENGTH

4.1.1 Effect of Fiber Length on Tensile Strength

Figure 4.1 presents the effect of varying fiber length on the tensile strength of the short okra fiber composite.

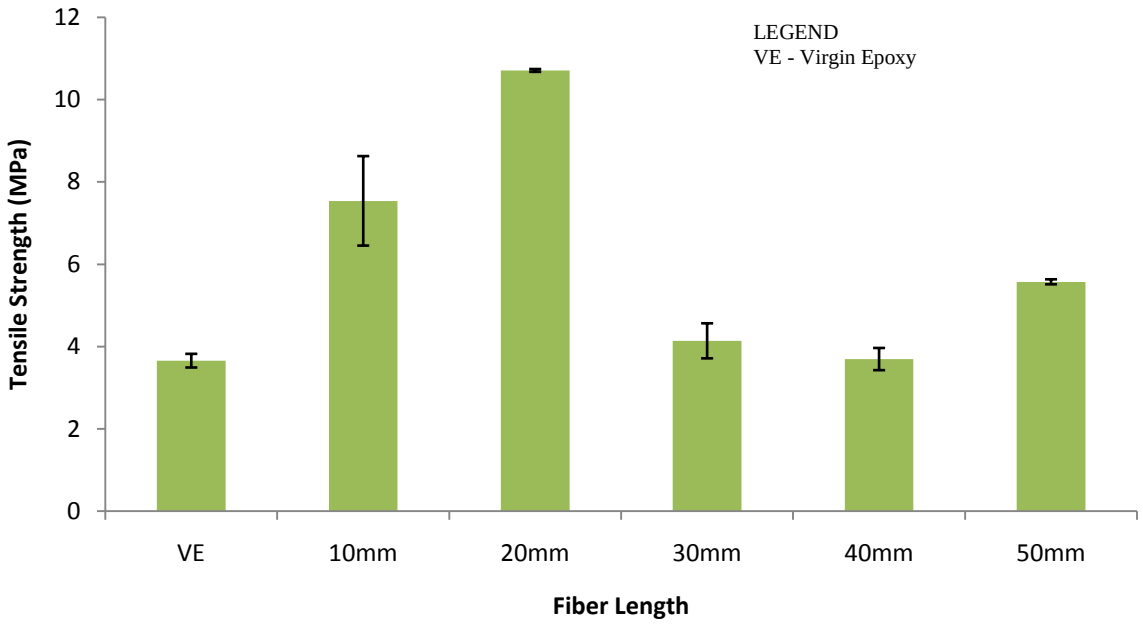


Figure 4.1: The Effect of Fiber Length on the Tensile Strength of Short Okra Fiber Reinforced Epoxy Composite

The result of the test showed that the 20mm fiber length composite has the highest average tensile strength value of 10.7MPa when compared to other composites reinforced with the 10mm, 30mm, 40mm and 50mm fiber length. The 10.7MPa obtained is low when compared with optimal value of 51.5MPa at 10mm established critical fiberlength and 20 wt % fiber loading for bamboo-epoxy composite reported byPongsathorn *et al.*, (2011), tensile strength value of 67.2MPa at 15mm established critical fiber lengthand 30 wt % for banana-epoxy composite (Sumaila *et al.*,2013) and 120MPa at 10mm established critical fiber lengthand 68% fiber loading for basalt fiber-polyester composite (Amuthakkannan *et al.*,2013). The variation could be as a result of the differences in the strength of the fibers, the matrix and the weight percent of the fiber loading. As shown in Figure 4.1, the tensile strength values increased from the 10mm fiber to a maximum peak at 20mm and then a downward trend was observed. The observed decrease could be attributed to improper fiber wetting due to increased tendency of fiber

entanglement with increasingfiber length as well as the possibility of increasing fiber-rich and/or matrix-rich areas within the composite (Sumaila *et al*., 2013).

The indicated error bars show that the 20mm and 50mm fiber lengths composite have the least errors. This suggests that minimal variations existed within the composites. The non-overlapping of the error bars is an indication that the tensile strengths of the composite for all the respective fiber lengths were significantly different from one another.

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4.1.2 Effect of Fiber Length on Modulus of Elasticity (MoE)

Figure 4.2 presents the results of the effect of varying fiber length on the MoE of the okra fiber epoxy composite. The 20mm fiber length exhibited the highest MoE of 698.8MPa.

This suggests that the 20mm fiber length composite exhibited higher degree of stiffness. It was higher than the composites reinforced with the 10mm, 30mm, 40mm and 50mm fiber lengths with a factor 0f 370, 287, 38 and 78 respectively. This was due to the fiber entanglements prevalent at longer fiber length (Joseph *et al*., 1999).

LEGEND
VE - Virgin Epoxy

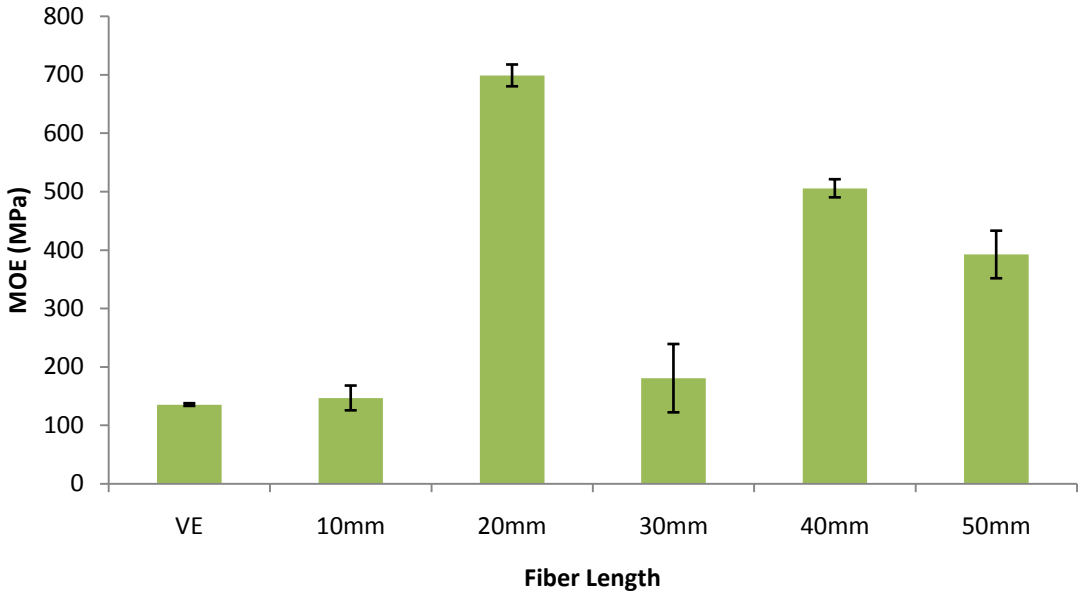


Figure 4.2: Effect of Fiber Length on the Modulus of Elasticity of Short Okra Fiber Reinforced Epoxy Composite.

It may also be attributed to the strong stress fields developed at the ends of the fibers in the composite beyond 20mm fiber length which made the composite samples less tough (Abdelmouleh *et al*., 2007) Shorter fibers are said to move to optimized position in a composite than longer fiber (Shibata et al., 2005) as observed with the 20mm length composite.

The result obtained is slightly higher than the optimal MoE of 690MPa at their established 6mmcriticalfiber lengthand 10 vol % fiber loading for short pineapple leaf reinforced polypropylene composite (Sanjay *et al*., 2009), 653.1MPa at 15mm established critical fiber length (Sumaila *et al.*,2013) for banana-epoxy composite and slightly lower than the 700MPa at 10mm established critical fiber length and 68 wt % fiber loading for Basalt fiber-polyester composite (Amuthakkannan*et al*., 2013). Nara *et al*., (2012) observed that the tensile modulus, which is an indication of load bearing capacity increases with fiber weight fraction. As fiber is the stiffer component in the composite, resistance towards deformation increases with increase in fiber content, this consequently increases the stiffness of the composite. Hence the variation in the modulus of elasticity observed in the various researches could be attributed to the variation in

the weight fractions of the fibers, the difference in matrix and the nature of the fibers used (Sreekala *et al.*, 2002).

The overlap in the error bar for the 10mm and 30mm fiber length composites suggests that there was no significant difference between the MoE of the two composites.

4.1.3 Effect of Fiber Length on Impact Strength of Composite

Figure 4.3 represents the effect of fiber length on the impact strength of the composite. The result showed that the 20mm fiber length composite exhibited the highest impact strength of 20kJ/m^2.

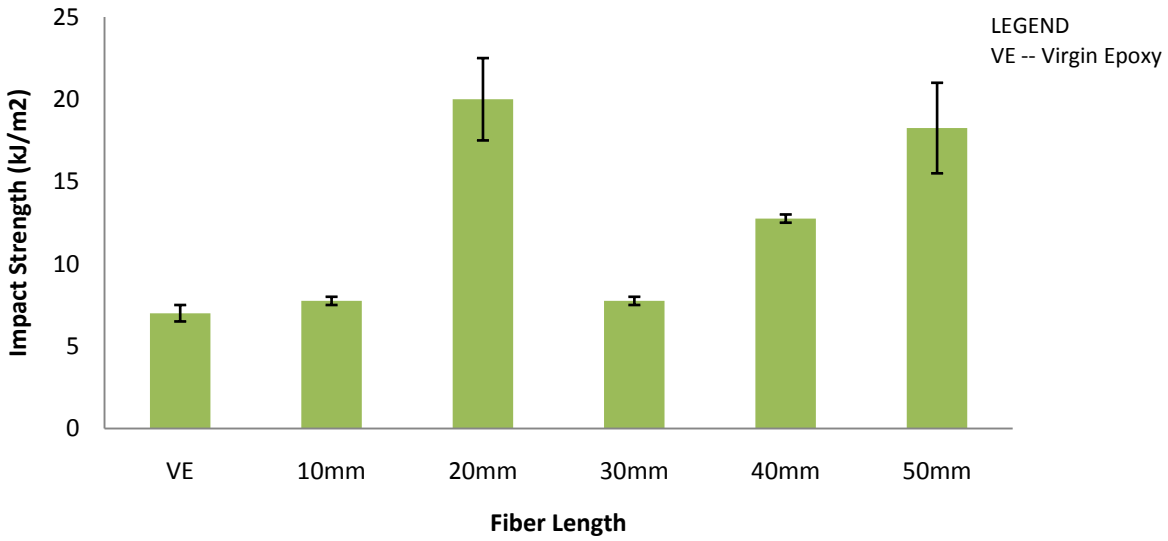


Figure 4.3: Effect of Fiber Length on the Impact Strength of Short Okra Fiber Reinforced Epoxy Composite

It is higher than the virgin composite, 10mm, 30mm, 40mm and 50mm fiber lengths composites by factors of 186, 158, 57 and 10 respectively. This increase in impact strength is primarily attributed to reinforcement effect imparted by the fibers, which allowed stress distribution from continuous polymer matrix to dispersed fiber phase as established(Colom *et al.*, 2003). Beyond 20mm size, a downward trend in impact strength was noticed due to poor fiber-matrix adhesion

resulting in non-uniform transmission of the applied stress. As the length is increased beyond 20 mm, during fabrication some fibers may be highly stressed, whereas others remained unstressed and during loaded condition, pre-stressed fibers had to support more load resulting in less observed values when compared with 20mm as reported (Chattopadhyay *et al.*, 2009). The decrease at higher fiber length can be attributed to micro-crack formation at the interface on account of poor fiber-matrix adhesion and non-uniform stress transfer due to fiber agglomeration within the matrix (Thwe and Liao, 2003).

The result obtained is higher than the 0.75J impact energy (Aseel and Ahmed, 2012) for 10mm established critical fiber length for short okra fiber reinforced epoxy matrix composite and lower than the 37.24J at 10 vol - % for short pineapple leaf fiber reinforced polypropylene composite reported by Chattopadhyay*et al.,* (2009). The variation in the weight fraction of the fiber used and the nature of the matrix used is responsible for the observed differences in the result.

The overlap in the error bar of the 20mm and 50mm suggests that there was no significant difference in the impact strength of the two composites.

4.1.4 Effect of Fiber Length on Flexural Modulus (MoR) of Composite

Figure 4.4 shows the variation of flexural modulus with fiber length, which is represented by the Modulus of Rupture (MoR). It was observed that the 50mm fiber length exhibited the highest flexural modulus of 33.25MN/m^2, which is about 31.4% higher than the virgin epoxy composite. There wasa noticeable increase in MoR with increasing fiber length between 20mm and 50mm until a maximum at 50mm fiber length was reached. The increase is attributed to enhanced fiber-to-fiber contact when the composite was impregnated with the 50mm fiber length (Joseph *et al*., 1999). Deflection during bending initiates rupture of the matrix and resulted in early fiber pullout

from matrix for the 20mm, 30mm and 40mm fiber length, hence the low value of the MoR when compared to 10mm and 50mm fiber length composites.

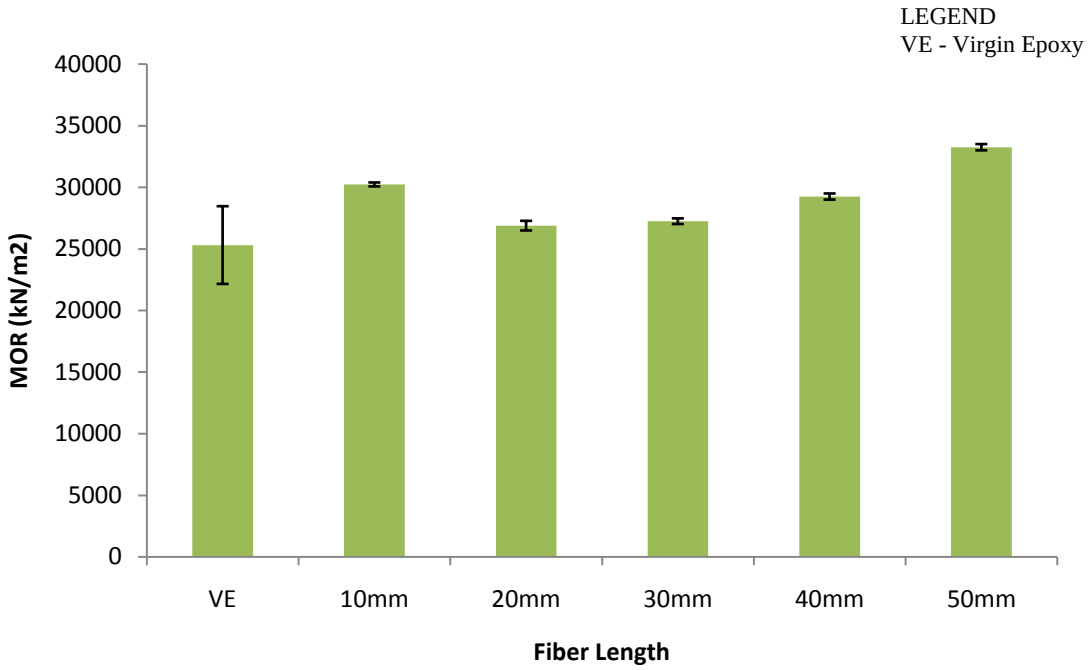


Figure 4.4: Effect of Fiber Length on the Flexural Modulus of the Composite

The highest result obtained at 50mm fiber length is far lower than the 2.7GPa at 25mm fiber length at 30% wt fiber loading (Sumaila *et al*., 2013) for short banana reinforced epoxy matrix composite. The nature of the fiber, length and relative composition of the individual fibers, the fiber-matrix interface bonding and arrangement of both the fibers and also on the failure strain of individual fibers could be responsible for the observed variations in the results (Sreekala *et al*., 2002).

The overlap in the error bars shows that there was no significant difference between the MoR values of the 10mm and 30mm fiber lengths composites but they are different from composites made with other lengths.

4.1.5 Effect of Fiber Length on Hardness of the Composite

The result of effect of fiber length on the hardness of the composite presented in Figure 4.5 indicated that there was no significant difference in the hardness of the composites made with the 10mm, 30mm, 40mm and 50mm fiber lengths. It indicates that composites made with these fiber lengths exhibit minimal variations in their hardness.

The 20mm fiber length exhibited the highest hardness value of 39.7 HRF, which is about three times the value obtained for the rest of the fiber lengths. This could be as a result of better distribution of the fibers in the matrix with minimization of voids between the fiber and the matrix as reported by (Mishra *et al*., 2000).

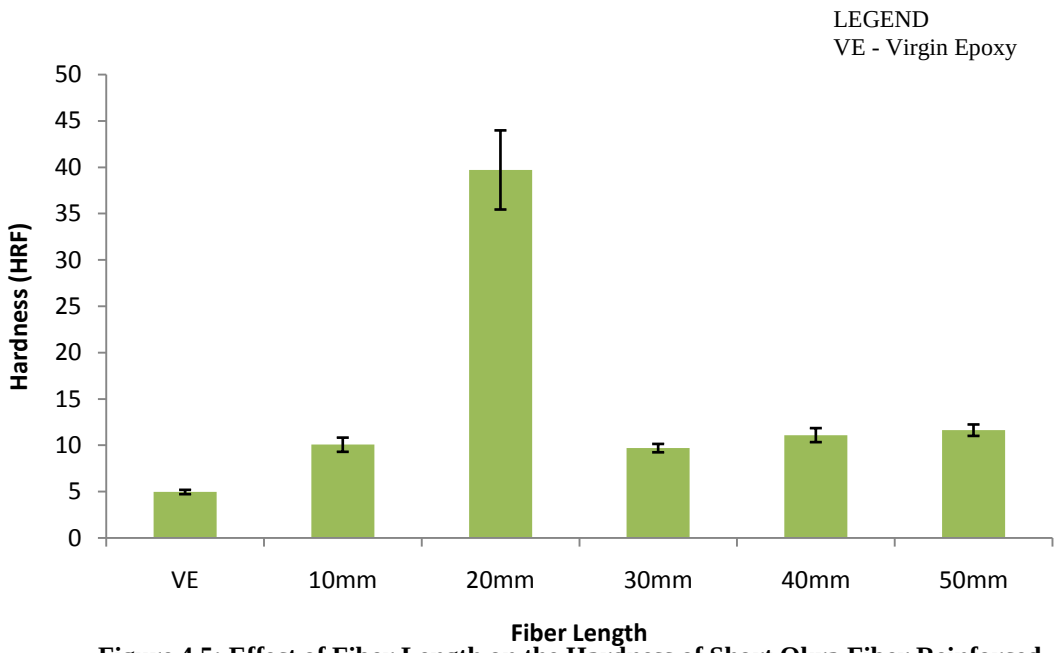


Figure 4.5: Effect of Fiber Length on the Hardness of Short Okra Fiber Reinforced Epoxy Composite

The error bar analysis indicated that there was no significant difference in the hardness value of the composite made with 10mm, 30mm, 40mm and 50mm fiber length composites but they differ significantly from the unreinforced and the 20mm fiber length composite.

4.1.6 Effect of Fiber Length on Elongation at Break

Figure 4.6 shows the variation of elongations at break of the composite with the fiber length. It was observed that there was great improvement in the elongation at break of the reinforced composite to those unreinforced with the various length of the okra fiber. The 40mm fiber length composite exhibited the highest extension at break of 10.2mm corresponding to 25.6% elongation. It is higher than the values obtained for the 10mm, 20mm, 30mm and 50mm fiber length composites by factors of 49, 189, 76 and 65 respectively. The 20mm fiber length composite has the least elongation at break which corresponds to 8.9% elongation. The stiff nature of the composite as observed from the MoE result may be responsible for this observation.

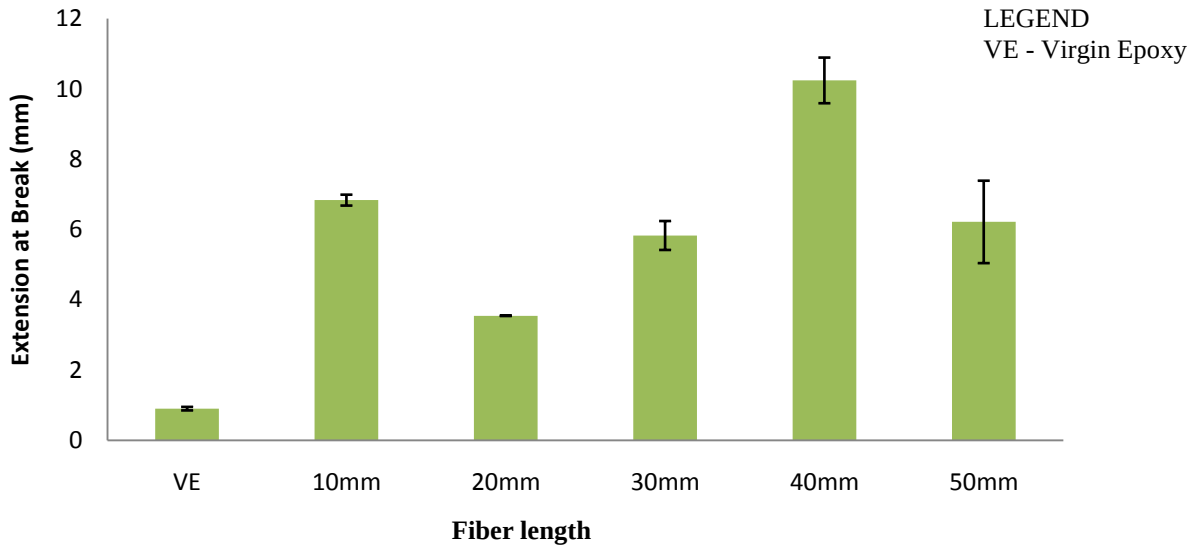


Figure 4.6: Effect of Fiber Length on the Elongation at Break of the Short Okra FiberReinforced Epoxy Composite

The 25.6% elongation at break observed with the 40mm fiber length composite is higher than the optimal 5.7% elongation at 15mm established critical fiber length as reported by Sumaila *et al.*,(2013) for banana fiber-epoxy composite, 7% elongation at 4mm established critical fiber for bamboo fiber-epoxy matrix composite as reported by Pongsathorn*et al.*,(2011) but lower than the

36% elongation at 2mm established critical fiber length for banana fiber-epoxy matrix composite as reported by Raghavendra *et al*., (2012).

The overlap in the error values obtained suggests that there was no significant difference between elongation at break of the 30mm and 50mm fiber length composites.

4.1.7 Effect of Fiber Length on the Energy at Break

Figure 4.7 shows the relationship between energy absorbed by the composite and fiber length. It was observed that there was significant improvement in the amount of energy absorbed before failure of the reinforced epoxy composite when compared to the virgin epoxy composite.

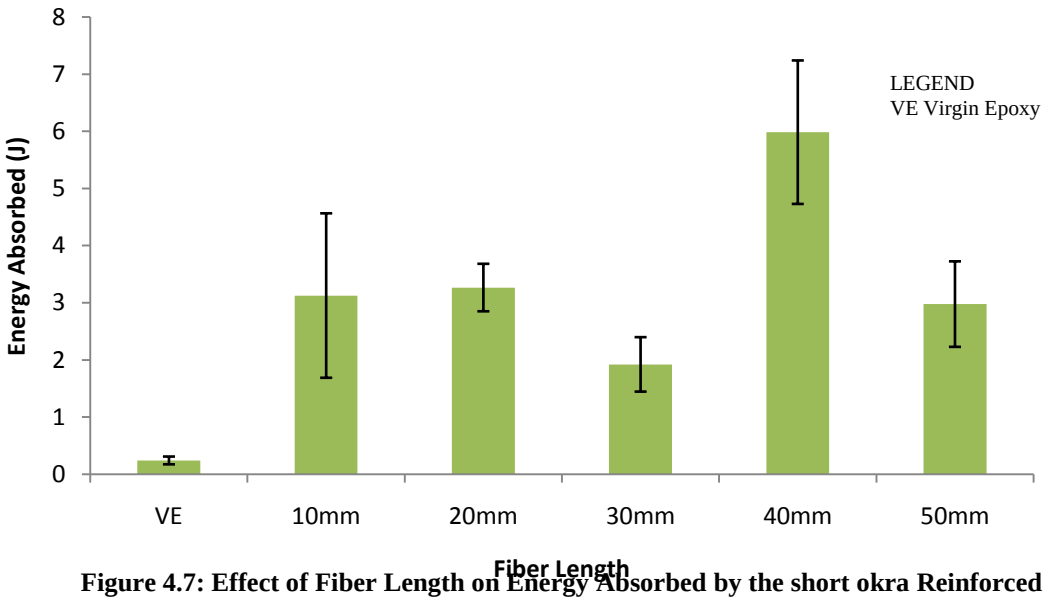


Figure 4.7: Effect of Fiber Length on Energy Absorbed by the short okra Reinforced Epoxy composite

The 40mm composites exhibited the highest energy at break value of 6.0J. The higher the elongation at break of a material, the more the energy required before the material fails.

The overlap in the error bar values suggests that there was no significant difference in the energy absorbed before failure for the 10mm, 20mm, 30mm and 50mm composite.

4.1.8 Effect of Fiber Length on the Water Absorption of the Composite

The result of the effect of fiber length on the water absorption behavior of the composite is presented in Figure 4.8.

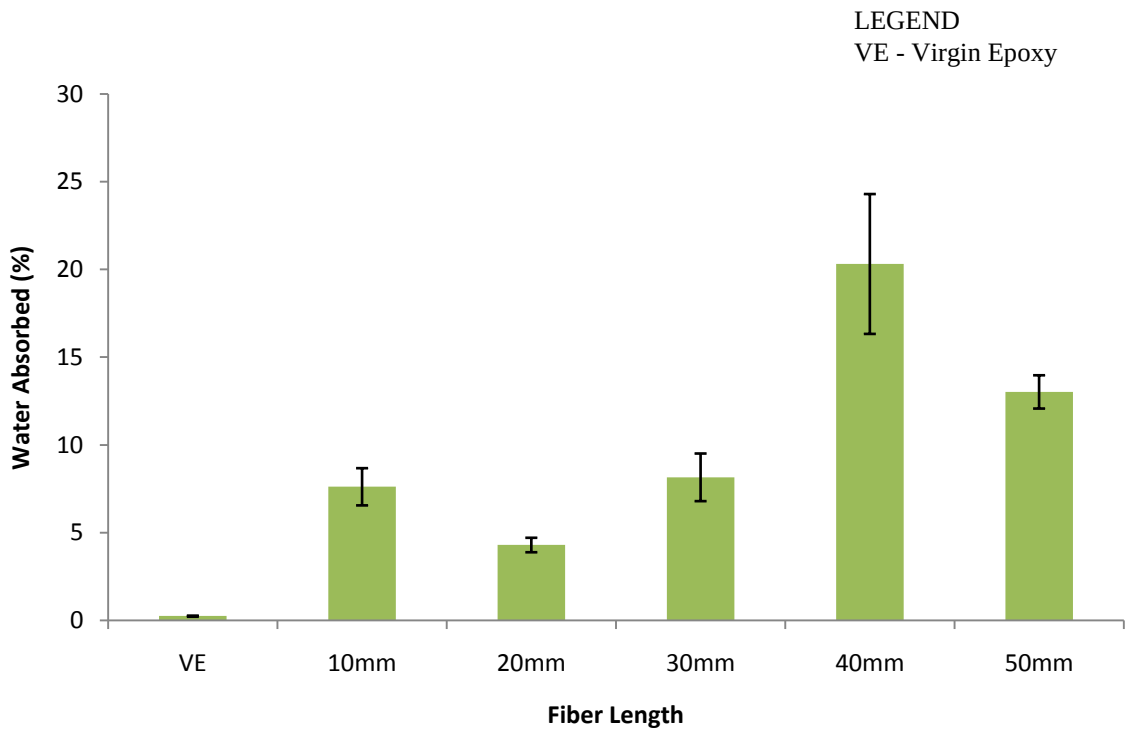


Figure 4.8: Effect of Fiber Length on Water Absorption Capacity of Short Okra Fiber Reinforced Epoxy Composite

It was observed that the unreinforced virgin epoxy composite absorbed the minimum amount of water due to its hydrophobicnature and on reinforcing it with the okra fibers, the ability to absorb moisture increased as a result of the introduction of the hydrophilic okra fibers. The result shows a decreasing trend from the 10mm composite with 7.6% to the 20mm composite having 4.3%. The 40mm fiber length composite has the highest percentage moisture uptake of 22%. The low moisture uptake of the 20mm fiber length composite could be attributed to the improved

interfacial adhesion that reduced water accumulation in the interfacial voids and prevents water from entering the composite (Thwe and Liao., 2003). The increasing moisture absorption might be attributed to the inability of the matrix material to completely saturate the fiber at higher fiber length as reported by Sumaila *et al*., (2013).

The minimum percentage water intake reported for the 20mm fiber length composite is almost twice lower than the 8% water absorption at 5mm established critical fiber length for short banana reinforced epoxy composite (Sumaila *et al*., 2013). The variation in the compared results could be attributed to the fiber content and environmental condition like temperature and humidity (Osmani*et al*., 2011).

It was observed from the error bar analysis that there no significant difference in the water absorption capacity of the 10mm and 30mm fiber length composites; they differ significantly from composites made from the other fiber length.

4.2 DETERMINATION OF OPTIMAL OKRA-GLASS HYBRIDIZATION RATIO

4.2.1Effect of Okra-Glass Fibers Hybridization on Tensile Strength of Composite

The tensile strength result of the okra-glass fiber hybridization is presented in Figure 4.9. It was observed that the tensile strength increases withincrease in percentage of glass fiber content. The result showed that the 50:50 okra-glass fiber ratios exhibited the highest tensile strength of 12.4MPa. It washigher than the un-hybridized okra fiber composite, 90:10, 80:20, 70:30 and 60:40 okra-glass fiber ratios by factors of 15, 14, 14, 9 and 8 respectively. The increase in tensile strength with increasing glass fiber content is attributed to the stronger and stiffer characteristics of the glass fibers compared to the okra fibers (Kasama and Suppakarn, 2009).

The results obtained for all the hybridized compositeswere higher than that obtained for the un-hybridized okra fiber reinforced epoxy composite.Glass fiber adherence to the matrix was better when compared to okra fiber and the interfaces between the fiber and the matrix is more. Hence, it was difficult for the prevailing forces to pull glass fibers from the matrix compared to that of okra fiber(Ravishankar*et al*., 2013). This was responsible for higher tensile strength observed.

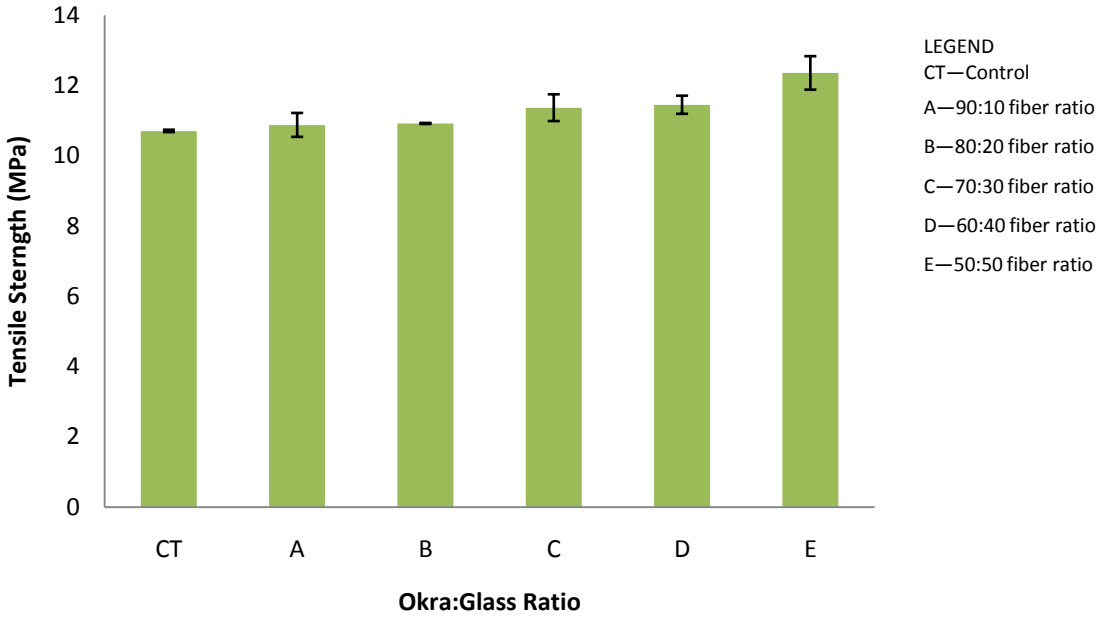


Figure 4.9: Effect of Glass Fiber Hybridization on the MOE of the

The 12.4MPa reported at the 50:50 okra: glass fiber ratios is lower than the 31.59MPa for the established optimal 10:20 hybridization ratio for sisal: glass fibers reinforced polypropylene composite at 30 wt % fiber loading (Kasama and Suppakarn, 2009), 29MPa for the established optimal 20:20 hybridization ratio for jute: glass fibers reinforced polypropylene composites at 40 wt % fiber loading (Ravishankar *et al*., 2013), 100MPa at established optimal 8 wt % glass fiber content for sisal-glass fiber reinforced polyester composite at 30% fiber loading and 70MPa at established 7 wt % glass fiber content for PALF/glass fibers reinforced polyester composite at 25% fiber loading (Mishra *et al.*, 2000). The 15% total fiber weight used in this research which

differs from other reported works may be responsible for the low tensile strength results observed in this research work.

The overlap observed in the error bars of the un-hybridized composite and the composite made from the 90:10 and 80:20 okra:glass fiber hybridization ratios was an indication that there was no significant difference in the tensile strength of the composites.

4.2.2Effect of Okra-Glass Fibers Hybridization on MoE of Composite

Figure 4.10 presents the effect of glass fiber hybridization on the Modulus of Elasticity characteristics of the composite. It was observed that the 50:50 okra:glass fiber hybridization ratio exhibited the highest MoE of 752MPa.

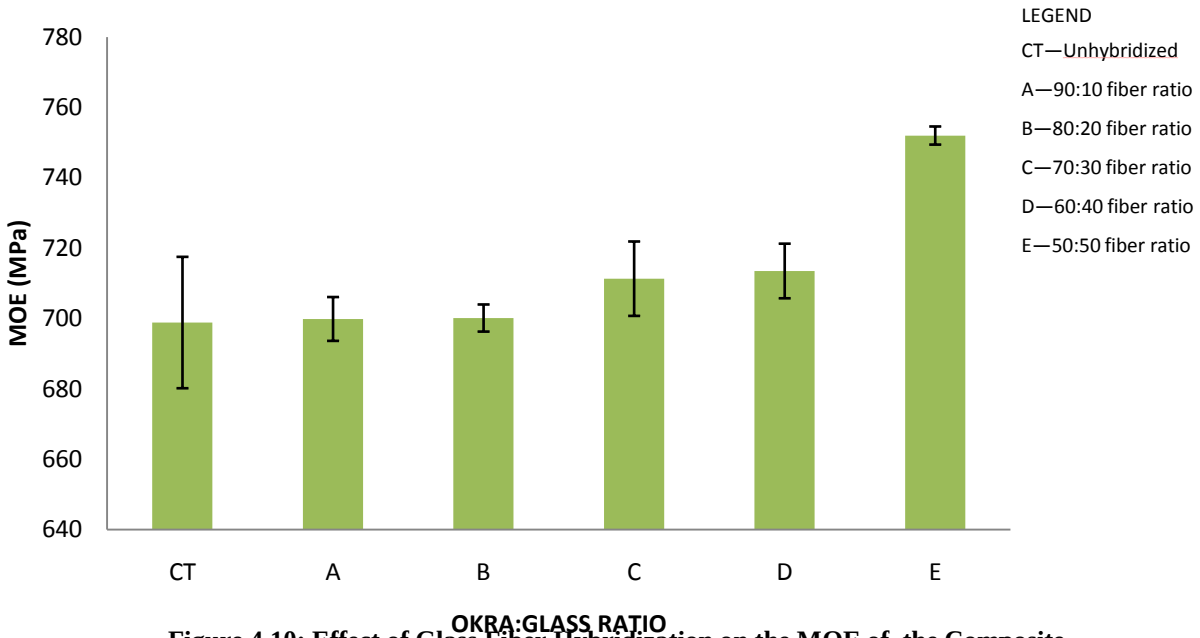


Figure 4.10: Effect of Glass Fiber Hybridization on the MOE of the Composite

The MoE obtained for the 50:50 okra:glass fiber hybridization ratioishigher than the un-hybridized, 90:10, 80:20, 70:30 and 60:40 ratios by factor of 8, 7, 7, 6 and 5 respectively. Glass fiber has a higher tensile modulus than the okra fiber and the incorporation of the high modulus glass fiber increases the modulus of elasticity of the composite. As glass fiber isthe stiffer

component in the composite, resistance towards deformation increases with increase in glass fiber content,which consequently increased the stiffness of the composite as reported in the work of Nara *et al*., (2012).

The optimal result of 752MPa obtained at 50:50 fiber ratio is less than the 7694MPa at the established 20:20 fiber ratio (Prasad and Mattam, 2011) for Bamboo-Glass epoxy hybrid composite and the 4800 MPa at established 55 wt % of glass fiber content as reported in the work of Velmurugan and Manikandan, (2005) for glass-palmyra fiber waste sandwich composites at total fiber weight of 60 wt %. The observed variation in the result is attributed to the strength and the orientation of the fibers and the fiber content used in the various works (Sreekala *et al*., 2000).

The overlap in error bars of the un-hybridized composite and the composites made with 90:10, 80:20, 70:30 and 60:40 hybridization ratio indicated that there was no significant difference in the MOE value of the composites. The composite made with the 50:50 hybridization ratio was significantly different from the other composites as indicated in Figure 4.10.

4.2.3Effect of Okra-Glass Fibers Hybridization on the Elongation at Break of the Composite

Figure 4.11 shows the variation of elongation at break of the composite with glass fiber hybridization. There isa decrease in the elongation of the composite by 59.5% on addition of the hybrid 90:10 okra: glass fiber when compared to the un-hybridized composite. Baker*et al*., 2005 and Kalaprasad *et al*., 1997 reported similar decline in the elongation at break of their composite on hybridization with glass fibers.

The negative hybrid effect was observed upto the 70: 30 okra: glass ratio and on further increase in the glass fiber content, a positive hybrid effect was observed. The decreasing elongation is attributed to the lower elongation value of the glass fibers compared to those of the natural fiber and the matrix used (Kalaprasad et al., 1997). This also indicated that the brittle nature of the okra fibers compositeincreases with the addition of the glass fiber.

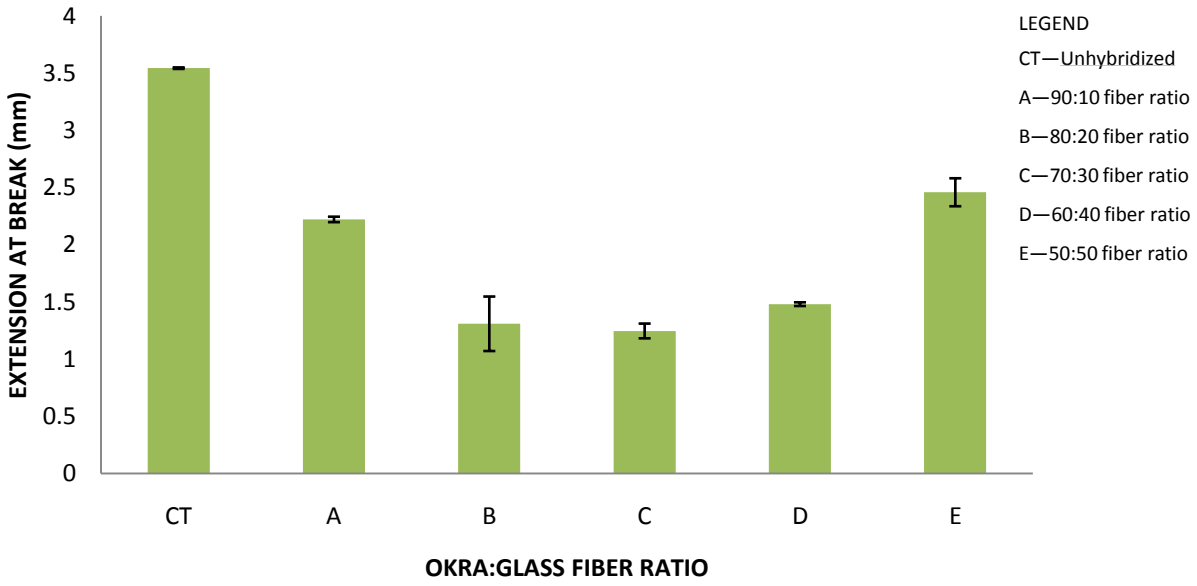


Figure 4.11: Effect of Glass Fiber Hybridization on the Elongation at Break of the Composite

Error bar analysis of the composites indicated that there was significant difference in the value of the elongation at break of the un-hybridized composite when compared with the composites made with all the okra:glass hybridization ratios as a result of the non-overlap of the error bars as shown in Figure 4.11. The composites made with 80:20 and 70:30 shows no significant difference in their values as indicated by the overlapping of their error bars.

4.2.4Effect of Okra-Glass Fibers Hybridization on the Energy at Break of the Composite

Figure 4.12 presents the effect of glass fiber hybridization on the energy at break of the composite. An increase of 3.18% over the un-hybridized composite was observed when hybridized 90: 10 okra: glass fibers ratios was used. At 70: 30 okra: glass hybridization ratios, a decrease in the energy at break of the composite was observed. Further increase in the glass fiber content of the composite to 50:50 okra : glass fiber ratios, resulted in an increase in energy at break value to a maximum of 4.574J.

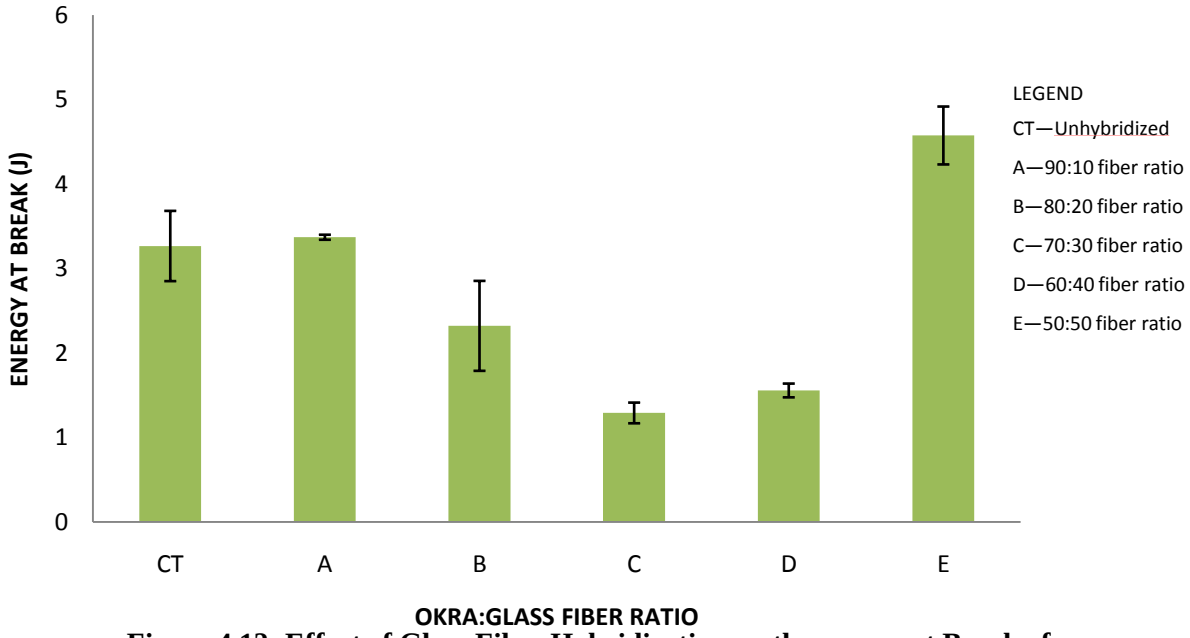


Figure 4.12: Effect of Glass Fiber Hybridization on the energy at Break of Composite

Error bar analysis of the composites indicated that there was significant difference in the elongation at break of the un-hybridized composite with the composites made with the different okra:glass hybridization ratios as a result of the non-overlap of the error bars as shown in Figure 4.12.

4.2.5Effect of Okra-Glass Fibers Hybridization on the Impact Strength of the Composite

The effect of glass fiber hybridization on the impact strength of the composite is shown in Figure 4.13. The 50:50 fiber ratioshave the highest impact strength of 27.8kJ/m^2.It is higher than the strength obtained for the control, 90:10, 80:20, 70:30 and 60:40 by factors of 39, 34, 30, 15 and 6 respectively.

The improvement in the impact strength of the composite with increasing glass fiber content isattributed to the improved resistance developed with the addition of high strength glass fibers in the composites (Panthapulakkal and Sain, 2007). The okra fibers are more brittle than glass fibers, hence at higher natural fiber content, the overall brittleness of material increases and lower impact strength values are observed (Bindal *et al*., 2013).

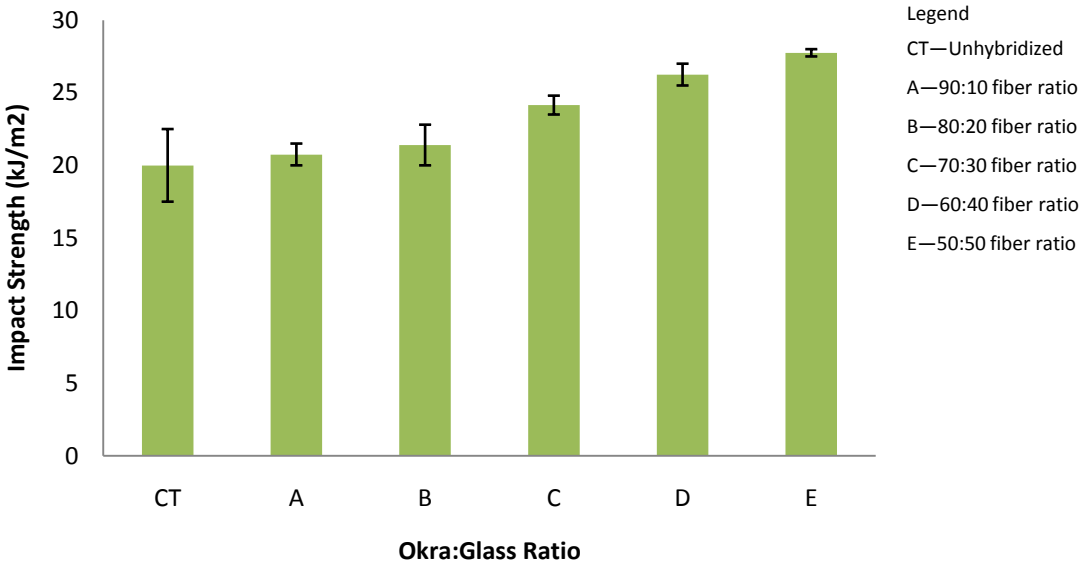


Figure 4.13: Effect of Glass Fiber Hybridization on the Impact Strength of Composite

The optimal impact strength of 20kJ/m^2 for sisal-glass fibers hybridized polypropylene composite at established 20 wt % of glass fiber content by Kasama and Suppakarn, (2009) is lower compared to the 27.7kJ/m^2 observed in this study. Mishra *et al*., (2003) reported

impactstrength of 128J/m at established 8.6 wt % of glass fiber for a total fiber weight of 25 wt % in PALF-glass fiber hybrid composite and 147J/m at established 8.5 wt % of glass fiber for a total fiber weight of 30 wt % in sisal-glass fiber polyester hybrid composites. Raghavendra*et al*., (2011) reported optimal impact strength of 430J/m at established 30:10 glass-bamboo percent ratios.The observed variations in the results areattributed to the type of fibers and the nature of matrix used in the various works (Sreekala *et al*., 2002). It couldalso be attributed to total weight percentage of the reinforcement in the composite (Bindal *et al*., 2013).

The overlapping in the error bars of the unhybridized composite and the composite made with 90:10 and 80:20 hybridization ratios is an indication that there was no significant difference in their impact strength.

4.2.6Effect of Okra-Glass Fibers Hybridization on the Flexural Modulus of the Composite

Figure 4.14 presents the effect of glass fiber hybridization on the flexural modulus (MoR) of the hybrid composite.

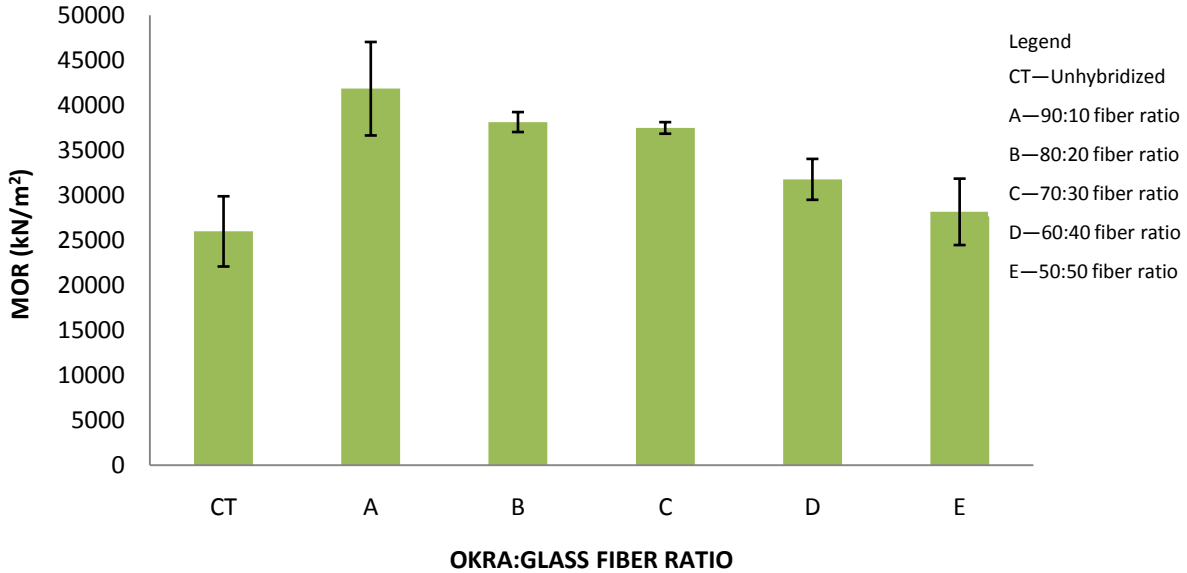


Figure 4.14: Effect of Glass Fiber Hybridization on the MoR of the Composite

A sharp increase of 61% was observed on hybridization with 10% (90:10 okra : glass fiber ratio) of glass fibers. Thereafter a decrease was observed. The 90:10 fiber ratios exhibited the highest flexural modulus of 41.8MN/m^2. It is greater than the 80:20, 70:30, 60:40 and 50:50 fiber ratios by factors of 10, 12, 32 and 49 respectively.

The glass fiber provided more resistance to shearing which resulted to the increase in flexural modulus on addition of hybdid 90:10 okra:glass fiber (Mishra *et al*., 2003) and the declining trend observed beyond that was due to the fiber - fiber interactions and the problem with the dispersion of the fibers in the matrix phase (Baker*et al*., 2005).

The optimal MoR values of 4.1 GPa (Kasama and Suppakarn, 2009) and 9.4 GPa (Velmurugan and Manikandan., 2005) for sisal-glass fiber ratio at total established fiber weight of 30 wt % and Palmyra-glass hybrid composite at established 20:80 hybridization ratio respectively are higher than the 41.8MPa reported in this study. The type of fiber and weight percent of the fibers could be responsible for the observed difference.

The non-overlapping of the error bars of the un-hybridized and the hybridized composites is an indication that significant difference existed in flexural strength of the composites but comparatively, the composites made with 90:10, 80:20 and 70:30 shows no significant difference in their flexural strength due to the overlapping of their error bars as shown in Figure 4.14.

4.2.7Effect of Okra-Glass Fibers Hybridization on the Hardness of the Composite

The effect of glass fiber hybridization on the hardness of the composite is illustrated in Figure 4.15.

An increasing composite strength with increasing glass fiber content was observed resulting in the 50:50 okra/glass fiber ratio having the highest hardness strength of 56.8HRF. It exhibited43.1% improvement in hardness compared to the un-hybridized (control) composite.

The increasing hardness with higher glass fiber content is attributed to the high modulus of the glass fibers and the distribution of the test load on the fibers which decreases the penetration of the test ball to the surface of the composite material (Al-Mosawi, 2012).

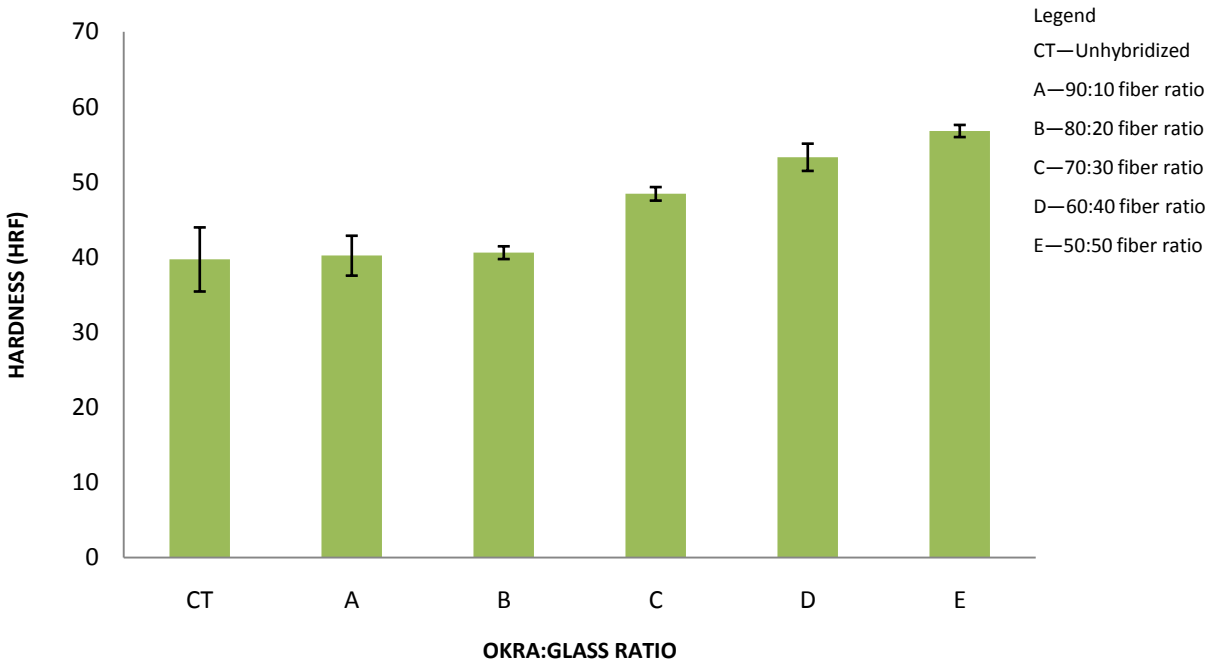


Figure 4. 15: Effect of hybridization ratio on the hardness of the Composite

The higher modulus of the glass fibers compared to the natural fibers is responsible for the decreasing hardness of the composite at high natural fiber content (Maneesh *et al*.,2012). The optimal hardness 53HRM at established 15:5 bagasse:glass weight percent ratio (Maneesh *et al.*, 2012) is slightly lower than the 56.8HRF obtained in this work. The observed variation is attributed to the type of the natural fibers, the length of the fibers (Sreekala *et al*., 2002).

The overlapping of the error bars of the un-hybridized and the composites made from the 90:10 and 80:20 hybridization ratios shows that there was no significant difference in their hardness values. They differ significantly from the composites made with the 70:30, 60:40 and 50:50 hybridization ratios as shown in Figure 4.15.

4.2.8 Effect of Okra-Glass Fibers Hybridization on the Water absorption capacity of the Composite

Figure 4.16 presents the effect of glass fiber hybridization on the water absorption characteristics of the composite. It was observed that there wasa decrease in the percentage of water absorbed by the composite with increasing glass fiber content. The 50:50 okra:glass fiber ratio exhibited the least percentage water absorption capacity of 2.6%. It was66.4% lower than the un-hybridized okra fiber composite and 41.75%, 28.73%, 9.53% and 0.95% lower than the 90:10, 80:20, 70:30 and 60:40 hybridized composites respectively.

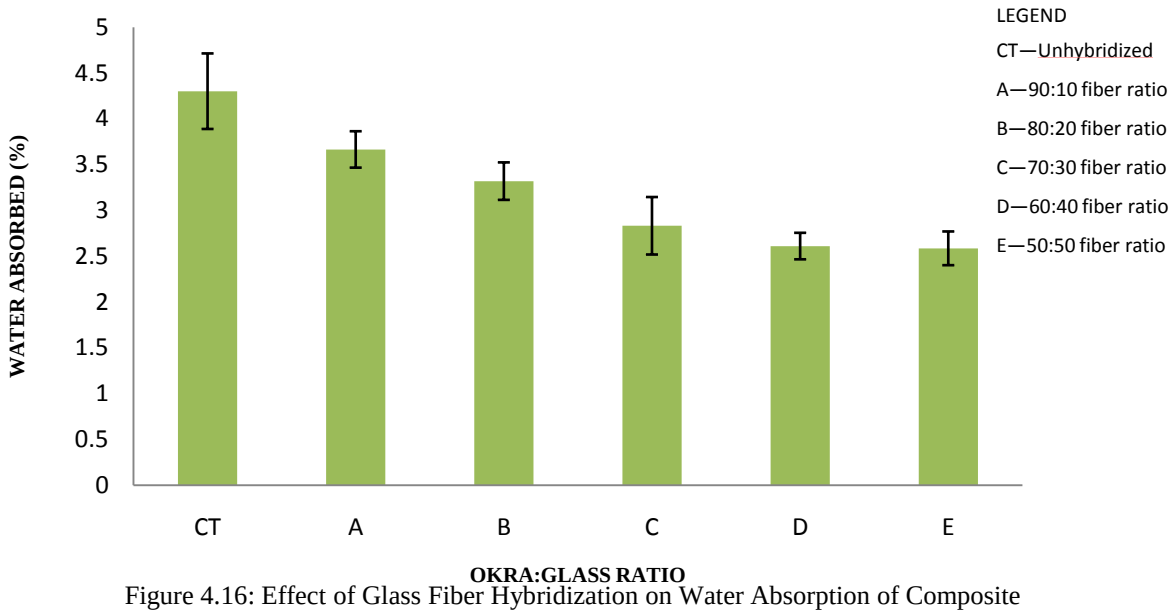


Figure 4.16: Effect of Glass Fiber Hybridization on Water Absorption of Composite

This could bedue to the decreasing quantity of the hydrophillic component in the composite (Kasama and Suppakarn, 2009). Fibers in these composites werearranged in a closed packed manner in which the water impermeable glass fiber acts as barriers and prevents the contact between water and the hydrophillicokra fibers. (Mishra *et al*., 2003).

The optimal result of 2.6% at the 50:50 ratio is low compared to the 7.6% for PALF-glass hybrid polyester composite at established 16.4 wt %:8.6 wt % PALF:glass ratio, 7.2% sisal-glass hybrid

polyester composite at established 24.3 wt %:5.7 wt % sisal:glass fiber ratio (Mishra *et al*., 2003). The type of the fiber and the nature of the matrix could be responsible for the difference observed.

Statistical analysis result as shown by the non-overlap in the error bars indicated that there was a significant difference in the water absorption capacity of the un-hybridized composite. The overlapping in the error bars of the composite made from the 70:30, 60:40 and 50:50 hybridization ratios shows no significant difference in their water absorption capacity.

4.3 DETERMINATION OF OPTIMAL TREATMENT CONCENTRATION

In this step, 50:50 okra:glass fiber was used. That ratio generally gave the best properties; therefore the okra fiber content was treated at different concentrations of NaOH and used in the hybridization.

4.3.1 Effect of Fiber Treatment on the Tensile Strength of Hybridized Composite

The tensile strength result of the treated okra fiber hybridized composite is presented in Figure 4.17. A positive treatment effect was observed with fibers treated with the 5 vol % and 10 vol% concentrated NaOH solution. They gave 46.7% and 98.1% respectively increase in their tensile strength values as compared to the untreated hybrid composite. As the concentration of the NaOH solution increased to 15% and 20%, a negative effect of treatment was observed.

The positive treatment effect observed with the composite treated with 5% and 10% concentrated NaOH solution may be attributed to the fact that the alkali treatment resulted in an improvement in the interfacial bonding by giving rise to additional sites of mechanical interlocking, hence

promoting more resin-fiber interpenetration at the interface as reported in the work of Bledzki and Gassan, (1997) on jute polypropylene composite.

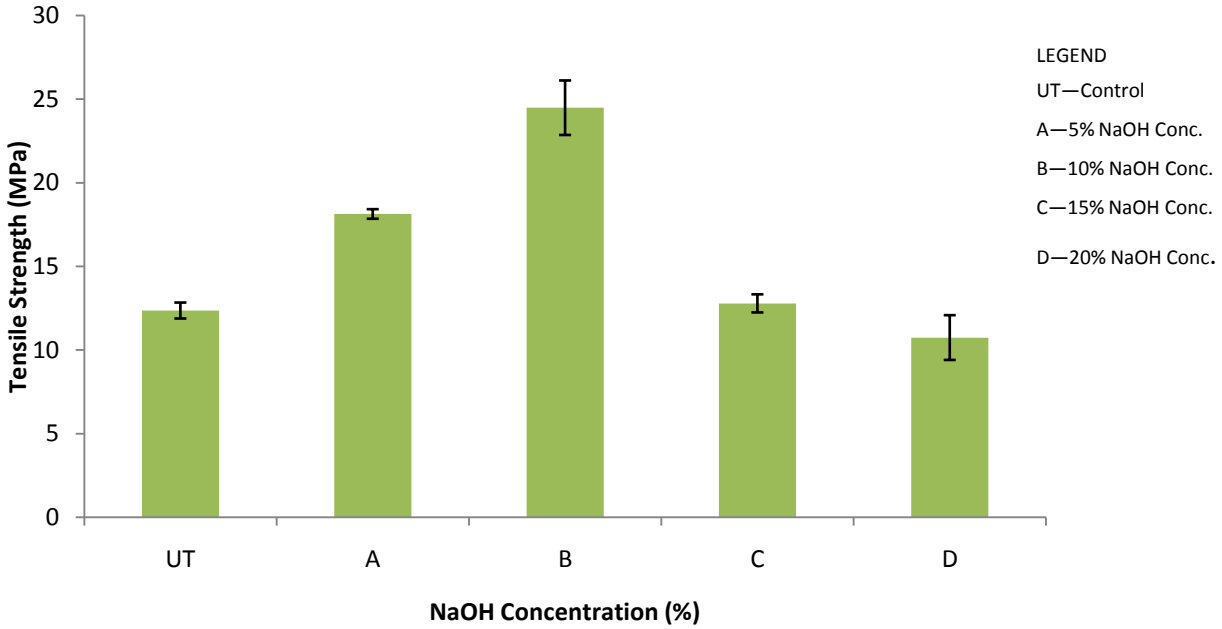


Figure 4.17: Effect of Fiber Treatment on the Tensile Strength of the Composite

The alkali treatment improves the surface adhesive characteristics by removing natural and artificial impurities, thereby producing rough surface topography. After certain optimum concentration or at higher percentage of alkali treatment, the tensile strength of thecomposite decreased sharply. At high alkali concentration, excess delignification of okra fiber occurs which makes the fiber weaker as reported by Mishra *et al*., (2003). Thus for 15% and 20% alkali treated fiber composites, the lowering of strength was observed. Mwaikambo *et* al., 1999, reported that the X-ray diffraction shows a slight initial improvement in the crystallinity index of the natural fibers at low NaOH concentration; however the high NaOH concentrations lowered the fiber crystallinity index which leads to lowering of the mechanical properties as observed by the X-ray diffraction. The appearance of excess notched grooves on the surface of the fiber as the concentration was increased could also be responsible for the decrease in tensile strength of the composite (Eichhorn *et al*., 2001).

The optimal 10% alkali (NaOH) treatmentobtained in this work is higher than the established 5% optimal treatment concentration reported by Mishra *et al*., (2003) for sisal-glass fiber hybridized polyester composite at 30% total fiber loading. Optimal mercerization conditions like the NaOH concentration, time and temperature will vary for each type of fiber as a result of chemical constituent variation as reported by MohdYussni*et al*., (2012), and these could be responsible for the variation observed in the results compared to other works.

The non-overlapping of the error bars as shown in Figure 4.17 suggested that there was significant difference in tensile strength values of the untreated fiber composite and the composites made from the fibers treated with different concentrations of NaOH.

4.3.2 Effect of Fiber Treatment on the Elongation at Break of the Hybridized Composite

Figure 4.18 presents the effect of fiber treatment on the elongation at break of the hybridized composite.

A positive treatment effect was observed on treating with the 5% and 10% concentrated NaOH solution, thereafter a negative effect was observed.

The composite resulting from the 10% concentrated NaOH solution treated fiber exhibited the highest elongation at break of 2.9mm, corresponding to 19% which was higher than that of the untreated fiber composite.

The enhanced elongation on treatment wasdue to the fact that more hemicelluloses are removed from the fiber as a resultof the treatment, whichprovided more surface roughness, hence giving rise to better interlocking with the matrix (Bledzki and Gassan, 1999).

However, at very high alkali (15% and 20%) treatment concentrations, deterioration in the strength of the composite was observed. This may be due to cellulosic chain scission at high

alkali concentration, resulting in loss of strength of the fibers (Khan *et al*., 2014, Mishra *et al.*, 2003).

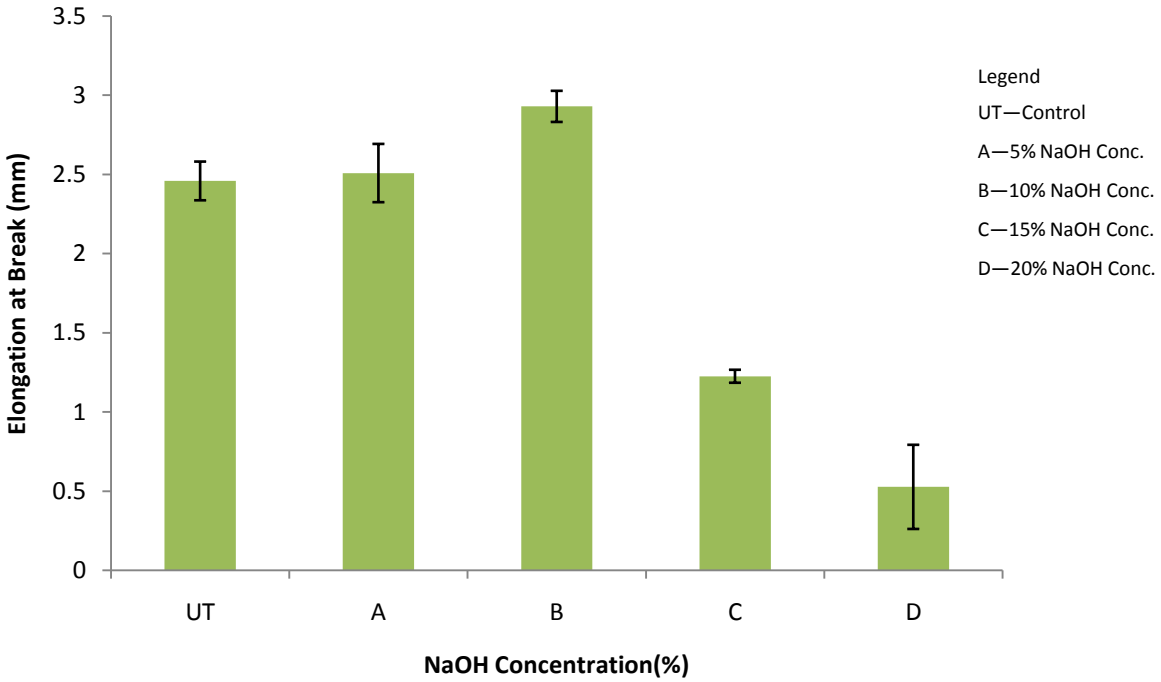


Figure 4.18: Effect of Fiber Treatment on the Elongation at Break of the Composite

The optimal 10% treatment concentration observed in this work issimilar to that reported by Khan *et al*., (2014), where 10% was the established optimal concentration for the elongation at break for okra bast reinforced phenol formaldehyde composites.

The error bars indicated significant difference in the average elongation at break values for each of the fabricated composites.

4.3.3 Effect of Fiber Treatment on the Impact Strength of the Hybridized Composite

Figure 4.19 presents the effect of fiber treatment on the impact strength of the hybridized composite. A positive treatment effect was observed with the treated fiber composites compared to the untreated fiber composite. There was about 131.5% increase in the impact strength of the composite made with the 5% concentrated NaOH solution compared to the untreated fiber

composite. After the optimal 5% treatment concentration, the impact strength decreased with increasing concentration of the NaOH solution. The increase of impact strength might be attributed to the increase in the surface roughness as a result of the treatment, resulting in better mechanical interlocking and the increased amount of cellulose exposed on the fiber surface hence increasing the number of possible reaction sites (Bledzki and Gassan, (1999), Karthikeyan *et al.*, 2012). Denser NaOH solution provided more Na^{+} and OH^{-} ions to react with the fiber, causing greater amount of the lignin and pectin to leach out, hence decreasing the diameter of the fibers and ultimately decreasing the impact strength of the composites (Karthikeyan *et al*., 2012), as observed with the composites made with the 10%, 15% and 20% concentrated NaOH solution treated fibers.

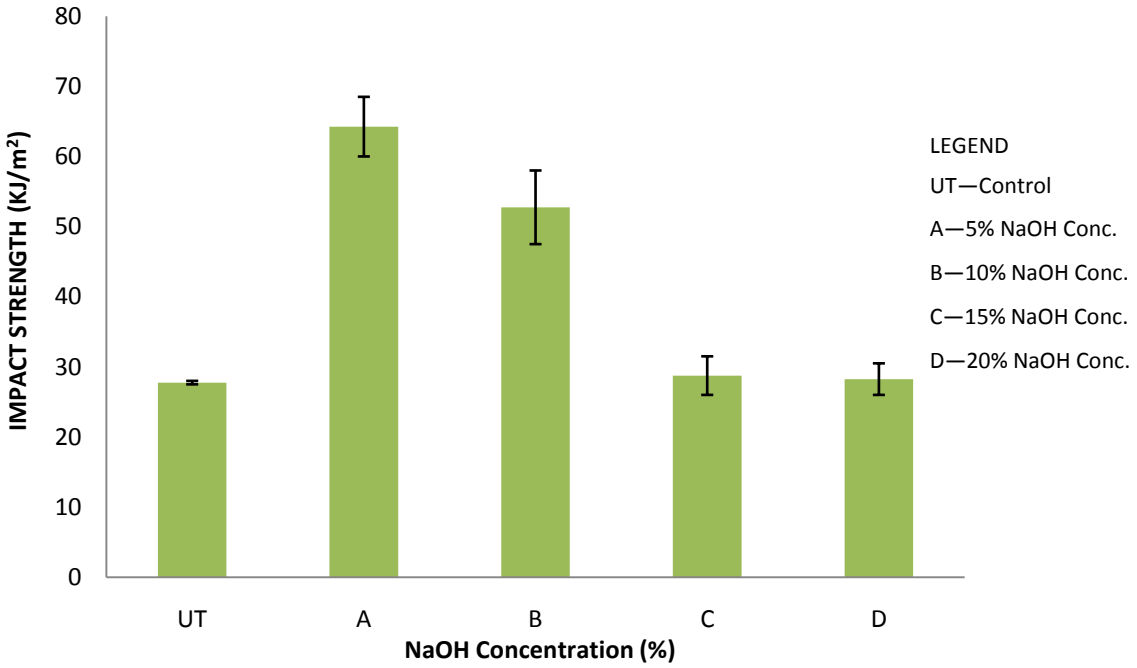


Figure 4.19: Variation of Fiber Treatment with the Impact Strength of Composite

Venkata *et al.*, (2013) and Karthikeyan *et al.*, (2012) made similar observations for Napier grass fiber reinforced epoxy composite and coir fiber reinforced epoxy composite. It was concluded

that 10% and 6% were the optimum NaOH treatment concentration respectively. The strength of the individual fibers used in the researches could be responsible for the variation in the optimum treatment concentration reported when compared to the 5% NaOH concentration obtained in this work.

The non-overlapping of the error bars as observed in Figure 4.19 indicates that there was no similarity in the impact strength of the individual composite.

4.3.4 Effect of Fiber Treatment on the Modulus of Elasticity (MoE) of the Hybridized Composite

Figure 4.20 presents the effect of fiber treatment on the MoE of the composite. It was observed that treated fibers improve the tensile modulus of the composite.

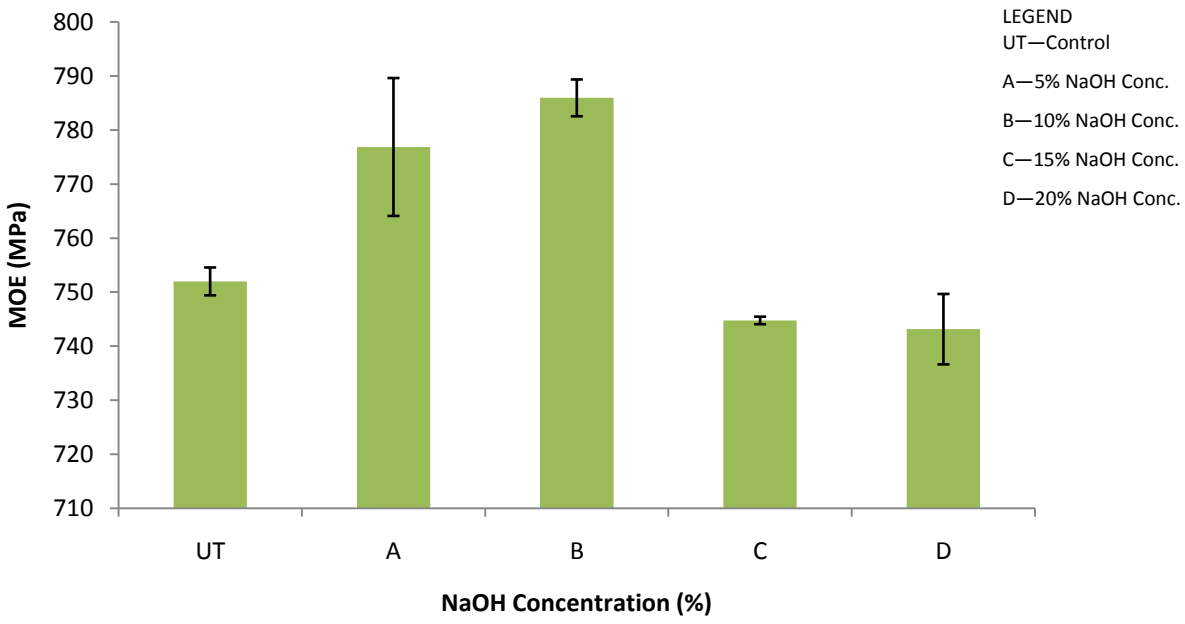


Figure 4.20: Variayion of Fiber Treatment with the MoE of the Composite

Improvement of about 1.2% and 4.5% were recorded with the 5% and 10% concentrated NaOH treated fiber composites respectively. It could be observed that the composite made with 10%

concentrated NaOH treated fiber exhibited highest average MoE value. Further increase in the concentration of the NaOH resulted in the reduction in the MoE value of the composite.

The enhancement in the MoE of the alkali treated composite could be attributed to the improved wetting of the fibers (Siregar *et al*., 2010). It could also be attributed to the fact that alkali treatment improves the adhesive characteristics of fiber surface by removing natural and artificial impurities, thereby producing a rough surface topography. It also leads to fibrillation, creating more available surface area on the fiber to interact with the matrix (Mohanty *et al.,* 2000). The increase in tensile modulus for the treated fiber may be due to the structural transformation of fiber from cellulose-I to cellulose-II. Therefore at 10% NaOH, better compatibility and adhesiveness is achieved (Venkateshwaran *et al*., 2013).

The decreasing MoE value observed after the optimal 10% concentration may be attributed to the fibers losing its characteristics structure (Siregar *et al.,* 2010). It could also be attributed to damaged fiber surface as a result of the high concentration of alkali (Venkateshwaran *et al.,* 2013).

An optimal treatment concentration of 4% was reported by Siregar *et al*.,(2010) for short pineapple reinforced high impact polystyrene composites, 4% optimal treatment concentration for sisal reinforced polyester composite (Xue *et al*., 2007) and 10% optimal concentration for sisal reinforced polymer biocomposite (Syndenstricker et al., 2003) The variation in the results compared to the present work may be attributed to the type of the fibers used. Since composition differs for individual fibers, it will also affect the level of treatment required for a particular fiber.

The overlap in the error bars of the composites made with the fibers treated with the 10% and 5% concentrated NaOH concentrations suggests there was no significant difference in the MoE of the two composites.

4.3.5 Modulus of Rupture (MoR) of Hybridized Treated Okra –Glass Fiber Composite

The effect of fiber treatment on the flexural modulus of the hybridized composite is presented in Figure 4.21. The results showed that fiber treatment concentrations strongly affect the flexural modulus of the composite.

Positive treatment effect was observed with the 5% alkaline concentrated treated fiber composite when compared to the untreated composite, hence represents the best flexural modulus of 50345.2kN/m^2 (50.4MPa), which was about 78.8% higher than the untreated fiber composite. With higher concentration of alkaline treatment, a negative effect was observed when compared to the 5% alkaline concentrated treated fiber composite.

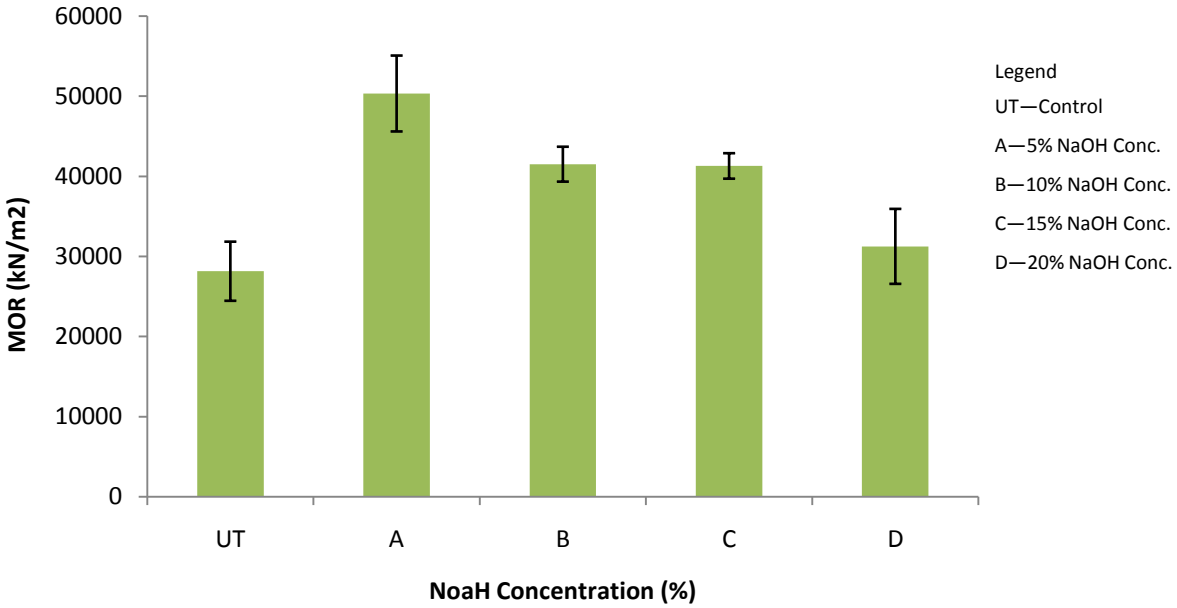


Figure 4.21: Effect of Fiber Treatment on the MoR of the Composite

The increasing flexural modulus with alkaline treatment could be as a result of formation of single fibers(fibrillation). Fibrillation is observed in treated fibers and this may be due to the leaching out of the waxy substances. After alkaline treatment, the materials in the inter-fribillar region reduces with increasing concentration of alkaline solution and treatment time, hence the interfacial interaction between the fiber and the matrix was increased. It also increases the surface area available for contact with matrix and possibly increases the possibility of load transfer between the fiber and the matrix (Osmani*et al.,* 2011). The decreasing trend observed after the optimum 5% alkaline treatment concentration may be as a result of excessive delignification of the okra fiber with increasing alkaline concentration resulting in a weaker fiber.

The optimal result of 50.4MPa at 5% alkaline concentration was much lower than the 3GPa at 10% optimal alkaline concentration for Alfa fiber reinforced polyester composite (Osmani*et al*., 2011) and the 4559.3MPa at 4% treatment concentration for short pineapple leaf fiber reinforced high impact polystyrene composite (Siregar *et al*., 2010). The type of fibers and matrix used in the various researches (Mishra *et al*., 2003) could have been responsible for the observed variation in the results obtained.

The over-lap in the error bars values of the composites made from fibers treated with the 10% and 15% alkaline concentrations suggest no significant difference exist in the MOR strength of the two composite.

4.3.6 Effect of Fiber Treatment on the Water Absorption Capacity of the Hybridized Composite

The effect of fiber treatment on the water absorption capacity of the composite is presented in Figure 4.22. It was observed that the water absorption capacity of the untreated fiber hybrid composite dropped from 2.6% to 2.0%, when the fibers were treated with 5% concentrated

NaOH solution. Denser NaOH solution treatment further increased the water uptake of the composite when compared to the 5% concentrated NaOH solution treated fiber composite. The reduction in the water absorption could be attributed to the greater adhesion between the fiber and the matrix, which could be possible due to the surface treatment of the fibers (Mishra *et al.*, 2003). Hetal et al., 2012 also concluded that by providing additional sites for mechanical interlocking, alkali treatment leads to improvement of interfacial bonding hence, promoting resin-fiber interpenetration at the interface. This hydrophobic resin pick-up could also account for the reduction in water absorption.

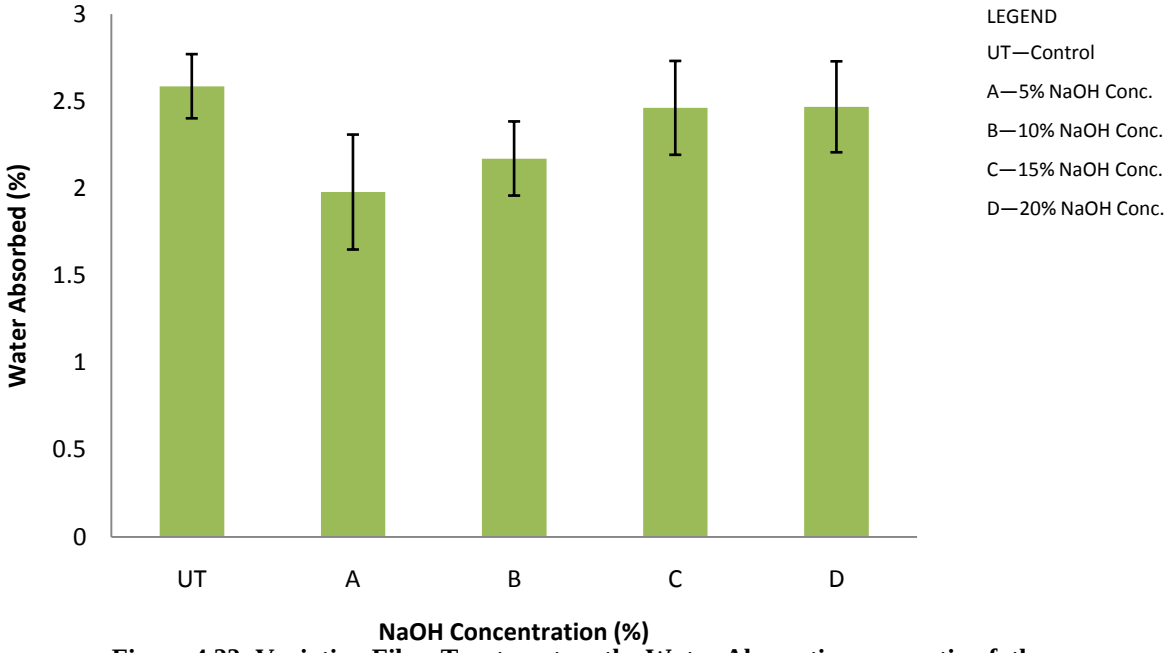


Figure 4.22: Variation Fiber Treatment on the Water Absorption propertiy of the Composite

As the treatment concentration was increased, the water absorption capacity of the compsite increased. This showed that extra alkaline treatment had removed the protecting cell fibers and swelling process was much faster, leading to higher water uptake (Dhanalakshmi*et al.*, 2012).

The optimal treatment concentration of 5% observed in this work was similar to the reported optimal treatment concentration of 6% by Mohd Nazarudin *et al.*, 2013 and the established 5% treatment concentration by Mishra *et al*., 2003.

The over lapping of the error bars of the untreated fiber composite and the composites made from fibers treated with 15% and 20% NaOH concentration indicated that there were no significant difference in the water absorption capacity of the composites.

4.3.7 Hardness of the Hybridized Treated Okra-Glass Fiber Composite

Figure 4.23 shows the effect of varying treatment concentration on the hardness of the hybrid composite. An increase in the hardness value of the composite was observed on modifying the fiber surface with 5% concentrated NaOH solution until an optimum was reached with the 10% concentrated NaOH solution.

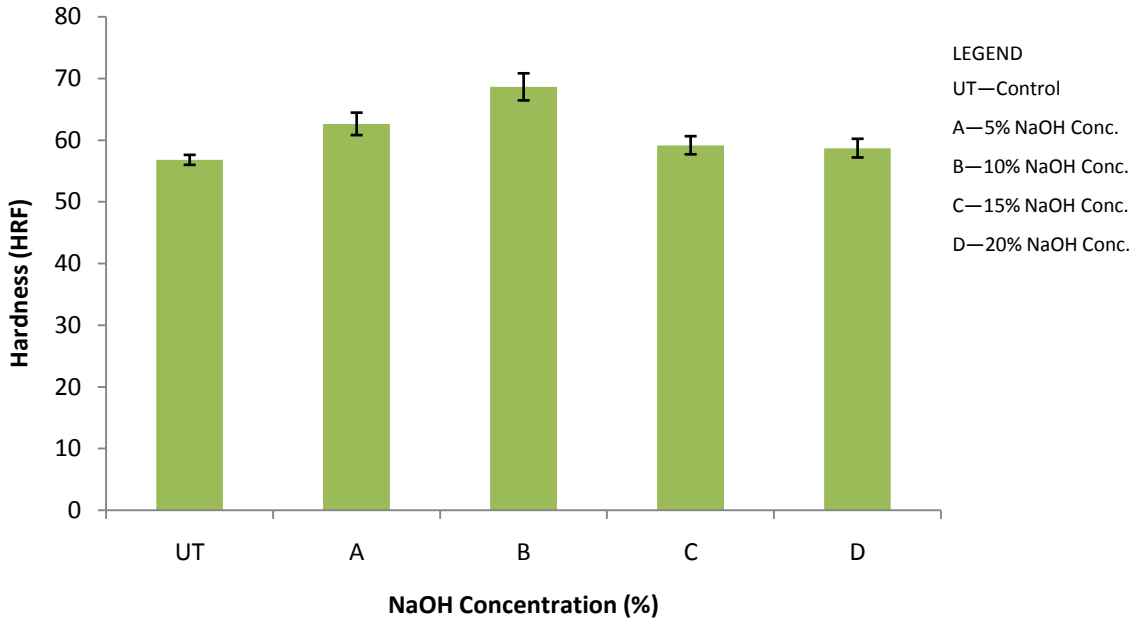


Figure 4.23: Variation of Fiber Treatment on the Hardness of the Composite

On further increasing the concentration of the NaOH solution, a decrease in the hardness value of the composite was observed. The 5% and 10% concentrated NaOH solution modification lead to a 10.3% and 20.8% increase in the hardness value of the composite when compared to the untreated fiber composite.

The observed increase in the hardness value could beattributed to strong interface and the closed packing arrangement in the composite. This could be attributed to the increase in stiffness and the dispersion of the fiber into the matrix and the minimization of voids and stronger interfacial bonding between the matrix and the fiber as a result of the treatment as established by Siregar*et al.*,(2010).

The optimal 10% NaOH concentration observed washigher than the 4% NaOH concentration reported by Siregar *et al*., (2010) and Rahman *et al*., (2010) in their works on short pineapple leaf reinforced high impact and rice husk reinforced polyethylene composites respectively.

The non-overlapping of the error bars observed with the various composites as shown in Figure 4.23 suggests that there was significant difference in the hardness of the composite. Each composite is different from the other in terms of their hardness strength

4.3.8 Energy at Break of the Hybridized Treated Okra – Glass Fiber Composite

Figure 4.24 presents the effect of fiber treatment on the breakage energy of the composite. It could be observed that there wasan increase in the energiese of the treated composites compared to the untreated ones. The energy absorbed before failure for the 5% and 10% concentrated NaOH treated fiber composites were 1.1% and 27.4%, which were higher than the energy obtained for the untreated fiber composite.

The increase could be attributed to the fact that the alkali treatment result in an improvement in the interfacial bonding by giving rise to additional sites of mechanical interlocking, hence promoting more resin-fiber interpenetration at the interface (Bledzki and Gassan, 1999). This results in improved mechanical properties and subsequently higher amount of energy required to cause failure. A decrease in energy was observed with further increase in NaOH solution concentration to 15% and 20% concentrations.

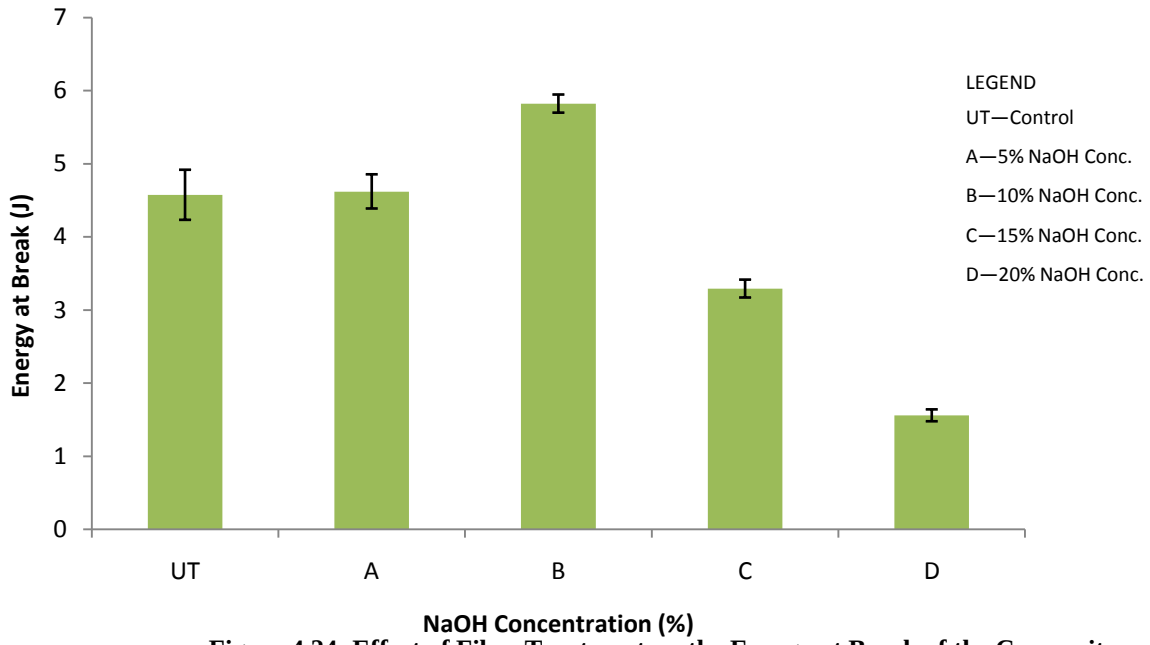


Figure 4.24: Effect of Fiber Treatment on the Energy at Break of the Composite

At higher alkali concentration, excess delignification of okra fiber occurs which makes the fiber weaker. Thus for 15% and 20% alkali treated fiber composites, the lowering of strength is observed (Mishra *et al*., 2003). This might ultimately be responsible for lowering the energy required to cause failure when compared to the composite made of lower concentration treated fibers.

It could also be observed from the non-overlapping of the error bars that the energy at break of the composites made from the fibers treated with 10%, 15% and 20% NaOH concentration are

significantly different from the other. The overlapping of the error bars noticed in the untreated fiber composite and the composite made from the fibers treated with 5% concentrated NaOH was an indication that there was no significant difference in the energy at break of both composites.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The mechanical properties of the short okra and glass fibers reinforced epoxy composite at 15 wt % fiber loading and varying fiber lengths from 10mm to 50mm, varying hybridization ratio and varying treatment concentrations have been investigated in this work.

The 20mm fiber length composite, 50:50 okra: glass fiber ratios and the composite made with the 10%concentrated NaOH treated okra fiber gave better fiber impregnation, better fiber wetting by the matrix and good interfacial bonding. The maximum tensile strength, modulus of elasticity, flexural strength, impact strength and hardness values were obtained at the 20mm fiber length composite;it also has the least water absorption properties.

Based on the results obtained from the study, the following conclusions are drawn:

i. Better mechanical properties were exhibited the 20mm fiber length composite; this might be taken to advantage for structural application.
ii. The 20mm fiber length composite exhibited the least water absorption properties of 4.3%, hence it is a good material for structural applications.
iii. 50:50 okra:glass fibers hybridization ratio exhibited the best properties.
iv. 5 wt % of NaOH treatment concentration of the composite gave better MoR, impact and water absorption properties compared to the remaining concentration while better tensile

strength, hardness, MoE, elongation was observed with composites made withthe 10 wt % NaOH concentration.

5.2 Recommendations

The following recommendations are proposed

i. Within the limitations of this present study, the 20mm fiber length compositewas observed to present the maximum mechanical properties, hence it is the critical fiber length needed for effective load transfer.
ii. The effect of soaking time and temperature on the properties of short okra fiber composites should be investigated.
iii. Other treatment options should be employed to determine how much modification will be achieved using other chemicals.
iv. Morphological examination of the composite should be undertaken to study the microscopic structure of the composite.
v. Other natural fibers should be explored in combination with okra as hybrid with glass fiber in a matrix.
vi. The composite can find application in construction of outdoor living decks, structural building components, material handling applications, paneling, flooring and furniture; when Compared with properties of wood and wood based composite materials (Tensile strength range of 22-31MPa, MoR range of 31-53MPa), Cai and Ross (2010), that are presently used in such applications. This will help preserve the environment by reducing the number of trees cut for such applications.

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APPENDIX A-1.

Mechanical Properties of Unreinforced Virgin Epoxy Composite

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of Unreinforced Virgin Epoxy Composite Material

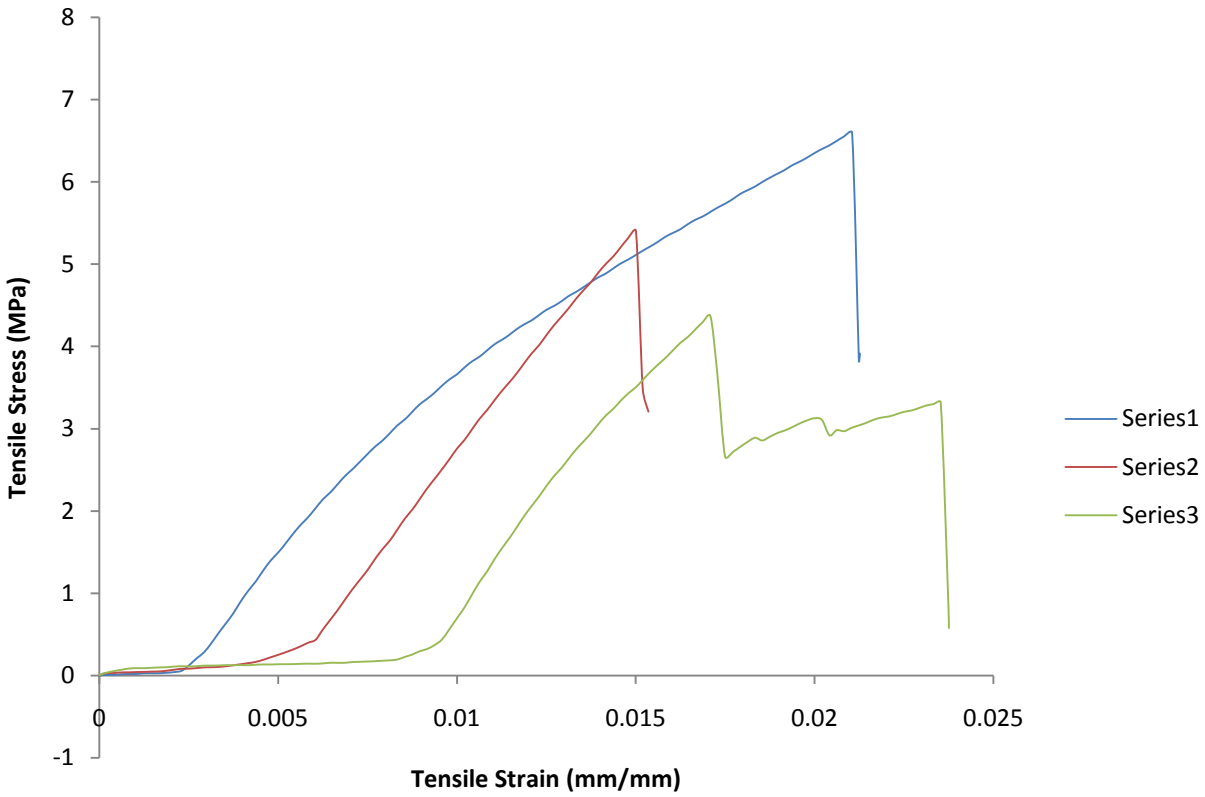


Figure 1; Stress-Strain curve for the Virgin Epoxy Composite

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	3.65000	40.00000	686.37123
2	3.65000	40.00000	571.15173
3	3.65000	40.00000	454.78912
Mean	3.65000	40.00000	570.77069

	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation	0.00000	0.00000	115.79153

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	6.59814	0.02105	605.68401	0.84969
2	5.49052	0.01520	571.15173	0.60806
3	4.37192	0.01709	82.15710	0.95006
Mean	5.48686	0.01778	419.66428	0.80260
Standard Deviation	1.11311	0.00298	292.79932	0.17579

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	3.82249	0.02124	-----	-----
2	3.49052	0.01520	-----	-----
3	0.78978	0.02375	4.37192	0.01709

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	4.03426	0.02007	4.37192	0.01709
Standard Deviation	2.81470	0.00439	-----	-----

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	0.30828	0.30319	-----	-----
2	0.11973	0.11973	-----	-----
3	0.17202	0.08773	0.08773	454.78912
Mean	0.20001	0.17022	0.08773	454.78912
Standard Deviation	0.09734	0.11627	-----	-----

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	-----	559.84827	138.34201	0.02083

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	-----	297.51770	132.69411	0.01509
3	0.68362	300.88408	108.05600	0.01695
Mean	0.68362	386.08335	126.36404	0.01762
Standard Deviation	-----	150.49424	16.10475	0.00293

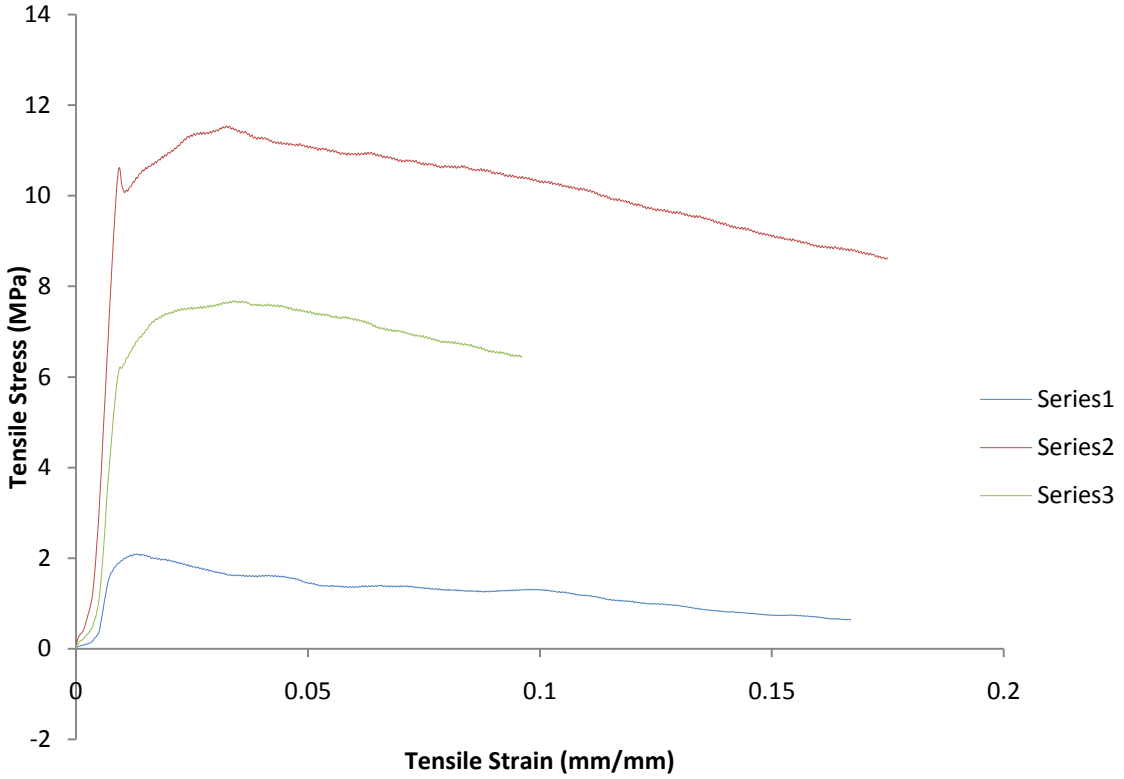
	True stress at Maximum Load (Pa)
1	6736997.14526
2	5573988.24793
3	4446640.22893
Mean	5585875.20737
Standard Deviation	1145224.72725

APPENDIX A-2.

Mechanical Properties of 10mm Fiber Length ReinforcedEpoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 10mm Fiber Length ReinforcedEpoxy Composite Material



Stress-Strain curve for 10mm fiber length composite

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
1		5.50000	40.00000	137.92572
2		5.50000	40.00000	761.73972
3		5.50000	40.00000	506.93019
Mean		5.50000	40.00000	468.86521

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation		0.00000	0.00000	313.64420

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	2.08978	0.01314	42.72085	6.67987
2	11.54151	0.03229	569.34282	6.99200
3	7.68076	0.03375	425.84222	3.84150
Mean	7.10402	0.02639	345.96863	5.83779
Standard Deviation	4.75218	0.01150	272.24533	1.73587

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	0.64729	0.16700	2.08978	0.01314
2	8.62641	0.17480	11.54151	0.03229
3	6.45215	0.09604	7.68076	0.03375

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	5.24195	0.14594	7.10402	0.02639
Standard Deviation	4.12493	0.04340	4.75218	0.01150

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	0.54641	0.03820	0.03820	137.92572
2	4.56613	0.76007	0.76007	761.73972
3	1.68715	0.51877	0.51877	506.93019
Mean	2.26657	0.43902	0.43902	468.86521
Standard Deviation	2.07155	0.36748	0.36748	313.64420

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	0.52544	137.45357	-----	0.01305

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	1.29162	757.25629	-----	0.03178
3	1.35006	504.60463	-----	0.03319
Mean	1.05571	466.43817	-----	0.02601
Standard Deviation	0.46016	311.65905	-----	0.01124

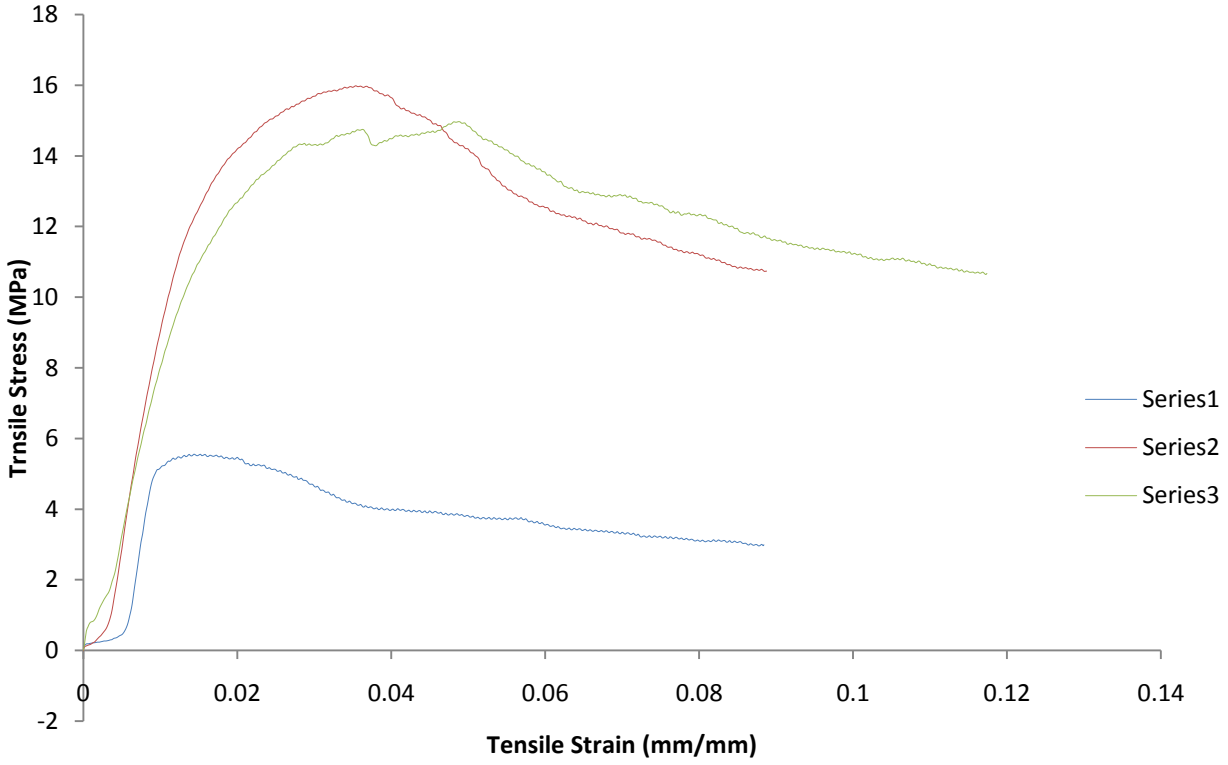
	True stress at Maximum Load (Pa)
1	2117234.87589
2	11914193.50336
3	7939998.11514
Mean	7323808.83146
Standard Deviation	4927460.45261

APPENDIX A-3.

Mechanical Properties of 20mm fiber length reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 20mm fiber length reinforced Epoxy Composite Material



Stress-Strain curve for 20mm fiber length composite

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
1		5.50000	40.00000	366.45401
2		5.50000	40.00000	1054.93087
3		5.50000	40.00000	988.04319
Mean		5.50000	40.00000	803.14269

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation		0.00000	0.00000	379.65938

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	5.55233	0.01438	197.42020	3.53669
2	15.98380	0.03542	708.89457	3.54994
3	14.97035	0.04875	704.42129	4.69681
Mean	12.16883	0.03285	536.91202	3.92781
Standard Deviation	5.75241	0.01733	294.01705	0.66601

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	2.99122	0.08842	5.55233	0.01438
2	10.74083	0.08875	15.98380	0.03542
3	10.67305	0.11742	14.97035	0.04875

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	8.13503	0.09820	12.16883	0.03285
Standard Deviation	4.45480	0.01665	5.75241	0.01733

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	0.87537	0.10449	0.10449	366.45401
2	2.85104	1.03954	1.03954	1054.93087
3	3.68207	1.46363	1.46363	988.04319
Mean	2.46949	0.86922	0.86922	803.14269
Standard Deviation	1.44173	0.69539	0.69539	379.65938

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	0.57506	359.83822	-----	0.01427

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	1.41687	900.18809	717.50884	0.03481
3	1.94994	971.68246	-----	0.04760
Mean	1.31396	743.90292	717.50884	0.03223
Standard Deviation	0.69319	334.52523	-----	0.01681

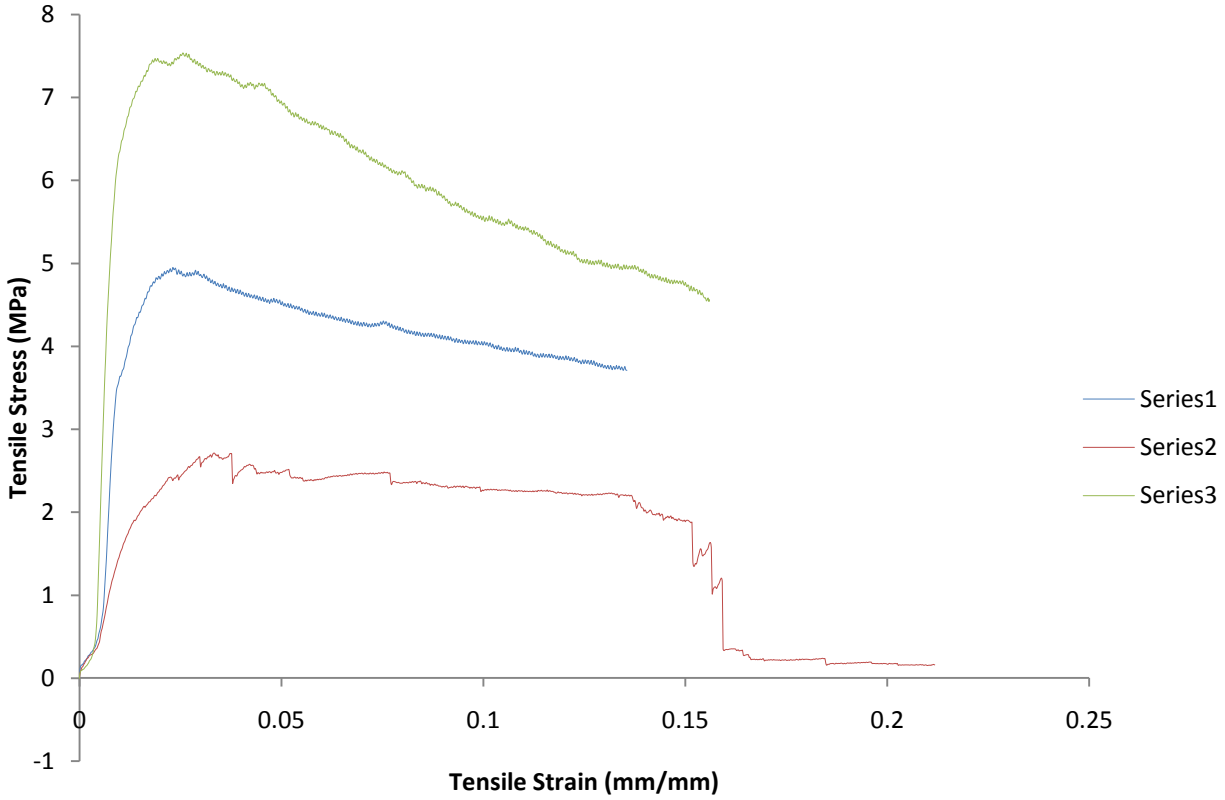
	True stress at Maximum Load (Pa)
1	5632156.98228
2	16549977.20608
3	15700132.56564
Mean	12627422.25133
Standard Deviation	6072961.47827

APPENDIX A-4.

Mechanical Properties of 30mm fiber length reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 30mm fiber length reinforced Epoxy Composite Material



Stress-Strain Curve for 30mm fiber length composite

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
1		5.50000	40.00000	326.86049
2		5.50000	40.00000	178.93538
3		5.50000	40.00000	497.67676
Mean		5.50000	40.00000	334.49087

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation		0.00000	0.00000	159.50763

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	4.95243	0.02313	245.07309	5.41656
2	2.71114	0.03334	10.62898	8.46694
3	7.54056	0.02562	301.23228	6.23937
Mean	5.06804	0.02736	185.64478	6.70762
Standard Deviation	2.41678	0.00532	154.14721	1.57818

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	3.71323	0.13541	4.95243	0.02313
2	0.16105	0.21167	2.71114	0.03334
3	4.56413	0.15598	7.54056	0.02562

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	2.81280	0.16769	5.06804	0.02736
Standard Deviation	2.33556	0.03945	2.41678	0.00532

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	1.44501	0.18801	0.18801	326.86049
2	0.93498	0.15689	0.15689	178.93538
3	2.39840	0.36356	0.36356	497.67676
Mean	1.59280	0.23615	0.23615	334.49087
Standard Deviation	0.74282	0.11143	0.11143	159.50763

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	0.92519	306.71419	-----	0.02287

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	1.33356	163.29826	-----	0.03280
3	1.02500	494.82225	-----	0.02530
Mean	1.09458	321.61157	-----	0.02699
Standard Deviation	0.21289	166.26331	-----	0.00517

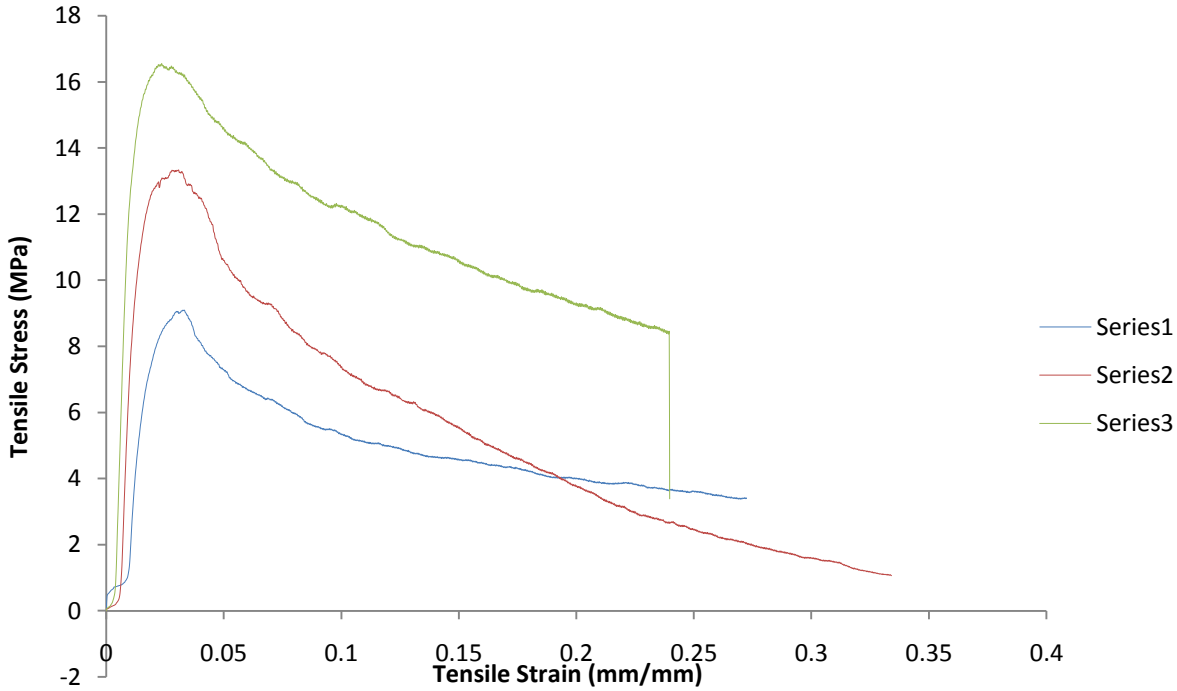
	True stress at Maximum Load (Pa)
1	5066979.79909
2	2801529.02193
3	7733783.67499
Mean	5200764.16534
Standard Deviation	2468847.44023

APPENDIX A-5.

Mechanical Properties of 40mm fiber length reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 40mm fiber length reinforced Epoxy Composite Material



Stress-Strain Curve for 40mm Fiber Length Composite

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
1		5.50000	40.00000	600.66311
2		5.50000	40.00000	880.34859
3		5.50000	40.00000	1092.74164
Mean		5.50000	40.00000	857.91778

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation		0.00000	0.00000	246.80494

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	9.10096	0.03271	226.10503	10.89194
2	13.33861	0.03084	70.28484	13.36662
3	16.55669	0.02354	553.51364	9.59275
Mean	12.99875	0.02903	283.30117	11.28377
Standard Deviation	3.73947	0.00485	246.63955	1.91721

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	3.42583	0.27230	9.10096	0.03271
2	1.06492	0.33417	13.33861	0.03084
3	3.39652	0.23982	16.55669	0.02354

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	4.29244	0.28209	12.99875	0.02903
Standard Deviation	3.73696	0.04793	3.73947	0.00485

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	3.55607	0.45278	0.45278	600.66311
2	4.72998	0.70398	0.70398	880.34859
3	7.24180	0.66609	0.66609	1092.74164
Mean	5.17595	0.60761	0.60761	857.91778
Standard Deviation	1.88290	0.13542	0.13542	246.80494

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	1.30850	600.66311	-----	0.03219

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	1.23362	878.58625	-----	0.03037
3	0.94162	1083.47898	1452.57502	0.02327
Mean	1.16125	854.24278	1452.57502	0.02861
Standard Deviation	0.19385	242.32673	-----	0.00471

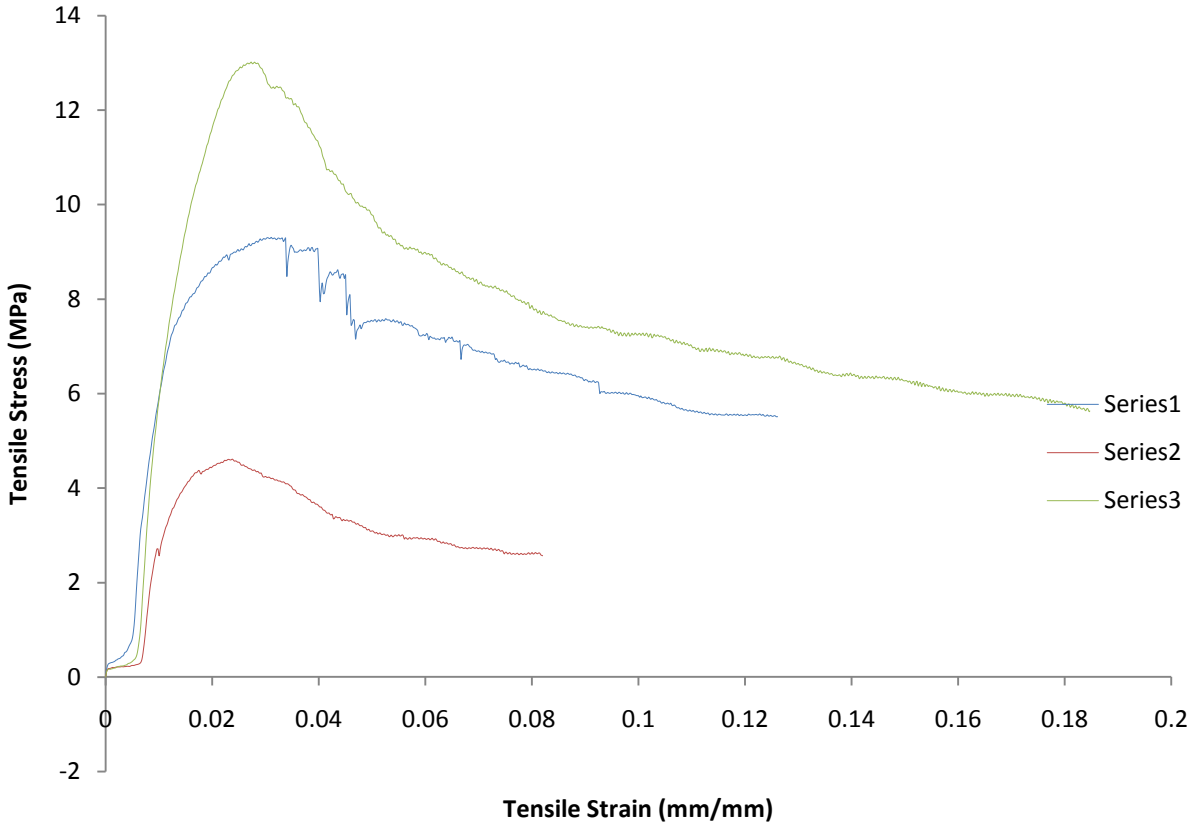
	True stress at Maximum Load (Pa)
1	9398671.14284
2	13749986.14155
3	16946446.31302
Mean	13365034.53247
Standard Deviation	3788583.94534

APPENDIX A-6.

Mechanical Properties of 50mm fiber length reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 50mm fiber length reinforced Epoxy Composite Material



Stress-Strain curve for 50mm fiber length composite

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
1		5.50000	40.00000	614.25604
2		5.50000	40.00000	304.19151
3		5.50000	40.00000	859.37530
Mean		5.50000	40.00000	592.60762

	Diameter (mm)	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation		0.00000	0.00000	278.22428

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	9.30691	0.03105	363.69551	5.04169
2	4.60896	0.02376	169.62850	3.27500
3	13.02084	0.02730	371.75862	7.38837
Mean	8.97890	0.02737	301.69421	5.23502
Standard Deviation	4.21552	0.00365	114.44329	2.06349

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	5.51054	0.12604	9.30691	0.03105
2	2.57013	0.08187	4.60896	0.02376
3	5.63271	0.18471	13.02084	0.02730

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	4.57112	0.13088	8.97890	0.02737
Standard Deviation	1.73399	0.05159	4.21552	0.00365

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	2.22752	0.52269	0.52269	614.25604
2	0.66759	0.16669	0.16669	304.19151
3	3.72479	0.52519	0.52519	859.37530
Mean	2.20663	0.40486	0.40486	592.60762
Standard Deviation	1.52871	0.20626	0.20626	278.22428

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	1.24200	612.38445	-----	0.03058

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	0.95031	254.69789	-----	0.02348
3	1.09200	857.64453	-----	0.02693
Mean	1.09477	574.90896	-----	0.02700
Standard Deviation	0.14586	303.21522	-----	0.00355

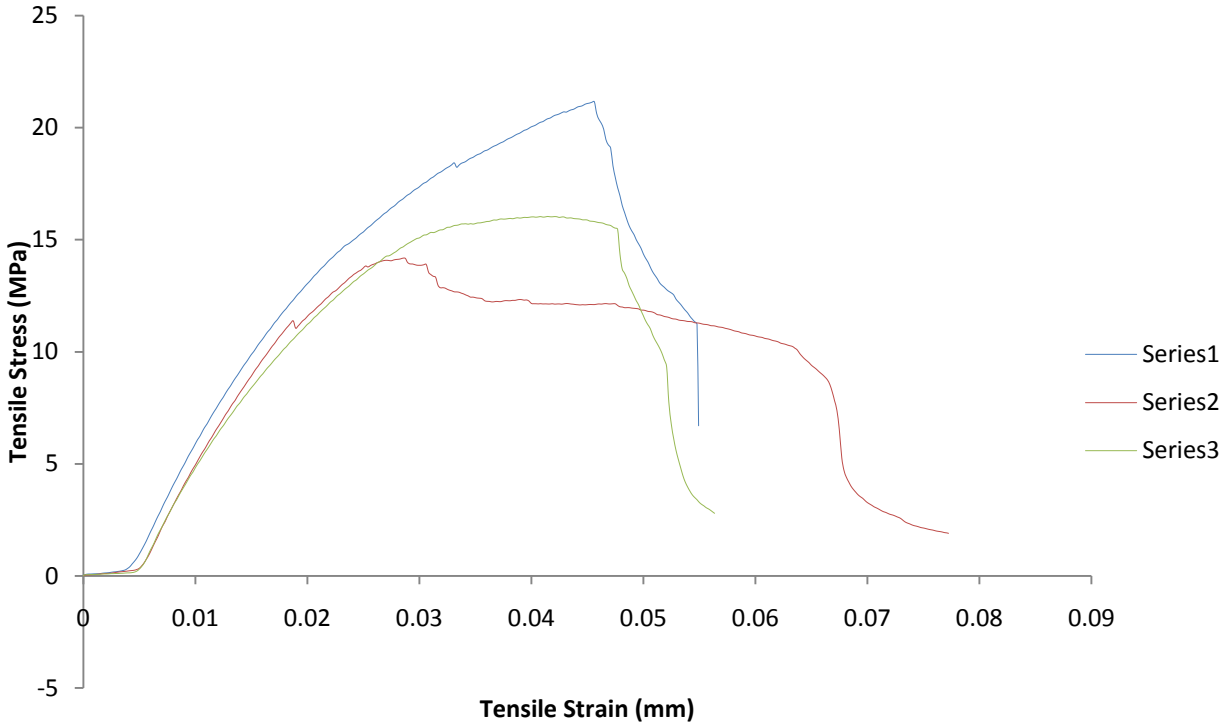
	True stress at Maximum Load (Pa)
1	9595889.16345
2	4718461.16758
3	13376306.65771
Mean	9230218.99625
Standard Deviation	4340490.54095

APPENDIX B-1.

Mechanical Properties of 9:1 Okra:Glass hybridized reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 9:1 Okra:Glass hybridized reinforced Epoxy Composite Material



Stress-Strain Curve for 90:10 Okra-Glass Fiber ratio Composite

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	4.00000	40.00000	2538.09541
2	4.00000	40.00000	1700.72690
3	4.00000	40.00000	1923.90811
Mean	4.00000	40.00000	2054.24347

	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation	0.00000	0.00000	433.63232

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	21.15080	0.04563	1346.23358	2.19200
2	14.17272	0.02854	230.03728	3.08319
3	16.03257	0.04146	339.27641	2.25025
Mean	17.11870	0.03854	638.51576	2.50848
Standard Deviation	3.61360	0.00891	615.33055	0.49856

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	11.21861	0.05480	21.15080	0.04563
2	10.14981	0.06355	14.17272	0.02854
3	10.53767	0.05104	16.03257	0.04146

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	10.63536	0.056463	17.11870	0.03854
Standard Deviation	0.541056	0.006419	3.61360	0.00891

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	3.40663	2.74923	2.74923	2538.09541
2	3.33440	1.02779	1.02779	1700.72690
3	2.77880	1.96707	1.96707	1923.90811
Mean	3.17328	1.91470	1.91470	2054.24347
Standard Deviation	0.34353	0.86192	0.86192	433.63232

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	1.82519	1777.28944	706.08487	0.04462

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	1.14162	1455.80033	668.375	0.02814
3	1.65831	1886.73884	693.62846	0.04062
Mean	1.54171	1706.60953	689.3628	0.03779
Standard Deviation	0.35639	223.99495	19.21342	0.00860

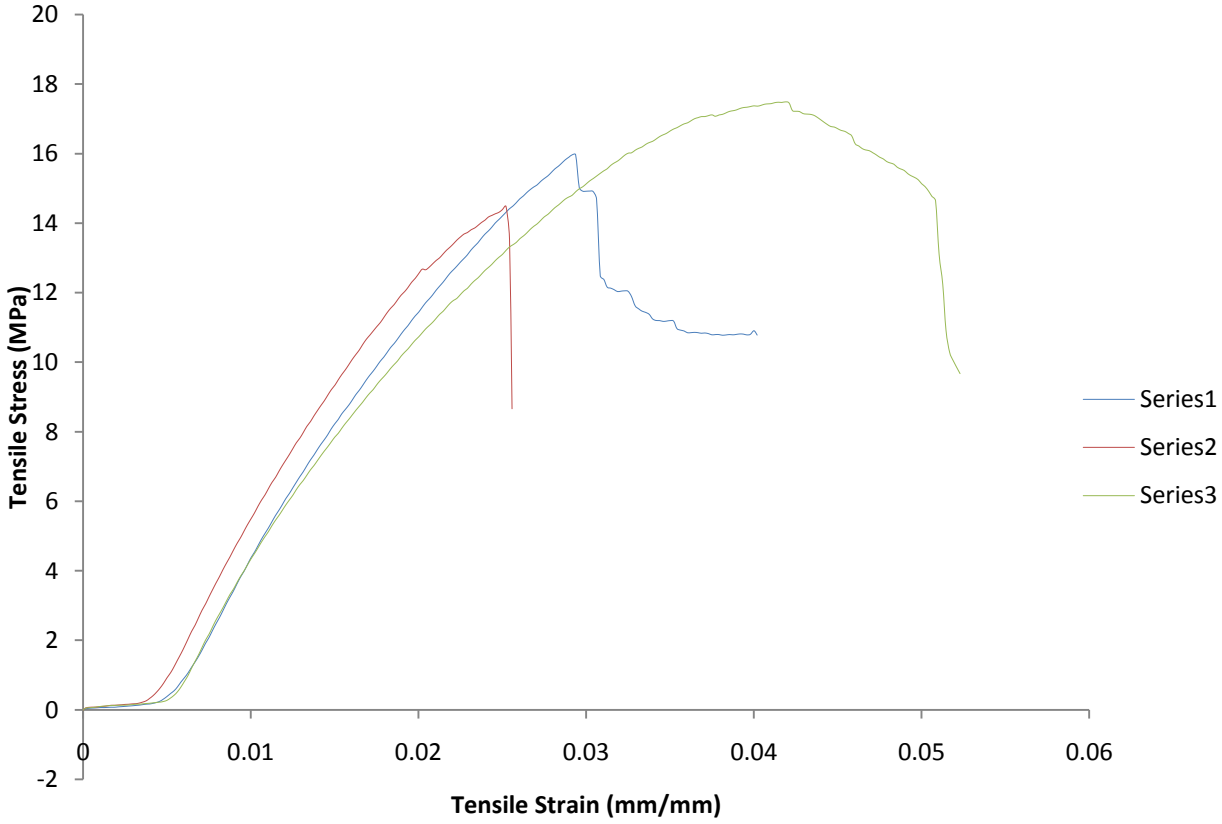
	True stress at Maximum Load (Pa)
1	22115899.21726
2	14577222.50321
3	16697242.63721
Mean	17796788.11923
Standard Deviation	3887757.94642

APPENDIX B-2.

Mechanical Properties of 8:2 Okra:Glasshybridized reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 8:2 Okra:Glasshybridized reinforced Epoxy Composite Material



Stress-Strain Curve for 80:20 okra-Glass fiber composite

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	4.00000	40.00000	1916.31634
2	4.00000	40.00000	1743.14566
3	4.00000	40.00000	2098.93845
Mean	4.00000	40.00000	1919.46682

	Thickness (mm)	Length (mm)	Maximum Load (N)
Standard Deviation	0.00000	0.00000	177.91732

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	15.96930	0.02937	1296.52657	1.60025
2	14.52621	0.02542	1743.14566	1.01687
3	17.49115	0.04187	957.49740	2.27500
Mean	15.99556	0.03222	1332.38987	1.63071
Standard Deviation	1.48264	0.00859	394.05004	0.62962

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	10.90439	0.04001	15.96930	0.02937
2	13.52621	0.02542	14.52621	0.02542
3	10.93449	0.05145	17.49115	0.04187

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
Mean	11.78836	0.03896	15.99556	0.03222
Standard Deviation	1.505095	0.013047	1.48264	0.00859

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	1.66979	1.07111	1.07111	1916.31634
2	0.88077	0.88077	0.88077	1743.14566
3	2.97336	2.00363	2.00363	2098.93845
Mean	1.84131	1.31850	1.31850	1919.46682
Standard Deviation	1.05679	0.60092	0.60092	177.91732

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	1.17487	1343.60464	696.26396	0.02895

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
2	1.01687	1521.27799	650.970	0.02510
3	1.67487	1930.36869	703.97	0.04102
Mean	1.28887	1598.41711	683.7347	0.03169
Standard Deviation	0.34349	300.89175	28.63543	0.00830

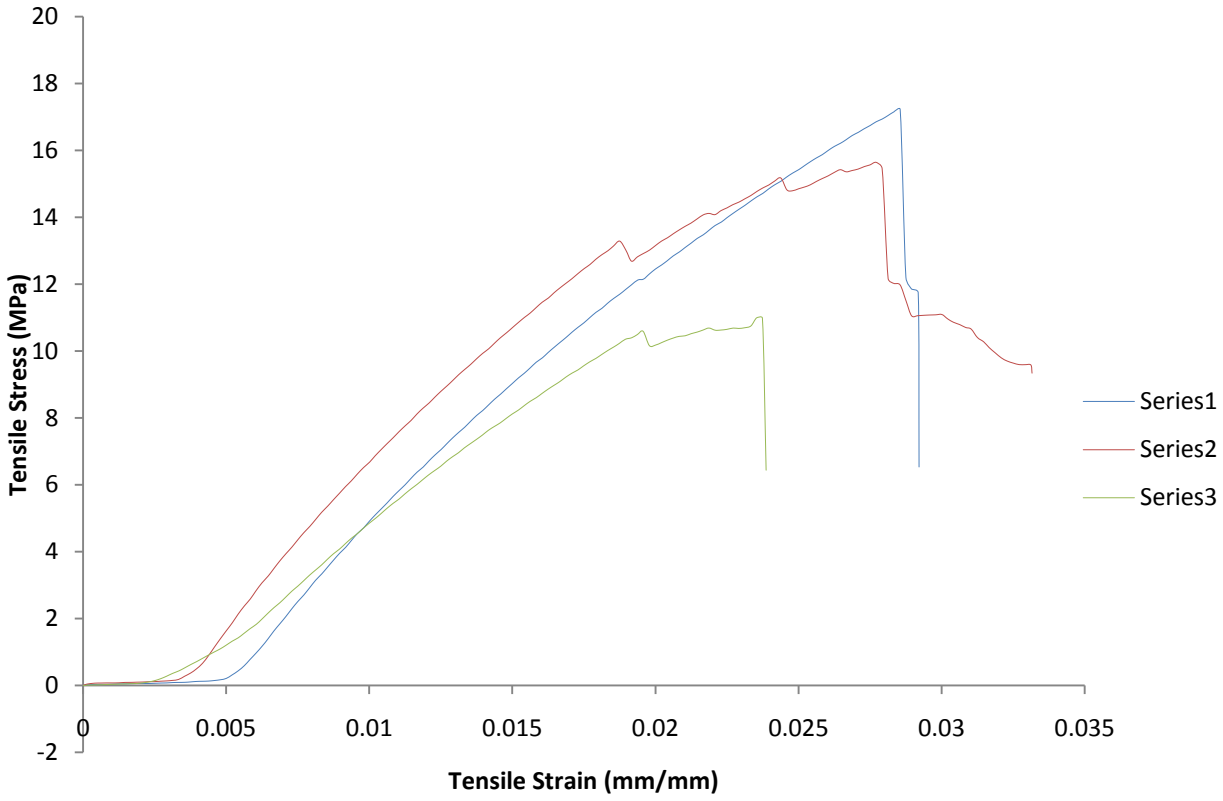
	True stress at Maximum Load (Pa)
1	16438351.12240
2	14895497.35372
3	18223541.06878
Mean	16519129.84830
Standard Deviation	1665491.71246

APPENDIX B-3.

Mechanical Properties of 7:3 Okra:Glasshybridized reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 7:3 Okra:Glasshybridized reinforced Epoxy Composite Material



Stress-Strain Curve for 70:30 Okra-Glass Fiber composite

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	4.00000	40.00000	2067.56908
2	4.00000	40.00000	1877.26747
3	4.00000	40.00000	1295.93294

	Thickness (mm)	Length (mm)	Maximum Load (N)
Mean	4.00000	40.00000	1746.92317
Standard Deviation	0.00000	0.00000	401.99230

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	17.22974	0.02855	1062.85615	1.16706
2	15.64390	0.02771	1124.61289	1.32475
3	10.79944	0.02354	1291.50264	0.94962
Mean	14.55769	0.02660	1159.65723	1.14715
Standard Deviation	3.34994	0.00268	118.28306	0.18835

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	11.75013	0.02918	17.22974	0.02855
2	9.58407	0.03312	15.64390	0.02771

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
3	10.98752	0.02374	10.79944	0.02354
Mean	10.77391	0.02868	14.55769	0.02660
Standard Deviation	0.98569	0.00471	3.34994	0.00268

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	1.14117	1.10471	1.10471	2067.56908
2	1.44121	1.15628	1.15628	1877.26747
3	0.65480	0.64453	0.64453	1295.93294
Mean	1.07906	0.96851	0.96851	1746.92317
Standard Deviation	0.39687	0.28176	0.28176	401.99230

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	1.14194	1754.26845	719.420	0.02815
2	1.10831	1808.56287	721.87319	0.02733
3	0.94169	1215.69177	700.730	0.02327
Mean	1.06398	1592.84103	714.0077	0.02625
Standard Deviation	0.10723	327.74707	11.56409	0.00261

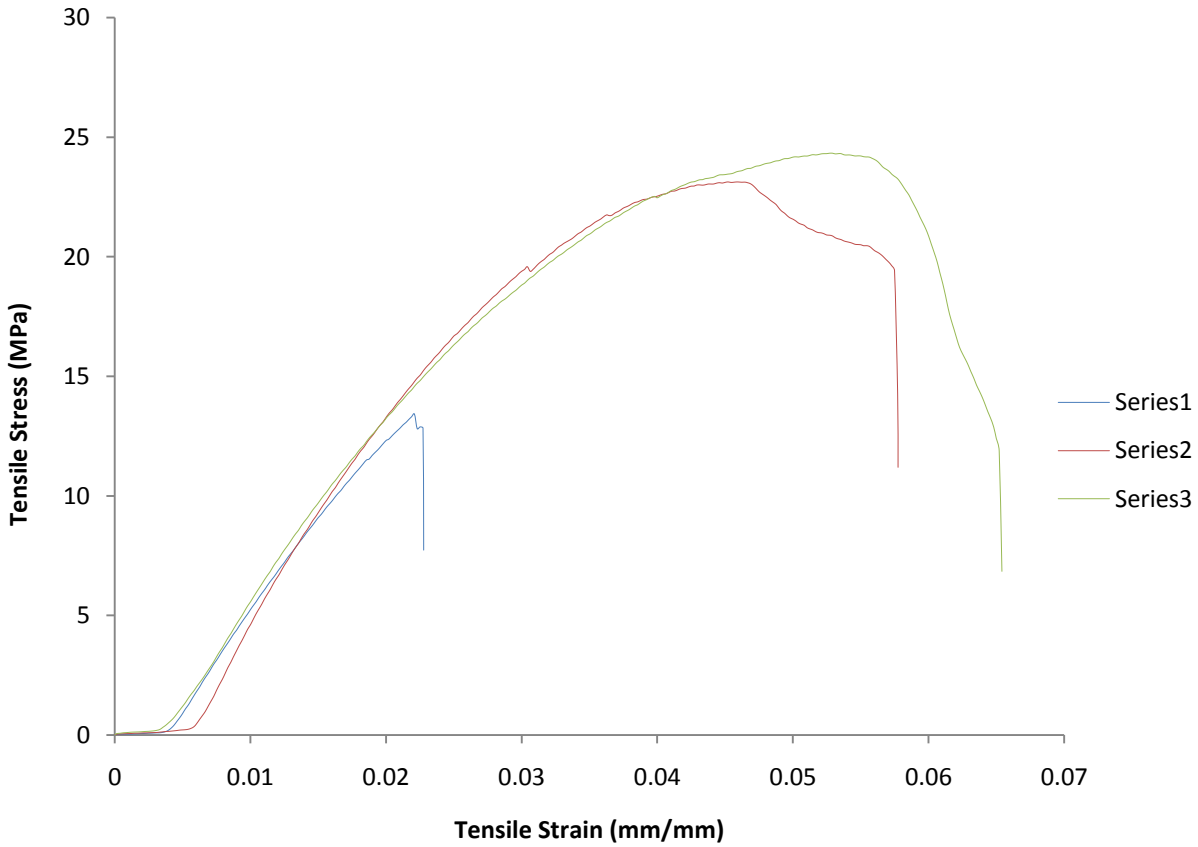
	True stress at Maximum Load (Pa)
1	17721624.51562
2	16077353.64416
3	11053683.61674
Mean	14950887.25884
Standard Deviation	3473766.52147

APPENDIX B-4.

Mechanical Properties of 5:5 Okra:Glasshybridized reinforced Epoxy Composite Material.

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 5:5 Okra:Glasshybridized reinforced Epoxy Composite Material



Stress-Strain Curve for 50:50 Okra-Glass Fibers Composite

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	4.00000	40.00000	1611.03699
2	4.00000	40.00000	2775.64842
3	4.00000	40.00000	2919.98014

	Thickness (mm)	Length (mm)	Maximum Load (N)
Mean	4.00000	40.00000	2435.55518
Standard Deviation	0.00000	0.00000	717.69116

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	13.42531	0.02209	1540.15357	0.90862
2	23.13040	0.04521	1710.93866	2.30875
3	24.33317	0.05292	1425.72820	2.60825
Mean	20.29629	0.04008	1558.94014	1.94187
Standard Deviation	5.98076	0.01604	143.53032	0.90726

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	12.83461	0.02272	-----	-----
2	14.25782	0.05772	23.13040	0.04521

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
3	11.88107	0.06521	24.33317	0.05292
Mean	12.99117	0.04855	23.73179	0.04907
Standard Deviation	1.19609	0.02268	0.85048	0.00545

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	0.67747	0.63885	-----	-----
2	4.15453	2.87383	2.87383	2775.64842
3	4.99369	3.79279	3.79279	2919.98014
Mean	3.27523	2.43516	3.33331	2847.81428
Standard Deviation	2.28852	1.62209	0.64980	102.05794

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	-----	1314.06104	754.560	0.02185
2	1.80844	2579.17102	749.40462	0.04422
3	2.11687	2917.88243	665.87715	0.05157
Mean	1.96266	2270.37150	723.2806	0.03921
Standard Deviation	0.21810	845.32752	49.77962	0.01548

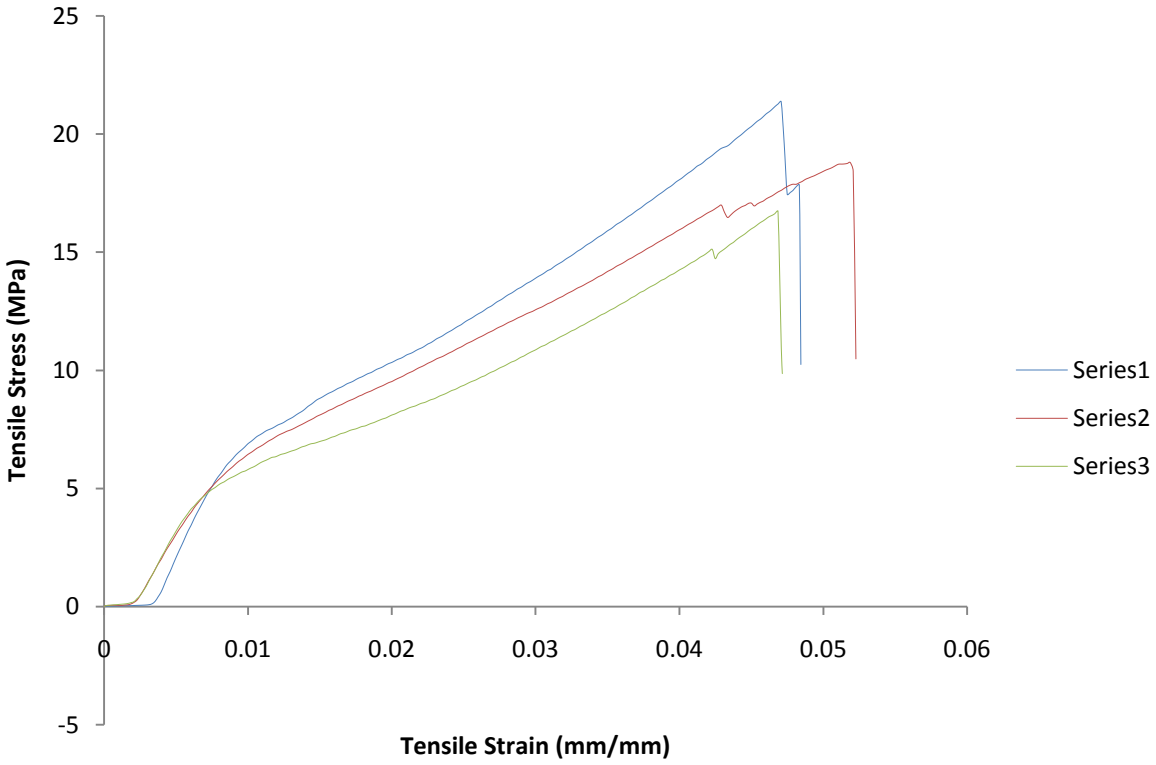
	True stress at Maximum Load (Pa)
1	13721923.64755
2	24176150.59167
3	25620924.40089
Mean	21172999.54670
Standard Deviation	6493130.36071

APPENDIX C-1

Mechanical Properties of 5%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material.

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 5%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material



Stress-Strain Curve for Fiber Treated with 5% concentarated NaOH

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	3.65000	40.00000	2223.01148
2	3.65000	40.00000	1953.87378
3	3.65000	40.00000	1739.52654
Mean	3.65000	40.00000	1972.13727

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	21.36997	0.04708	1856.23262	1.93369
2	18.78273	0.05188	1915.96113	2.08312
3	16.72220	0.04687	1135.98937	1.88387
Mean	18.9583	0.04861	1636.06104	1.96689
	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	17.84410	0.04834	-----	-----
2	18.41828	0.05208	18.78273	0.05188
3	10.92035	0.04710	16.72220	0.04687
Mean	15.72758	0.04917	11.83498	0.032917

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	4.90663	3.21433	-----	-----
2	4.33368	2.36869	2.36869	1953.87378

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
3	2.77563	2.76278	1.76278	1739.52654
Mean	4.00531	2.78193	1.37716	1231.13344

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	-----	2022.42341	761.23220	0.04601
2	2.07537	1825.66680	792.47635	0.05058
3	1.87494	1544.40980	623.78411	0.04581
Mean	1.31677	1797.50000	725.83091	0.04747

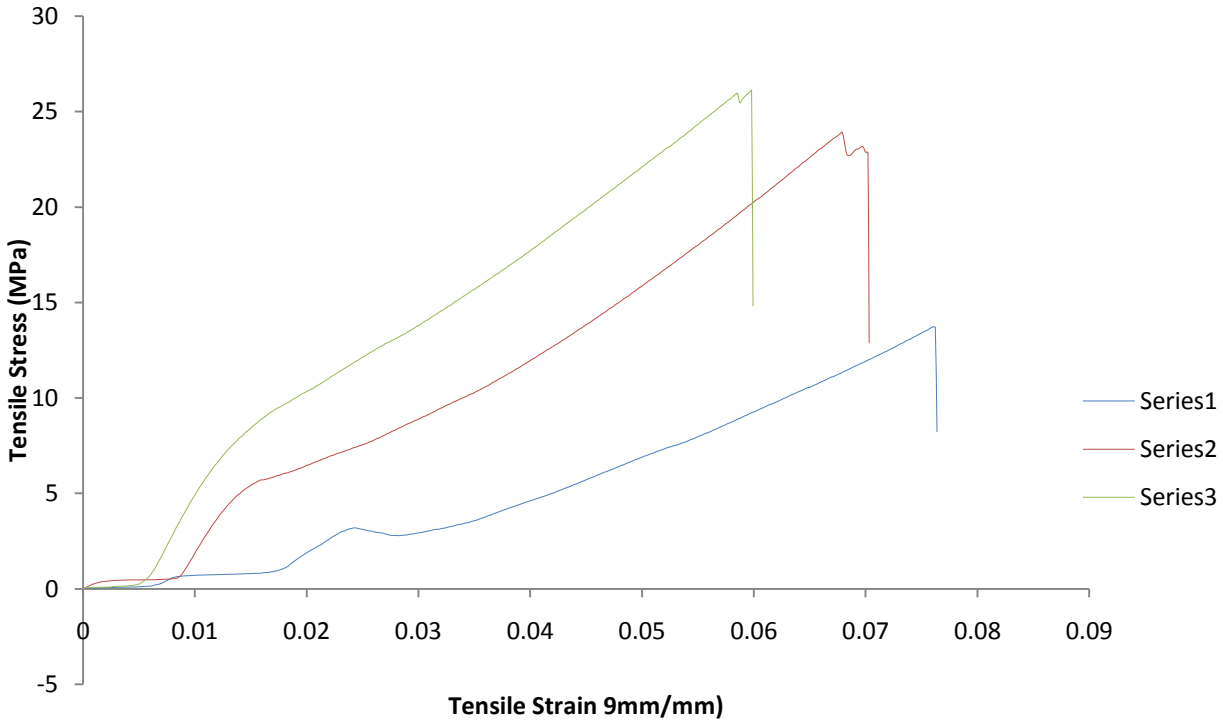
	True stress at Maximum Load (Pa)
1	22376098.30511
2	19757263.02664
3	17506023.74228
Mean	19879795.02468

APPENDIX C-2

Mechanical Properties of 10%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 10%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material



Stress-Strain Curve for Composite made from10% Concentrated NaOH

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	3.65000	40.00000	1427.78670
2	3.65000	40.00000	2487.56055
3	3.65000	40.00000	2716.54520
Mean	3.65000	40.00000	2210.63082
Standard Deviation	0.00000	0.00000	687.56249

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	13.72542	0.07604	1423.78025	3.04969
2	23.91310	0.06792	2377.40837	2.80856
3	26.11435	0.05980	2716.54520	2.39187
Mean	21.25096	0.06792	2172.57794	2.75004
Standard Deviation	6.60959	0.00812	670.28124	0.33279

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	13.68690	0.07624	3.18619	0.02437
2	22.85420	0.07021	23.91310	0.06792
3	26.11435	0.05980	26.11435	0.05980
Mean	20.88515	0.06875	17.73788	0.05070
Standard Deviation	6.44346	0.00832	12.65011	0.02315

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	3.66238	2.65098	0.09674	331.44308
2	5.66981	3.03125	3.03125	2487.56055
3	5.97336	3.36554	3.36554	2716.54520
Mean	5.10185	3.01592	2.16451	1845.18294
Standard Deviation	0.95203	0.90891	1.79853	1315.92734

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	0.97494	1271.27366	824.34233	0.07329
2	2.71669	2350.77478	790.11083	0.06571
3	2.39187	2511.60115	781.77149	0.05808
Mean	2.02783	2044.54986	798.7414	0.06569
Standard Deviation	0.92618	674.48747	22.55968	0.00761

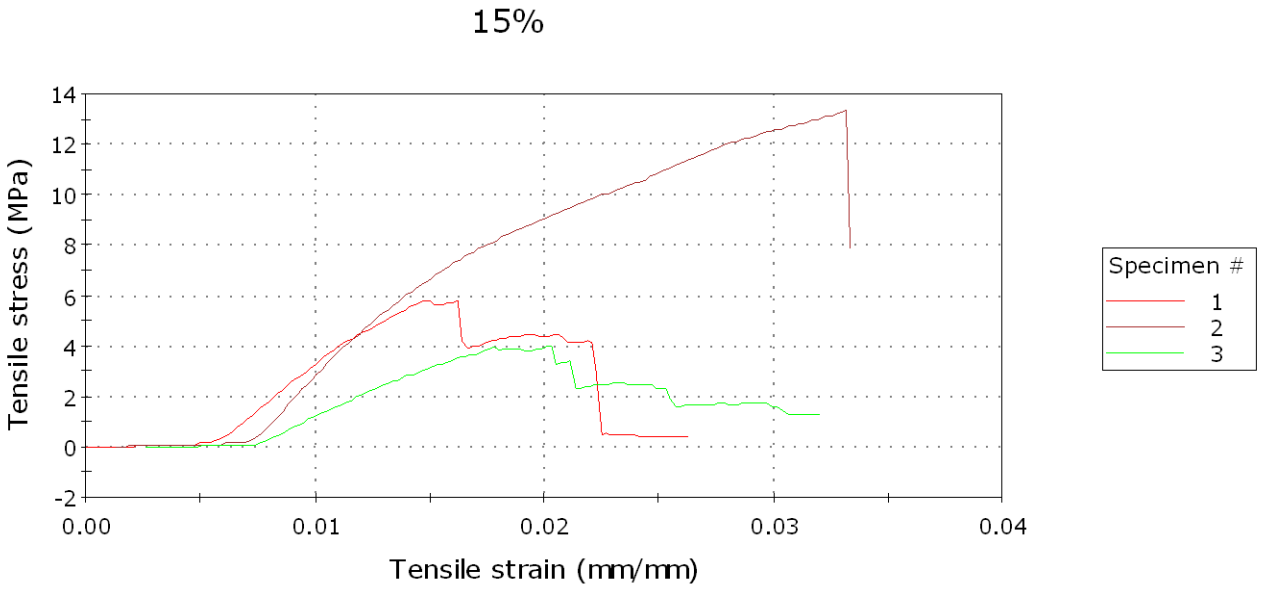
	True stress at Maximum Load (Pa)
1	14769129.64263
2	25537213.40746
3	27675905.67286
Mean	22660749.57432
Standard Deviation	6917495.93503

APPENDIX C-3

Mechanical Properties of 15%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 15%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material



	Thickness (mm)	Length (mm)	Maximum Load (N)
1	3.65000	40.00000	601.61985
2	3.65000	40.00000	1386.32841
3	3.65000	40.00000	414.23622
Mean	3.65000	40.00000	800.72816
Standard Deviation	0.00000	0.00000	515.72657

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	5.78342	0.01479	38.47337	1.04981
2	13.32688	0.03188	1386.32841	1.27531
3	3.98208	0.01771	129.38158	1.17487
Mean	7.69746	0.02146	518.06112	1.16667
Standard Deviation	4.95772	0.00914	753.31411	0.11297

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	10.36985	0.02625	5.78342	0.01479
2	13.32688	0.03188	13.32688	0.03188
3	12.24375	0.02937	3.94399	0.01520
Mean	11.98016	0.02917	7.68476	0.02063
Standard Deviation	1.496034	0.00282	4.97202	0.00975

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	1.27368	0.12401	0.12401	601.61985
2	3.14121	1.90896	0.90896	1386.32841
3	3.44121	2.13507	0.09463	410.27376
Mean	2.61871	1.38934	0.37586	799.40734
Standard Deviation	0.37899	0.45003	0.46190	517.21426

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	0.59162	406.89111	677.16202	0.01468
2	1.27531	1247.93639	745.61249	0.03139
3	0.60812	405.49571	743.90811	0.01756
Mean	0.82502	686.77440	722.2275	0.02121
Standard Deviation	0.39005	485.98104	39.03719	0.00893

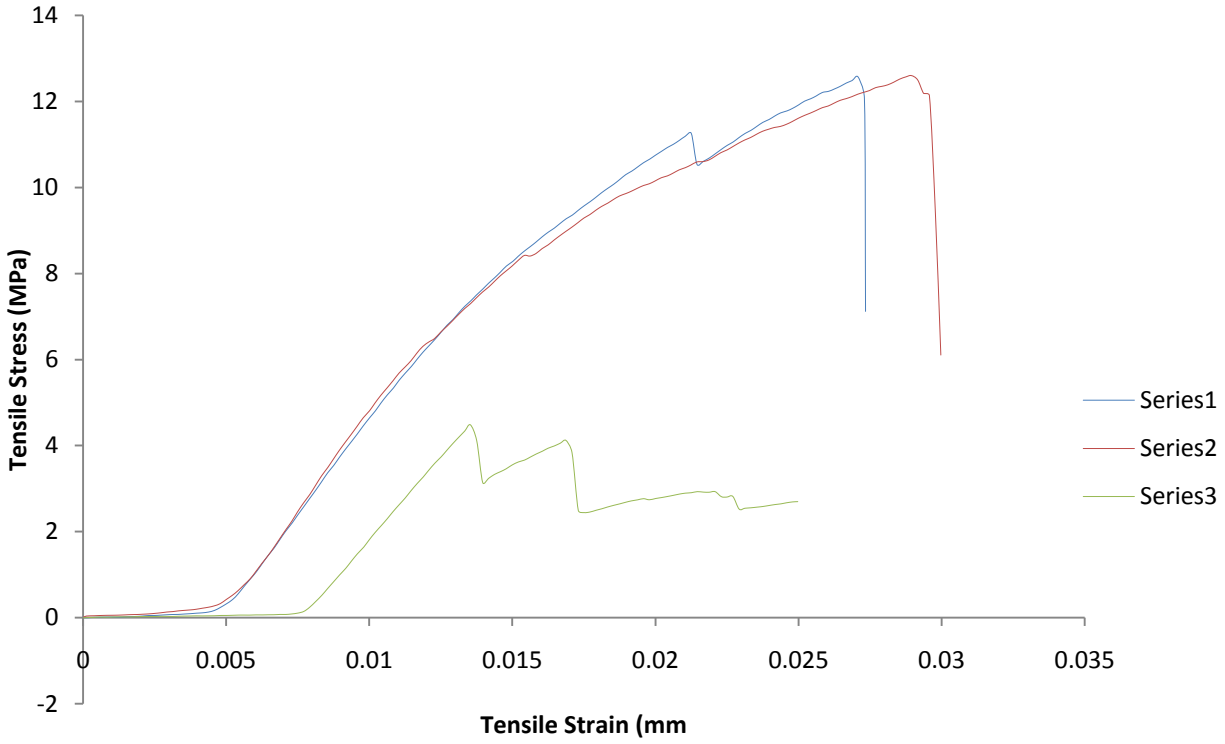
	True stress at Maximum Load (Pa)
1	5868956.38155
2	13751775.57374
3	4052615.95006
Mean	7891115.96845
Standard Deviation	5156090.70882

APPENDIX C-4

Mechanical Properties of 20%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material

Raw Plot obtained from CERD, IFE OSUN STATE.

Tensile test to determine the Mechanical Properties of 20%v/v concentrated NaOH treated Okra:Glass hybridized reinforced Epoxy Composite Material



Stress-Strain Curve for Composite made with 20% Concentated NaOH Treated Fiber

	Thickness (mm)	Length (mm)	Maximum Load (N)
1	3.65000	40.00000	1307.94952
2	3.65000	40.00000	1310.90293
3	3.65000	40.00000	466.23508
Mean	3.65000	40.00000	1028.36251
Standard Deviation	0.00000	0.00000	486.81888

	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (mm/mm)	Load at Break (Standard) (N)	Extension at Break (Standard) (mm)
1	12.57342	0.02708	1256.64715	1.09181
2	12.60181	0.02895	978.10561	1.19169
3	4.48195	0.01353	280.59164	0.99862
Mean	9.88572	0.02319	838.44813	1.09404
Standard Deviation	4.67983	0.00841	502.79146	0.09655

	Tensile stress at Break (Standard) (MPa)	Tensile strain at Break (Standard) (mm/mm)	Tensile stress at Yield (Zero Slope) (MPa)	Tensile strain at Yield (Zero Slope) (mm/mm)
1	12.08024	0.02730	12.57342	0.02708
2	9.40260	0.02979	12.60181	0.02895
3	2.69735	0.02497	-----	-----
Mean	8.06006	0.02735	12.58761	0.02802
Standard Deviation	4.83337	0.00241	0.02008	0.00132

	Energy at Break (Standard) (J)	Energy at Maximum Load (J)	Energy at Yield (Zero Slope) (J)	Load at Yield (Zero Slope) (N)
1	0.73710	0.72604	0.72604	1307.94952
2	0.85196	0.81015	0.81015	1310.90293
3	0.20096	0.05696	-----	-----
Mean	0.59668	0.53105	0.76810	1309.42622
Standard Deviation	0.34748	0.41272	0.05947	2.08838

	Extension at Yield (Zero Slope) (mm)	Load at Tensile Strength (N)	Modulus (E-modulus) (MPa)	True strain at Maximum Load (mm/mm)
1	1.08319	1121.69534	735.16750	0.02672
2	1.15806	1187.88211	751.11605	0.02854
3	-----	421.86189	318.25410	0.01344
Mean	1.12062	910.47978	601.5126	0.02290
Standard Deviation	0.05294	424.44759	245.4386	0.00824

	True stress at Maximum Load (Pa)
1	12913899.30134
2	12966648.50555
3	4542612.58689
Mean	10141053.46460
Standard Deviation	4848463.75829