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Flexural Properties of Sisal Fibre/Epoxy composites

A dissertation submitted by

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ABSTRACT

Nowadays, using natural fibres is becoming a very promising reinforcement for polymeric composites for different applications in mechanical and civil engineering. From research and industrial point of views, there are demands to understanding the potential of using such fibres and their impact on the mechanical properties of the composites. Moreover, exploring the potential of different types of natural fibres is an aim to overcome environmental pollution and degradation issues. Based on the literature, there is still demand on the need to understand natural fibre with polymer matrix for different loading conditions. This motivates the current study on flexural behaviour of sisal fibres reinforced epoxy composites. The composites were fabricated using hand layup techniques considering treated and untreated sisal fibres. 6% of NaOH chemical treatment was used owing to improve the interfacial adhesion of the fibres with the matrix. Three point bending technique was used in this study. SEM (Scanning Electron Microscopy) has been used to study the morphology of the failure surface of the composite after flexural tests.

The result revealed that untreated fibres did not improve the composite’s flexural strength due to a poor interfacial adhesion of the fibre with the matrix, which is consistent with the morphology study, i.e. debonding, detachment, and fibre pull out were observed on the fractured surfaces. However, 6% NaOH treated sisal fibres significantly improved the composite’s flexural strength and modulus by about 76% and 162%, respectively compared to pure epoxy. Morphology study on flexural fracture surfaces of treated sisal fibre composite showed the bonding between epoxy matrix and treated sisal fibre has much improved with the aid of the 6% NaOH. Also, epoxy resin penetrated into core of the treated sisal fibres which in turn assisted to interlock the fibre in the bulk of the composites (high interfacial adhesion) resulting in the high performance of treated sisal fibre/epoxy composite’s flexural properties compared to the untreated fibres.

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own work and effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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TABLE OF CONTENTS

ABSTRACT 2

DISCLAIMER 3

CERTIFICATION 4

ACKNOWLEDGEMENTS 5

CHAPTER 1 11

INTRODUCTION

1.1 INTRODUCTION 11

1.2 OBJECTIVES 12

1.3 REPORT ORGANISATION 12

CHAPTER 2 14

LITERATURE REVIEW 14

2.1 INTRODUCTION 14

2.2 POLYMERS AND ITS TYPE 15

- 2.2.1 Thermoplastic 16
- 2.2.2 Thermosets 18

2.3 POLYMER COMPOSITES 18

2.3.1 Fibre Polymer Composites........19

2.3.2 Synthetic Fibre Reinforced Polymer Composites........20

2.4 NATURAL FIBRES........21

Effect and Comparison of Fibre Reinforced Synthetic Fibre and Natural Fibre........22

2.4.1 Natural Fibre Reinforced Polymer Composites........23

2.5 MECHANICAL PROPERTIES OF FIBRE POLYMER COMPOSITES........28

2.6 FLEXURAL PROPERTIES OF FIBRE POLYMER COMPOSITES........33

2.7 RECENT ISSUES AND RECOMMENDATIONS........34

CHAPTER 3........35

METHODOLOGY........35

3.1 MATERIAL SELECTION........35

3.1.1 Sisal Fibre........35

3.1.2 NaOH treatment........37

3.1.3 EPOXY RESIN........39

3.2 COMPOSITE FABRICATION........39

3.3 EXPERIMENTAL PROCEDURE AND SETUPS........40

CHAPTER 4........42

RESULTS AND DISCUSSION........42

4.1 INTRODUCTION........42

4.2 FLEXURAL BEHAVIOUR OF SISAL FIBRES/EPOXY........43

4.2.1 Pure Epoxy........43

4.2.2 Untreated sisal fibre/epoxy 44
4.2.3 Treated sisal fibre/epoxy...45
4.2.4 Effect of treated and untreated fibres on epoxy composites 46
4.3 FRACTURE OBSERVATION..48
4.3.1 Morphology study on cross sections of sisal fibre composite’s flexural breakage after testing 48
4.4 COMPARISON WITH THE PREVIOUS WORKS 53
CHAPTER 5 56

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION 56
5.2 RECOMMENDATIONS 57
REFERENCES...58
Appendix 65

LIST OF TABLES

Tab.2.1: Synthetic Fibre compare with Natural Fibre (Oksman, Skrifvars & Selin 2003) ………………………………………………………………………………. 22

Tab.4.1: Comparison with previous works on flexural properties of natural fibre composites ……………………………………………………………………….. 55

LIST OF FIGUERS

Fig. 1.1 LAYOUT OF THE THESIS…………………………………………… 12

Fig.2. 1 Structure of Polypropylene (Pascault et al. 2002) …………………………14

Fig.2. 2 Structure of PE (McCrum, Buckley & Bucknall 1997)………………….....15

Fig.2. 4 Structure of Polystyrene (Ebnesajjad 2012)……………………………16

Fig.2. 3 Structure of PVC (Eyerer 2010)……………………………………....16

Fig.3. 1 Raw sisal fibres photo ………………………………………………. 34

Fig.3. 2SEM micrographs of untreated Sisal Fibre………………………………... 35

Fig.3. 3 Sisal fibre soaked in 6% NaOH solution ………………………………. 36

Fig.3. 4 SEM micrographs of treated Sisal Fibre……………………………….. 37

Fig.3. 5 Sisal fibre/Epoxy composite specimen fabrication process……………… 39

Fig.3. 6 Drawing of the flexural test ASTM D790-07…………………………….. 39

Fig.3. 7 Specimen under flexural testing ……………………………………….. 40

Fig.3. 8 SEM and sample gold coating………………………………………….. 40

Fig.4. 1 Stress-Deflection curve of Pure epoxy ………………………………….45

Fig.4. 2 Stress-Deflection curve of Untreated sisal fibre composite………………..46

Fig.4. 3 Stress-Deflection curve of Treated sisal fibre composite…………………. 47

Fig.4. 4 Flexural strength comparison between three systems…………………….. 48

Fig.4. 5 Flexural modulus comparison between three systems……………………. 49

Fig.4. 6 Pure epoxy cross-section morphology after flexural breakage…………… 51

Fig.4. 7 Cross section morphology of Untreated sisal fibre composite……………. 52

Fig.4. 8 Cross section morphology of Treated sisal fibre composite ……………... 54

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

Natural fibres received more attention to be used in composite structure in recent years. Comparing to synthetic fibres, natural fibres have some advantages such as low cost, low weight, renewable resources, etc. The natural fibres composites can be used in automobile and construction industry due to their relatively high specific strength/modulus. Natural fibres such as flax fibres have density about 1.5g/cm^3 and cost between \$0.22~\$1.1/kg. In comparison, synthetic fibre such glass fibre's density is about 2.6 g/cm^3 and cost between \$1.30~\$2.00/kg, (Scarponi & Andreotti 2009) . So it is very attractive for industry to use natural fibres to replace synthetic fibres. According to literature, Mercedes-Benz used epoxy/jute fibre composite to manufacture door panels in its E-class vehicles, (Kavelin 2005). Toyota used kenaf fibres to reinforce PLA matrix, making parts for its vehicles. Many researchers have done their work on natural fibres composites and their applications. However, most of their works are done on jute fibres, hemp fibres, bamboo fibres …etc (Faruk et al. 2014). On the other hand, there is one more attractive fibre which is sisal fibre and need attention in term of its impact on the flexural properties of polymer composites, i.e. it has less understanding in the literature.

This project intends to study sisal fibre/epoxy composite's flexural properties. Sisal is a natural product with long natural fibre inside and relatively low density, so the sisal fibre's mechanical property is better than many other natural fibres. In this research, sisal fibres will be modified by some NaOH solution to improve its surficial stress, making it a better cohesion with polymers. Then a sisal fibre/epoxy composite will be manufactured using pressure molding process. The flexural property, one of the most important mechanical properties of composites, of sisal fibre/epoxy composite will be studied and comparison between treated and untreated sisal fibres will be performed. Also the morphology of sisal fibre's interaction inside the composite structure will be studied using a scanning electron microscope (SEM) methodology.

1.2OBJECTIVES

The main goal of this study is to explore the potential of using sisal fibres as reinforcement for epoxy composites. Specifically, the project covers the followings

- To prepare sisal fibres to be used as reinforcement for epoxy composites and prepare the sisal fibre reinforce epoxy composites. The influence of the fibres on the flexural properties of the epoxy will be investigated
- Study the influence of the NaOH chemical treatment to the sisal fibres microstructure and its impact on the composites properties.
- To study the possibility of replacing the glass fibre with sisal fibres in term of flexural properties.
- To categorize the damage features on the fractured samples using scanning electron microscopy

1.3 REPORT ORGANISATION

This report focuses on flexural properties of sisal fibre/epoxy composites, including both theoretical background, experimental design, and results discussion, Fig. 1.1. Chapter 1: Introduces the background of natural fibre composite materials and this project’s objectives. Chapter 2: Reviewed all relevant research papers regarding natural fibre composite materials, ranging from polymer types, fibre types, and composite’s chemical, mechanical properties. Recent researches on sisal, bamboo fibre reinforcement on polymers are widely and deeply reviewed. Chapter 3: Designs the experimental plan for investigation of flexural properties of sisal fibre/epoxy composites. Chapter4: Characterization on composite material and results discussion also included Comparison with previous works on flexural properties of natural fibre composites .Chapter5: Is the conclusion of this thesis report.

LAYOUT OF THE THESIS

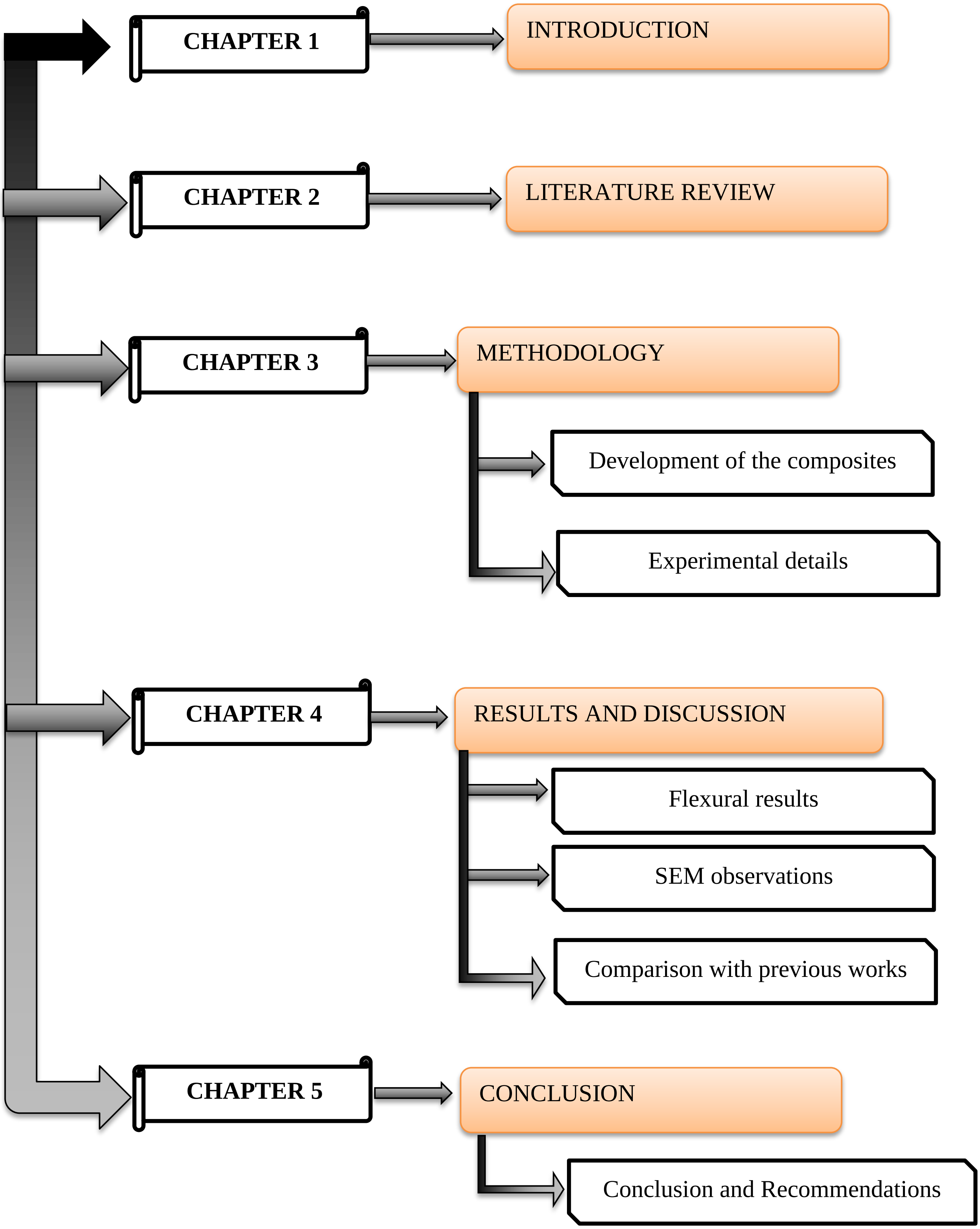


Fig.1.1 Layout of The Thesis

CHAPTER 2
LITERATURE REVIEW

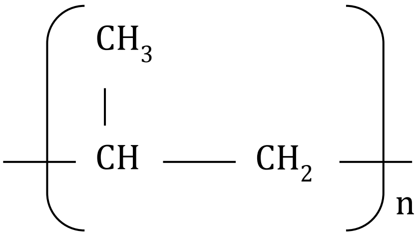
2.1 INTRODUCTION

This chapter presents the literature review on the polymer and its composites. In this chapter, different reported works on the polymer and its flexural properties are given. The introduction to the fibre polymer composites is addressed. The potential of using natural fibres in polymer composites is covered as well. The related issues and initial project motivation is drawn. There are a number of uses of polymer composition reinforced with fibre and widely used as the polymeric compositions with synthetic fibre because it comprises of finer mechanical properties like higher potency and resilient; and is utilised in tanks, sports' goods, pipes, construction of bridges, boat hulls, automotive industry and aircraft secondary structure such as leading gear doors and elevator rudders because the fibre utilised is mainly of synthetic fibre very common, durable and eminent throughout the world including carbon fibre and glass fibre (Avci, Arikan & Akdemir 2004).

Apart from its positive aspects, synthetic fibre has certain limitations like it causes health problems, serves to be as non-renewable and non-biodegradable and most importantly it has abrasion on processing equipment where all these factors are not suitable for a better environment while in contrast with the natural fibre as the natural fibre is renewable and biodegradable along with being eminent for its smoothness and harmless nature. People are now focussed on utilising natural fibre as it is cheaper than synthetic fibre and proves to be accessible in low weight and low density. For instance, European car industry is utilising natural fibre amalgamated with thermoplastics and thermosets in the manufacturing of headliners, seat backs, and door panels (Cheung et al. 2009).

2.2 POLYMERS AND ITS TYPE

(Odian 2004) has described polymers as large molecule having numerous frequent subdivisions. Synthetic polymers and natural polymers are the major types of the polymers. Human life is very evident with both types of polymers, e.g., a human fabricated polymer, polyethylene (PE) is used in the supermarket shopping bag, the NR (natural rubber) is being used in the tyres of our cars and the NR is believed to be a natural product produced from the rubber tree (Carraher Jr 2012). Before the development of polymer science and engineering around 1900s, many kinds of polymer materials were existed, such as: Natural polymers which cover: amber, shellac, wool, silk, and cellulose. Whereas Synthetic polymers cover: Phenol formaldehyde resin, Synthetic rubber, Nylon, Neoprene, chloride, Polyvinyl , Polyethylene, Polystyrene, Polypropylene, Epoxy resin, and Polyacrylonitrile (Faruk et al. 2012). There is an organic procedure known as "polymerization" that is conducted on several monomers in order to obtain the polymers. A few chemical groups can be lost from each monomer during the polymerization process, for instance, the PP (polypropylene) is composed of the reiterated elements as demonstrated in the below Fig. 2.1:



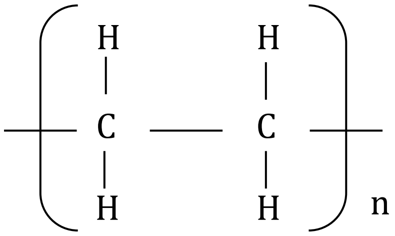
$$-\left(\begin{array}{l} CH_3 \\ | \\ CH - CH_2 \end{array}\right)_n-$$

Fig.2. 1 Structure of Polypropylene (Pascault et al. 2002)

The alphabet "n" is known as the "degree of polymerization" and it basically shows the number of units accumulated and reiterated. Because of their chemical and mechanical attributes, the polymers have large scale applications in the industry like flexural / tensile / impact attributes. Moreover, thermoplastic and thermosets are considered to be the two groups in which polymer can be separated which are the most frequent category (Pascault et al. 2002) . There is another type of polymers, known as elastomers which is not as prominent as others and its usage is also restrained. The polymer is divided into two different categories and its application is mentioned below (Brandrup et al. (1999).

2.2.1 Thermoplastic

The thermoplastic is a type of polymer which has the potential to stream upon heating at certain temperatures and reshapes itself to solid state upon cooling. Because of its exclusive attribute, it is considered to be a reprocess material one (Brydson 1999). Thermoplastics have the ability to be reshaped since the polymer chains connected by intermolecular relations are likely to be increased when they are cooled and the majority of the attributes get re-established. The thermoplastics have different qualities than thermosets, by which chemical bonds are developed during the remedial procedure (Bhowmick & Stephens 2000). Given below is a brief introduction of majority of the industrial applied thermoplastic polymers: The first commercially developed polymer with basic composition is known as the PE (Polyethene). The ethene is assumed to be its compound and the fig 2.2 will illustrate the configuration of polyethene. Polyethylene has a desirable friction and mostly its applications are observed in packaging industry, such as plastic bag, geomembranes, bottle containers and plastic film etc(McCrum, Buckley & Bucknall 1997).



$$\left[-CH_2-CH_2- \right]_n$$

Fig.2. 2 Structure of PE (McCrum, Buckley & Bucknall 1997).

The PP(Polypropylene) has identical nature as that of polyethene, the presence of the CH3 sub-group in the sub-chain is the only variance. Fig.2.1 has already illustrated the composition of the PP. The PP(Polypropylene) has the ability to be used in recyclable piping system, diaper lining, plastic food containers, carpets, ropes, plastic moulding along with sanity pad lining and casing etc. Following the polypropylene and polyethylene, the PVC(Polyvinyl chloride) is the third generally used polymer. Its arrangement is demonstrate in fig.2.3, with a chlorine atom alternate hydrogen atom as compared to polyethene.

Features of the PVC are hard, acid-resistant and lightweight. The construction industry is evident of its application, like, drainpipes, vinyl siding, roofing sheets and gutters. It can also be changed into elastic shapes and being used as tubing, hoses, coats, electrical insulation, upholstery and jackets after added plasticizers(Eyerer 2010). The PS(Polystyrene) is a fabricated aromatic polymer produced from the styrene compound, which is a liquid petrochemical. Fig. 2.4 will demonstrate its composition. Polystyrene is normally tough, clear and brittle. Its application are broadly observed in protective packaging (such as DVD and CD cases), lids, containers and bottles, etc (Ebnesajjad 2012) .

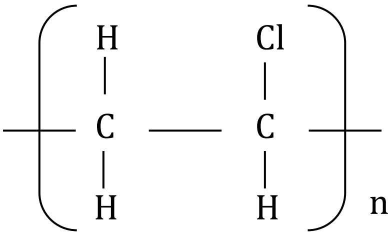


Fig.2. 3 Structure of PVC (Eyerer 2010).

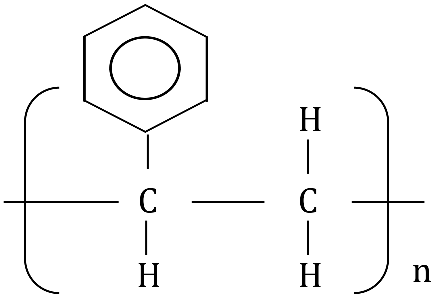


Fig.2. 4 Structure of Polystyrene (Ebnesajjad 2012).

2.2.2 Thermosets

They are described as a polymer that transforms conclusively into an insoluble network structure through remedial measures and develops into a soft solid position. Heating or a suitable radiation is likely to prompt the curing. A cross-linking structure will eventually be emerged through the curing procedure, by which the resin is transformed into rubber or plastic. Because, the thermosets are having 3D cross-link configuration, so they are normally robust than thermoplastics, and are desirable for high-temperature applications. But, their heavy brittleness than thermoplastics is one of the problems. Epoxy resin and unsaturated polyester are extensively used materials among all the thermosets materials (Rudin & Choi 2012).

- **Unsaturated Polyester (Abbreviation: UP)**

When dibasic organic acids are reacted with polyhydric alcohols, we obtain the unsaturated polyester resins, which are applied in bulk moulding compound, sheet moulding compound and in the toner of laser printers (Forrest 2007).

- **Epoxy Resin (Abbreviation: EP)**

The epoxide functional group is enclosed in the epoxy that is a preserved thermoset resin. Before use, the hardener (which cures epoxy resin) and epoxy resin are usually blended together.

Many industries observe the use of Epoxy, e.g., structural adhesives electronic and electrical components, metal coatings, fibre-reinforced plastic materials and high tension electrical insulators (Nassar & Nassar 2013).

2.3 POLYMER COMPOSITES

Two or more primary materials are combined together to produce composite material, which are having different attributes regarding chemical or physical nature, that upon combination deliver a material with features different from the specific constituents (Jones 1998). One of the categories of composite materials is polymer composites, in which there is at least one of the polymer components. The organic or inorganic fillers, other polymers like elastomers and plastics, or several fibres (synthetic or natural) can be among the other components.

Typically, the fibres or fillers are viewed as reinforcements and the polymers in composites are being used as matrices. However, coarse fillers are non-strengthening and simply associated to disclose certain performance like better combustion resistance or to devalue the polymer in some scenarios. The mechanical / physical actions of polymers are enriched by integrating the fibres, being used as reinforcements, performance of polymers are strength, modulus, and thermal expansion and creep resistance. The extrusion procedures and traditional moulding are applied to fabricate the polymer. In the meantime, refined compound materials can be constructed through some other methods such as Autoclave moulding, RTM (Resin Transfer Moulding), and vacuum bagging moulding (Saheb, D. N. & Jog, J. 1999).

2.3.1 Fibre Polymer Composites

The FRP (Fibre Reinforced Polymer) or Fibre polymer composites, is a composite material prepared with a polymer matrix strengthened with fibres and it is widely used in industry. The fibres are commonly simulated ones like carbon, glass, natural fibres or aramid fibres like sisal, hemp, bamboo and jute etc. While the polymer matrices are normally the thermosets plastics for instance, vinyl-ester, epoxy or unsaturated polyester. The automotive, aerospace, construction and marine industries commonly observe the application of the FRP.

The substantial and automated characteristics of mostly utilized profitable boosting fibres are displayed in below. Also determines the high quality of tensile modulus that is found in carbon and boron fibres. Whereas, the figures are as follows

1. Carbon fibre: 231 GPA
2. Boron fibre: 393 GPA (better than glass fibres - 72.4 GPA)
3. Aramid fibres (131 GPA).

On the basis of excessive tensile modulus, fibres can essentially enhance the mechanical features of entire compound FRP for instance tensile power and modulus. According to (Mallick 1993) it is significant to disseminate the orientation directions of fibres properly while crafting the framework of an FRP. However, in the orientation direction, fibres display amazing presentation, but the performance of fibres becomes much lesser in the upright position. A number of factors are present for fibre to be utilised so extensively throughout the world as the fibre reinforced in Polymer composition has the potential to amplify the mechanical properties inclusive of fracture toughness and tensile strength of the composition while contrasting the fibre and the polymer (Cheung et al. 2009).

There are two kinds of fibres available i.e. natural fibre and synthetic fibre. Natural fibre, being non-toxic and harmless, is composed of vegetables, minerals and animals where vegetables utilised for this purpose are: bamboo, hemp, sugarcane bagses, flax, curana, and banana while the animals' components include wool, skin, and hair. The minerals like ceramic and asbestos are required for manufacturing natural fibre. The second form, synthetic fibre is manufactured by men while it is a combination of glass fibre, carbon fibre, and aramid (John, Gangadhar & Shah 2001). There is a huge market and demand for the fibre reinforced polymeric composition specifically for the synthetic fibre as it is utilised in making pipes, in tanks, sports' goods, and construction of bridges, boat hulls, automotive industry and aircraft secondary structure while thermo set matrices and thermoplastic require natural fibre(Powell 1994).

2.3.2 Synthetic Fibre Reinforced Polymer Composites

Nylon fibre, Polyolefin fibre, Carbon fibre, Glass fibres etc, all these fibres is known to be the profitable manufactured goods. These products are mostly utilized on the basis of their excessive automated features like high tensile power and modulus; they are used with thermoplastics and thermosets polymer in order to construct good quality compounds in diversified corporations. While, artificial fibres are made from artificial substances like petrochemicals (Crawford 1998).

In 2014, the curvature power of epoxy resin hybrid was studied by Dong and Davies; they reinforced it by S-2 glass and T700S carbon fibres. The findings of the study determined that on the whole the utmost flexural hybrid effect can be attained when the ratio of hybrid is 0.25, the power increases are 16.6% if it is contrasted with full carbon configuration while the increases are 42.58% if it is compared with glass configuration. In general the highest tensile hybrid effect is pulled off with the hybrid ratio of 0.125 (Dong & Davies 2014). In 2013, Ozger et al utilized nylon fibres to reinforce concrete and evaluated the automated and thermal characteristics of this fibre. The results of the study showed that nylon concrete, which tends to be fibre-reinforced was to some extent more flexible and solid as compared to the simple concrete since the fibres have a vital part after failure (Ozger et al. 2013).

The properties of different artificial fibres plus the effect of fibre-reinforced concrete are studied here. Likewise, the current paper evaluates the ongoing research regarding the quality and presentation of artificial fibre-reinforced concrete on the basis of polyethylene (PE), polypropylene (PP), acrylics (PAN), poly (vinyl alcohol) (PVA), polyamides (PA), aramid, polyester (PES) and carbon reinforcements, all these tends to be capable for the production of cementations compound substances (Zheng & Feldman 1995). Meanwhile, the increasing interest in the consumption of fibre-reinforced concrete in the manufacturing corporation tries to shed light on the significance of its performance.

2.4 NATURAL FIBRES

Natural fibres tend to be the strengthening fibres that are produced from plant, animal and mineral sources. Natural fibres have good characteristics in particular, if contrasted with artificial fibres like glass fibre, because natural fibres have low concreteness(Pickering 2008). Natural fibres are biodegradable, which becomes a significant benefit and thus the compounds of natural fibres can be reprocessed as compared to artificial fibres. In the recent times, the concern for eco-friendly environment has raised which also increases the demands of green and biodegradable substances. While, in this regards a vital role can be played by natural fibres (John & Thomas 2008). However, Plant fibres are composed of cellulose and it includes bast fibres, leaf or hard fibres, seed, fruit, wood, cereal straw, and other grass fibres. On the contrary, animal fibres consist of proteins such as hair, silk, and wool(Mohanty, Misra & Drzal 2005).Along with the benefits natural fibres also contain negative aspects for instance bad connections with the hydrophobic polymer, the propensity to structure cumulative and poor resistance to humidity. Thus, before utilizing a natural fibre to reinforce polymers, it should be processed chemically.

Effect and Comparison of Fibre Reinforced Synthetic Fibre and Natural Fibre

The materials made from the composition of synthetic polymer are widely identified on a larger scale due to its heavy potency and modulus, long-lasting feature as compared to other materials like alloys and steels (Saiter et al. 2013). Apart from its positive aspects, synthetic fibre has certain limitations like it causes health problems, serves to be as non-renewable and non-biodegradable and most importantly it has abrasion on processing equipment where all these factors are not suitable for a better environment but as they have been extensively used now they are bearing disposal problems while in contrast with the natural fibre as the natural fibre is renewable and biodegradable along with being eminent for its smoothness and harmless nature(Middleton & Tipton 2000).

On the other hand, the utilisation of natural fibre harms the environment and ozone layer to a great extent and for such reasons; European Union has passed laws for diminishing the use of such detrimental materials, forthcoming a heavy effort required for discovering the components related to natural resources to benefit the environment. People are now focussed on utilising natural fibre as it is cheaper than synthetic fibre and proves to be accessible in low weight and low density, ecological, stiffness, flexibility in usage and modulus, impact resistance, vibration damping and cause less skin irritation(Jain, Kumar & Jindal 1992). The merits of natural fibre are summarized below in the table.

Tab.2. 2 : Synthetic Fibre compare with Natural Fibre (Oksman, Skrifvars & Selin 2003)

Synthetic Fibre	**Natural Fibre**
• Health problems • Non renewable • Disposal problem • Abrasion on processing equipment • Non biodegradable	• Biodegradable • Combustibility • Non-abrasivity • Non toxicity • Renewable • Flexibility in usage • Less skin irritation • Lower cost • Lower density

2.4.1 Natural Fibre Reinforced Polymer Composites

In accordance to the branch of polymer science, natural fibre reinforced compounds tends to be a promising field. Such natural fibres have low concreteness, high particular characteristics, cheap in terms of cost, recyclable and non-abrasive. The compounds made of natural fibres comprise particular features as compared to the compounds made of conventional fibres. Conversely, the fibres become incompatible during the production of these compounds and their resistance to humidity also decreases the capability of natural fibres, thus all these disadvantages lead to a serious problem. This analysis shows the detailed study on natural fibre reinforced composites, specifically referring to the classification of fibres, matrix polymers, treatment of fibres and fibre-matrix interface (Saheb, D. N. & Jog, J. P. 1999).

The automated characteristics of widely consumed natural fibres are tensile power, Young’s modulus, the extension rate of break and thickness. While, the kenaf comprises the highest tensile power (930 MPa) and the young’s modulus of hemp has the power of (70 GPa). In 2014, El-Sabbagh utilized three natural fibres namely flax, hemp, and sisal in order to strengthen thermoplastic matrix Polypropylene and also analysed the effect of pairing agent Maleic anhydride grafted polypropylene (MAPP). The findings of the study show that for various sources of the MAPP and natural fibre type, most favourable MAPP to fibre ratio in the average ranges between 10% to 13.3% in accordance with the examined characteristics i.e. firmness, power and effect (El-Sabbagh 2014).

Sisal fibre is extracted from the leaves of sisal (Agave sisalana), which is widely grown in Tanzania, Brazil and other tropical countries with an annual yield of 4.5 million tons. Sisal fibres are composed of three main constituents: cellulose, hemicellulose, and lignin. Cellulose is the most part constituent but its portion varies in different areas. The physical properties of sisal fibre are its density range from 1400~1450 kg/m3, and fibre diameters from 100~300 μm. Its tensile strength ranges from 400~700 MPa, with the tensile modulus from 7~22 GPa. In order to used sisal fibre to reinforce polymers, the modification on it is necessary. The common used methods included Benzol/alcohol, Alkali, Acetylated, Silane, Thermal and combined treatments. Those treatment methods will improve sisal fibre's interfacial bond with polymers and have a good effect on reinforcing those polymer matrices.

Research reported that epoxy resin's mechanical properties are improved through reinforced by treated sisal fibres, with an increase of compressive strength of 120 MPa to 184.8 MPa (Silane treatment), and flexural strength from 95 MPa to 262.1 MPa (Mercerised treatment), and flexural modulus from 3.1 GPa to 17.63 GPa (Mercerised treatment). Sisal fibres are also able to reinforce thermoplastic such as polyethylene and polypropylene, and rubber as well. Sisal fibre can be used to combine with glass fibre together for a hybrid reinforcement to matrix, to take advantage of their distinct fibre properties, and it is been proved to be positive hybrid effects on sisal/glass fibre hybrid composites (Li, Mai & Ye 2000).

Ahmed Belaadi et al. tested the tensile and fatigue properties of sisal fibres from Algeria, with approximately 250μm of diameter and 0.8-1 m of length. Over 15 samples were measured and it is found higher maximum force (9N~22N) than previous figures in open literature. The S-N curves results received from the fatigue testing can be used to predict a fatigue and structural integrity behavior of sisal reinforced polymer composites, and involve this natural fibre composite into design envelope(Belaadi et al. 2013). Ahmed Belaadi et al. investigated over 40 sisal fibres samples on their mechanical properties statistical model versus fibre diameters. A Weibull distribution statistics were estimated on their tensile strength and modulus results in comparing with experimental data. At the gauge length 20 mm, high tensile strength / modulus were obtained at the finest fibre diameters around 140 microns. In addition, FTIR and DSC results revealed its structure of cellulose, lignin, and hemicellulose components respectively (Belaadi, Ahmed et al. 2014).

Flavio de Andrade Silva et al. tested sisal fibre’s tensile properties using four different gage lengths (10, 20, 30, 40 mm). The sisal fibre’s cross-section area is measured in the Scanning Electron Microscope (SEM) images. The results showed that the tensile strength was irrelevant to the gage length, and the tensile modulus after correction from machine compliance, was around 18 GPa and not impacted by the gage length. The fracture mode through SEM images was found to be resulted in delamination between primary and tertiary wall, and between fibre-cells (Silva, Chawla & Filho 2008).

Adriana R. Martin et al. analyzed raw and defatted sisal fibre’s thermal properties through TG and DSC analysis. The DSC curves showed in inert atmosphere, the sisal fibre and its constituents have different peaks, but in air atmosphere there are two exothermic peaks for all constituents (cellulose, hemicellulose and lignin). TGA results showed cellulose and hemicellulose degraded at lower temperatures than sisal fibre, due to lignin’s removal. The thermal degradation of sisal fibre and its constituents is similar to other natural fibres such as jute and hemp (Martin et al. 2010).

Feng Zhou et al. used silane coupling agents to modify sisal fibre and investigated the chemical reaction between sisal fibre and silane. Through SEM, FTIR, TG, DSC, TG/MS, it is found there is a layer composed of siloxane and polysiloxane on the sisal fibre surface. Chemical bonds were formed between sisal fibre and silane agent. Those results indicate that silane changed sisal fibre's surface topography, chemical structure, and result in a better cohesion, which could be used to design new types of sisal-fibre reinforced polymer composites(Zhou, Cheng & Jiang 2014).

A.C.H. Barreto et al. modified sisal fibres using alkali solution NaOH at 5% and 10% concentration and bleached with sodium hyplochlorite $NaClO/H_2O$ (1:1) at 60-75 degrees, and then combined with phenolic matrix derived from cashew nut shell liquid (CNSL) to make the biocomposites. It is found the alkali chemical treatment increased the crystalline fraction and improved the thermal stability of sisal fibres comparing to raw state. Meanwhile, the morphological study through SEM found that this chemical treatment exposed the cellulose inside fibre and increased the superficial area, and finally reached into a better cohesion between sisal fibre and phenolic matrix material (Barreto et al. 2011).

Jun Tae Kim et al. mercerized sisal fibres under tension and no tension, in order to improve their tensile properties and interfacial connection with soy protein matrix. The sisal fibres were treated in 2 M NaOH solution under different tensions (from 0g to 100g weight per fibre) for 2h, and then soaked into the procured Soy Protein Concentrate (SPC) resin to fabricate composites and cured at 120 ℃. The composite's fracture stress and stiffness were found to increase 12.2% and 36.2%, compared to unmercerized sisal fibre reinforced composites. Morpholoy study through SEM on the composite's fracture surfaces indicated that there is better adhesion between sisal fibre and soy matrix after the mercerization treatment (Kim & Netravali 2010).

T.P. Mohan et al. used combine alkali (NaOH) and clay to chemically treat sisal fibre, in order to improve the fibre-matrix compatibility and interfacial strength as well. Structure and morphology study through FTIR, EDX and XRD revealed the treated sisal fibre has a dissolution of amorphous lignin phase and crystalline fraction of 76%, and with 20% clays in the treated sisal fibre in weight. Mechanical properties such as tensile strength, modulus and strain are increased comparing to the untreated sisal fibre by 14~18%, and 10% increase in dynamic stiffness. The improvement in glass transition temperature Tg was also observed in treated sisal fibre composites (Mohan & Kanny 2012).

Min Zhi Rong, et al. investigated the fibre treatment and their effects to mechanical properties of unidirectional sisal fibre reinforced epoxy composites. Many treatment methods such as alkalization, acetylation, cyanoethylation, silane coupling agent, and hearting were applied to modify sisal fibre’s structures. Through FTIR, XRD, SEM investigations, it is found that the adhesion between matrix- epoxy and sisal fibres are improved. This improved adhesion between matrix and fibre resulted in mechanical properties improvement , i.e. higher tensile strength and modulus and higher flexural stiffness in treated sisal fibre composites. Among those chemical treatment methods, AT (Alkali- Treated) + HT (Heat- Treated) treatment seemed to have the best effect in improving flexural stiffness (Rong et al. 2001).

2.5 MECHANICAL PROPERTIES OF FIBRE POLYMER COMPOSITES

Researchers, Engineers and Scientist are drawn towards the Natural Fibres, which has become a substitute and alternate sources of Fibre reinforced polymer (FRP) compounds. Because of their properties of bio-degradability, environment friendly, cheap in terms of cost, automated features, high particular power and non-abrasive, they are subjugated as the alternative of the usual fibre for e.g. glass, aramid and carbon. The tensile characteristics of both the natural fibre-reinforced polymers (thermoplastics and thermo sets) are essentially affected by the bond of the matrix interface and the fibres resulting in the adhesion of improvement of tensile features by the numerous chemical alterations to improve the matrix-fibre interface and its compound properties. The natural fibre, due to its tensile, hardness, the fibre reinforced polymer properties is increased within the fibre substance to the maximum and best possible grade, before its worth is decreased. With the increase of fibre loading, the natural fibre reinforced polymer compounds are also increased. (Khoathane, Vorster & Sadiku 2008) evaluated that due to the tensile strength and Young's modulus in the compounds reinforced with bleached hemp fibres risen up extremely with enhancing fibre loading (Ku et al. 2011).

The automated features of natural fibre polymer compounds depend on the inherent characteristics of natural fibres and significantly on the bond among the fibre and matrix interface. Mostly in the cases of natural fibres reinforced polymer compounds, enhanced automatic aspects are demonstrated as compared to the matrix interface. On the whole it is validated that the mechanical features of the compounds like tensile and compressive power, flexibility's modulus, flexural power and flexural modulus enhanced with the reinforcement of natural fibres which are flax, jute, hemp (Shalwan & Yousif 2013).

In 2013, a researcher, Lu et al. investigated through the impacts of surface modification agents like silence coupling agent and Sodium Hydroxide (NaOH) over bamboo/epoxy compositions. The composition's tensile and effects revealing the properties were notified before and after the surface treatment due to which it was discovered that the NaOH solution treatment was the main reason behind enhancing the entire tensile strength up to 34%, elongation break rate up to 31% while the silence treatment enhanced the tensile potency by 71% and elongation break rate by 53%. Therefore, the outcomes proved that the surface treatment is actually responsible for increasing mechanical properties along with enhancing the correlation between epoxy resin and bamboo cellulose(Saiter et al. 2013) .

While in 2014, Lu et al. studied the bamboo cellulose/poly (lactic acid) composite's mechanical properties with respect to three variations including silane coupling, maleic anhydride grafting, and alkali soaking. As per the outcomes demonstrated, silane coupling treatment enhanced the effects of composite with its stiffness and elongation by means of 62% and 115% which was much higher than the original ones. When maleic anhydride grafting was utilized, it showed more balanced impact on the upgrading of inflexibility and ductility along with representing the finest properties. Also, the alkali soaking treatments enhanced the Young’s modulus and the composite’s tensile potency by 34.6% and 28.6% correspondingly(Lu et al. 2014).

In 2008, Khoathane et al. scrutinized two kinds of bamboos’ mechanical properties i.e. Kao Zhu and Mao Zhu. During his evaluation, he discovered that both kinds of bamboos have compressively high potency ranging between 45~65 N/mm_2. Moreover, the compressive potency of top section tends to be greater than that of the one present in the bottom area. In addition, the top section’s bamboo’s fibre area is found better than the bottom one’s bamboo if seen with the perception of microstructure counting (Khoathane, Vorster & Sadiku 2008).

Supranee Sangthong et al. modified sisal fibre through a poly(methyl methacrylate, MMA) film’s admicellar polymerization on the surface to improve the interfacial connection between sisal fibre and matrix- unsaturated polyester. The composite’s mechanical properties such as tensile strength/modulus, flexural strength/modulus, impact strength and stiffness were tested and compared under different MMA portion. It is observed generally the composite’s mechanical property increased alongside the increment of MMA amount, and the best mechanical properties is obtained at 30 vol% sisal fibre and MMA amount 0.075% v/v. SEM results on the fracture surface also showed the bonding is stronger after MMA treatment comparing to untreated ones, and the failure tend to occur with fibre breakage rather than interfacial debonding (Sangthong, Pongprayoon & Yanumet 2009).

M.Ramesh et al. fabricated hybrid fibre composites – polyester reinforced by sisal fibre, jute fibre and glass fibre, and evaluated their mechanical properties such as tensile strength, flexural strength and impact strength. It is found that the sisal fibre and jute fibre are able to alternate glass fibre to reinforce polyesters and improved their flexural and tensile strength. SEM results also revealed the breakage occurred in the sisal/jute fibres (Ramesh, Palanikumar & Reddy 2013).

Xuefeng Zhao et al. studied sisal fibre reinforced high-density polyethylene (HDPE) composite's mechanical properties and critical parameters' impact such as fibre content, interfacial compatibilization and manufacturing process. The increment of fibre content and maleic anhydride grafted HDPE (MAPE) which has a better interfacial compatibilization was found to improve the composite's mechanical properties. A pre-impregnation process with compatibilzer MAPE is found to be better than the simultaneous blending. Meanwhile the general Power-Law equation fits the composite's creep curve quite well and is able to predict the composite's creep behavior (Zhao, Li & Bai 2014).

A.Belaadi et al. studied the fatigue property of sisal fibre reinforced polyester biocomposite. The samples are made following the fibre directions laminates with [0/90]s sequence; Three-point bending static and cyclic tests (frequency 1.5 Hz) were carried out for study. The results revealed that failure occurred after the first few cycles for high loading levels, and for low values of loading level variance fracture is partial even after 1 million of cycles (Belaadi, A. et al. 2014).

Jackson D. Megiatto Jr. et al. studied the optimized process parameters for manufacturing thermoset phenolic composites reinforced with sisal fibres. The criterion is to control the vaporization of water release during the curing reaction of thermosets. The results showed that higher pressure before the phenolic matrix's gel point can reach to a composite with higher performance. SEM images revealed there is less void in the matrix with the application of higher molding pressure during curing. Meanwhile a better filling of fibre channels reduced the water molecules diffusing (Megiatto Jr et al. 2009). Flavio de Andrade Silva et al. studied the sisal fibre's fatigue behviours through tensile experiments. The sisal fibres were tested at stress between 80 ~ 400 MPa. It is found fibres subjected to a ratio of 0.5 of ultimate tensile strength have survived 10^6 cycles, and failed when ratio between 0.6 to 0.8 and fatigue lives between 10^3 and 10^6 cycles. No significant stress-strain hysteresis was found during fatigue (Silva, Chawla & de Toledo Filho 2009).

K.L. Fung et al. applied a pre-impregnation technique for the injection moulding of sisal fibre reinforced polypropylene composites. Through thermal analysis, it is found the composite can be processed at a lower barrel temperature after pre-impregnation treatment, and a significant thermal degradation of sisal fibre can be avoided. This process also resulted in lighter colour and no odor (Fung et al. 2003).

Arnold N. Towo et al. used 0.06 M NaOH to treat sisal fibres and combined with polyester and epoxy resin in hot press to fabricate composites. Fatigue tensile tests under loading levels of 75%, 60%, 50% and 35% were performed to evaluate the thermoset sisal fibre composite's fatigue behaviors. It is showed that epoxy matrix composite had a longer fatigue life than polyester matrix composite. DMTA results showed that the composite's glass transition temperature Tg lowered after the NaOH treatment of sisal fibres. Static tensile test results showed an improvement on both polyester and epoxy matrix composites after the NaOH treatment. The sisal fibre thermosets composite's fatigue strengths are suitably high for many commercial applications (Towo & Ansell 2008).

Antich et al. studied the short sisal fibre's reinforcement to high impact polystyrene (HIPS) through mechanical tests such as tensile, fracture tests. In the uniaxial tensile test, it was found that an increase in the composite's Young's modulus (from 1.91 GPa to 2.51GPa, 25% sisal), but a decrease in the tensile strength (from 21.66 MPa to 11.52 MPa, 25% sisal) and elongation break rate (3.96% to 0.76%, 25% sisal). On the other hand, the composite's impact strength decreased from 2.97 kJ/m2 (0% sisal) to 1.67 kJ/m2 (25% sisal). Through morphologic study, the decrease in mechanical properties are due to poor adhesion between HIPS matrix and sisal fibre, and therefore the restriction of matrix yielding(Antich et al. 2006).

Andressa Ceclia Milanese et al. fabricated woven sisal fabrics/phenolic resin composites using compression moulding, and tested its tensile and flexural strength. Experimental results showed that with the introduction of sisal fibre, the phenolic resin's tensile strength increased from 4.9 MPa to 25.2 MPa, with the elongation yield from 0.14% to 7.9%, which makes this materials turns from a brittle material to a ductile one. In the flexural experiment, the phenolic resin's flexural strength increased from 8.6 MPa to 10.7 MPa (sisal without heat treatment), and 11.2 MPa (heat treated sisal), with the deflection increased from 3.0mm to 14.0mm and 17.5mm, respectively (Milanese, Cioffi & Voorwald 2012).

2.6 FLEXURAL PROPERTIES OF FIBRE POLYMER COMPOSITES

Flexural power refers to the resistance of a material from the deformation under load while, the flexural power is normally evaluated with the help of the transverse bending test(Takagi et al.). In 2003, Li & Yao went through the flexural behaviour of bamboo utilised for fire lightning purposes reinforced with the mortar laminates. Further it was discovered that the bamboo has the intensity to enhance its mortar's potency while diminishing the entire weight of laminate and this happens due to its greater potency to weight ratio. The tests were carried out divulging the fact that the flexural strength of bamboo or mortar laminates is greater than 90 MPa (Yao & Li 2003).

In 2013, Cioffi, Brocks, & Voorwald investigated for the flexural characteristics of carbon fabrics which was reinforced with the composites of epoxy also evaluating the impacts of features of carbon fibre where the outcomes divulged that these comprise of high mechanical properties because of its high interfacial adhesion while coarseness is revealed in the carbon fibre, T800HB in contrast to other type, IM7. As per the test outcomes of Dynamic Mechanical Analyses, by utilising the carbon fibre, IM7, greater flexural potency of composites are attained (Brocks, Cioffi & Voorwald 2013) .

In 2014, Reddy & Sen scrutinized by utilisation of sisal fabrics which was intended to support polymer; even the flexural characteristics and the composite's tensile are contrasted along with providing support to glass and carbon fabrics. It is also deemed that the format of composite structures is Reinforced Concrete (RC) beams; furthermore, the RC beams are reinforced by sisal illustrating a great enhancement in flexural potency and deflection which is equivalent to the reinforced versions of glass and carbon fibre. On the contrary, the RB beams are reinforced by sisal producing the greatest ductility along with setting back the cracks devoid of shatter failure of the FRP as it has been illustrated in the case of reinforced versions of glass and carbon fibre. Consequently, the outcomes demonstrated that sisal fabric is responsible for reinforced polymer composites and they have the potential to be utilised in the place of glass and carbon fibres along with utilising in flexural strengthening of the RC beams (Sen & Reddy 2014). (Yousif et al. 2012) evaluated by investigating the flexural characteristics of unidirectional long kenaf fibre reinforced epoxy composites. Then, it was discovered that the composite's flexural characteristics were enhanced by the modification of 6% of the kenaf fibres through the NaOH solution while the flexural potency of kenaf fibres was enhanced by 20% in an unmodified case. The reason lies in the NaOH chemical treatment improved the interfacial adhesion between the kenaf fibres and matrix. Also the porose inner structure of composites prevented the debonding, detachment and pull out of fibres. The modified kenaf/epoxy composite has superior properties comparing to previous natural and synthetic fibre reinforced ones.

In 2012, Sawpan et al conducted a study on the flexural power, the modulus of the hemp fibre reinforced polylactide that is processed chemically and dried out polyester compounds. The flexural power of the compounds tends to be reduced with the enhancing fibre content, ranging from 0~50 wt% fibre substance, whereas the flexural modulus has risen up with the increased fibre substance (Sawpan, Pickering & Fernyhough 2012). In accordance with the reduction of flexural power and increase of flexural modulus tends to be the common rule of natural fibre compounds.

2.7 RECENT ISSUES AND RECOMMENDATIONS

On the whole, after evaluating all the concerned books and educational work, a conclusion can be made that the natural fibres are Eco friendly having high particular characteristics and are utilized in numerous manners to swap artificial fibres. Nevertheless, the automated features of the natural fibre compounds like flexural power and effect strength are their drawbacks. At last, this field requires a lot of work to be done in order to produce improved quality natural fibre polymer compounds.

CHAPTER 3

METHODOLOGY

3.1 MATERIAL SELECTION

In this study, sisal fibre is used as reinforcement in the composite due to its low cost, low density, high specific strength and modulus and renewability as a natural product. Epoxy resin is used as matrix in the composite because epoxy exhibit higher mechanical properties than other resin such as polyester and vinyl-ester. It is expected the sisal fibre can reinforce the epoxy's mechanical properties especially flexural properties. But the sisal fibre must be chemically treated before used to reinforce epoxy according to references.

3.1.1 SISAL FIBRE

The Western Kenya in East Africa supplied the Sisal fibre used in this study as showed in Fig.3.1 The Sisal fibre is 100% clean, and doesn't contain any other organic residue. The sisal fibre was firstly hand-washed, and then dried for 48 h.

Fig.3. 1 Raw sisal fibres photo

Fig.3.2 shows the SEM (Scanning Electron Microscopy) graphs of raw sisal fibre's morphology. Sisal fibre is a natural plant fibre, so its structure is more amorphous, and containing cellulose, hemicellulose and lignin, as showed in Fig.3.2 SEM micrographs showed that the sisal fibre is about 150~160 μm and surface covered with waxy layers and impurities (cellulose, hemicellulose and lignin). The fibre cell wall structures are very rough and irregular.

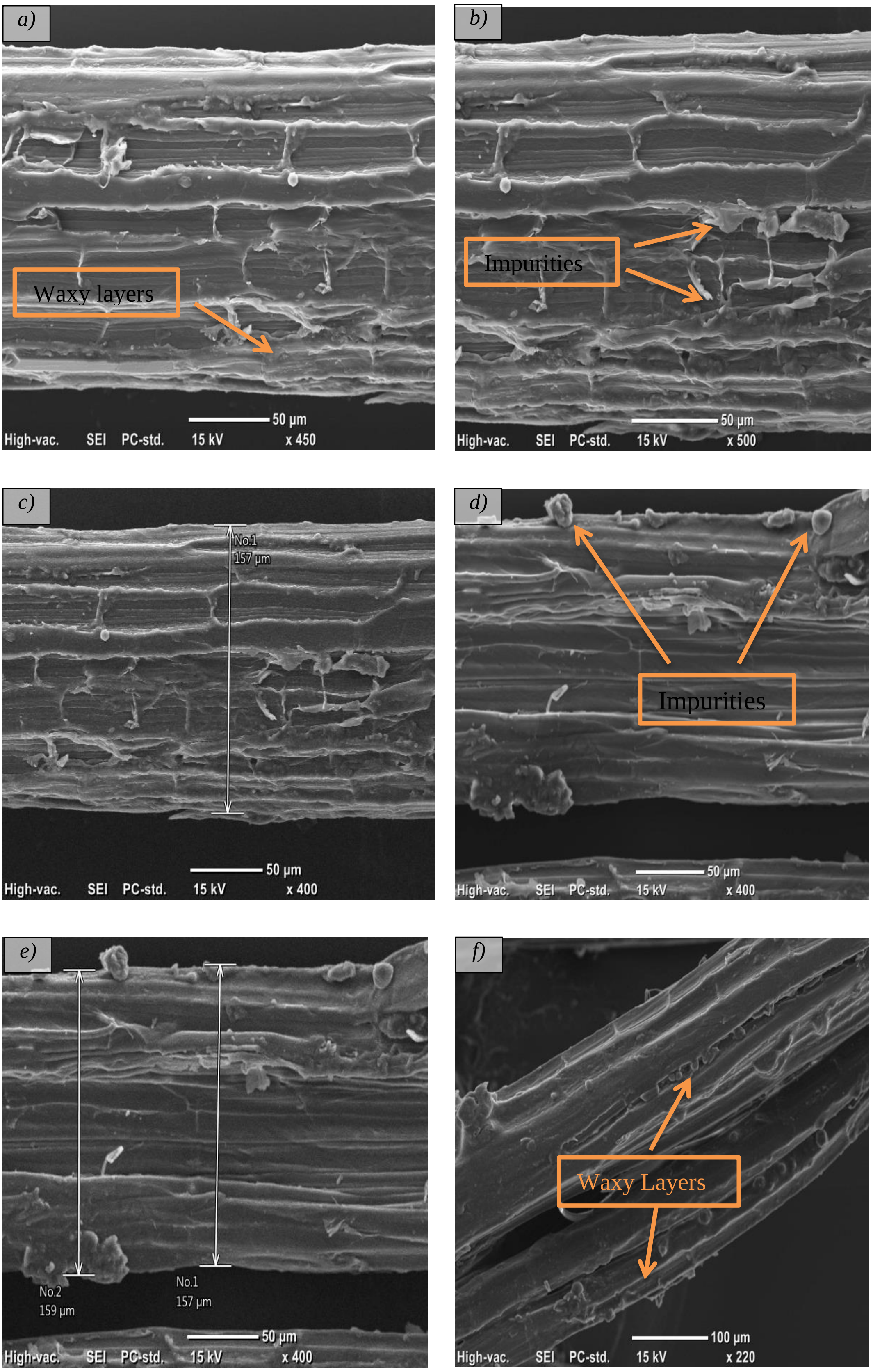


Fig.3. 2 SEM micrographs of untreated Sisal Fibre

3.1.2 NAOH TREATMENT

According to literature, alkali solution has a good effect on treating natural fibres. In this study, a 6% NaOH solution was used to treat the raw Sisal fibres, in order to modify their fibre structures. During this process, the fibres were soaked in the 6% NaOH solution for 24 hours, and then washed and dried in an oven for 24 hours at a temperature of 40C as showed in Fig.3.3

Fig.3. 3 Sisal fibre soaked in 6% NaOH solution

After the alkali NaOH treatment, as showed in Fig.3.4, the sisal fibre’s diameter is shorter (around 120 µm), which indicates the previous surface waxy layer and impurities have been washed out, due to the chemical reaction between NaOH and sisal fibre’s hydroxyl groups. So this gives a rougher surface of sisal fibre and is able to provide a better bonding between sisal fibre and epoxy resin, in order to acquire a better interfacial bonding natural fibre composite materials, which has been proved in further flexural testing results.

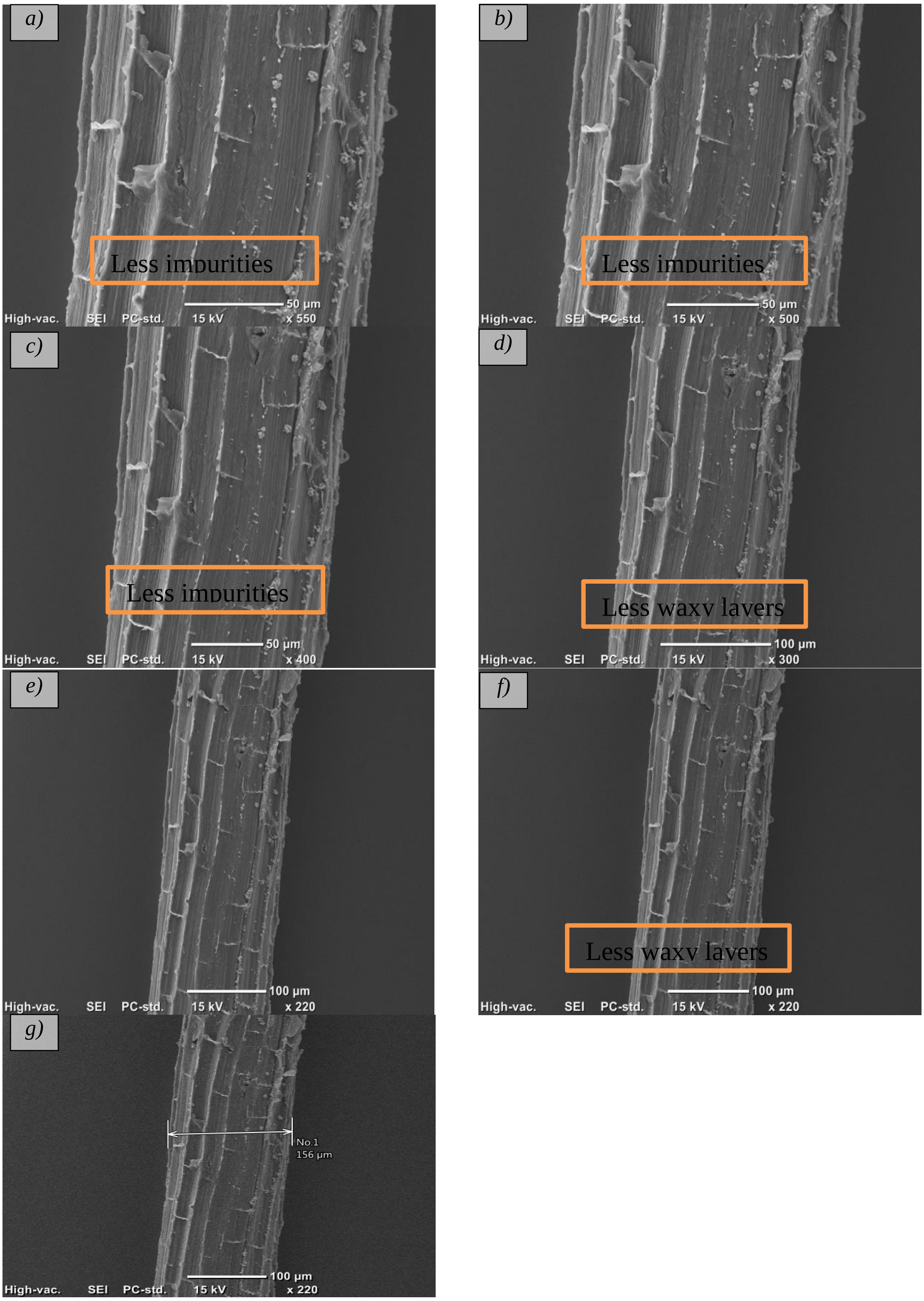


Fig.3. 4 SEM micrographs of treated Sisal Fibre

3.1.3 EPOXY RESIN

In this study, the Kinetix R246TX Liquid Epoxy Resin and Kinetix H160 as Hardener have been used. Kinetix R246 is a solvent free, low viscosity epoxy resin developed by ATL Composites Pty Ltd, with hardener H160, it is able to cure at room temperature or low elevated temperatures. According to its specification, its pot life under 25 C is 120 mins, mixing viscosity 300 MPa. and the demolding time is 28 hours. So it is very suitable for laboratory to fabricate suitable composite systems. And this epoxy resin system has a variety industry application in boat and automobile industry, so we use this epoxy resin in preparing for further industry application of our sisal fibre/epoxy composite system.

3.2 COMPOSITE FABRICATION

This experiment used a metal mould (100X100X10 mm^3), which contains 6 specimen dimensions for flexural testing. The mould was first cleaned with cloth and then covered with a layer of release agent (Huntsman Nu-Cearawax) as showed below. The effect of the release agent is to form an interphase layer between metal mould surface and epoxy resin matrix, so it is easily to peel off the sisal fibre composite specimen when the epoxy resin is cured. The dried treated sisal fibre was cut into 80 mm length and first laid up in the specimen shape mould as showed in the below pictures. The directions of sisal fibre must be align with the specimen/mould’s direction, and this is the key process to control a specimen’s mechanical property. Then the Kinetix epoxy resin and hardener were mixed and stirred, and poured into the mould carefully without bubbles. A steel roller was used on the mould surface in order to remove the air. Lastly a mould cover was applied on the mould, and left the epoxy resin to cure for 24 hours. After the epoxy resin is final cured in an oven at 100 C for another 24 hours, the specimen were be pulled out from the mould, for the further mechanical testing step. All process showed in Fig.3.5 The pure epoxy resin specimen and untreated sisal fibre composite are fabricated following the basically same procedures.

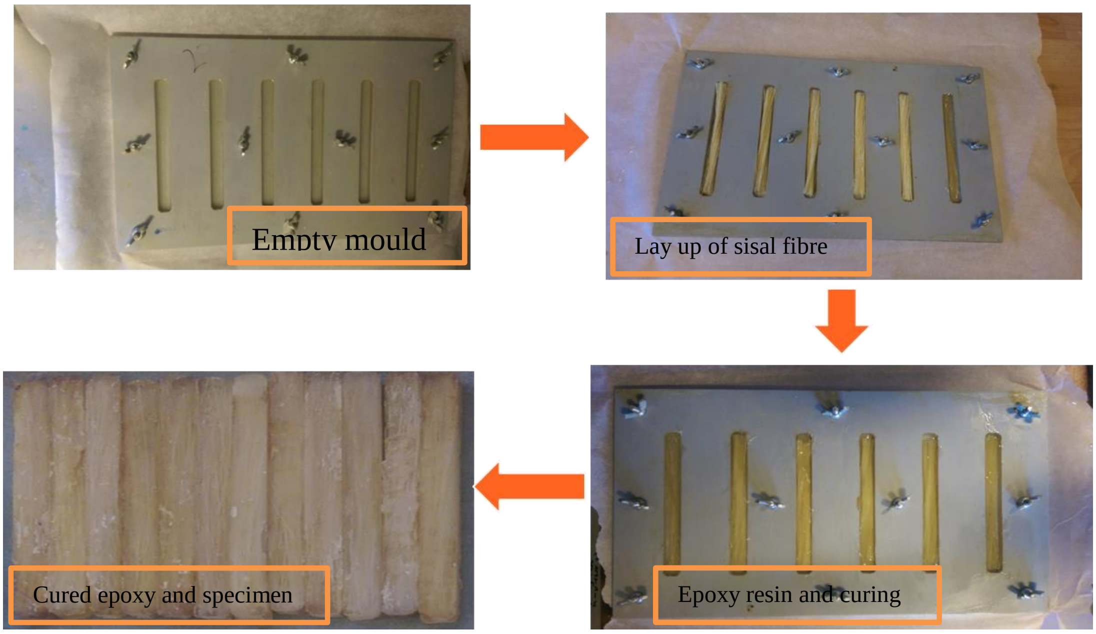


Fig.3. 5 Sisal fibre/Epoxy composite specimen fabrication process

3.3 EXPERIMENTAL PROCEDURE AND SETUPS

When all the three system (pure epoxy; untreated sisal fibre; treated sisal fibre composite) specimen (80 mm X10 mm X4 mm) are ready, a 3 point flexural testing, based on standard ASTM D790-07 (Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials), was performed on a HOUNSFIELD Universal Testing Machine. The cross-head speed was maintained at 2mm/min according to recommendation. The flexural testing is showed in Fig.3.6~3.7

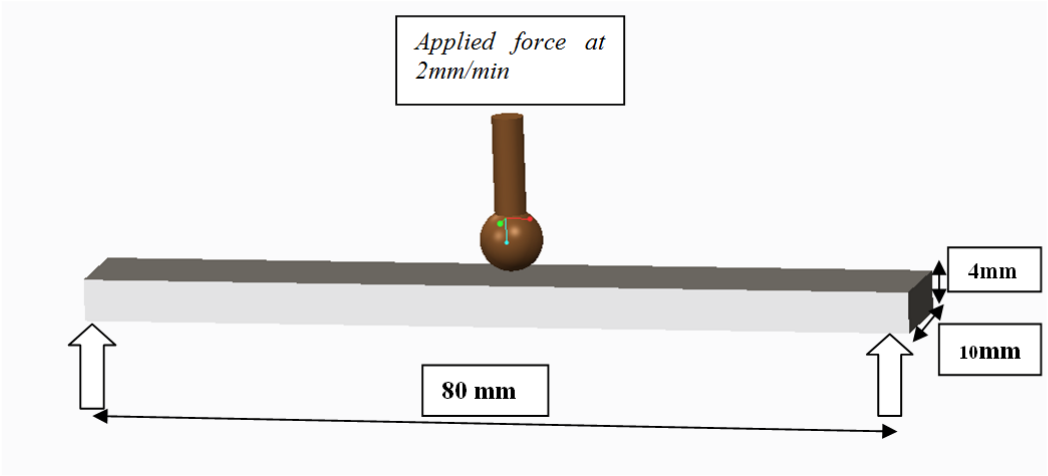


Fig.3. 6 Drawing of the flexural test ASTM D790-07

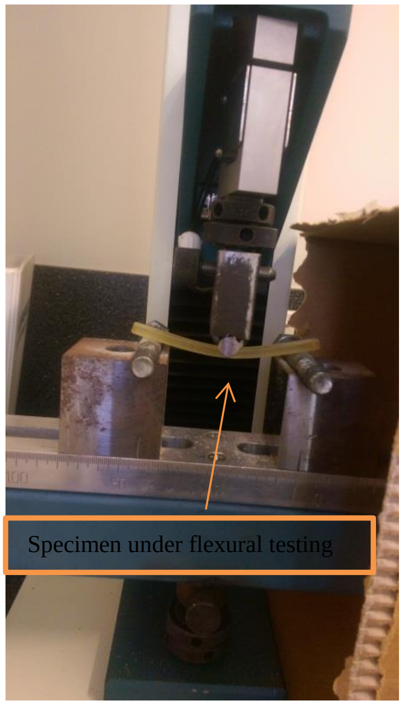


Fig.3. 7 Specimen under flexural testing

SEM (Scanning Electron Microscopy) technique was used to investigate the cross section of fracture surfaces of untreated and treated sisal fibre composites. In this study we use SEM machine JOM-6000, manufactured by JEOL. In order to perform a SEM observation, the specimen's cross section surface is coated with gold, so it become conductive and is able to be magnified by SEM machine, and we can investigate its micro structure inside the composite.

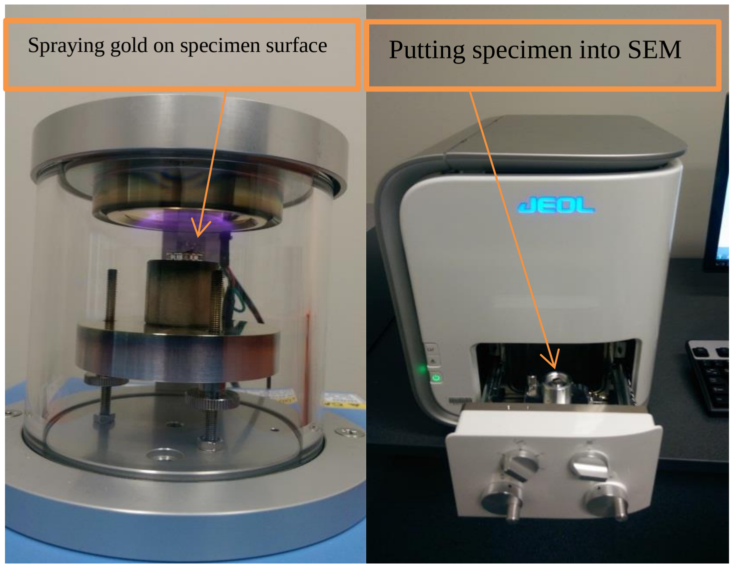


Fig.3. 8 SEM and sample gold coating.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the results of three different systems (pure epoxy; untreated sisal fibre/epoxy; treated sisal fibre/epoxy) flexural experiments are discussed and compared. Firstly the pure epoxy's flexural properties are tested, in order to give a benchmark for further comparisons with sisal fibre reinforced systems. The most important parameters in a flexural testing such as specimen's stress, deflections, flexural strength, and flexural modulus – which illustrates a material's stiffness, are fully presented through stress-deflection curves acquired from material testing machines. Detailed and intensive analysis and comparisons have been made to show sisal fibre's reinforcement effects on epoxy resin especially after NaOH solution treatment.

Another aspect will be discussed in this chapter is the fracture surface morphology study regarding the composite's fracture surfaces after flexural testing breakage. Morphology study is important because it shows the composite's inner structures and can explain why materials behave brittle or tough. Micrographs acquired through SEM (Scanning Electron Microscopy) about all three systems (pure epoxy; untreated sisal/epoxy; treated sisal/epoxy) have been analysed in details, and illustrate its unique inner structures and differences between other two systems. Many phenomenons such as fibre detachment, fibre debonding, and fibre pull-out are discovered in the SEM micrographs. Those SEM micrographs help to explain the sisal fibre's bonding and reinforcement effects in improving epoxy resin's flexural properties.

4.2 FLEXURAL BEHAVIOUR OF SISAL FIBRES/EPOXY

4.2.1 Pure Epoxy

The stress against deflection of pure epoxy is presented in Fig. 4.1 for different samples. In general, there are clear matching trends for all the samples. Moreover, the variation in the values of the stress and the deflection is within the accented range of about 7%. However, there is one curve a bit far from the date which is omitted. Basically, there is a clear elastic region followed by a short plastic deformation which ended by the failure. This indicates the brtille nature of the epoxy matrix, (Shalwan & Yousif 2014). Flexural testing results validated the morphologic study. For pure epoxy resin, its flexural stress is between 60~95 MPa, with a mean value strength at 77.1 MPa according to 9 specimen testing results, as showed in Fig.4.1 And the specimen deflections are between 15~20 mm. The ultimate flextural strength can be seen about 80 MPa.

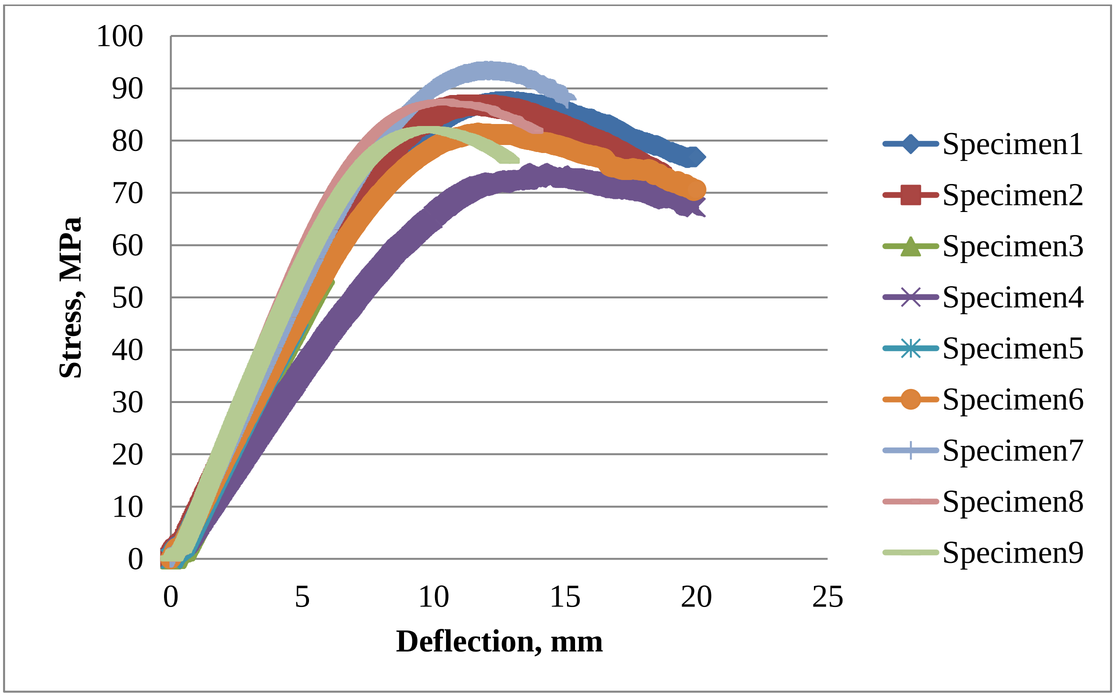


Fig.4. 9 Stress-Deflection curve of pure epoxy

4.2.2 Untreated sisal fibre/epoxy

The stress against deflection of untreated sisal fibre/epoxy composite is presented in Fig. 4.2 for 6 different samples. Clear matching trends are received for all samples. Moreover, the variation in the values of the stress and the deflection is within the accented range of about 5%. Basically, like pure epoxy, there is a clear elastic region followed by a short plastic deformation which ended by the failure. However, its stress at breakage is lower than pure epoxy. For untreated sisal fibre/epoxy composite, its flexural stress is between 60~80 MPa, with a mean value strength at 60.3 MPa according to 6 specimen testing results, as showed in Fig.4.2. The specimen deflections are between 4~8 mm. The ultimate flexural strength can be seen about 80 MPa. The reason why its flexural strength is lower than pure epoxy, after further SEM investigation, is due to the poor adhesion between sisal fibre. From SEM micrographs, the waxy layers and impurities alongside the sisal fibre did not make a good bonding between epoxy resin and sisal fibre; so the untreated sisal fibre composite broke earlier than pure epoxy.

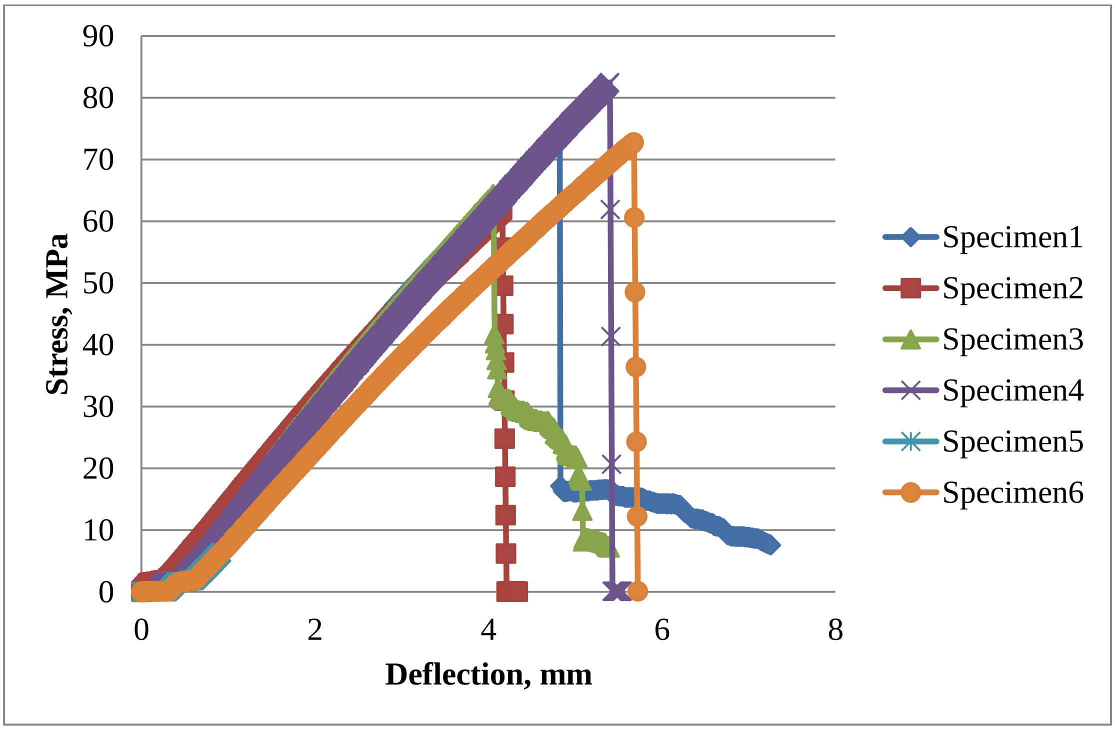


Fig.4. 10Stress-Deflection curve of Untreated sisal fibre composite

4.2.3 Treated sisal fibre/epoxy

The stress against deflection of treated sisal fibre/epoxy composite is presented in Fig. 4.3 for 9 different samples. There is a clear matching trend found for all samples. Moreover, the variation in the values of the stress and the deflection is within the accented range of about 5%. Clearly, after treatment, sisal fibre/epoxy composite showed a great improvement on flexural properties and exhibit a ductile behaviour under flexural loading. Its flexural stress is between 100~160 MPa, with a mean value strength at 135.5 MPa according to 9 specimen testing results, as showed in Fig.4.3. The specimen deflections are between 4~7 mm. The ultimate flexural strength can be seen about 160 MPa. Those results showed the alkali NaOH treatment greatly improved the interfacial situation between sisal fibre and epoxy resin, which is found in further fracture surface morphology studies, and therefore increase the composite's flexural strength.

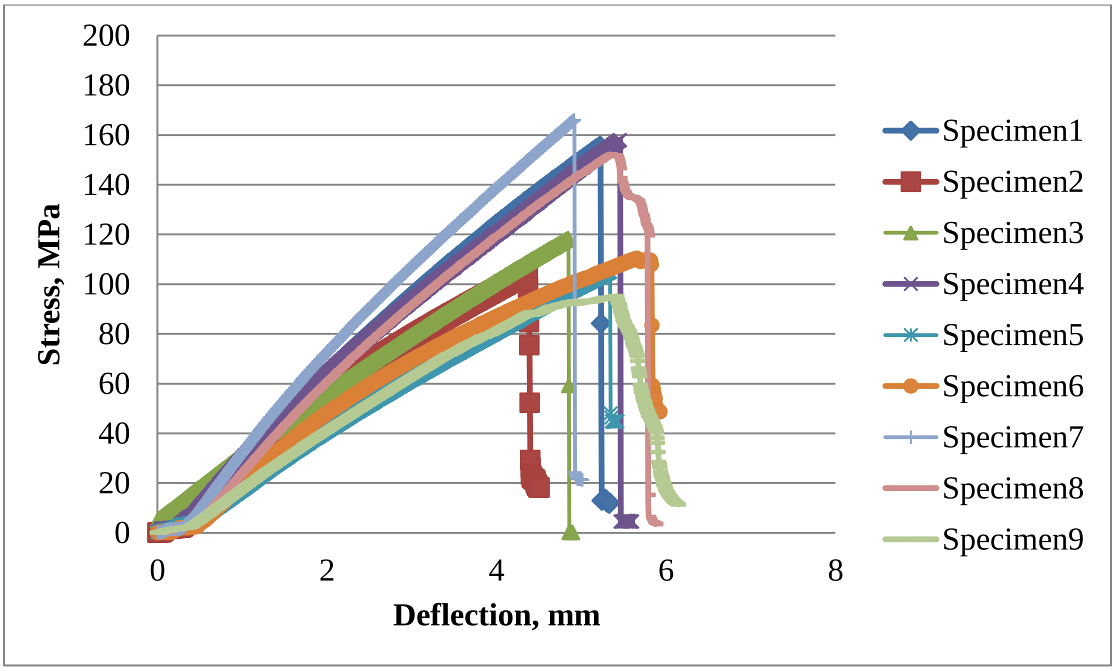


Fig.4. 11 Stress-Deflection curve of Treated sisal fibre composite

4.2.4 Effect of treated and untreated fibres on epoxy composites

Fig.4.4 compared the three systems (pure epoxy, untreated sisal, and treated sisal) flexural strengths. There is a clear phenomenon that the untreated sisal fibre/epoxy composite is the lowest, and the untreated sisal fibre failed to improve the epoxy's flexural strength. As indicated in Chapter 4.2.2 before, the flexural strength of untreated sisal fibre composite (60.3 MPa) decreased due to the poor interfacial bonding between sisal fibre and epoxy reason; but after alkali treatment, the treated sisal fibre composite's flexural strength (135.5 MPa) increased highly, which is an substantial improvement comparing pure epoxy's flexural strength 77.1 MPa. This result proved that it is crucial to chemically treat sisal fibre when using them to reinforce polymers.

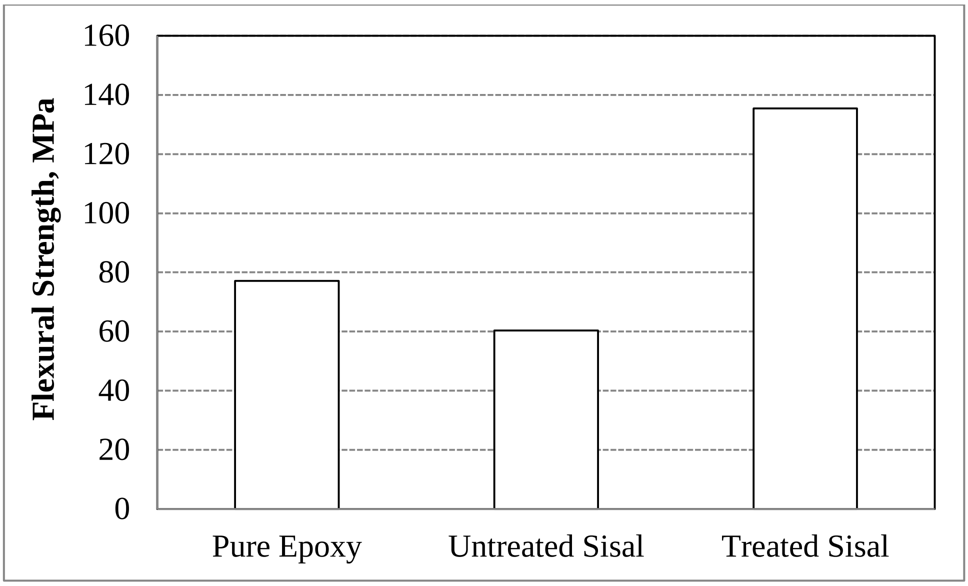


Fig.4. 12 Flexural strength comparison between three systems

Regarding flexural modulus illustrated in Fig.4.5, although untreated sisal fibre failed to increase the system’s strength, but it indeed increased its flexural modulus. This is because even its interfacial bonding is poor, the sisal fibre itself’s high length/diameter is much higher than pure epoxy’s, and helped to improve the modulus under loading. The treated sisal fibre composite had the highest flexural modulus among the three systems, with a mean value of 6429 MPa, comparing to untreated sisal fibre’s 3342 MPa and pure epoxy’s 2455 MPa. It reaches to the conclusion that sisal fibre, especially after alkali treatment, greatly improved epoxy’s flexural strength and modulus, and is able to be used in many industry applications. The reason for this high improvement of modulus will be well explained in the following SEM morphology study regarding cross sections of untreated and treated sisal fibre composite’s fracture cross section after flexural failure.

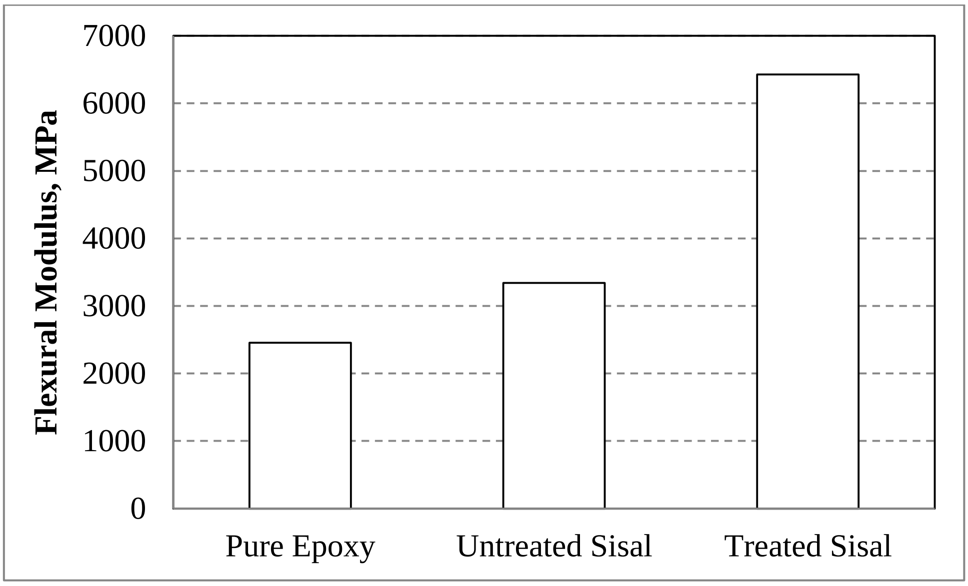


Fig.4. 13 Flexural modulus comparison between three systems

4.3 FRACTURE OBSERVATION

4.3.1 Morphology study on cross sections of sisal fibre composite's flexural breakage after testing

Fig.4.6 is the pure epoxy's cross section surface morphology study on SEM after flexural breakage. It is showed in the graphs that the most failure mechanism is shear yielding in the matrix itself. Different layers are overlapped due to the flexural force. The epoxy itself shows brittle fracture behaviour under critical flexural loading, and also indicates that pure epoxy is a brittle material that needs to be reinforced by various fibres.

With the introduction of sisal fibre, the composite's flexural breakage shows different characteristics comparing to pure epoxy. The fibre debonding and detachments were found in the interface of matrix-epoxy and sisal fibre. As also showed in Fig.4.6, some of the fibre has been found to be pulled out due to the flexural force. This proves that the composite's flexural fracture mechanism is different to pure epoxy's. The sisal fibre has borne most of the flexural loading. But due to the bad bonding between untreated sisal fibre and epoxy matrix, those detachment, debonding and fibre pull out impaired the sisal fibre's reinforcement effects on epoxy matrix.

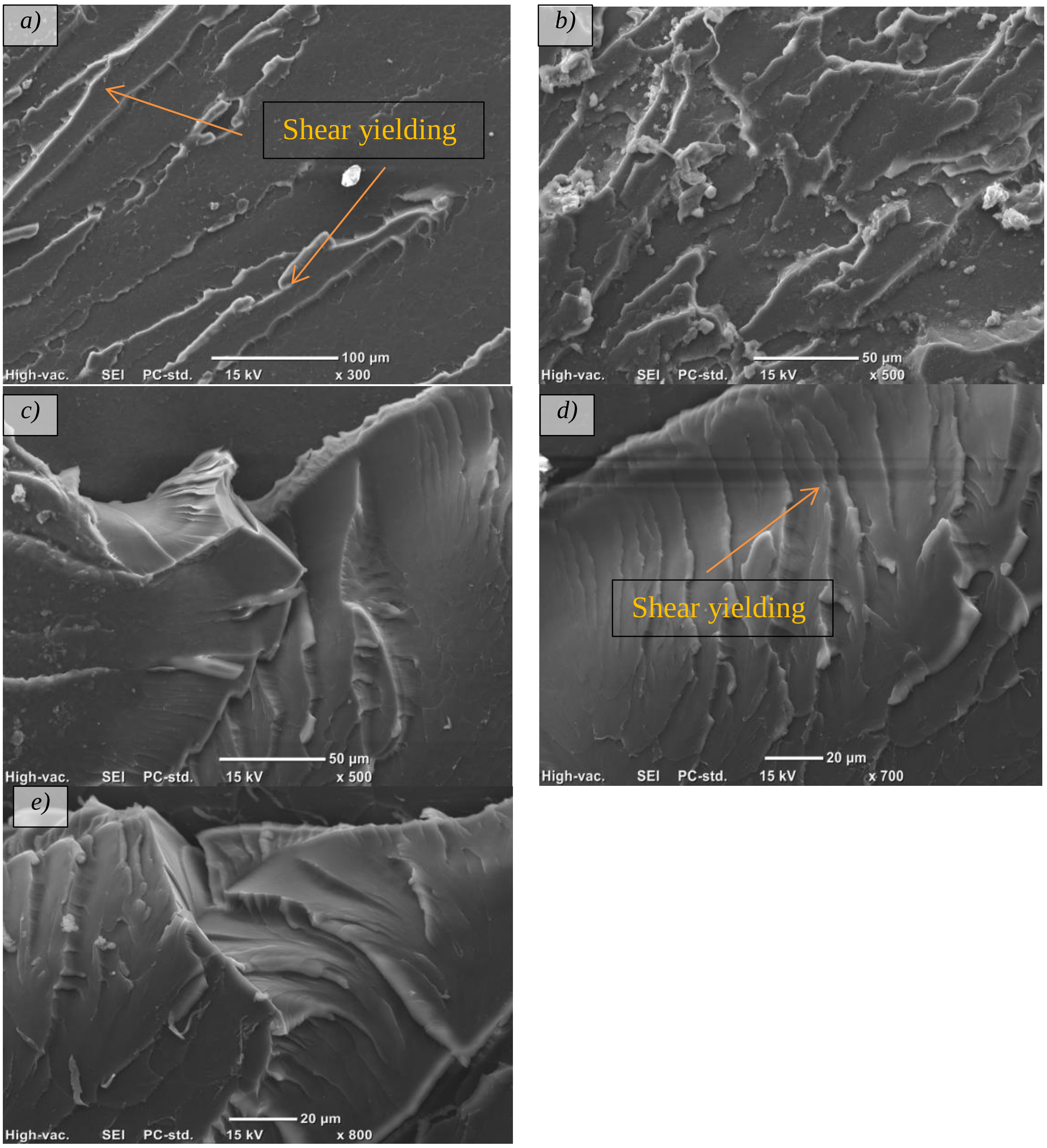


Fig.4. 14 Pure epoxy cross-section morphology after flexural breakage

Through the untreated sisal fibre composite’s SEM micrographs, it also can conclude that the interfacial adhesion between matrix-epoxy and untreated sisal fibre is very poor, so debonding, detachment and fibre pull out are easily to find out, as illustrated in Fig.4.7 Those imperfections lead to the poor flexural performance of untreated sisal fibre composite in Fig.4.7 where its flexural strength is even lower than pure epoxy. On the other hand, it proves that sisal fibre, even in general all natural plant fibre, do not have a good reinforcement effect on polymer matrix if without a chemical treatment.

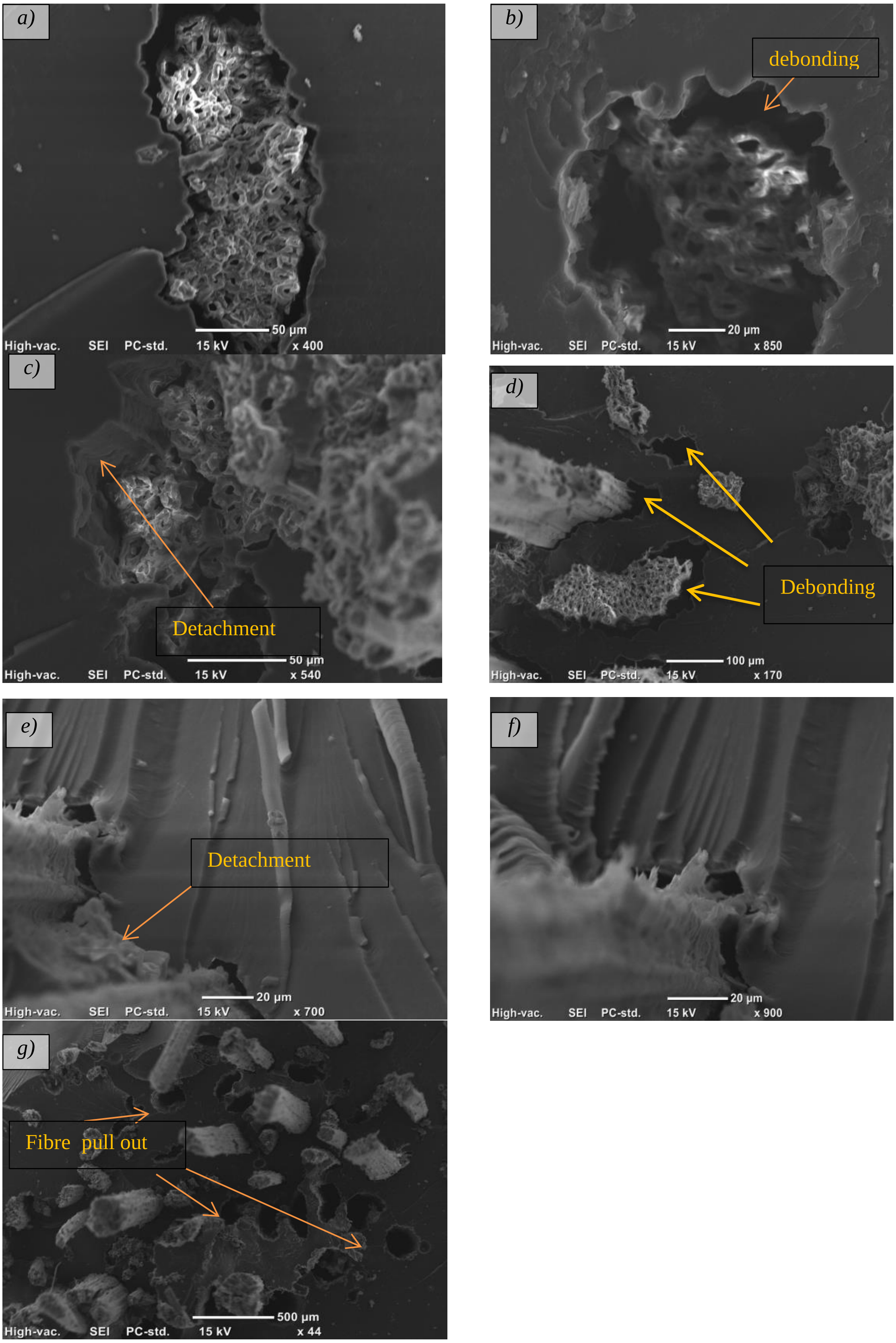


Fig.4. 15 Cross section morphology of Untreated sisal fibre composite

Fig.4.8 showed the SEM micrographs of treated sisal fibre composite' flexural breakage cross-sections. Comparing to untreated sisal fibre composite, there are many improvements can be observed.

1) Interfacial bonding between matrix and fibre are greatly improved. There is no obvious boundary between epoxy and treated sisal fibre. This can prove that the alkali treatment indeed removes the waxy layer and impurities of sisal fibre and make it rougher and more easily to be interlocking with epoxy resin. So epoxy is more likely to penetrate into fibre's inner structures and result in much better interfacial bonding as showed in Fig.4.8 Sisal fibre also bundles due to the improvement of interfacial bonding.
2) There are no obvious sisal fibre debonding, detachment and pulled out been found on the treated sisal fibre composite's cross sections, which indicates sisal fibres are more bundled together and bonding with matrix epoxy. So when the composite is under flexural loading, the sisal fibre bore the loads and is able to transfer it through epoxy matrix, which makes the composite system able to bear more loading, comparing to bad interfacial bonding in which fibre tend to pull out due to bad bonding. Meanwhile the less porosity also leads to the high flexural strength. In this analysis the treated sisal fibre composite will have the highest flexural strength and modulus, and this is in good agreement with flexural testing results in Fig.4.4 and 4.5.

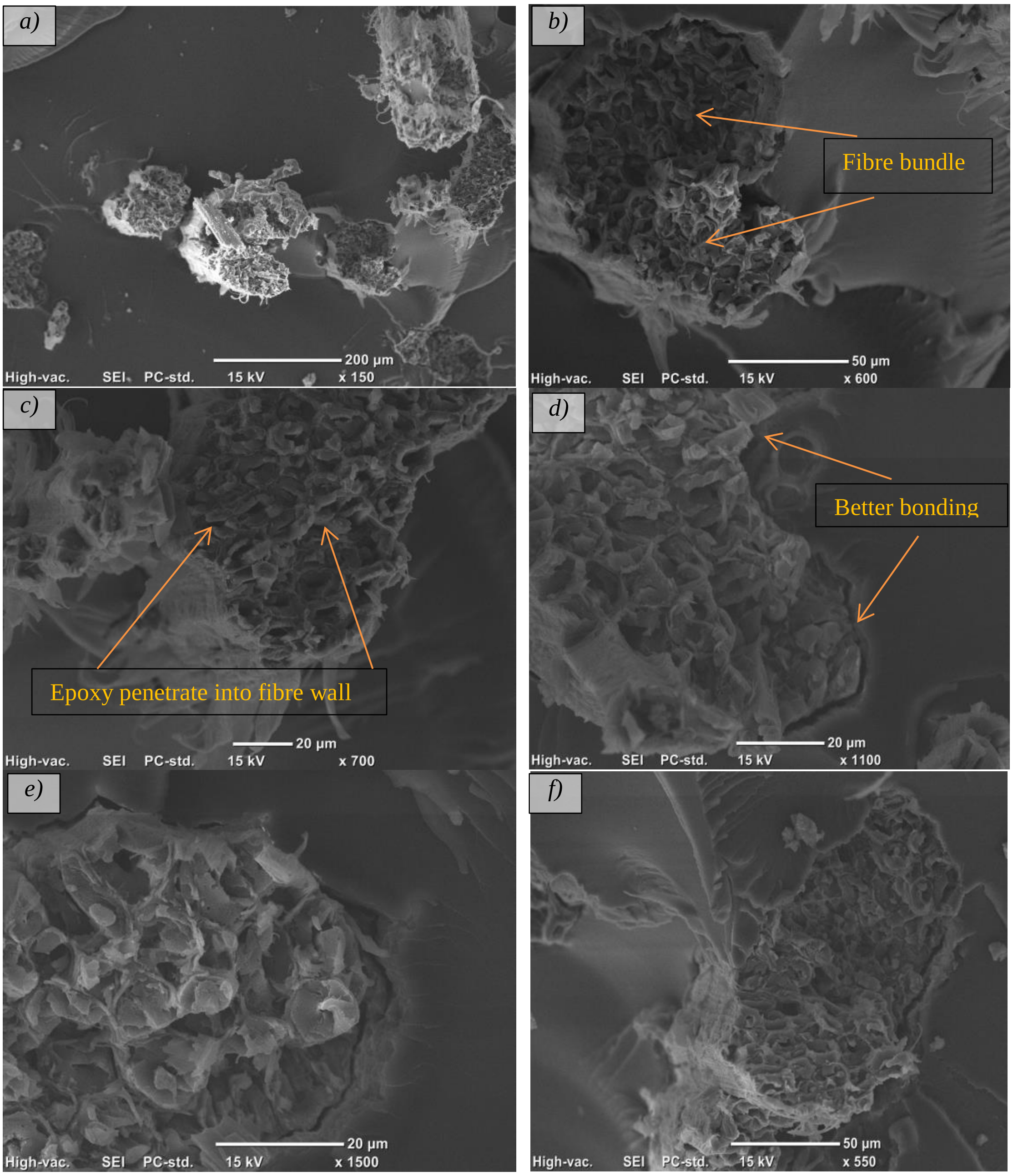


Fig.4. 16 Cross section morphology of Treated sisal fibre composite

4.4 COMPARISON WITH THE PREVIOUS WORKS

Some of other researchers working regarding flexural properties of natural fibre composites are compared with the Current work. From table 4.1, the matrix's property is important for a composite's performance after fibre reinforcement. If the matrix is a thermoplastic resin such as PP (Polypropylene), it intrinsic flexural properties are low comparing to thermoset resins, so we cannot acquire a high performance composite material. So it is critical to choose a thermoset resin such as epoxy resin as the matrix, if you focusing on industry applications. Among the natural fibres listed, sisal fibre has the comparable flexural modulus as kenaf fibre (6.43 GPa vs 6.74 GPa), although its flexural strength is inferior to kenaf fibre (135 MPa vs 350 MPa). But Rong's work showed a much higher flexural modulus of 18 GPa of sisal fibre/epoxy composite, which indicates the sisal fibre is more suitable to be used in structure parts which needs high flexural modulus. Bamboo fibre showed an equivalent flexural strength comparing to sisal fibre, and a higher flexural modulus to our work, but lower than Rong's work. Glass fibre, due to its intrinsic property, has a much higher flexural strength and modulus, than all natural fibres. The glass fibre/polyester composite showed a flexural strengths between 590~720 MPa and flexural modulus between 31~38 GPa. But glass fibre has its drawbacks such as a higher price, and a higher density comparing to natural fibres. So natural fibres still have a promising future in industrial applications of fibre reinforced polymer composites.

In some industrial applications which does not need a very high mechanical performance, but need light weight and recyclability, such as interior panel in an automotive, or reinforced concrete (RC) beams, it is feasible to replace the current glass fibre composite into natural fibre composites . (Gajewski & Sadowski 2014) studied the flexural properties of natural fibre reinforced concrete beams (RC) beams, and discovered an increase in the flexural strength and deflections, similar to glass fibre reinforced RC beams. Sisal fibre reinforced RC beams also showed the highest amount of ductility, and it is possible to use natural fibre as an alternate fabric reinforcement to replace glass fibre reinforced RC beams. Another area where natural fibre is able to replace glass fibre, is in the automotive industry. In Alves's paper, not only natural fibre composite can be used to manufacture door panels and truck liners, but also jute fibre has been used to manufacture an automobile’s frontal bonnet. Compared with the glass fibre composite bonnet, jute fibre composite bonnet achieved the technical project requirements (damage requirements), and with its advantages such as low price, low density, and recyclability; Natural fibre composite is able to manufacture a more renewable, lighter, engine economic automobile, and replacing glass fibre composite in automobile industry(Alves et al. 2010).

Table 4.1 Comparison with previous works on flexural properties of natural fibre composites

Matrix	Fibre	Flexural strength, Matrix, MPa	Flexural Strength, Composite	Flexural Modulus, Matrix, GPa	Flexural Modulus, composite	References
Epoxy	**Sisal**	**77.1**	**135.5**	**2.46**	**6.43**	**Current work**
PP	Hemp	48	63			(Yan et al. 2013)
Phenolic	Sisal	8.6	11.2			(Milanese, Cioffi & Voorwald 2012)
PP	Bamboo		45.49		2.08	(Chattopadhyay et al. 2011)
Epoxy	Bamboo		149.00		9.5	(Kushwaha & Kumar 2009)
Epoxy	Bamboo		119		11.9	(Kushwaha & Kumar 2010)
Epoxy	Kenaf	180-200	300-350	1.73	6.74	(Yousif et al. 2012)
PP	Sisal		23		1.6	(Wambua, Ivens & Verpoest 2003)
Epoxy	Sisal		225		18	(Rong et al. 2001)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

In this project sisal fibres reinforcement epoxy composites have been fabricated and investigated using treated and untreated fibres associated with pure epoxy. Based on the flexural experiment data and the morphology studies in this work, few points can be concluded as follows:

1. Pure epoxy exhibited a brittle nature when under flexural loading, and led to micro crack in the inner structure. The pure epoxy broke due to micro crack growing and shear yield inside.

2. Untreated sisal fibre did not improve epoxy resin's flexural strength, due to bad interfacial adhesion between sisal fibre and matrix – epoxy. However it did improve the composite's flexural modulus, from pure epoxy's 2455 MPa to 3342 MPa. In morphology study, there are debonding, detachment, and fibre pull out been found in the matrix in SEM micrographs.

3. 6% NaOH alkali treatment is an effective chemical treatment in improving interfacial adhesion between sisal fibres and the epoxy. After treatment, sisal fibre are bonded better with matrix epoxy and the epoxy is able to penetrate into sisal fibre core, i.e. the interfacial adhesion has been greatly improved after 6% NaOH solution treatment in this project.

4. Flexural experiment results are in agreement with morphology study results that the sisal fibre is in better interfacial adhesion with epoxy resin. The flexural strength and modulus of treated sisal fibre/epoxy composite comparing to pure epoxy have increased 76% and 162%, respectively.

5. The treated sisal fibre/epoxy composite system has a high mechanical performance especially flexural strengths and modulus, besides its low

density, and green nature, it is able to replace glass fibre in some aspects of industrial application such as automotive interior panels.

5.2 RECOMMENDATIONS

Due to the time limit of this project there many recommendations can be given as future work to assist in understanding the sisal fibre impact on the polymer composites. Some of the recommendation can be as follows

1. Fragmentation test can be done to further understanding the interfacial adhesion of the sisal fibre with the epoxy composites.
2. Numerical study can be recommended to save some time in conducting other loading conditions such as fatigue, torsion …etc.
3. X-Ray facility will assist in understanding the inner of the composites characteristics which may help the understanding the fibre behaviour in the build of the composites.

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Appendix A

Project Specification

Flexural Properties of Sisal/Polyester composites

For: Rafi Ali Alqahtani

Supervisor: Dr. BELAL YOUSIF

Project Aim: the main goal of this study is to study and understand the flexural behaviour of polymer composites based on natural fibres. In details, the project covers the following objectives

1. To address the issue with regard of the flexural properties of glass fibre reinforced polymers
2. To create new composites based on natural fibres
3. To evaluate the flexural properties of the developed composites
4. To study the fracture behaviour of the samples after the test

Program:

- Build the literature using about 50 international articles related to the field
- Study the fundamental flexural properties
- Evaluate the flexural performance of the epoxy composites
- Examine the surface fracture of the sample after the test using optical microscopy
- Discuss and analysis the collected data
- Write and submit an academic dissertation on the topic

As time permit: ?

Scanning electron microscopy may be conducted for further study and evidences to the results

Appendix B

Materials properties

The epoxy resin used in this project is KINETIX R246/H160 system. KINETIX R246 is a solvent free, low viscosity epoxy resin specifically formulated for use with H160 hardener to cure at room temperature. Its physical state is clear liquid, and the hardener is clear brown liquid. R246 resin has a viscosity of 750-900 mPa.s @ 25 C and specific gravity 1.10 g/ml. The hardener H160's viscosity is 30 mPa.s @25 C and specific gravity 0.95 g/ml.

Appendix C

Project Schedule Details

Table.1 Timeline of the thesis

Phase/Task	From	To	Deliverable(s)
Brainstorm	09/03/2014	20/03/2014	Review my knowledge about fibre
polymer composites research, literature research	20/03/2014	30/03/2014	References
Research and review the literature review	1/04/2014	05/05/2014	The first draft of the literature review
Complete initial research and literature review component.	05/05/2014	20/05/2014	The finalised literature review
Complete the preliminary report	20/05/2014	04/06/2014	The first draft of the preliminary report
Review the preliminary + start working on the USQ lab	05/06/2014	10/06/2014	The finalised preliminary report
prepare the sisal fibre, epoxy ,treatment of the fibre + report writing	10/06/2014	17/06/2014	Complete the preparing of the material
Prepare the samples to flexural test	17/06/2014	21/07/2014	Collecting the data from the testing machine
Flexural test + writing the result	21/07/2014	11/08/2014	Finch the result
Discuss the results	11/08/2014	28/08/2014	The first draft of the result.
Complete the partial draft dissertation	1/09/2014	17/09/2014	The finalised Result Discussion section
Assembly the thesis	17/09/2014	15/10/2014	The first draft of the thesis
Review the thesis	15/10/2014	29/10/2014	The finalised thesis
Submit the thesis	30/10/2014	30/10/2014	

Appendix D

Risk assessment

Though to different extents, all engineering projects are subjected to risks. For that reason, assuring safety of all individuals involved in the project is of high priority. Compliance with different laws like *Workplace Health and Safety Act 1995* is important while addressing safety issues. This particular act which is implemented in different ways is aimed at prevention of illness, injury of death of individuals at workplace or an area related to workplace by any procedure carried out or substance used at the workplace (Workplace Health and Safety Act, 1995).

Risk identification, evaluation and control

This project is about natural fibre/epoxy composite research, the main predictable hazards in this project is in the chemical protection of epoxy resin as it contains some chemicals ingredients which are harmful for humans, also the risk happens in the operation of flexural testing machines. All potential predictable hazards in this project were detected so that the associated risks could be evaluated. These hazards and control strategies are outlined below.

Risk	Hazard	Control strategy
Inhalation of epoxy	Will damage human consciousness	Keep good ventilation in the laboratory
Skin touch of epoxy	Will damage human skin and body	Wear Protection equipment such as protective mask, glasses, hand gloves; If eye contact occurs, immediately flush with running water and seek medical advice.
Operation of flexural testing machine	Specimen burst out when broke failure, may damage human in operation.	Professional training on use of the testing machine. Operators should wear PPE, safety glasses, boots, lab coat to avoid risk happens.