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Experimental Investigations on Mechanical Properties of Sisal Fiber Reinforced Polyester Resin Composite Material

A Thesis Submitted In Partial Fulfillment of the Requirements for the Degree of Masters of Science

In

MANUFACTURING ENGINEERING

By

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ADVISOR'S APPROVAL SHEET

To: Mechanical Design and Manufacturing Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled "Experimental Investigations on Mechanical Properties of Sisal Fiber Reinforced Polyester Resin Composite Material" submitted in partial fulfillment of the requirements for the degree of Master's in Manufacturing Engineering, the Graduate program of the department of Mechanical Design and Manufacturing Engineering, and has been carried out by Mikeale Kahsay Tikue, Id. No GSR/0094/09, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

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This Thesis entitled "**EXPERIMENTAL INVESTIGATIONS ON MECHANICAL PROPERTIES OF SISAL FIBER REINFORCED POLYESTER RESIN COMPOSITE MATERIAL"** is approved for the partial fulfillment of the requirements for the Degree of Masters of Science

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **"EXPERIMENTAL INVESTIGATIONS ON MECHANICAL PROPERTIES OF SISAL FIBER REINFORCED POLYESTER RESIN COMPOSITE MATERIAL"** in partial fulfilment of the requirements for the award of the degree of Masters of Science in Manufacturing Engineering is an authentic record of my own work carried out from November 2017 to September 2018 under the supervision of Dr. Desalegn Wogaso (Asst. Professor) Mechanical Design and Manufacturing Engineering Program, Adama science and Technology University, Ethiopia. The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been duly acknowledged.

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This is to certify that the above declaration made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval:

Dr. Desalegn Wogaso (Asst. Professor) …… ……

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ABSTRACT

Now a day plant based fiber composites may become materials to replace synthetic fiber polymer based composites due to their low cost, renewable, abundance, lightweight and less abressive …etc. Sisal fiber usually obtained from the leaves of the Agave Sisalana plant, which is largely available in Ethiopia. The main purpose of this research is to develop sisal natural fiber reinforced polyester resin composite material and investigate its mechanical properties under various experimental conditions for automotive applications. In this paper sisal fiber was collected from Arengude Bahir, extracted manually by the process of decortications from the sisal plants, and treated with 8% NaOH for further removal of lignin, hemicelluloses and other fiber remnants for the improvement of bond & interfacial shear strength of the sisal fiber. Then the test were manufactured using volume fraction of 10/90%, 20/80% and 30/70 fiber/ matrix for both treated and untreated random oriented chopped sisal fiber using hand lay-up assisted by vacuum bagging technique (HAVBT). The tensile, compression and impact properties of sisal fiber reinforced polyester composite material were investigated using sisal fiber reinforced polyester composite samples according to the ASTM standard and water absorption test was carried out. 30% treated sisal fiber polyester composite material (SFPCM) was found as a material with higher tensile strength of 50.77Mpa, 10% treated SFPCM has a higher compressive strength of 144.74Mpa, 30% treated sisal fiber polyester composite material has a higher impact resistance of 7.6 J and 30% untreated SFPCM gained higher water absorption percentage weight of 1.428g. Considering the entire mechanical and physical laboratory test obtained from the tensile, compressive, impact and water absorption results concluding that it was better to manufacture door trim panel locally in the combination ratio of 30/70% of sisal/matrix. For validation of experiment result of tensile and compressive strength, ANSYS software was used. Optical microscopy was used to evaluate and analyze the fractography information of the composite material.

Key Words: Composites, Polyester Resin, Sisal Fiber, ANSYS and Optical Microscopy

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List of Symbols and Abbreviations

ASTM	American Standard Test Methods
BC	Boundary Condition
CS	Compressive strength
CS1	Untreated 10% Fiber Compression Specimen
CS2	Untreated 20% Fiber Compression Specimen
CS3	Untreated 30% Fiber Compression Specimen
DAVI	Dejen Aviation Industry
FEA	Finite Element Analysis
FEM	Finite Element Method
GP	General purpose Polyester
IS1	Untreated 10% Fiber Impact Specimen
IS2	Untreated 20% Fiber Impact Specimen
IS3	Untreated 30% Fiber Impact Specimen
MEKP	Methyl Ethyl Ketone Peroxide
NaOH	Sodium Hydroxide
NFC	Natural Fiber Composite
PR	Polyester Resin
SF	Sisal Fiber
SFPCM	Sisal Fiber Polyester Composite Material
TCS1	Treated 10% Fiber Compression Specimen
TCS2	Treated 20% Fiber Compression Specimen
TCS3	Treated 30% Fiber Compression Specimen
TIS1	Treated 10% Fiber Impact Specimen
TIS2	Treated 20% Fiber Impact Specimen
TIS3	Treated 30% Fiber Impact Specimen
TS	Tensile strength
TS1	Untreated 10% Fiber Tensile Specimen
TS2	Untreated 20% Fiber Tensile Specimen
TS3	Untreated 30% Fiber Tensile Specimen
TTS1	Treated 10% fiber Tensile Specimen
TTS2	Treated 20% fiber Tensile Specimen

TTS3	Treated 30% fiber Tensile Specimen
TWS1	Treated 10% Fiber Water Absorption Specimen
TWS2	Treated 20% Fiber Water Absorption Specimen
TWS3	Treated 30% Fiber Water Absorption Specimen
UP	Unsaturated Polyester
Vc	Volume of Composite (cm^3)
VF	Fibers Volume Fraction
Vf	Volume of Fibers (cm^3)
Vm	Volume of Matrix (cm^3)
Wc	Weight of Composite (g)
WF	Fiber Weight Fraction
Wf	Weight of Fiber (g)
WM	Matrix Weight Fraction
Wm	Weight of matrix (g)
WS1	Untreated 10% Fiber Water Absorption Specimen
WS2	Untreated 20% Fiber Water Absorption Specimen
WS3	Untreated 30% Fiber Water Absorption Specimen
ρc	Density of Fiber (g/cm^3)
ρf	Density of Fiber (g/cm^3)
ρm	Density of matrix (g/cm^3)

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Natural fiber is defined as fibrous plant material produced as a result of photosynthesis. These fibers are sometimes referred as vegetable, biomass, photomass, phytomass, agro mass, solar mass, or photosynthetic fibers [Hari et al., 2015]. The importance of the natural fiber polymer composite is increasing in the day to day industrial and human application. Fiber reinforced polymer composites are being used in almost every type of applications in our daily life and its usage continues to grow at an impressive rate. The manufacture, use and removal of traditional composite structures usually made of synthetic fibers are considered critically because of the growing environmental pollution. It creates interest in the use of bio fibers as reinforcing components for thermoplastics and thermosets.

Sisal or sisal hemp is an agave, Agave sisalana, which grows with sword-shaped leaves about 1.5-2 m tall, is a biodegradable and environmental friendly plant. Sisal fiber (SF) is a strong, durable, stable and versatile material and it has been recognized as an important source of fiber for composites [Kumaresan et al., 2015]. It has generally accepted that the mechanical properties of fiber reinforced polymer composites are controlled by factors such as type of matrix, fiber-matrix interface, fiber volume or weight fraction, fiber aspect ratio, fiber orientation... etc. Composites reinforced with natural fibers have been received increasing interest from industries in a wide field of application such as automobile, construction, aerospace and packing.

Recently, because of their interesting properties, natural fibers are being studied as reinforcement material in composite components [Mwaikambo, 2006]. They are low cost fibers, combining very low density with high specific properties, biodegradable and nonabrasive. Unlike other reinforcing fibers, they can allow a high volume of filling in composites and are readily available.

Sisal fiber is one of the suitable plants with great potential for the production of natural fiber; there are about 300 different species of these succulent plants, which are characterized by the formation of large rosettes of thick, fleshy leaves [Arpitha et al., 2014]. The roots tend to be long to capture as much water as possible. All that water is stored in the leaves as an energy

reserve for the blossom. In the plant kingdom, agaves are the most efficient producers of biomass in water deficient conditions.

Natural fibers are received more attention to be used in automotive structural application in recent years both for external and internal components such as underbodies, seat backs, door trim panels, interior parts …etc.[Mwaikambo, 2006; Ermias, 2012]. Even though there are several factors that influence the entire product development process to realize a lightweight vehicle, from the point of view of vehicle structural design, the main governing criteria for material selection are stiffness and strength properties that will determine the overall performance of vehicle during static and dynamic loading conditions.

However, these natural fibers are associated with some challenges including high moisture uptake, low thermal stability and low bonding with polymer matrices because of incompatibility between hydrophilic natural fibers and the hydrophobic polymer matrices [Alhayat and Omprakash, 2014]. Previous studies have shown that alkali treatments have been proven effective in removing impurities from the fiber, decreasing moisture absorption and enabling mechanical bonding, and thereby improving matrix-reinforcement interaction and mechanical properties. In order to obtain these improved properties of SF reinforced polyester resin, the extracted Sisal fiber is treated by sodium hydroxide solution.

The aim of this research was to fabricate composite material with different fiber/matrix ratio and mechanical property characterization of sisal fiber reinforced polyester composite to have the alternative materials for automotive industry.

1.2. Statement of the Problem

The use of the natural fiber composite materials for automotive application has been continuously increasing in the recent decades due to their advantageous properties when compared with the synthetic composite materials. In Ethiopia, also there is a significant development in automotive industries in the last two decades, which incorporates assembling of different types of automobile vehicles in both governmental and privatized industries. However the automobile body parts are not manufactured here in Ethiopia rather they have been imported from other countries of vehicle manufacturing industries particularly China. Nevertheless, some fiber composite body parts are manufacturing here in Ethiopia by Dejen aviation industry (DAVI) in the fiber workshop department. However, the fiber input for this

industry is imported synthetic fibers for the fabrication of lightweight automotive body parts. Conversely, the drawbacks of the synthetic fiber composite are high abrasive wear on processing machinery, high production cost, heavy weight than natural fiber, health risks among people who work around it and environmental pollution during the disposal of the used composite material.

Therefore, this paper was conducted in order to fill this research gap, which occurs on the composite manufacturer here in DAVI, by the use of Sisal fiber reinforced polyester composite material for the production of door trim panels for Automotive body parts in the country. This paper tries to replace synthetic fiber composite by sisal natural fiber composite in Dejen aviation industry (DAVI) which contributes directly to the Automotive industry in Ethiopia and expand opportunities for the rural people as the sisal fiber can be produced domestically in Ethiopia.

1.3. Objective of the Research

1.3.1. General Objective

The general objective of this research is to develop sisal fiber reinforced polyester resin composite material and investigate its mechanical properties under various experimental conditions.

1.3.2. Specific Objectives

The specific objectives of the research are:

- To effectively extract sisal fiber from sisal plant leaves.
- To design and fabricate molds for composite production
- To fabricate the composite materials for different experimental condition.
- To experimentally investigate and study the effect of fiber weight fraction on mechanical behavior (tensile strength, compressive strength and impact strength) of sisal natural fiber polymer composite material.
- To Modeling and simulating the composite specimen on ANSYS for validation of experimental results.
- To experimental investigate and study the effect of fiber volume fraction on water absorption behavior of the composite material.
- To analysis microstructure of the composite using optical microscope.

1.4. Scope of the Research

This study experimentally discovers the feasibility of using sisal fiber reinforced polyester composite in automotive industry for development of lightweight, strong and ecofriendly materials. The study was focused in some processing variables like fiber weight fraction, fiber orientation and concentration of alkali used in fiber modifications. For this study, chopped random fiber orientation with 8% alkali treated and untreated fiber, three variable weight fractions 10%, 20% and 30% of the SFPCM and optical microscope were used to evaluate the mechanical properties and microstructural details of the composite material.

1.5. Limitation of the Study

The study was limited to fibers from leaves that was manually harvested from only one location. The study employed only the decortications process to extract the fibers. Evaluation on the effect of mechanical properties of fibers was limited to some selected properties. There is no highly competitive testing laboratory setup for the characterization of natural fiber composite and there is no workshop for the fabrication of composite material. Due to unavailability of the material chopping machine chopping of the fiber was made manually to the required fiber length.

1.6. Significance of the Research

The demand of replacing glass fibers with natural fibers in composite materials is increasing. The achievement of natural fiber composites (NFCs) depends on their ability to overcome their main disadvantages of low fiber/matrix adhesion, fluctuations in fiber properties, low thermal and fire resistance and the possibility of using well-studied processing techniques. Replacing synthetic fiber with natural fiber has significant implication in the composite material sector .It means that natural fiber is lightweight in automotive body parts, there will be a wide market for farmers that can harvest the natural fiber and small scale workshop that can produce parts made from composite materials. Ethiopia has good opportunity to cultivate sisal plant widely. The resource is available and can manufacture automotive vehicle interior parts in Ethiopia and improve efficiency of the products of automotive vehicle internal accessories. This will solve large amount of unemployment in Ethiopia by creating job opportunity and source of income for rural/agricultural community.

1.7. Organization of the Thesis

This thesis is organized in five chapters.

Chapter 1: describes the introduction part of the study mainly, the background of natural fiber composite materials, general and specific objectives, problem statement, scope, significance and limitations.

Chapter 2: reports about the literature review on composite materials regarding natural fiber composite materials, ranging from polymer types, fiber types, and composites chemical, mechanical properties. Previous research works on mechanical properties of natural fiber reinforced composite materials are deeply reviewed and presented in this chapter.

Chapter 3: deals with the experimental setups, which focused on materials used, test specimen preparations, experimental methods, conditions and the experimental plan for investigation of impact, tensile, compressive and water absorption properties of SFPCM.

Chapter 4: presents about results and discussion of the research work focusing on presenting the results of characterization of composite material.

Chapter 5: is dedicated to presenting conclusions and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Strong emphasis on environmental awareness has been brought the development of recyclable and environmentally sustainable composite materials since the last decade. Environmental legislation as well as consumer demand in many countries are imposing higher pressure on manufacturers of materials and products. They have to consider the environmental impact of their products at all stages of their life cycle, including recycling and ultimate disposal [Srinivasakumar et al. 2013; Gironès et al. 2012]. These environmental issues have recently generated considerable interest in the development of recyclable and biodegradable composite materials. Therefore, research in the field of using natural fibers has fascinated much attention in the material science and engineering discipline.

Natural fiber is certainly a renewable resource that can be grown and made within a short period of time, in which the supply can be unlimited when compared with traditional glass and carbon fiber for making progressive composites [Gironès et al. 2012]. This natural fiber mixing with polymers can produce new class of materials in bio-medical application and lightweight structural application.

The dissimilarity in mechanical properties of natural fibers is due to the conditions during growth. Depending on the extraction process, the chemical composition, fiber shape, fiber strength, flexibility, and ability to adhere to other fibers or matrix differ widely between different types of woods [Srinivasakumar et al. 2013]. This makes it difficult to predict the mechanical properties of the natural fiber reinforced composites.

2.2. Diversity and Utilization of Sisal Plant

The genus Agave possesses over 300 species where all of them are native to tropical and subtropical North and South America [Donald et al., 2005] .Even if agaves are tropical by origin; there are very few commercial plantations outside the Tropics. Century plant (Agave Americana) and sisal (Agave Sisalena) are among such agaves. They grow from sea level to mountains over 8000 feet above sea level. Agaves have been used for food,

drink, soap, clothing, rope and other fibers, needles and thread, paper, glue, medicines, red coloring matter, and as ornamental and hedge plants.

Sisal (Agave Sisalena) is a perennial succulent crop with good growing conditions forms an inflorescence after 6-9 years after producing 200-500 leaves and then it dies [Laird 2012; Donald et al. 2005]. Leaves arranged spirally around the thick stem and their average length is about 120 cm. Sisal has a shallow root system but it extends up to 3.5 m from the stem. Long fibers (greater than 90 cm long) used for ropes and binder twine. Approximately, 25% of fibers are shorter (flume tow and tow fiber) and these are used for padding, mat and stair carpet, paper, and building panels.

2.3. Composite Materials

Currently the need for a material with lightweight and high performance is increasing day to day [Autar, 2006]. The performance of material is limited when it is made from only one composition. Therefore, there have to be a new material with high performance, when it made from two or more conventional materials. A composite materials are structural materials in which two or more distinct materials are combined together with different chemical or physical properties, which remain separate and distinct within the finished structure or remain uniquely identifiable in the mixture, having strong fibers surrounded by a weaker matrix material.

In general, the composite materials consist of a matrix phase and reinforcing phase. The matrix phase materials are generally continuous and its serves to distribute the fibers and to transmit the load to the reinforcing phase material. Whereas the reinforcing phase material may be in the form of fibers, particles, or flakes and it is continuous or discontinuous [Autar, 2006]. Natural fibers were used for reinforcing the matrix until early in to the mid-20th century. However, since 1950 there was an increased demand for stronger and stiffer, yet lightweight, composites, in fields such as aerospace, transportation and construction. This led to the incorporation of high performance fibers for reinforcement. These newer composites have low specific gravity, superior strength and modulus when compared to the traditionally engineering materials like metals [Autar, 2006; Daniel et al., 2003]. According to [Autar, 2006; Daniel et al. 2003] generally composite materials are classified and related to constituents as showed according to reinforcement used in Figure 2.1.

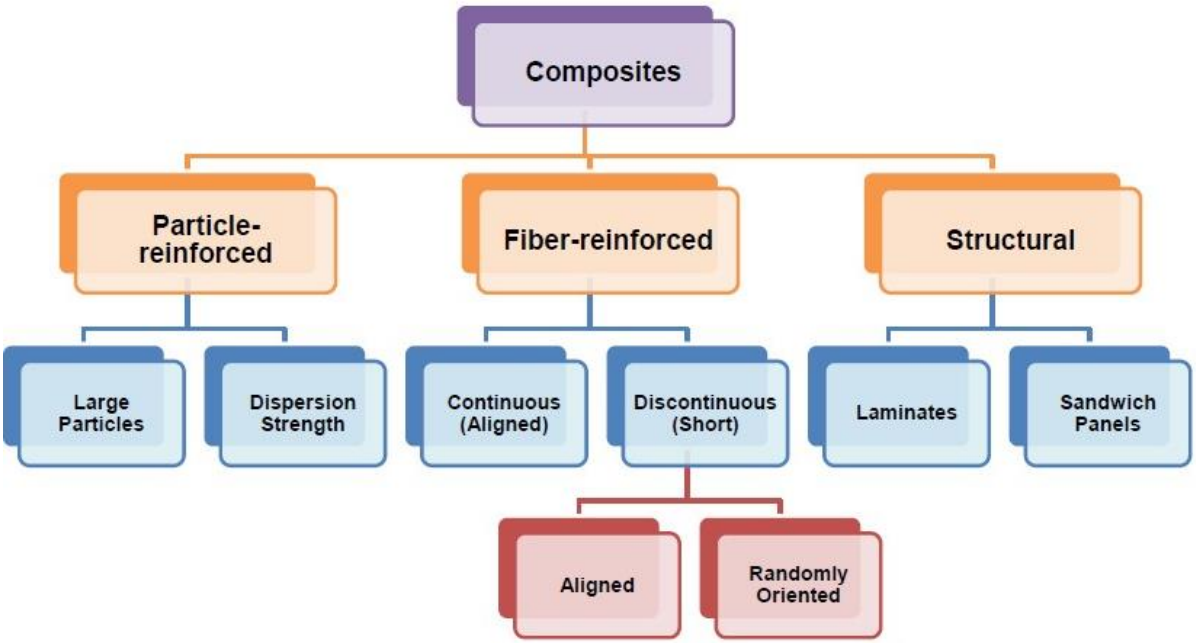


Figure 2.1 Composite materials classification [Autar, 2006; Daniel et al. 2003]

2.4. Fiber Reinforced Composites

Fiber-reinforced composite materials are mainly consist of fibers as reinforcement and matrix materials [Mohd et al. 2015]. The role of matrix resin is to keep the fibers in a desired location and orientation and acts as a binder for the fiber. The common matrix materials include epoxy, phenolic, polyester, polyurethane, polyetherethrketone (PEEK), vinyl ester …etc. In general, fibers are the principal load-carrying members, while the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages due to elevated temperatures, humidity, pressure …etc.

The laminas of the composite are constructed either by continuous (long) or discontinuous (short) fibers as shown in below figure 2.2 [Mallick, 1993]. The continuous fibers are arranged either in a unidirectional orientation (i.e. all fibers in one direction), in a bidirectional orientation (i.e., fibers in two directions, usually perpendicular each other), or in a multidirectional orientation (i.e. fiber in more than two direction). For a lamina containing unidirectional fibers, the composite material has the highest strength and modulus in the longitudinal direction of the fibers. However, in the transvers direction, its strength and modulus are very low. For a lamina containing bidirectional fibers, the strength and modulus can be varied using different amounts of fibers in the longitudinal and transverse directions. For a balanced lamina, these properties

are the same in both directions. The discontinuous (short) fibers arranged is in the random orientation.

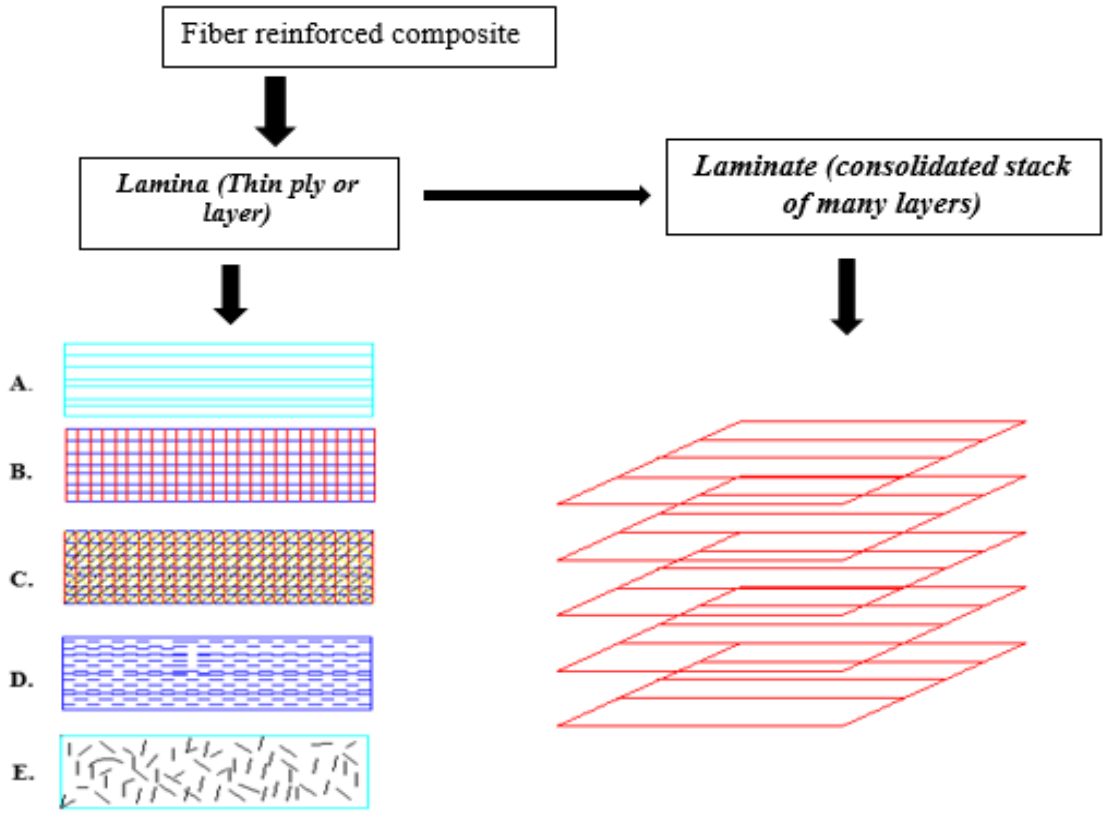


Figure 2.2 Fiber reinforced composite materials sub classification: (A) Unidirectional continuous fibers (B) Bidirectional continuous fibers (C) Multidirectional continuous fibers (D) Unidirectional discontinuous fibers (E) Random discontinuous [Mallick, 1993]

2.5. Natural Fibers

Examples of natural fibers are jute, flax, hemp, sisal, coconut fiber (coir), and banana fiber (abaca) [Mohanty et al. 2001]. All these fibers are grown as agricultural plants in various parts of the world and are commonly used for making ropes, carpet backing, bags, and so on. The components of natural fibers are cellulose micro- fibrils dispersed in an amorphous matrix of lignin and hemicellulose. Depending on the type of the natural fiber, the cellulose content is in the range of 60–80 wt% and the lignin content is in the range of 5–20 wt% [Garkheil et al. 2000]. In addition, the moisture content in natural fibers can be up to 20 wt.%. Natural fibers are renewable, cheap, completely or partially recyclable, biodegradable, and environment friendly materials. This is a new generation of reinforcements and supplements for polymer-based materials. Fibers from plants such as cotton, hemp, jute, sisal, pineapple, ramie,

bamboo, banana …etc., as well as wood and seeds of flax used as the reinforcement in polymer matrix composites. Their availability, low density and price as well as satisfactory mechanical properties, make them attractive alternative reinforcements to glass, carbon and other manmade fibers. The greatest problem of the synthetic fibers is that they are non-degradable, cannot be burned nor recycled and hence, they pose serious threat to the environment at the end of their service life. Recent trend towards environmentally friendly polymer composite systems have been focusing on the use of lingo-cellulosic (natural) fibers such as flax, hemp, sisal, jute, coil, oil palm and waste silk …etc. as replacements for glass fibers [Mohanty et al. 2015; Garkheil et al. 2000].

Natural fibers offer economical and environmental advantages over traditional inorganic reinforcements and fillers [Mohanty et al. 2001]. The growing interest in using natural fibers as a reinforcement of polymer-based composites is mainly due to their advantages such as low cost, renewability, acceptable specific properties, lower density, ease of preparation, lower energy requirement for processing, biodegradability, wide availability and relative non-abrasiveness over traditional reinforcing fibers such as glass and carbon.

2.6. Classification of Natural Fibers

Fibers are a class of hair-like material that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread [Chandramohan and Marimuthu, 2011]. They can spin into filaments, thread, or rope. They can use as a component of composites materials. They can also matted into sheets to make products such as paper or felt. Fibers are of two types: natural fiber and manmade or synthetic fiber. Classification of natural fibers shown in below figure 2.3.

2.6.1. Sisal Plant

Sisal or sisal hemp (Scientific name is agave sisalana) is an agave. Agave sisalana of Agavaceae (Agave) that yields a stiff fiber that traditionally used in making rope [Chandramohan and Marimuthu, 2011]. Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, west

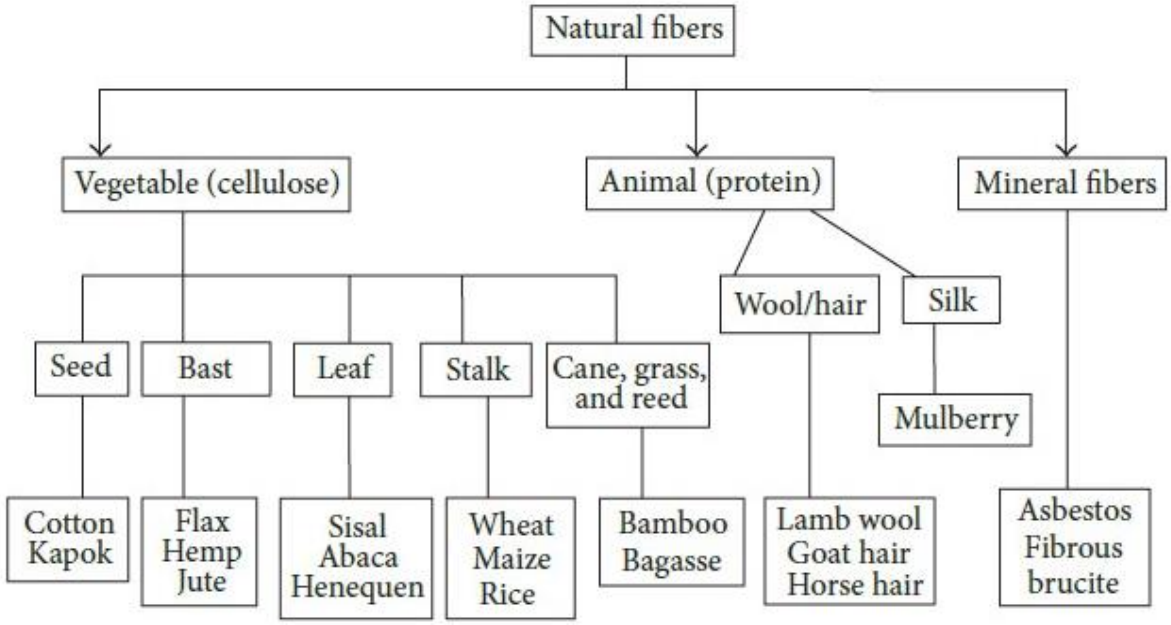


Figure 2. 3 Classification of natural fiber [Chandramohan and Marimuthu, 2011]

Indies and the Far East region. The sisal plant has a 7-10 year life span and typically produces 200-250 commercially usable leaves. A sisal leaf weighing about 600 g will yield about 3% by weight of fiber with each leaf containing about 1000 fibers. Each leaf contains fiber bundles, which is composed of 4% fiber, 0.75% cuticle, 8% dry matter and 87.25% water [Wilson, 1971]. It is grouped under the broad heading of the "hard fibers" among which sisal is placed second to manila in durability and strength [Weindling, 1992].The other important feature of sisal plant is that its cultivation process is very ease and also it can grow in all kinds of environment. Generally, sisal plant classified in to three as shown in figure 2.4 below.

2.6.2. Sisal Fiber

Sisal fiber having its scientific name as Agave sisalana is cultivated widely in high land areas [Weindling, 1992]. It is obtained or extracted from the leaves of sisal plant called Agave sisalana, which was originated from Mexico, and is now mainly cultivated in east Africa, Brazil, Haiti, India and Indonesia. It is a kind of natural fiber, which possesses high specific strength and modulus, low price, recyclability, easy availability. Using sisal fiber as reinforcement to make sisal fiber reinforced polymer composites has aroused great interest of materials scientists and engineer all over the world. Many researchers have been done in recent years, which include

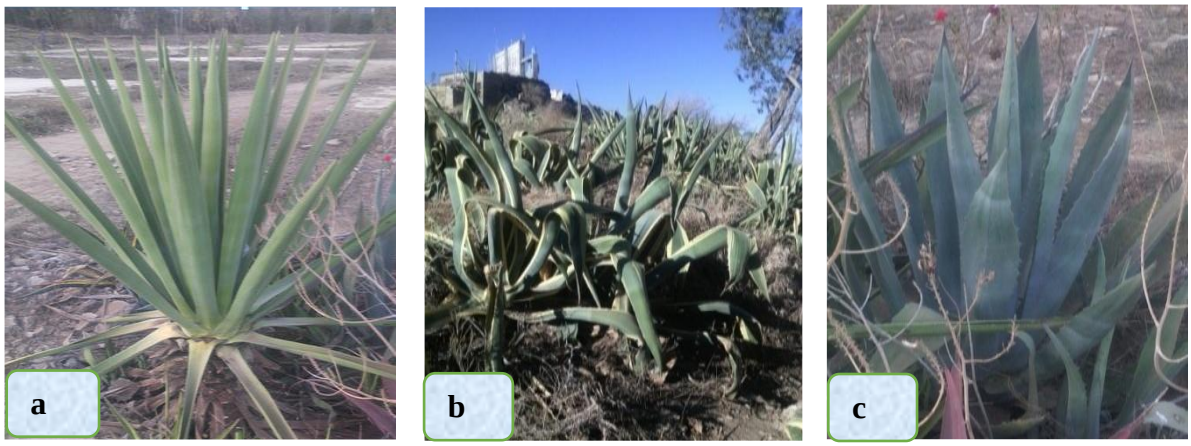


Figure 2. 4 Types of sisal plant: (a) normal leaf length sisal (b) long leaf sisal (Agave Americana) (c) moderate leaf length sisal [Weindling, 1992]

the study of mechanical properties of the composites, finding an efficient way to improve the interfacial bonding properties between sisal fiber and polymeric matrices and fiber surface treatment on the mechanical performance of the composites [Kuruvilla et al. 1999].

The chemical compositions of sisal fibers have been reported by several groups of researchers for example [Wilson, 1971] indicated that sisal fiber contains 78% cellulose, 8% lignin, 10% hemi-celluloses, 2% waxes and about 1% ash by weight; but [Rowell, 2005] found that sisal contains 43-56% cellulose, 7-9% lignin, 21-24% pentosan and 0.6-1.1% ash. More recently, [Joseph et al. 1996] reported that sisal contains 85-88% cellulose. These large variations in chemical compositions of sisal fiber are a result of its different source, age, measurement methods …etc. Indeed, [Chand and Hashmi, 1993] showed that the cellulose and lignin contents of sisal vary from 49.62-60.95 and 3.75-4.40%, respectively.

Depending on the age of the plant the length of sisal fiber is between 1.0 and 1.5 m and the diameter is about 100-300 mm. The fiber is actually a bundle of hollow sub-fibers. Their cell walls are reinforced with spirally oriented cellulose in a hemi-cellulose and lignin matrix. So, the cell wall is a composite structure of lignocellulose material reinforced by helical micro fibrillary bands of cellulose. The composition of the external surface of the cell wall is a layer of ligneous material and waxy substances, which bond the cell to its adjacent neighbors'. Hence, this surface will not form a strong bond with a polymer matrix. In addition, cellulose is a hydrophilic glycan polymer consisting of a linear chain of bonded hydro glucose units [Weindling, 1992] and this large amount of hydroxyl groups will give sisal fiber hydro-philic properties. This will lead to a very poor interface between sisal fiber and the hydrophobic matrix

and very poor moisture absorption resistance. The extracted sisal fiber from sisal plant is shown in figure 2.5.

Figure 2. 5 A typical view of extracted sisal fiber [Weindling, 1992]

2.7. Extraction of sisal Fiber

The sisal plant leaves are harvested from the field for fiber extraction [Carter, 1994]. Various methods can be employed to extract fibers from the source material. Some of the sisal-extracted methods are described below.

2.7.1. Mechanical Method

In the mechanical decoration process, leaves are crushed and beaten by a rotating wheel set with blunt knives, so that only fibers remain [Ashish et al., 2015]. Some decorticators are fed by hand and the pulp is first scraped from half of a leaf, the leaf is withdrawn, and then the opposite half is inserted for scraping. In some machines, the whole leaf is decorticated in single insert. Figure 2.6 shown a sectional view of the most important parts of fiber stripper/decorticator. Agave plant leaf is fed through the mouthpiece, and then it passes through the fluted feed rollers, which hold the leaves as they are fed in against a stationary bar, while the stripping drum is beating out the vegetable matter as the leaf passes between it and the beater bar. The stripping drum diameter, width and speed vary according to different makes. The drum, scraping against the leaf, held in position by the beating bar and feed rollers beats off the bulk of the vegetable matter and leaves the fibers somewhat roughened and with a residue of vegetable matter remaining upon it.

After completion of decortications and washing, the fibers are dried either with mechanical driers or in the sun. The operations of fiber removal, washing and drying must be done promptly after the leaves are cut, otherwise the gums in the leaves harden, causing the pulp to adhere with the fibers and making it difficult to clean the fibers properly [Carter, 1994]. Mechanical extraction methods are not efficient in the removal of cementing compounds (mostly waxes, hemicelluloses, lignin and hydrocarbons) between fibers [Ashish et al. 2015].

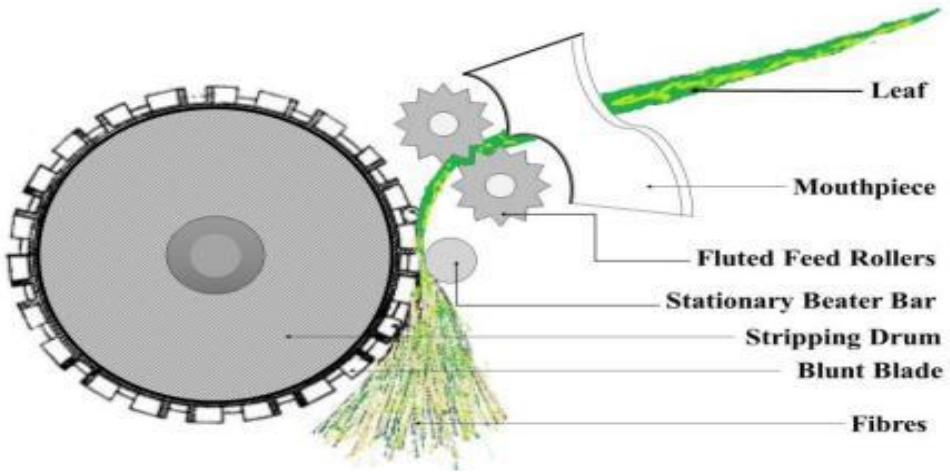


Figure 2. 6 Extraction of sisal fiber by mechanical decortication method [Ashish et al. 2015]

2.7.2. Retting Process Method

Retting is a well-studied method of extraction of fibers by a natural microbial process. Retting involves the degradation of non-fibrous matter, which acts as glue between the fibers in woody plant parts and fibers without damaging the fiber cellulose [Ehrensing, 2014]. This process allows easy separation of individual fiber strands and the woody core. Since retting is a biological process, it requires both moisture and a warm temperature for microbial action to occur.

2.7.3. Natural Retting Method

It is a preferential rotting process to separate the fiber from lignocelluloses biomass without damaging the fiber cellulose. Retting is the microbial freeing of plant fibers from their surroundings [Mignoni, 1999]. The process takes up to three weeks. Retting microbes consume the non-fibrous cementing materials mainly pectin and hemicelluloses. This gradually softens the leaves by the destruction of the less resisting intercellular adhesive substances. When fermentation has reached the appropriate stage, the fibers can be separated quite easily from the

leaves. If retting process is allowed beyond this point, fibers decline in quality. Under retting causes incomplete removal of gummy materials such as pectin substances, and extraction of fiber becomes difficult [Salit, 2014].

Hence, the progress of retting must be observed carefully at intervals to avoid fiber damage [Mignoni, 1999]. However, the natural retting takes more time, the process is economical. There are two traditional types of retting include water retting and field or dew retting. In water retting, plant leaves are immersed in water (river, pond or tanks). In field or dew retting, the crop is spread in the field where rain or dew provides moisture for retting. Water retting produces fibers of greater uniformity and higher quality than fibers extracted by field retting.

2.8. Applications of Natural Fiber Composites in Automotive Industry

Recently, natural fiber-reinforced polymers have created interest in the automotive industry for the following reasons. The applications in which natural fiber composites are now used include door inner panel, seat back, roof inner panel, and so on. [Madhukiran et al. 2013]

- They are environment-friendly, meaning that they are biodegradable, and unlike glass and carbon fibers, the energy consumption to produce them is very small.
- The density of natural fibers is in the range of 1.25_1.5 g/cm^3 compared with 2.54 g/cm^3 for E-glass fibers and 1.8–2.1 g/cm^3 for carbon fibers.
- The modulus–weight ratio of some natural fibers is greater than that of E-glass fibers, which means that they can be very competitive with E-glass fibers in stiffness-critical designs.
- Natural fiber composites provide higher acoustic damping than glass or carbon fiber composites, and therefore are more suitable for noise attenuation, an increasingly important requirement in interior automotive applications.
- Natural fibers are much less expensive than glass and carbon fibers [Madhukiran et al. 2013]

Generally, the uses of the natural fiber for automotive industries in different countries are dramatically increasing in the last decade. The main reason includes its low density (which may lead to weight reduction of 10 to 30%), good mechanical properties, favorable processing properties, and favorable accident performance. In addition, they are high stability, favorable Eco-balance for part production, favorable Eco-balance during vehicle operation due to weight savings, occupational health benefits compared to synthetic fibers during production, price

advantages for both the fibers and the applied technologies …etc. [Loan, 2005]. Some application of natural fiber in the automotive body parts has been exposed in the figure 2.7 below.

However, there are some limitations of natural fibers [Abiy, 2013]. The tensile strength of natural fibers is relatively low. Among the other limitations are low melting point and moisture absorption. At temperatures higher than 200^{o}C, natural fibers start to degrade, first by the degradation of hemicellulose and then by the degradation of lignin. The degradation leads to odor, discoloration, release of volatiles, and deterioration of mechanical properties.

Therefore, in order to improve the adhesion between the matrix and the fibers, several studies have shown the influence of various types of chemical modifications on the performance of natural fibers and fiber reinforced composites [Seenivasa and Karthicks, 2014; Vieira et al., 2012]. Therefore, in order to improve the adhesion between the matrix and the fibers, several

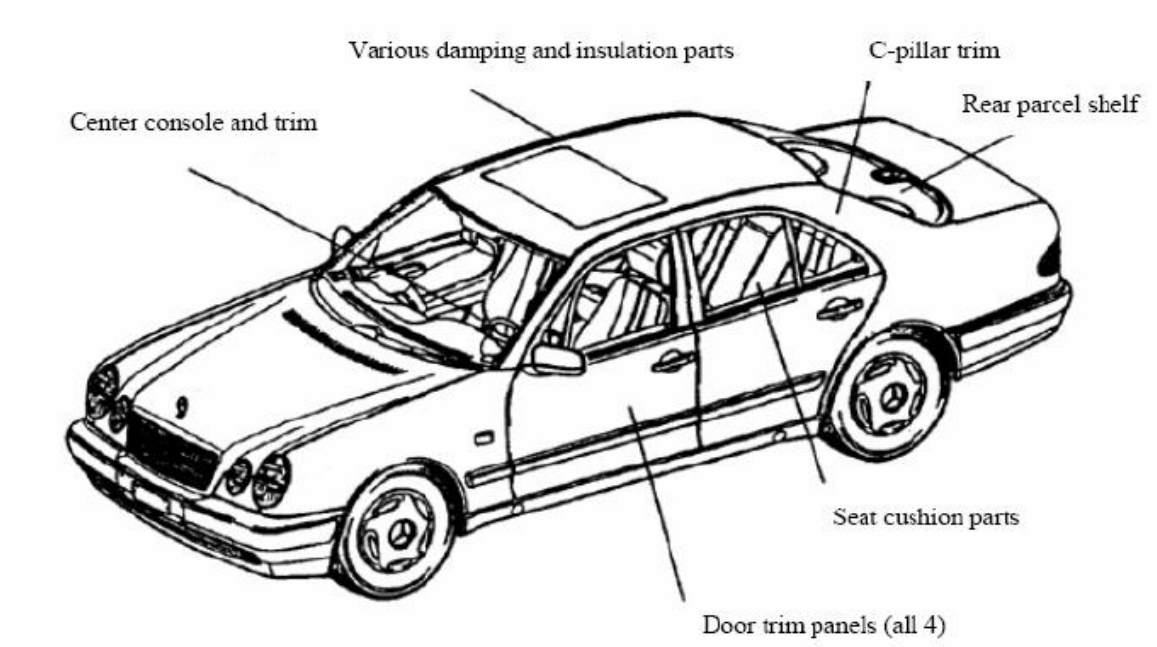


Figure 2. 7 Plant fiber applications in the current Mercedes-Benz R-class [Loan, 2005]

studies have shown the influence of various types of chemical modifications on the performance of natural fibers and fiber reinforced composites [Seenivasa and Karthicks, 2014; Vieira et al., 2012]. The different surface chemical modifications of natural fibers such as alkali treatment, silane treatment, isocyanate treatment, latex coating, permanganate treatment,

acetylation, monomer grafting under UV radiation, etc. have achieved various levels of success in improving fiber strength and fiber/matrix adhesion in natural fiber composites.

2.9. Basic Constituents of Composites

2.9.1. Matrix

The roles of the matrix in a fiber -reinforced composite are [Sanjay and Mazumdar, 2002]:

- to keep the fiber s in place
- to transfer stresses between the fibers,
- to provide a barrier against an adverse environment, such as chemicals and moisture, and
- To protect the surface of the fibers from mechanical degradation (e.g., by abrasion).

The matrix plays a major role in the tensile load -carrying capacity of a composite structure [Valadez et al. 1999]. In addition, selection of a matrix has a major influence on the compressive, inter laminar shear as well as in-plane shear properties of the composite material. The matrix provides lateral support against the possibility of fiber buckling under compressive loading, thus influencing largely, the compressive strength of the composite material.

The processing and defects in a composite material depend strongly on the processing characteristics of the matrix. For example, for epoxy polymers used as matrix in many aerospace composites, the processing characteristics include the liquid viscosity, the curing temperature, and the curing time [Naveen et al. 2015]. Various matrix materials have been used either commercially or in research. Among these, thermoset polymers, such as epoxies, polyesters, and vinyl esters, are more commonly used as matrix material in continuous or long fiber-reinforced composites, mainly because of the ease of processing due to their low viscosity. Thermoplastic polymers are more commonly used with short fiber -reinforced composites that are injection-molded; however, the interest in continuous fiber reinforced thermoplastic matrix is growing. Metallic and ceramic matrices are primarily considered for high temperature applications [Valadez et al. 1999]. Figure 2.8 blow showed that the broad classification of matrix materials.

2.9.2. Reinforcement

The purpose of the reinforcement in a composite material is to increase the mechanical properties of the neat resin system [Ashik and Sharma, 2015]. All of the different fibers used in composites have different properties and so affect the properties of the composite in different ways. For most of the applications, the fibers need to arrange into some form of sheet, known as a fabric, to make handling possible.

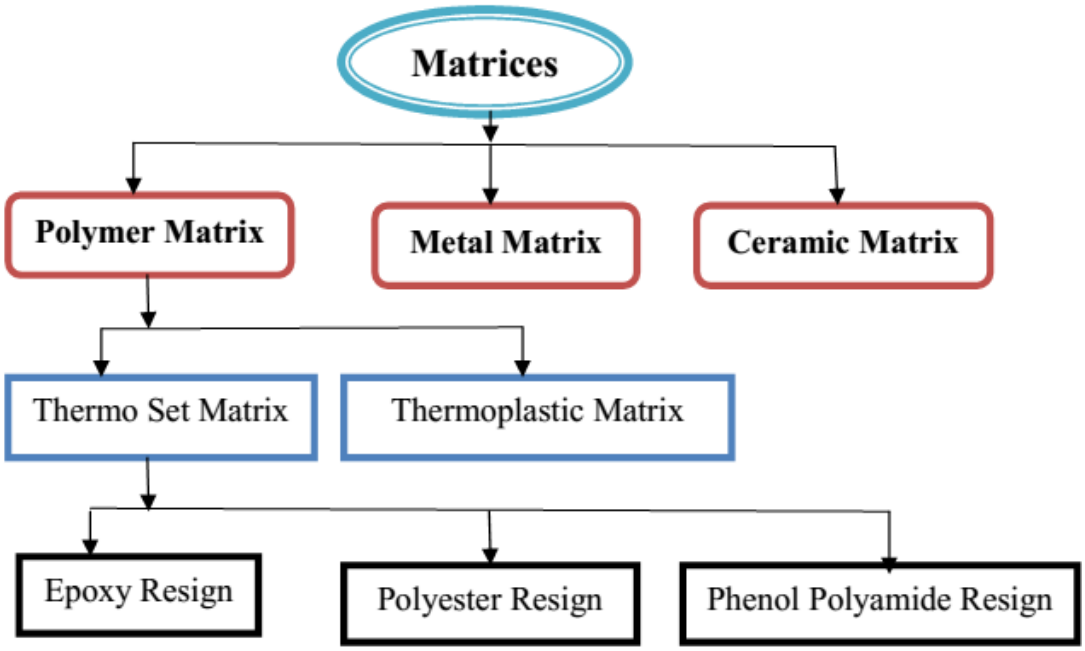


Figure 2. 8 Classification of matrixes [Valadez et al., 1999]

2.10. Composite Fabrication Techniques

The fabrication technique of a composite part depends mainly on three factors [Sabu et al. 2012]:

- The characteristics of matrices and reinforcements,
- The shapes, sizes and engineering details of products, and
- End uses.

The composite products are too many and cover a very wide domain of applications ranging from an engine valve to an aircraft wing. The fabrication technique varies from one product to the other. Some common composite fabrication processes are described as below.

2.10.1. Hand Lay-Up Technique

Hand lay-up is the oldest simplest, and the most commonly used method for the manufacture of both small and large reinforced products as shown in figure 2.9. Hand lay-up is an open molding process to produce polymer composite product. A flat surface, a cavity or a positive-shaped mold, made from wood, metal, plastic, or a combination of these materials may used for the hand lay-up method.

A mould release agent is applied onto the mould surface for ease of removing of finished composite products. The laying-up of a component begins with applying gel coat to the mould surface [Sabu et al. 2012]. It is resin-rich layer and the purpose is to prevent the fibres appearing on the mould surface. The composites are then prepared by placing a fibre reinforcement and by adding polymer resin onto it. A roller is used to consolidate the composites and the composites are made layer by layer. The process is repeated with more layers until the desired thickness is obtained. Then the composites are cured at room temperature or in an oven. Thermosetting resins like unsaturated polyester, vinyl ester, and epoxy are among the most commonly used resins.

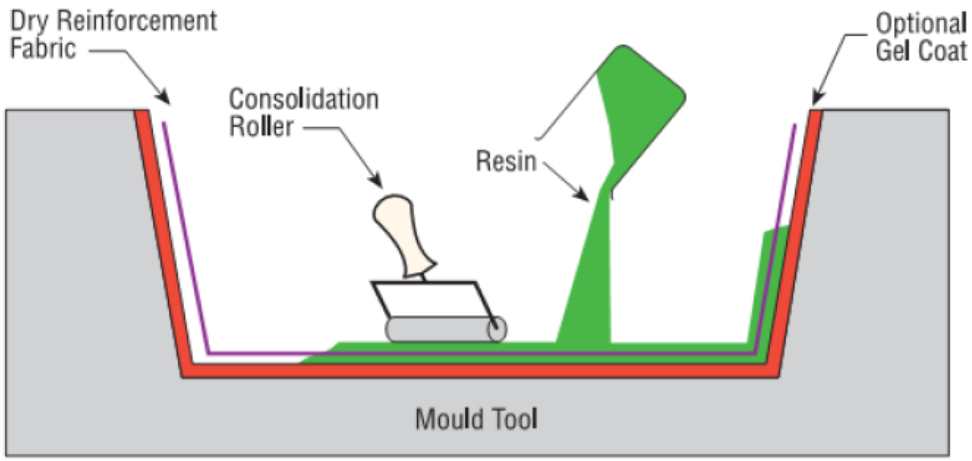


Figure 2. 9 Hand layup technique [Sabu et al. 2012]

2.10.2. Compression Molding

Compression molding is closed mold process done with matched metal molds utilizing. Sheet moulding compound (SMC) and bulk moulding compound (BMC) are two widely used thermosetting-based moulding compounds [Sabu et al. 2012]. A weighed charge of SMC or BMC, or a perform of glass reinforcement shaped to the mold is placed on a press ranging in

size from 300 to 4,000 tons. Resin is added with the preform while SMC and BMC contain all components including fiber, resin, fillers, catalyst etc. Heat and pressure is applied, with temperature ranges of 225 to 325 ^{o}F and 150 to 1,000 psi pressure required curing parts. Cycles can range from less than one to five minutes. Typical thermoset resins used in compression molded parts are polyesters, vinyl esters, epoxies, and phenolic. Compression molded products vary from dinnerware, trays, buttons, appliance housings, large containers, electrical, to recreational vehicle body panels such as snow mobiles, and jet skis.

2.10.3. Pultrusion

Pultrusion is a closed molding process combination of two words: pull and extrusion. The process is similar to extrusion process, but in pultrusion, the product is developed by pulling the materials rather than pushing the materials through the die as in the case of extrusion [Sabu et al. 2012]. Continuous fiber roving or tapes are pulled by means of a puller through a resin bath of thermosetting polymer. Examples of thermosetting polymers that can be used in this process include epoxy and unsaturated polyester. The resulting impregnated fiber composites leave the resin bath and are being pulled and passed through a series of forming dies. The shape of the final product follows the shape of the cross of the dies and the shape can be circular, rectangular, square, and I-shaped and H-shaped sections. The composite is also cured in one of the dies. The end products are normally in the form of rods and bars. At the end of the pultrusion process, the products are cut to the required lengths.

2.10.4. Filament Winding

Filament winding is a composite manufacturing process to produce components that are normally circular in shape [Sabu et al. 2012]. It is a technique used for the manufacture of surfaces of revolution such as pipes, tubes, cylinders, and spheres and frequently used for the construction of large tanks and pipe work for the chemical industry. High-speed precise lay down of continuous reinforcement in pre described patterns is the basis of the filament winding method.

2.10.5. Resin Transfer Molding

Resin transfer molding (RTM) is a low-pressure closed molding process for moderate volume production quantities, filling the gap between the slow, contact molding processes and the faster, compression molding process, which requires higher tooling costs [Sabu et al. 2012]. Continuous strand mats and woven reinforcement is laid up dry in the bottom mold half.

Preformed glass reinforcements are often used for complex mold shapes. The mold is closed and clamped, and a low viscosity, catalyzed resin is pumped in, displacing the air through strategically located vents. Metered mixing equipment is used to control resin/catalyst ratios that are mixed through a motionless/static mixer and injected into the mold port. Common matrix resins include polyester, vinyl ester, epoxy, and phenolic.

2.10.6. Spray-Up

Spray-up at it illustrated in figure 2.10 below is an open mold method that can produce complex parts more economically than hand lay-up [Sabu et al. 2012]. Chopped fiberglass reinforcement and catalyzed resin, and in some cases, filler materials, are deposited on the mold surface from a combination chopper/spray gun. Rollers or squeegees are used to manually remove entrapped air and work the resin into the reinforcements. Woven fabric or woven roving is often added in specific areas for greater strength. General purpose, room temperature cure polyesters are usually used to produce such parts as truck camper shells and tub & shower stalls. As in hand lay-up, gel coats are used to produce a high quality colored part surface.

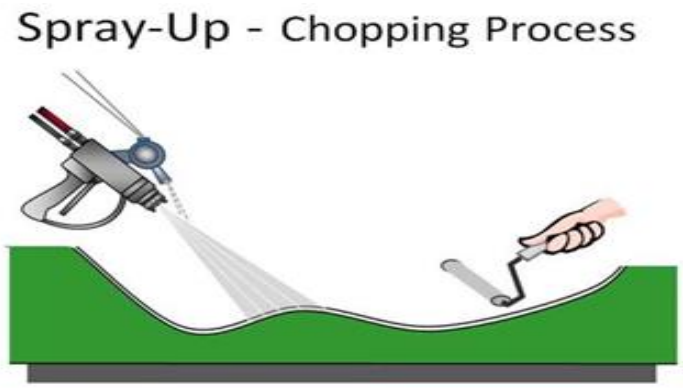


Figure 2. 10 Spray-up technique [Sabu et al. 2012]

2.11. Previous Research Works Regarding Natural Fiber Composites

Several research works have been conducted on the investigations of mechanical behavior of natural fiber reinforced composite materials. Some of them are reviewed as follows:

Hari et al. (2015) investigated on mechanical properties of epoxy composite using short sisal fiber resulted shown that maximum tensile strength. In the same way, they have observed that

sisal mixture composites sample is capable having maximum flexural strength, and maximum impact strength was obtained for the sisal fiber composite.

Ranganna et al. (2012) and Goswami el al. (2013) developed sisal natural fiber composites with and without silica by incorporating 100% biodegradable sisal fibers as reinforcement in the polyester matrix. The results showed that the tensile strength and tensile modulus of composites with silica are 1.5 and 1.08 times greater than that of composite without silica respectively. The impact strength of composite with sand 1.36 and 1.8 times greater than that of composites without silica and plain polyester, respectively.

Joseph et al. (1999) have surveyed the research work published in the field of sisal fiber reinforced polymer composite. In this paper, authors have highlighted the tensile strength of sisal, coir and banana fiber and it is found that sisal fiber has better tensile strength compared to other two fibers. Sisal fibers have good potential as reinforcements in polymer (thermoplastics, thermo sets and rubbers) composites.

Joshi et al. (2004) compared life cycle environmental performance of natural fibre composites with glass fibre reinforced composites and found that natural composites are environmentally superior in the specific applications studied.

Shah and Lakkad, (1981) tried to compare the mechanical properties of jute reinforces and glass-reinforces and the result shows that the jute fibres, when introduced into the resin matrix as reinforcement, considerably improve the mechanical properties, but the improvement is much lower than that obtained by introduction of glass and other high performance fibres.

Ray et al. (2001) conducted research work on alkali treatment to jute fibres with 5% NaOH solution for 0,2,4,6 and 8 hrs at 30^0 C. It was found that there is improvement in properties for both fibres and reinforced composites. The fibres after treatment were finer having less hemi cellulose content, increased crystallinity, reduced amount of defects resulting in superior bonding with the vinyl ester resin.

Dash et al. (2013) worked epoxy resin with jute and bamboo fibre. The tensile and compressive properties of the composite were calculated and effect of orientation of fibre on the tensile properties determined and found that tensile properties of jute was less than the bamboo and vice-versa for compressive properties. The fibre orientation of composite affects the tensile properties and found maximum tensile properties for orientation angle 0°/90°.

Oksman et al. (2002) studied the effect of fiber loading with epoxy polymer. When the volume fraction of sisal fiber is significantly increased the tensile strength and Young's modulus of the epoxy composites increase. At 46% sisal fiber volume fraction the composite showed maximum Young's modulus and tensile strength.

Idicula et al. (2005) reported the mechanical performance of short randomly arranged banana and sisal inter crossed (hybrid) fiber strengthened polyester composites. With reference to the relative volume fraction of those two fibers, at a consistent aggregate fiber stacking of 0.40 volume fractions, keeping banana as the skin material and sisal as the centre material, the impact strength of the composites were increased with fiber stacking. The tensile and flexural properties of particular composite were observed to be better at 0.40 volume fraction.

After reviewing the existing literature available on natural fiber composites, it is observed that a lot of research on natural fiber reinforced polymer composites has been carried out. However a very less has been reported on the reinforcing potential of sisal fiber in spite of its several advantages over others natural fibers, and no previous research on fabrication of composite by hand lay-up assisted by vacuum bagging technique(HAVBT).

The conclusions drawn from this is the success of combining vegetable natural fibers with polymer matrices results in the improvement of mechanical properties of the composites compared with synthetic fiber reinforced polymer matrix composite materials. These composite fibers are cheap and nontoxic, can be obtained from renewable sources, and are easily recyclable. Moreover, despite their low strength, they can lead to composites with high specific strengths because of their low density.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

For the present experimental work the raw materials selected to prepare composite material were sisal fiber, polyester resin and hardener. In addition, sodium hydroxide (NaOH) and distilled water were used to treat the sisal fiber to improve the interfacial adhesive property. Sisal fibers were obtained from native farmers around Bisheftu Arengude Bahir, and polyester resin and hardener was purchased from the local fiberglass production industries in Addis Ababa, Ethiopia.

The experimental work consists of four phases namely,

- Extraction of fibers from sisal plant
- Design and fabrication of mold and other set ups
- Preparation of the composite material
- Specimen preparation and mechanical testing of the composite material

3.1.1. Polyester Resin

The resin used for this study was TOPAZ- 1110 TP Unsaturated Polyester (UP) GP resin general-purpose polyester resin, which was manufactured by Industrial Chemicals & Resins Co.Ltd. Saudi Arabia. As it shown in figure 3.1(b) GP resin is designed for general-purpose moulding mainly hand lay-up and spray up techniques. It exhibits good mechanical and electrical properties together with good chemical resistance compared to general-purpose resins. It has chemical resistance towards most mineral and organic acids, solvents.

3.1.2. Hardener (Catalyst)

Polyester resin was cured by adding a catalyst, which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the polyester resin and monomer ingredient from liquid to a solid state. The curing agent applied in this work for the liquid polyester resin was hardener with brand name of MEKP (Methyl Ethyl Ketone Peroxide) W 1900 HARDNER and manufactured by Industrial Chemicals and Resins Co. Ltd. Saudi Arabia as shown in figure 3.1(c). MEKP has the chemical formula of $C_8H_{18}O_6$ and is

widely used in polymer industry. It is highly sensitive to heat, friction, shock, flame or other sources of ignition, causing risks in production, storage and transportation.

3.1.3. Sisal Fiber

Sisal is a natural fiber (scientific name is agave sisalana) of agave family yields, a stiff fiber traditionally used in making twine and rope extracted sisal fiber is shown in figure 3.1 (a).Suitable quantity of sisal plant leaves was collected from the farmers in the Arengude Bahir rural area of Bisheftu.

3.1.4. Roller

Composite roller are safe and easy to handle in any application of composite preparation. A roller was used to remove air bubbles during the preparation of the fiber matrix composite as shown in figure 3.1 (e).

3.1.5. Electronic Balance

It is advice used very commonly in laborites for weighting chemicals to ensure a precise measurement of those chemicals for use in various experiments as shown in figure 3.1 (d).

3.1.6. Release Wax

It is a chemical agent used to stop the bonding of the molding material with the mold. Mold release wax, in particular, was used in laminating and prevents the part from attaching to the surface of the mold as shown in figure 3.1(f).

3.1.7. Sodium Hydroxide (NaOH)

Sodium hydroxide, also known as lye or caustic soda, has the molecular formula NaOH and is a highly caustic metallic base and alkali salt. Pure sodium hydroxide is a whitish solid, which is available in pellets, flakes, granules, and as a 50% saturated solution. Sodium hydroxide is soluble in water, ethanol and methanol. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents [Greenwood, 1997]. Sodium hydroxide, which used in this work, was in pellets form, purchased from local suppliers with the brand name and code of RANKEM, S0290 respectively and performed chemical treatment of sisal fiber shown in figure 3.1 (g).

Figure 3. 1 Materials used: (a) extracted sisal fiber (c) polyester resin (c) hardener (d) electronic balance (e) roller (f) release wax (g) Sodium Hydro Oxide

3.2. Fiber Preparation

The major constituent material in composite was the reinforcement. SF used in this research was extracted from the matured 3 years and above of sisal plant .SF can be extracted from the sisal plant through different ways such as by mechanical means using different machines such as advanced mechanical machine; by chemicals or natural means rating process technique.

3.2.1. Fiber Extraction Process

For this research, SF was extracted by the way known as decortications. Decortication was done manually whereby the leaves pounded and the pulp scraped away with a sharp edge wood due to the following reasons;

- Economically which is cost effective
- Low energy consumption
- Easy way of fiber extraction process and
- Protect the fiber from damage

In general, the extraction process of the SF is summarized as below figures 3.2, 3.3, and 3.4. To extract the fiber, the mature sisal plant as shown in the figure 3.2(a) were collected from the wild as shown in figure 3.2 (b). Then the thrones which is shown in the figure 3.3 (c) has been removed as shown in figure 3.3 (d), where leaves compressed by sharp wood then only fibers would remain as shown in the Figure 3.4 (e), the rest unnecessary part was cleaned by immersing in the water for about 2hour shown in figure 3.4 (f). Finally, the extracted fiber are dried for about three days at room temperature. The entire fiber extraction process took 8-12 days.

3.2.2. Fiber Alkali Treatment and its Processing

Alkali treatment or mercerization using sodium hydroxide (NaOH) is the most commonly used treatment for bleaching and cleaning the surface of natural fibers to produce high quality fibers. According to literatures in this research, alkali-treatment used 8% NaOH solution was prepared using sodium hydroxide pellets and distilled water. Sisal fibers were then dipped in the solution for 24 hours to remove the unwanted soluble cellulose, pectin, lignin …etc. from the fiber. The fiber to solution weight ratio was maintained at 1: 11 then it was washed with distilled water to remove excess of NaOH and dried at room temperature for about three- four days. In general, removal of these fatty like components from sisal fiber leads the fibers to:

- Improve an adhesive properties for fiber–matrix interface
- Improve fiber's shear strength
- Improve fiber's rigidity and stiffness
- Improve moisture absorption problems
- Reduce fiber's weight …etc.

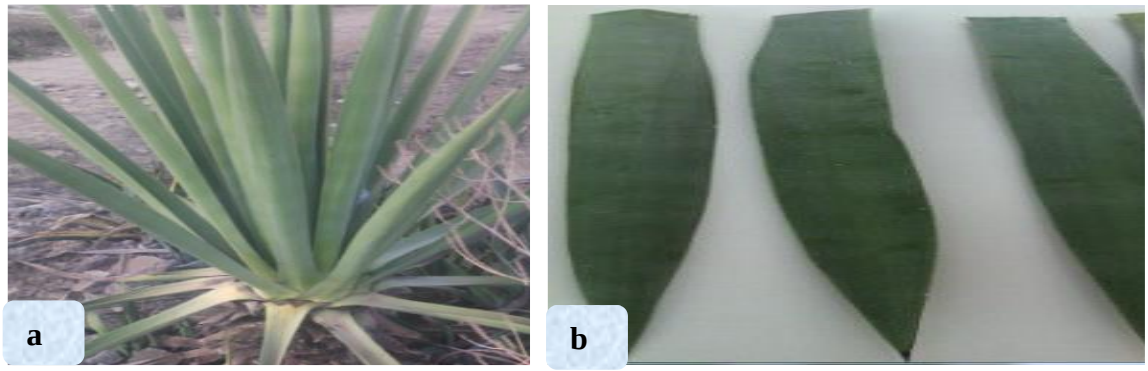


Figure 3. 2 (a) sisal tree and (b) cutted sisal leaf

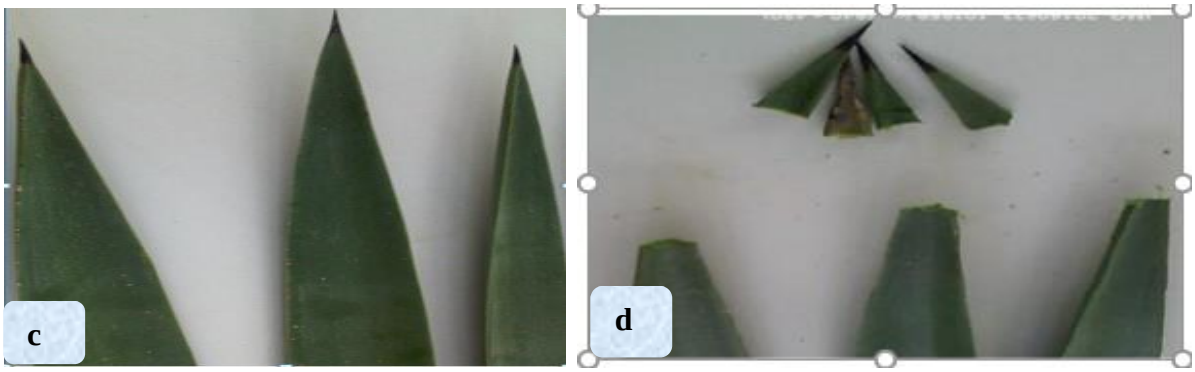


Figure 3. 3 (c) leaf tip and (d) removed leaf tip

Figure 3. 4 (e) Sisal Fiber manually extracted mechanism and (f) sisal Fiber

However when the percentage of NaOH is increased it affect the fibers properties by reduce the bonding capacity during preparation of the composites [Sabu et al. 2012]. Based on several literatures, the medium percentage of NaOH (i.e. 8%) was used for this work. In general, for this study 245gm of NaOH pellet was mixed with 2817gm of distilled water at ambient temperature. The sisal fiber then dipped in the solution for twenty-four hour. Then it washed

several time with distilled water in order to neutralize it as shown in figure 3.5(b). Lastly, the fibers were allowed to dry in sun light for at least 3 day as shown in figure 3.6.

In this process the solution of the sisal fiber and NaOH must kept under the vacuum, since NaOH can react with air, as a result that can absorb moisture. This cause to increase the water content in the solution. Due to this as shown in below figure 3.5(a), the bucket was covered with plastic sheet in order to create the vacuum inside the bath.

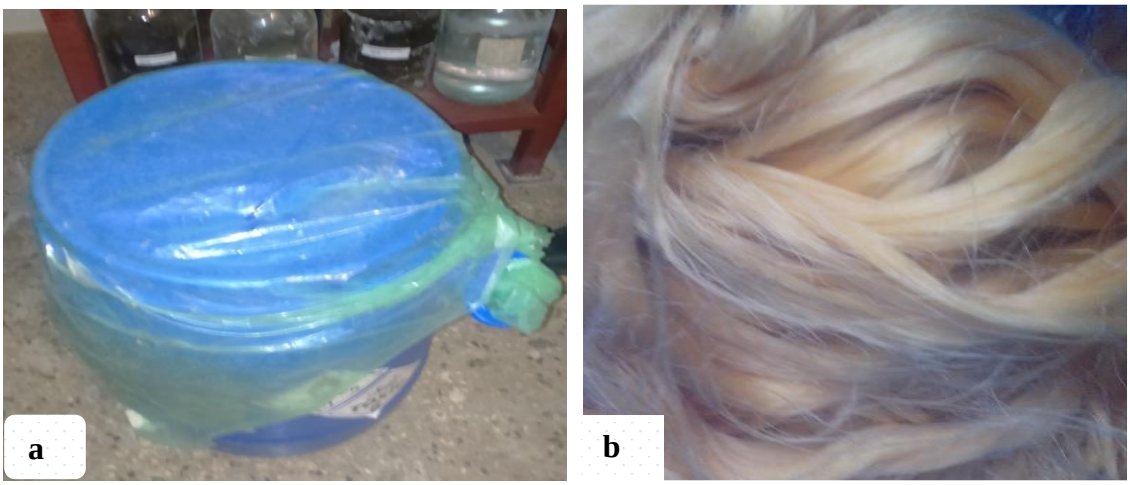


Figure 3. 5 Steps for alkaline treatment of sisal fiber: (a) Sisal fiber soaked by NaOH under the vacuum for 24 hours (b) Sisal fiber after soaked by NaOH washed in distilled water several times

Figure 3. 6 Washed Fiber dried using air at room temperature

3.3. Mould Preparation

The Mould was selected according to literatures and used for preparing the specimen and made of wood material has a rectangular wood plate and wood frames with a dimension of 250 x 190 x 10mm as shown in below figure 3.7. The mould consists of three parts:

1. Rectangular side plate or frames,
2. Cavity and
3. Base plate

The frame is the size and thickness of the composite material. The base plate is very thin plate it is the bottom- lining. The function of base plate is to cover and compress the fiber after the polyester is applied, and to avoid the debris from entering into the composite parts during the curing time. Cavity is the necessary composite material working area.

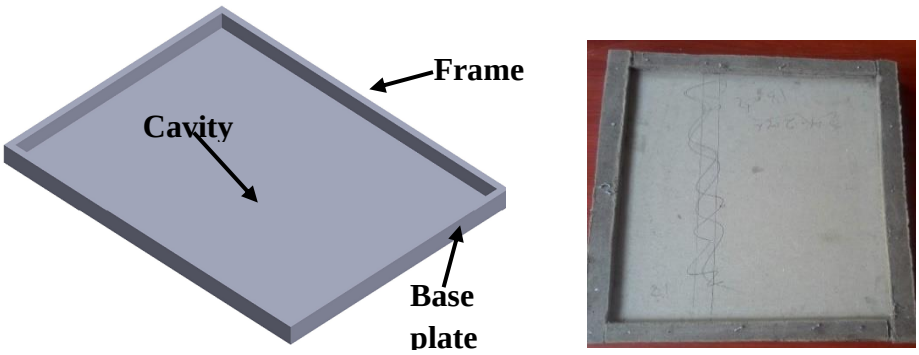


Figure 3. 7 Wooden molds used for fabricating the composite specimens

3.4. Fiber and Matrix Weight and Volume Fraction Content of the Composite

In the research, the ratio of the polyester resin and sisal fiber used in the sample preparation was based on the weight ratio. This means the weight of both polyester resin and fiber was measured using an electronic balance.

In design, fabrication and analysis of composite materials, the first and critical task is the determination of ingredient percentages such as sisal fiber and polyester matrix fraction presence in laminate [Mohd et al. 2015]. These components are micro structural elements of the composite laminate in which composites strength and properties are determined and limited by

these values. In generals, results obtained from the equations presented below are mandatory for:

- Composite laminate preparation
- In order to use ASTM standard to determine size of laminates that meets the ASTM requirements prior to laminate fabrication, these values are necessary.
- The improvement of fabricate laminated for the future by varying these values.
- These values can be used as a design manual in collaboration of composite laminate's different experimental results, which are fabricated, by this content.

3.4.1. Fiber and Matrix Volume Fraction (VF, VM)

Consider a composite material that consists of fibers and matrix material. The volume of the fiber is equal to the ratio of the weight of the fibers to the density of the fibers [Mallick, 1993]. Therefore,

$$Vf = \frac{Wf}{\rho f} \qquad (3.1)$$

Where Vf is volume of fiber; Wf is weight of fiber; ρf density of fiber

The volume of the matrix is also equal to the ratio of the weight of the matrix to the density of the matrix.

$$Vm = \frac{Wm}{\rho m} \qquad (3.2)$$

Where Vm is volume of matrix; Wm is weight of matrix; ρm density of matrix

The volume of the composite material is equal to the sum of the volume of the fibers and the volume of the matrix.

$$Vc = Vf + Vm \qquad (3.3)$$

Where Vc is total volume of composite; Vf is volume of fiber; Vm is volume of matrix

The fiber volume fraction of composite is describe by ratio of volume of fiber to volume of composite

$$VF = \frac{Vf}{VC} = \frac{Vf}{Vf+Vm} \qquad (3.4)$$

Where VF is fiber volume fraction

The matrix volume fraction of composite also describe by:

$$VM = \frac{Vm}{Vc} = \frac{Vm}{Vf+Vm} \quad (3.5)$$

Where VM is matrix volume fraction

The sum of fiber volume fraction and matrix volume fraction is equals to unit.

$$VF + VM = 1 \quad (3.6)$$

From this volume fraction of fiber and volume fraction of matrix can be described;

$$VF = \frac{Wf \times \sigma m}{Wf * \rho m + Wm * \rho f} \quad (3.7)$$

$$VM = \frac{Wm \times \rho f}{Wm * \sigma f + Wf * \sigma m} \quad (3.8)$$

3.4.2. Fiber and Matrix Weight Fraction (WF, WM)

Assuming that the composite material consists of fibers and matrix material, the weight of the composite material is equal to the sum of the weight of the fibers and the weight of the matrix. Therefore,

$$Wc = Wf + Wm \quad (3.9)$$

Where Wc is total weight of composite

The weight fractions (mass fractions) of the fiber and the matrix are defined as

$$WF = \frac{Wf}{Wc} = \frac{Wf}{Wf + Wm} \quad (3.10)$$

Where WF is fiber weight fraction, and

$$WM = \frac{Wm}{Wc} = \frac{Wm}{Wm + Wf} \quad (3.11)$$

Where WM is matrix weight fraction

$$WM + WF = 1 \quad (3.12)$$

3.4.3. Density of the Composite

The density of composite material can be defined as the ratio of weight of the composite material to the volume of the composite material and is expressed as:

$$\rho c = \frac{Wc}{Vc} \tag{3.13}$$

Where ρc is total density of the composite.

but, $Vc = Vf + Vm$, and $V = \frac{W}{\rho}$, therefore equation (3.13) can be rewritten as:

$$\frac{Wc}{\rho c} = \frac{Wf}{\rho f} + \frac{Wm}{\rho m} \tag{3.14}$$

By multiplying with ratio of one by weight of composite both sides we can get

$$\frac{1}{\rho c} = \frac{1}{\rho f}\left(\frac{wf}{wc}\right) + \frac{1}{\rho m}\left(\frac{Wm}{Wc}\right) \tag{3.15}$$

3.4.4. Calculation to Find the Weight of Fiber and Matrix for Tensile Specimen Properties

The volume of the composite was calculated by multiplying the length, width and breadth of the mould prepared for molding the composite material. The dimension of the mould for this research is taken based on the literatures.

Volume of the mould = 235 × 154 × 5 = 180,950mm^3 = 180.95cm^3

From literatures the density of polyester resin and sisal fiber are 1.2g/cm^3 and 1.33g/cm^3 respectively.

$$Vcomposite = V\,fiber + V\,polyester$$

To calculate the density of the composite the volume fraction of each composite sample for treated and untreated sisal fiber i.e. 10%, 20% and 30% sisal fiber and the remaining percentage of polyester resin is used. For 10% Sisal fiber reinforced polyester Composite material using equation (3.15) the density of the composite sample is calculated:

$$\frac{1}{\rho c} = \frac{1}{\rho f}\left(\frac{Wf}{Wc}\right) + \frac{1}{\rho m}\left(\frac{Wm}{Wc}\right)$$

$$\frac{1}{\rho c} = \frac{1}{1.33}\left(\frac{0.1}{1}\right) + \frac{1}{1.2}\left(\frac{0.9}{1}\right)$$

$$\frac{1}{\rho c} = 0.825$$

$$\rho c = 1.21 g/cm3$$

From equation (3.13) we have

$$Wc = Vc \times \rho c$$

$$Wc = 180.95 \times 1.21 = 218.95g$$

$$W_{\text{Polyester +Hardener}} = 0.9 \times 218.95 = 197.1g$$

$$W_{\text{Polyester}} = 179.1g, \qquad W_{\text{Hardener}} = 17.9g$$

$$W_{\text{Fiber}} = 0.1 \times 218.95 = 21.895g$$

In addition, the other tensile testing specimen weight for 20% and 30% calculation was calculated in similar manner and the final calculated results was offered in below table 3.1. The calculated result is for both treated and untreated fiber in all properties.

Table 3. 1 Weight for tensile test composite specimen

Weight of Treated Fiber ,Matrix and Hardener							
Samples specification	Polyester (%)	Sisal (%)	Total composite weight(g)	Fiber Weight(g)	Total Matrix and Hardener Weight(g)	Matrix Weight (g)	Hardener Weight (g)
TTS1	90	10	218.95	21.895	197	179.1	17.9
TTS2	80	20	221.5	44.3	177.2	161.1	16.1
TTS3	70	30	222.57	66.771	155.8	141.64	14.16

3.4.5. Calculation to Find the Weight of Fiber and Matrix for Compression Specimen Properties

The volume of the composite for compression properties also calculated by multiplying the length, width and breadth of the mould prepared for molding the composite material.

Volume of the mould = $150 \times 90 \times 5 = 67{,}500mm^3 = 67.5cm^3$

The weight of fiber and matrix in compression properties is also calculated in similar way to the tensile properties. The calculated data are tabulated in below table 3.2.

Table 3. 2 Weight for compression test composite specimen

	Weight of Treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite weight(g)	Fiber Weight (g)	Total Matrix and Hardener Weight(g)	Matrix Weight(g)	Hardener Weight (g)
TCS1	90	10	81.657	8.20	73.5	66.82	6.68
TCS2	80	20	82.62	16.524	66.1	60.1	6.00
TCS3	70	30	83.025	24.91	58.1175	52.83	5.28

3.4.6. Calculation to Find the Weight of Fiber and Matrix for Impact Specimen Properties

The weight of sisal fiber and polyester resin for impact properties can also calculated in similar method as tensile properties and results are tabulated in below table 3.3.

The volume of the composite for impact properties was calculated by multiplying the length, width and breadth of the mould prepared for molding the composite material.

Volume of mould = 165 × 65 × 5 = 53625 mm^3 = 53.625 cm^3

Table 3. 3 Weight for impact test composite specimen

	Weight of treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite weight(g)	Fiber Weight(g)	Total Matrix and Hardener Weight(g)	Matrix Weight (g)	Hardener Weight (g)
TIS1	90	10	64.88	6.50	58.4	53.10	5.30
TIS2	80	20	65.637	13.13	52.51	47.73	4.77
TIS3	70	30	66.00	19.89	46.20	42.00	4.20

3.4.7. Calculation to Find the Weight of Fiber and Matrix for Water Absorption Specimen Properties

The volume of the composite for water absorption properties was calculated by multiplying the length, width and breadth of the mould prepared for molding the composite material.

Volume of mould = $170 \times 90 \times 5 = 76500\ mm^3 = 76\ cm^3$

Weight of sisal fiber and matrix of water absorption specimen results was presented in below table 3.4.

Table 3. 4 Weight for water absorption test composite specimen

	Weight of treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite weight(g)	Fiber Weight (g)	Total Matrix and Hardener Weight(g)	Matrix Weight (g)	Hardener Weight (g)
TWS1	90	10	92.565	9.26	83.31	75.71	7.57
TWS2	80	20	93.636	18.72	74.91	68.1	6.81
TWS3	70	30	94.095	28.23	65.866	59.866	6.00

In the other hand the volume of treated and untreated sisal fibers and matrix has been calculated to tensile, compression, impact and water absorption specimens from equation (3.1), (3.2) and (3.3) the result suggested in below tables 3.5, 3.6, 3.7and 3.8 respectively.

Table 3. 5 Volume for tensile test composite specimen

	Volume of treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite volume(cm^3)	Fiber volume (cm^3)	Total Matrix and Hardener volume(cm^3)	Matrix volume (cm^3)	Hardener volume (cm^3)
TTS1	90	10	180.95	18.10	162.85	148.05	14.80
TTS2	80	20	180.95	36..18	144.77	131.60	13.16
TTS3	70	30	180.95	54.285	126.66	115.156	11.51

Table 3. 6 Volume for compression test composite specimen

	Volume of treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite volume(cm^3)	Fiber volume (cm^3)	Total Matrix and Hardener volume(cm^3)	Matrix volume (cm^3)	Hardener volume (cm^3)
TTS1	90	10	67.50	6.75	60.75	55.227	5.523
TTS2	80	20	67.50	13.5	54.00	49.09	4.91
TTS3	70	30	67.50	20.25	47.25	42.95	4.30

Table 3. 7 Volume for impact test composite specimen

	Volume of treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite volume(cm^3)	Fiber volume (cm^3)	Total Matrix and Hardener volume(cm^3)	Matrix volume(cm^3)	Hardener volume (cm^3)
TIS1	90	10	53.625	5.362	48.26	43.87	4.387
TIS2	80	20	53.625	10.725	42.90	39.00	3.900
TIS3	70	30	53.625	16.10	37.561	34.15	3.410

Table 3. 8 Volume for water absorption test composite specimen

	Volume of treated Fiber ,Matrix and Hardener						
Samples specification	Polyester (%)	Sisal (%)	Total composite volume(cm^3)	Fiber volume (cm^3)	Total Matrix and Hardener volume(cm^3)	Matrix volume (cm^3)	Hardener volume (cm^3)
TWS1	90	10	76.5	7.650	68.85	62.591	6.26
TWS2	80	20	76.5	15.30	61.20	55.64	5.56
TWS3	70	30	76.5	22.95	53.55	48.682	4.87

3.5. Fabrication of Composite Specimen

3.5.1. Chopped Sisal Fiber Preparation

The chopped sisal fiber for both treated and untreated fiber was cut using a pair of scissors based on the length needed that was 8 mm length as shown figure in 3.8.

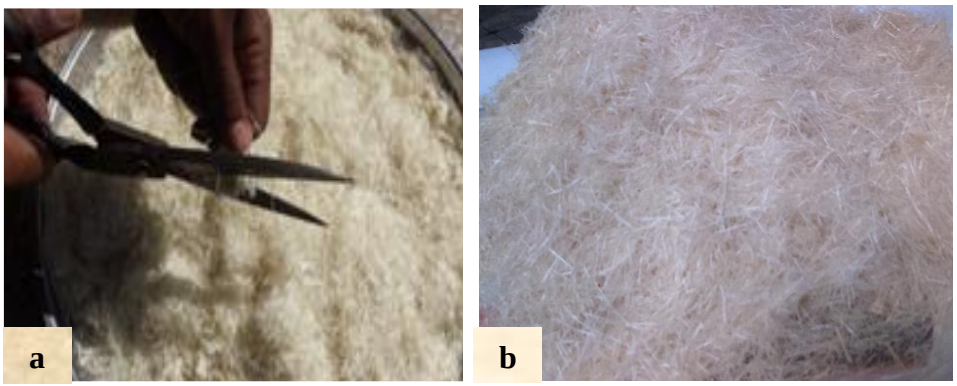


Figure 3. 8 Chopped Sisal Fiber: (a) untreated fiber (b) treated fiber

3.5.2. Preparation of Polyester and Hardener

Polyester resin TOPAZ- 1110 TP general-purpose, mixed with hardener MEKP W 1900 HARDNER as shown in figure 3.9 is used to prepare the composite plate. The weight ratio for mixing polyester and hardener was 10:1. Hardeners include anhydrides (acids), amines, polyamides, dicyandiamide …etc.

Figure 3. 9 Prepared polyester resin and hardener

The mixer is strewed with stirrer for about 2-5 minutes continuously. The mixing is performed in the mixing containers (Bowl); the bowl is made of plastic to prevent melting of the Bowl during the exothermic reaction. The mixing was done slowly to not entrain any excess air bubbles in the resin.

3.5.3. Hand Lay-up Assisted by Vacuum bagging Technique (HAVBT)

Hand-lay-up method was adopted to fill up the prepared mould with an appropriate amount of polyester resin mixture and random oriented chopped sisal fibers, such that starting and ending with layers of resin. The mold surface was treated with mold release compounds consisting of wax chemical. Advantages of hand lay-up are the relatively lower mold costs and strength requirements, the tools required for production are readily available, the molds are easy to maintain and the part's lay-up can usually be changed without altering the mold. However, the disadvantages are many. Hand lay-up is a manual process, and therefore results are very subject to the user that is doing the work. Since the fibers have the superior mechanical properties, it is often desirable to control and typically maximize the fiber volume percent, which is relatively difficult with hand lay-up [Mallick, 2007]. However, by using the vacuum bagging, this hand lay-up technique was greatly improved.

Hand lay-up assisted by vacuum bagging technique (HAVBT) is an extension of the hand lay-up process described above where pressure is applied to the laminate once laid-up during its curing cycle in order to improve its consolidation .This is achieved by sealing a plastic film over the wet laid-up laminate and onto the tool.

The main goal of HAVBT is to produce a homogeneous laminated composite by:

- Removes the trapped air between laminate layers.
- Compacts the fiber layers for more efficient force-transmission amongst fiber bundles
- Prevents shifting of fiber orientation throughout the curing process.
- Reduces humidity.

3.5.4. Processing Steps to Manufacture the Composite Material

In the fabrication of the composite material figure 3.10 shows that flow chart of the process steps.

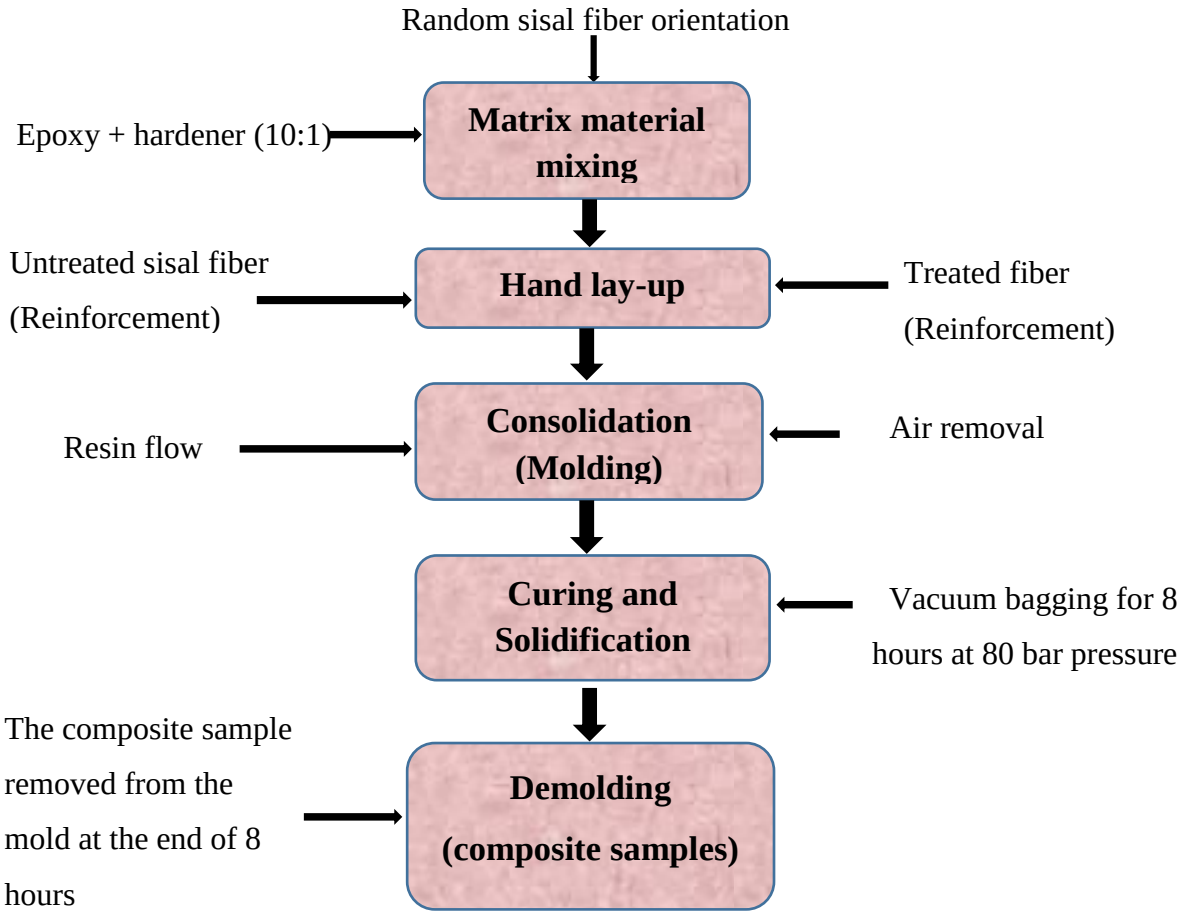


Figure 3. 10 Schematic flow diagram for fabrication of sisal fiber reinforced polyester resin composites

The polyester and hardener was mixed according to the ratio they had as we shown already. Manually the polyester mixture was mixed with chopped SF uniformly as shown figure 3.11 after that on the mould sisal fiber with polyester mix were laid. The components hardener, polyester resin and fiber was mixed with a pre-calculated amount to obtain required thickness and according to the composite samples of three different compositions with 10%, 20%, and 30% volume and weight fraction of fiber for both treated and untreated were prepared. The entrapped air bubbles are removed carefully with a sliding roller.

Figure 3. 11 Preparation of SFPCM by Hand Layup Method

3.5.5. Vacuum Bagging

Vacuum bagging is a technique employed to create mechanical pressure on a laminate during its cure cycle. Pressurizing a composite lamination serves several functions. First, it removes trapped air between layers. Second, it compacts the fiber layers for efficient force transmission among fiber bundles and prevents shifting of fiber orientation during cure. Third, it reduces humidity. Finally, and most important, the vacuum bagging technique optimizes the fiber-to-resin ratio in the composite part [Gougeon, 2010].

Main Vacuum Bagging Equipment's

I. Vacuum pump

A vacuum pump is a device that removes gas molecules from a sealed volume in order to leave behind a partial vacuum as shown in figure 3.12(a). It is the hearts of a HAVBT system. Vacuum pumps are designated by their vacuum pressure potential or "Hg maximum", their displacement in cubic feet per minute (CFM) and the horsepower required to drive the pump [Gougeon, 2010]. The pump used for this work is taken from Dejen Aviation, Unmanned Air Vehicle department that has the following specification:

Type: rotary Vacuum: 6.7×102Pa

Model No: 2TW-4C Power: 220-240v/50Hz

Capacity: 8cfm

II. Sealant Tape (mastic sealant)

The mastic sealant in figure 3.12(b) is used to seals the bag to the mold or provide an airtight seal between the tool / master model and bagging film. The tape must have sufficient tack to adhere well to the mould surface but not so much tack that the bag cannot be stripped away from the tape for re-positioning during lay-up. The tape must also strip cleanly from the mould surface after the cure cycle has been completed .

III. Release Fabric

It shows in figure 3.12(c) and commonly known as peel plies, is a smooth woven fabric that will not bond to polyester. It is used to separate the breather and the laminate. Excess polyester can wick through the release fabric and be peeled off the laminate after the laminate cures. It will leave a smooth textured surface that, in most cases, can be bonded to without additional preparation. Surfaces that will subject to highly-loaded bonds should be sanded. It is not recommended for post cure temperatures over 120°F (49°C).

IV. Vacuum Nylon

These materials are used to form the vacuum bag or to protect atmospheric air. The film is sealed to the edge of the mould with vacuum bag sealant tape. Vacuum bags must be completely airtight to ensure no leaks occur at full vacuum during the final cure. The most commonly used material is nylon film due to its excellent physical properties. As well as being extremely tough, it has good flexibility and high elongation. Special additives allow it to be used at high temperatures and make it the most cost effective material available and it has been shown in figure 3.12(d).

V. Perforated Film

A perforated plastic film in figure 3.12(e) used in conjunction with the release fabric. This film helps hold the resin in the laminate when high vacuum pressure is used with slow curing resin systems or thin laminates. Perforated films are available in a variety of holes sizes and patterns depending on the clamping pressure, and the resin's open time and viscosity.

VI. Breather

The breather shown in figure 3.12(f) is non-woven polyester bleeder or breather fabrics are used to allow the free passage of air across the bag face of a laminate while under vacuum or autoclave pressure. This allows air and volatiles to be pulled from the laminate and an even pressure applied to it. The secondary use of these fabrics is the absorption of any excess resin which is bled from the laminate during cure.

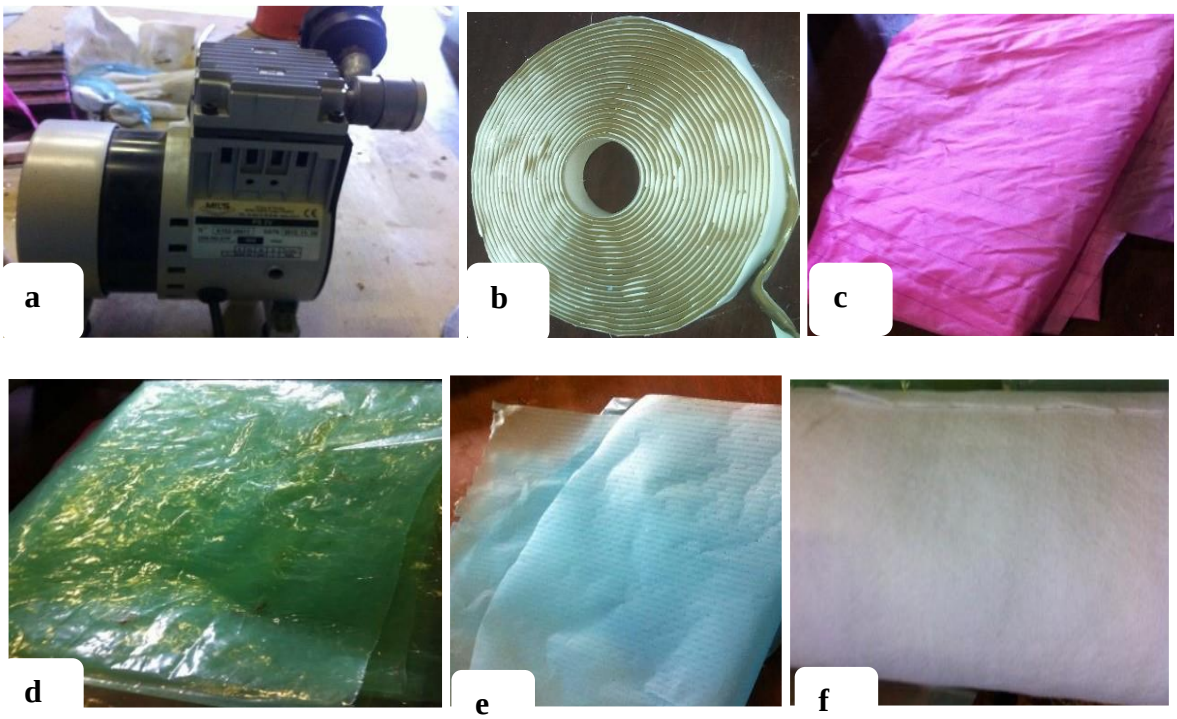


Figure 3.12 Vacuum bagging system materials: (a) vacuum pump, (b) sealant Tape (mastic sealant), (c) release Fabric, (d) vacuum nylon, (e) perforated film and (f) breather

The chopped SFPCM under vacuum bagging technique as shown in figure 3.13 was carried out after 30-60 minutes of the hand lay-up process to prevent curing of the SFPCM and it was removed at the end of 8 hours.

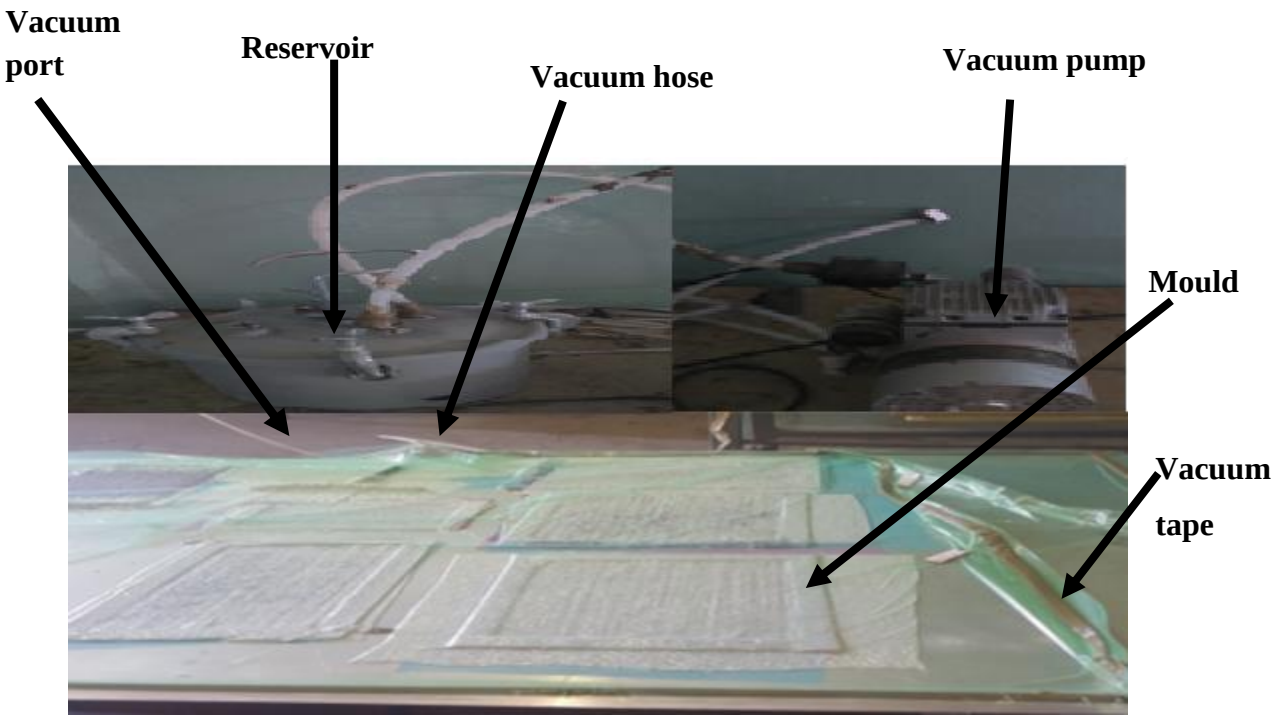


Figure 3. 13 Composite fabrication process using vacuum bagging process

3.5.6. Prepared Sample

The Chopped treated and untreated sisal fiber reinforced polyester resin composite material fabricated by hand lay-up assisted by vacuum bagging process with different fiber matrix composition is ready for test and typical view of some composite samples are shown below figure 3.14.

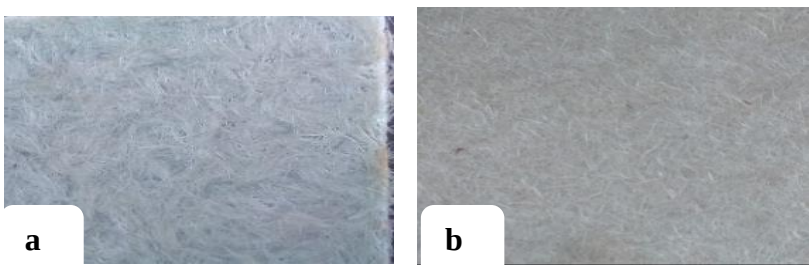


Figure 3. 14: (a) Untreated sisal fiber composite samples
(b) Treated sisal fiber composite sample

3.6. Mechanical Testing of the Composite Material

3.6.1. Specimen Preparation

The treated and untreated sisal fiber reinforced polyester resin for tensile test, compression test, impact test and water absorption test were prepared. Therefore, totally 114 specimen needed to fulfill all tests. After manufacturing the laminated composite materials, the specimen was cut in to desired dimension of testing specimen using fiber grinder machine from DAVI based on their respective ASTM standards.

3.6.2. Tensile Test

The tensile strength of a material was the maximum amount of longitudinal stress that it can take before failure using Universal Testing Machine. The commonly used specimen for tensile test were prepared according to ASTM D3039 / D3039M standards for composites, standard of specimen dimension were 235x 30 x5 mm [ASTM D3039, 2010].

Specimens are placed in the grips of a Universal Test Machine at a specified grip separation and each sample pulled step by step until failure. In each case, three samples were tested and average value tabulated in post processor of UTM machine installed in Ethiopian Conformity Assessment Enterprise workshop. A typical test speed for standard test specimens is 2 mm/min. During the application of tension, the elongation of the gauge section was record against the applied stress. The tensile strength and percentage elongation of composite material can be also calculated using equations (3.16) and (3.17). Figure 3.15 shown that the tensile test dimension per ASTM and prepared composite samples of both treated and untreated sisal fiber were shown in figure 3.16 and 3.17 respectively.

$$\text{Tensile strength} = \frac{\text{load at break}}{(\text{orginal width}) \times (\text{ original thickness})} \qquad (3.16)$$

$$\%\ \text{elongation} = \frac{\text{elongation at rupture}}{\text{intial gauge length}} \qquad (3.17)$$

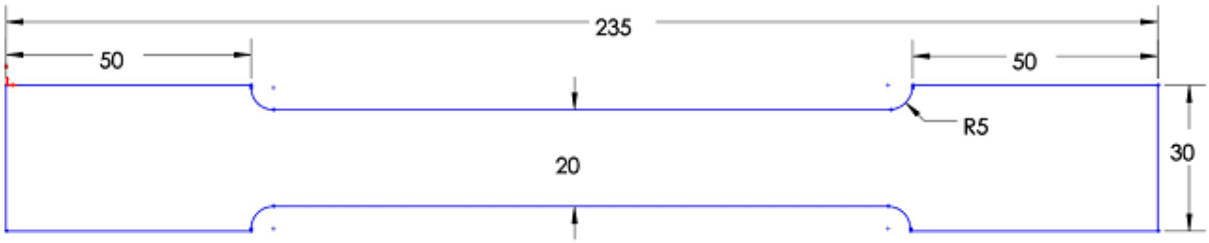


Figure 3. 15 Tensile testing specimen dimension [ASTM D3039, 2010].

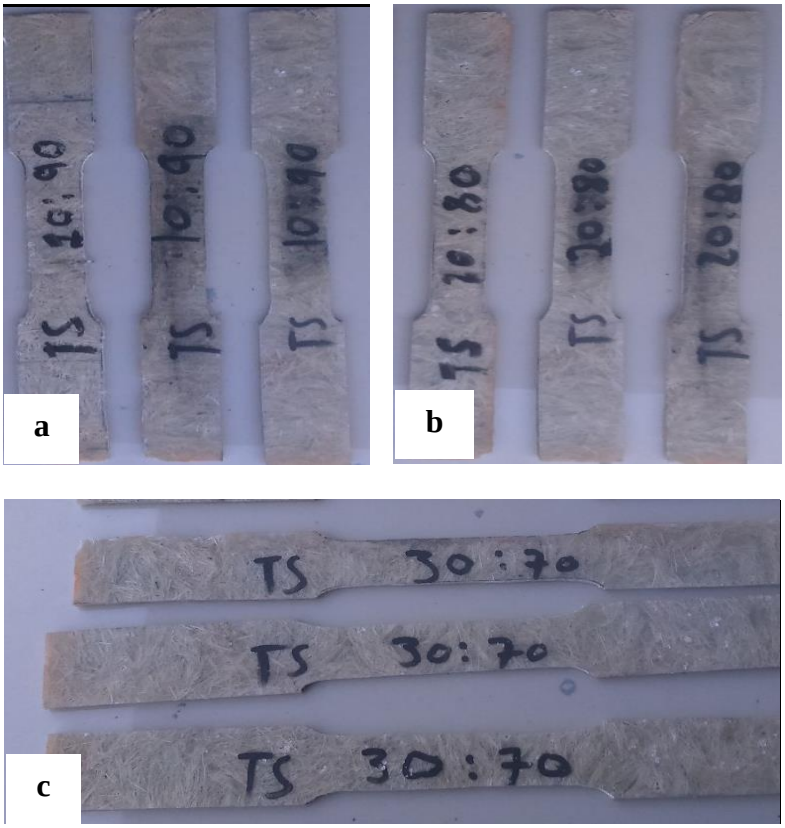


Figure 3. 16 Untreated fiber tensile test Specimens: (a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix, and (c) 30% fiber and 70% matrix

Figure 3.18 and 3.19 shown that the SFPCM under the grip of universal testing machine (UTM) and the UTM machine that installed at Ethiopian Conformity Assessment Enterprise workshop.

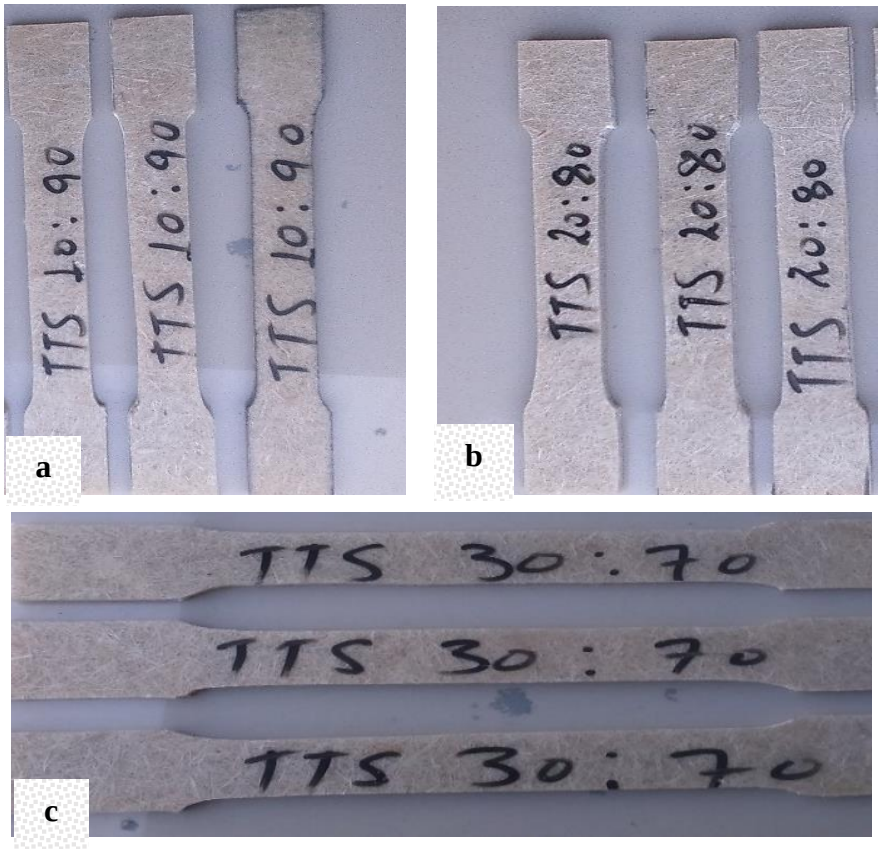


Figure 3. 17 Treated fiber tensile test tpecimens: (a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix and c) (30% fiber and 70% matrix

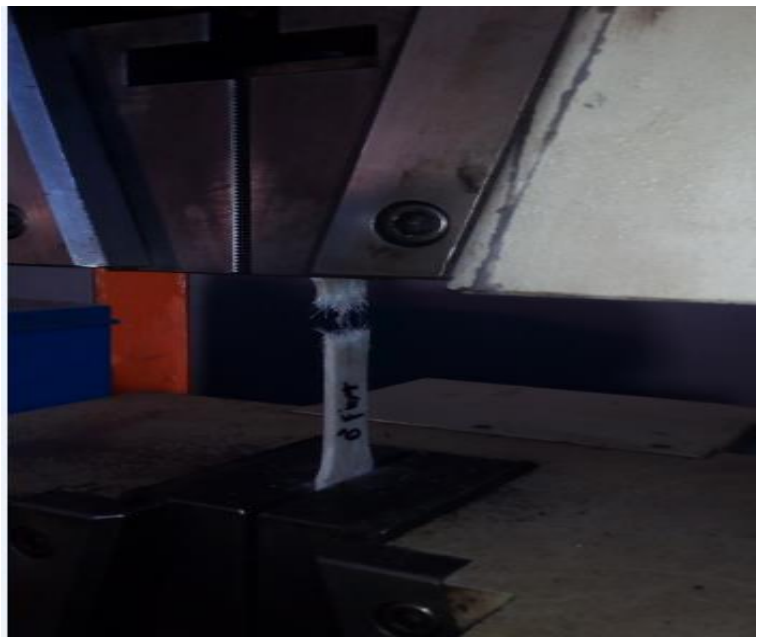


Figure 3. 18 Tensile specimen sample under tensile test

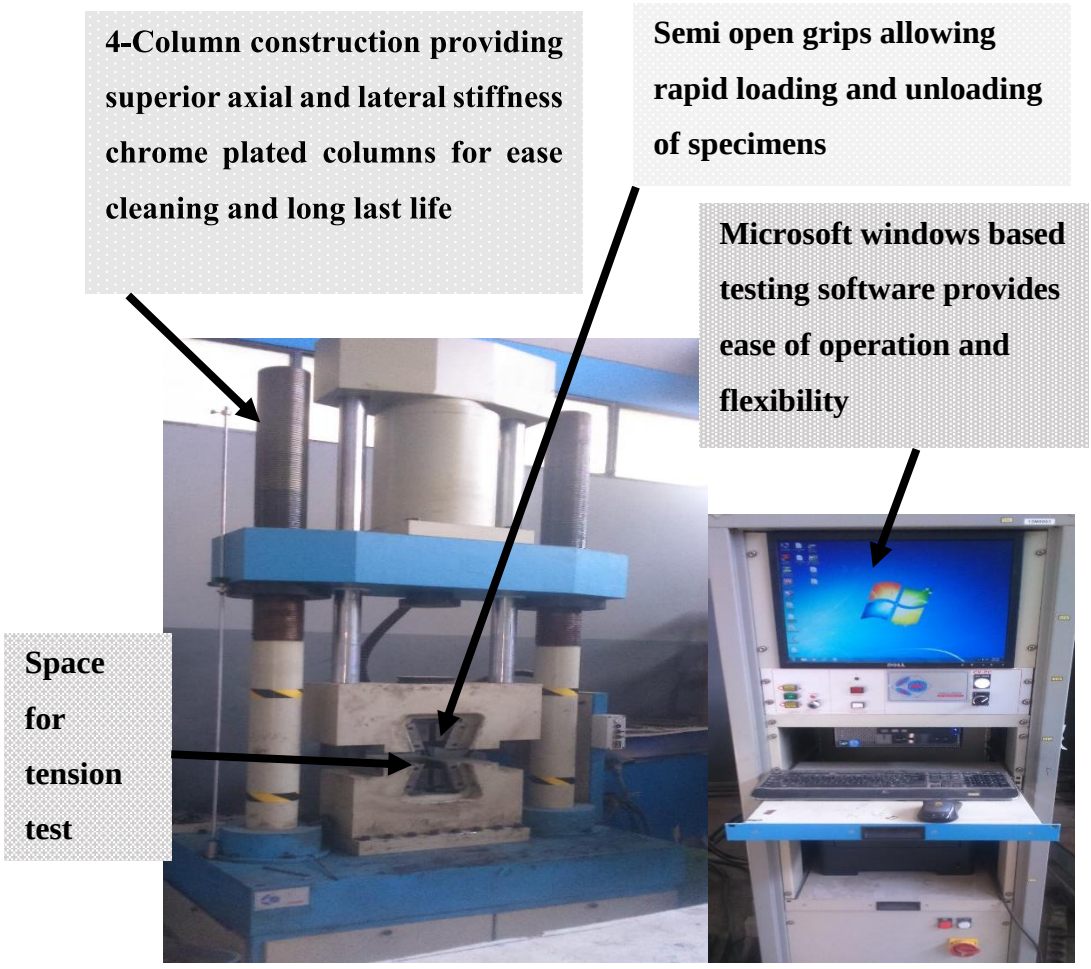


Figure 3. 19 UTM at Ethiopian Conformity Assessment Enterprise workshop

3.6.3. Compression Test

The compressive strength of SF reinforced composites was determined in accordance with ASTM D3410. The specimen were prepared to 25mm x 25mm x 5 mm as shown in figure 3.20. The test performed at the standard speed of testing was 1.3 ± 0.3 mm/min and maximum load of 50KN using Universal Testing Machine installed in mechanical workshop, Adama Science and Technology University.

The compression process involves placing the test specimen in the testing machine and applying compressive force to it until it fractures. For each type of sample test, the compressive strength has been taken average value of three specimen. Figure 3.21 and 3.22 shown that untreated and treated sisal fiber compression test specimens.

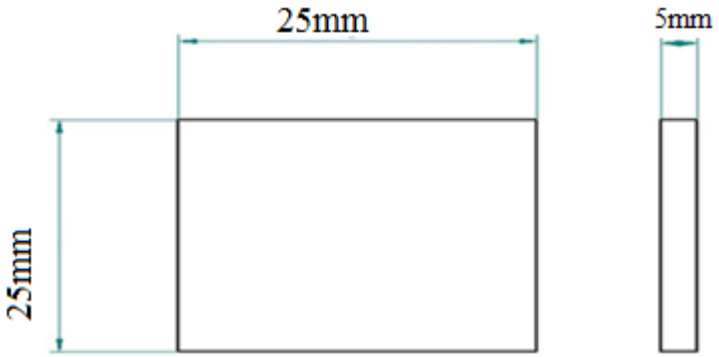


Figure 3. 20 Compression testing specimen dimension [ASTM D3410, 2003]

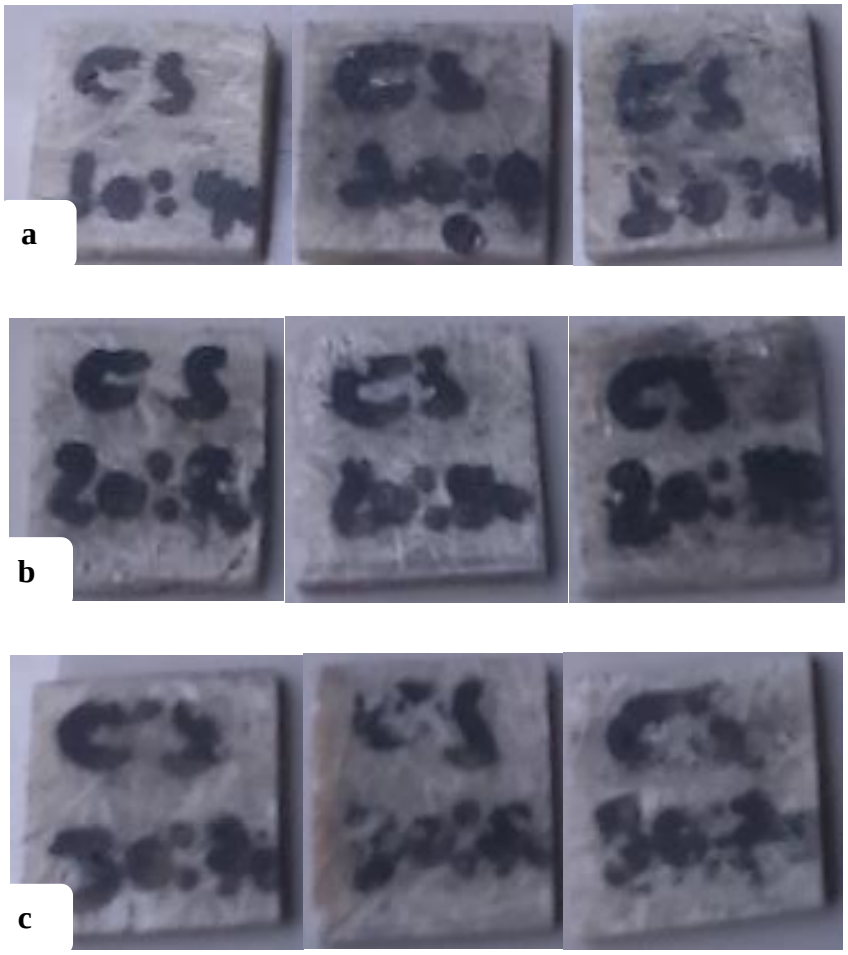


Figure 3. 21 Untreated sisal fiber compressive test specimens:
(a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix
and (c) 30% fiber and 70% matrix

Figure 3. 22 Treated sisal fiber compressive test specimens:
(a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix,
and (c) 30% fiber and 70% matrix

Figure 3.23 shown that UTM machine that installed at mechanical workshop, Adama Science and Technology University and SFPCM under the grip UTM machine.

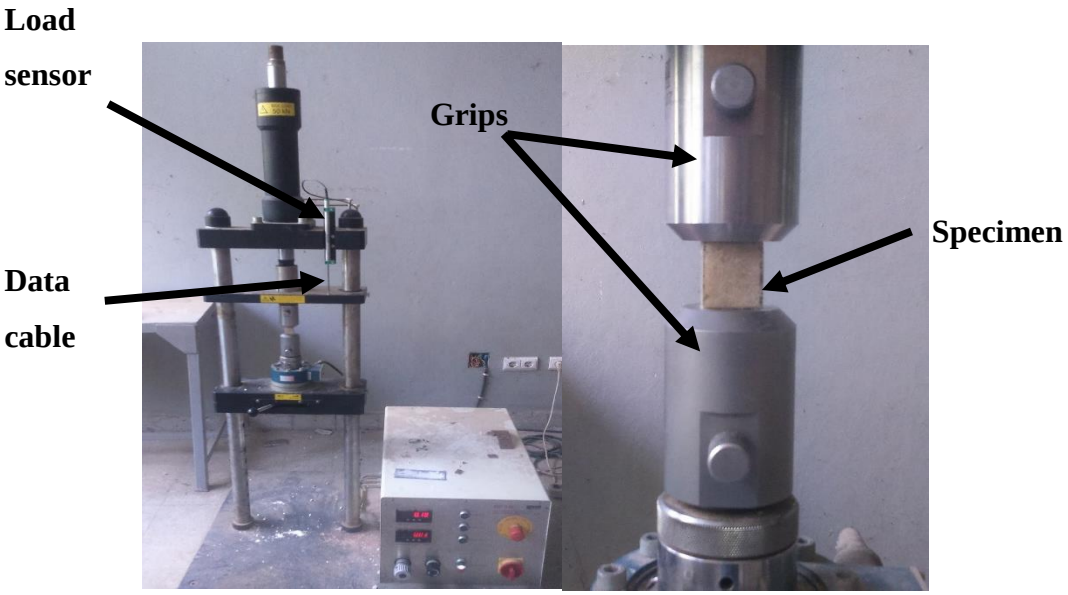


Figure 3. 23 Specimen at Compression Test

3.6.4. Impact Test

Impact test used extensively to determine the impact resistance of any material. The Charpy impact test was carried out for the samples specimens with dimensions of 55mm x10mm x 5mm in accordance with ISO 9001: 20001 as shown in figure 3.24. The specimen is clamped into the pendulum impact test fixture with the notched side facing the striking edge of the pendulum. The pendulum is released and allowed to strike through the specimen. Since many materials (especially thermoplastics) exhibit lower impact strength at reduced temperatures, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment. Using pendulum energy that employed for the testing purpose was 2 Joule with a speed of 2.9 m/s and having 20-kilogram weight mounted pendulum impact testing machine installed in material testing laboratory, Debrebrhan University.

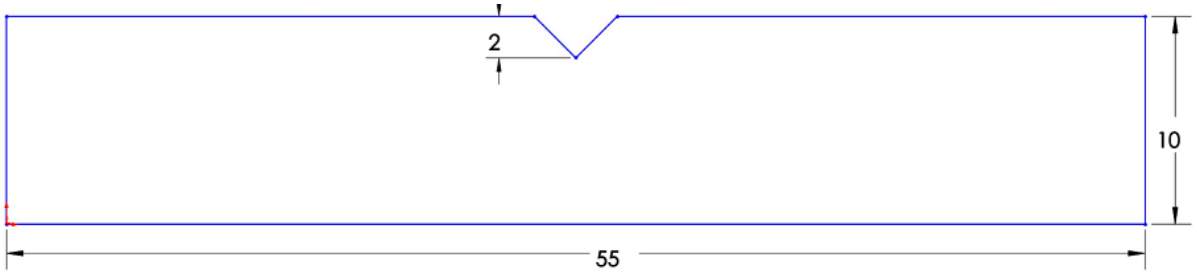


Figure 3. 24 Impact test specimen dimension [ISO 9001:2001, 2010]

The impact test specimens of SFPCM made from both treated and untreated sisal fiber for all weight fraction were shown in figure 3.25 and 3.26.

Figure 3. 25 Untreated fiber impact test specimen: (a) 10% fiber and 90% matrix (b) 20% fiber and 80% matrix (c) 30% fiber and 70% matrix

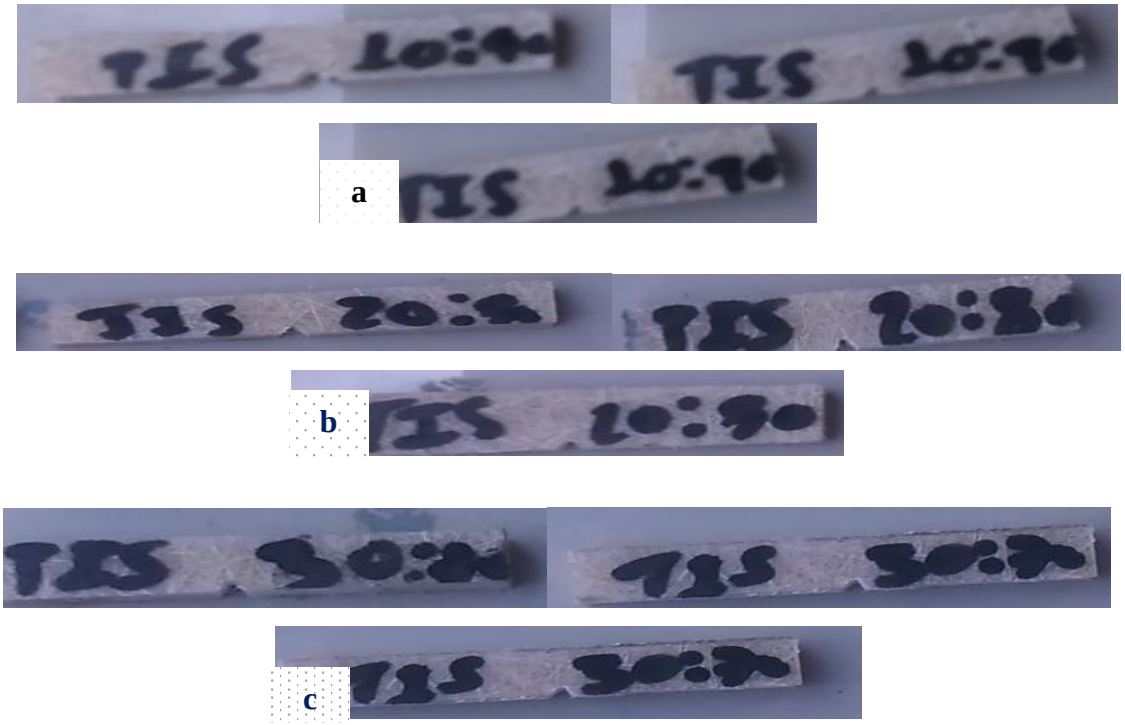


Figure 3. 26 Treated fiber impact test specimen: (a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix and (c) 30% fiber and 70% matrix

The Charpy impact tester shown below figure 3.27 that is installed in material testing laboratory of mechanical workshop at Debrebirhan University.

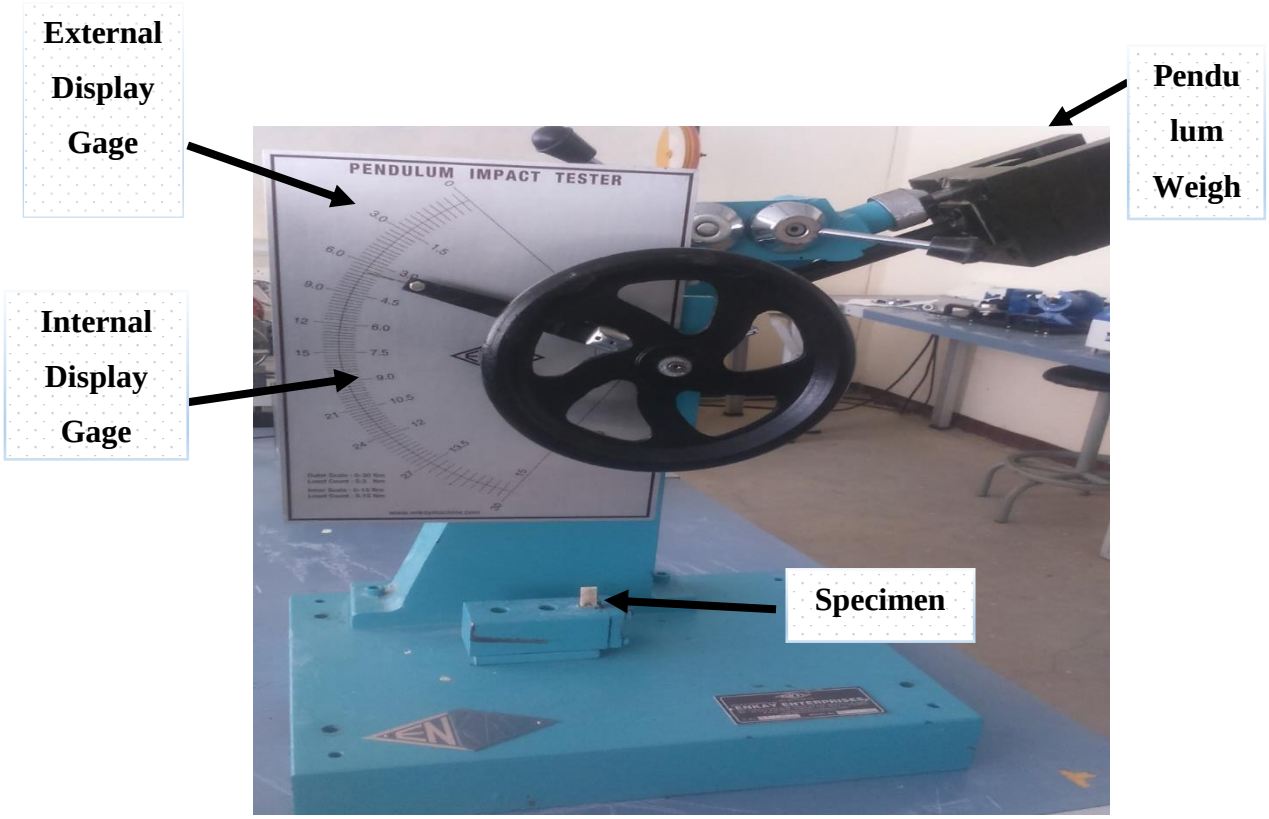


Figure 3. 27 Specimen at pendulum impact tester

3.6.5. Water Absorption Test of the Composite Material

Water absorption characteristic is another significant property for natural fiber composites since they are applied in automotive, aerospace and marine applications. The effect of water absorption on SFPCM was carried out as per ASTM D 570 as shown in figure 3.28 [D 570-98, 2012]. Hence, the test specimen described in this standard was used. The test specimen for the composite have dimension of 30 mm x 28mm x 5mm as shown in figure 3.29 and 3.30 for both treated and untreated SFPCM. First, the specimens dried by sun for at least three days and then allowed to cool until they reached room temperature. The dried specimen weighed before and after immersed using balance electro mass testing machine having a precession of 0.0001 (g). Water absorption tests of SFPCM conducted by immersing the composite specimen in distilled water in glass jar at room temperature for different time duration for both treated and untreated samples. The test samples, containing different fiber fractions were immersed in a distilled water.

Immersion Time

- 24, 48, 72, 96, 120, 144, 168, 192, 216 and 240 hours immersion-for all treated and untreated specimens and each specimen takes place at the end of 24, 48, 72, 96, 120,

144, 168, 192, 216 and 240 hrs. The specimen removed from the water one at a time with their respective time interval, all surface water wiped off with a dry cloth, and weighed.

$$\% \text{ water absorption} = \frac{Wf - Wi}{Wi} \times 100 \qquad (3.18)$$

Where Wi is the initial dry weight of the sample and Wf is the final weight of the sample after immersion in water.

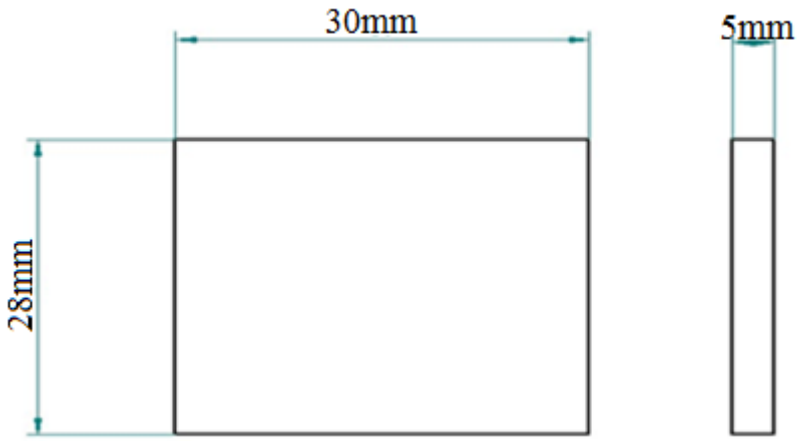


Figure 3. 28 Water absorption test specimen dimension [ASTM D 570-98, 2012]

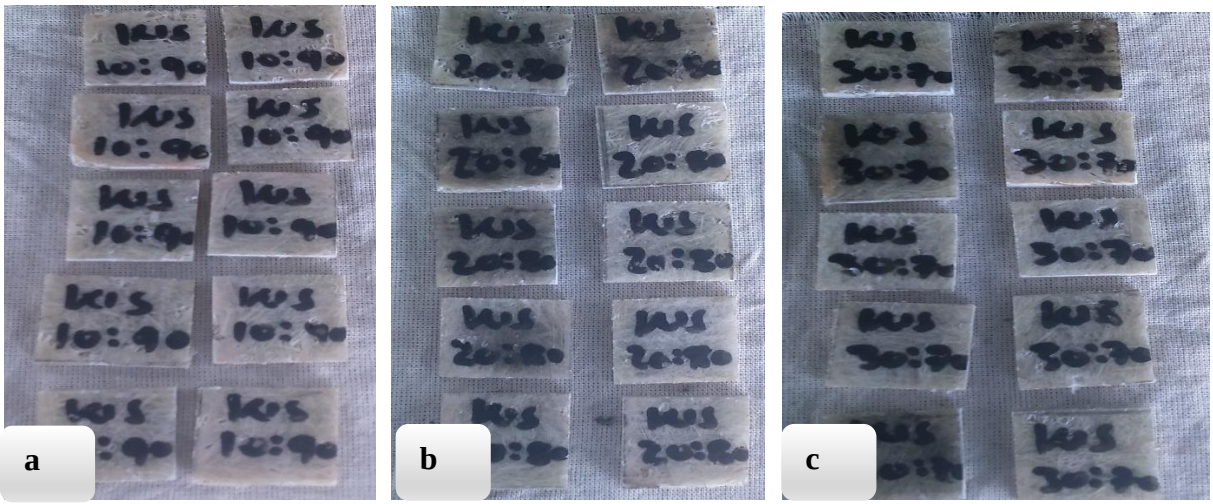


Figure 3. 29 Untreated fiber water absorption test specimen: (a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix, and (c) 30% fiber and 70% matrix

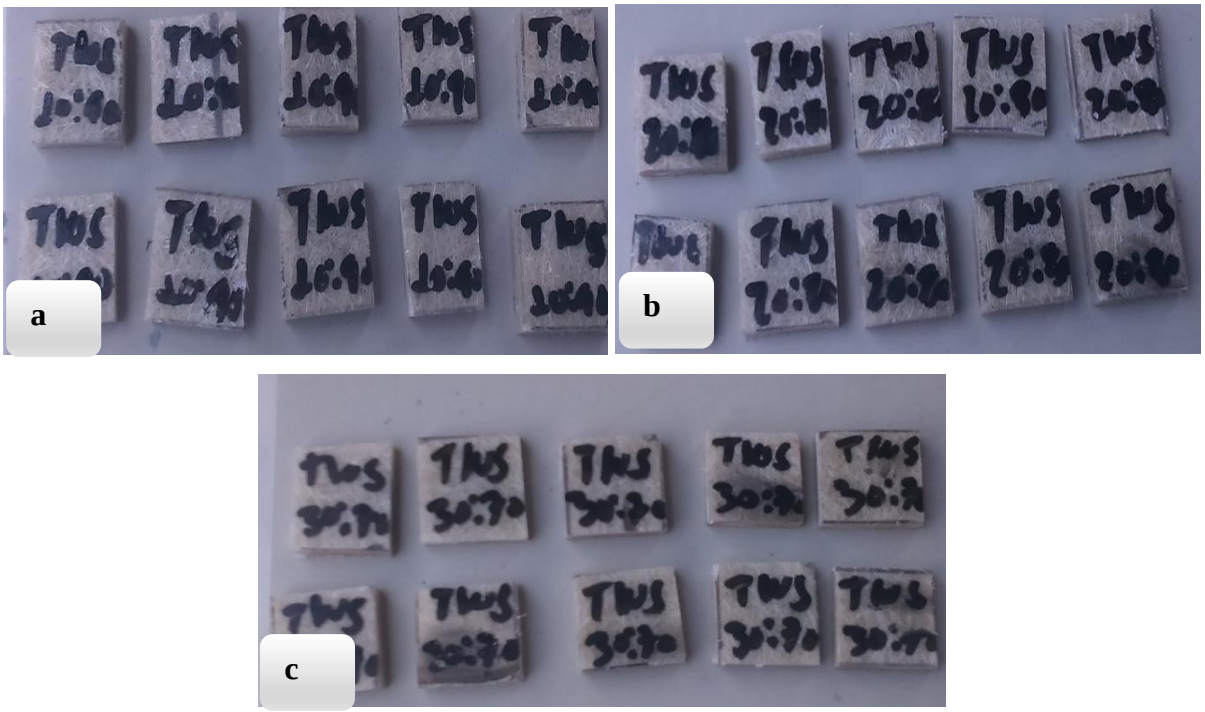


Figure 3. 30 Treated fiber water absorption test specimen: (a) 10% fiber and 90% matrix, (b) 20% fiber and 80% matrix, and (c) 30% fiber and 70% matrix

Figure 3.31 shown that water absorption test by immersing the composite specimen in distilled water at room temperature for different time duration of both treated and untreated samples.

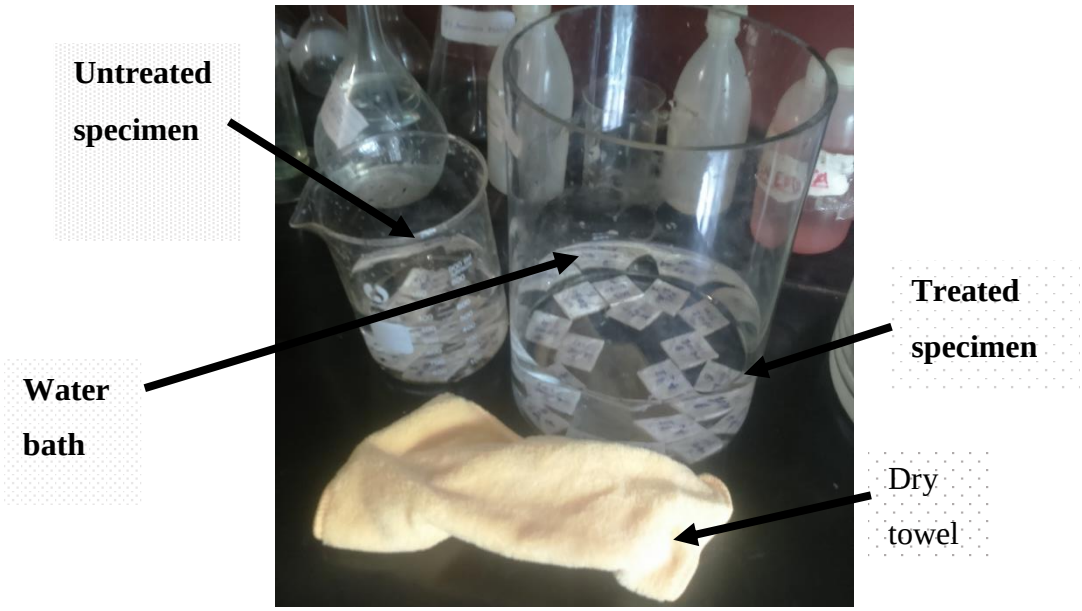


Figure 3. 31 Specimen at water absorption test

3.7. Microstructural Investigation of Sisal Fiber Composites

Study on microstructure fractured surfaces due to the mechanical loading of the sisal fiber reinforced composite, before and after treatments of sisal fiber were carried out, using an optical microscope model of HRM-300 microscope made of Holland installed in material testing laboratory, Adama Science and Technology University as shown in below figure 3.32. The objective was to characterize the structural changes that have occurred upon treated and untreated SF.

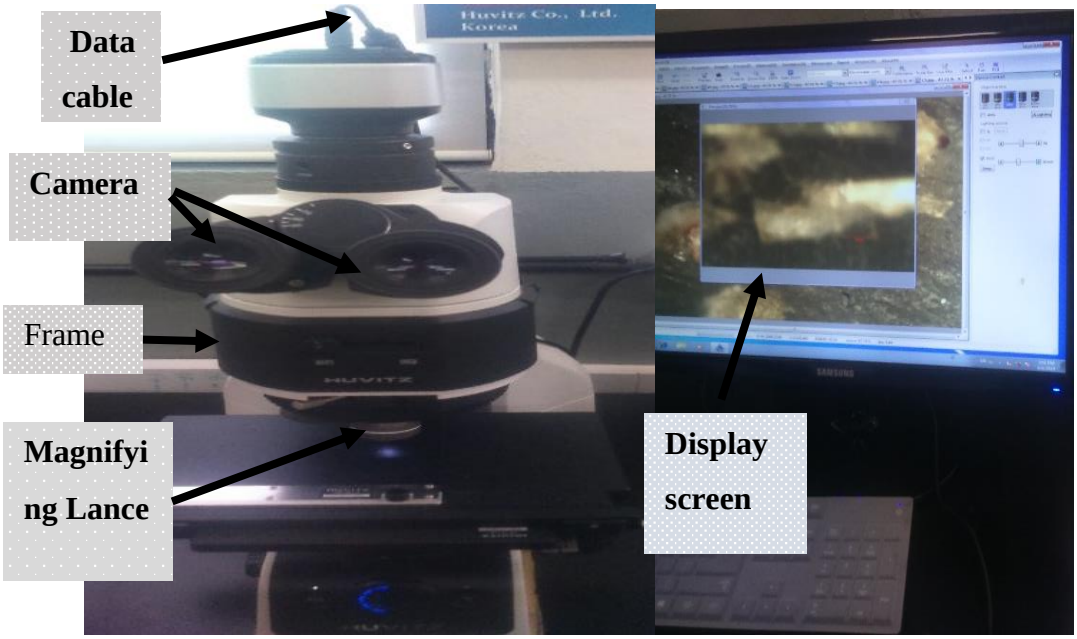


Figure 3. 32 Optical Microscope in Material Lab ASTU

The first step obviously was to cut the specimen to appropriate size in order to fit with the optical microscope specimen chamber, grind and polish the surface to expose the feature(s) of interest. These steps are commonly referred to as metallography even though they are applicable to all materials. For optical microscopy of non-conducting/electrically insulating specimens can absorb electrons and accumulate a net negative charge that repels the following electron beam, this leads to charge buildup on the specimens that makes imaging or other analysis difficult [Warrior et al, 2001]. To a certain extent, lowering the accelerating voltage or reducing the spot size can reduce this artifact, but that would limit the instrument capability considerably. The best way to counter this is to coat the specimen with a thin conducting film.

3.8. Finite Element Simulation Using ANSYS Software

There are many software packages available to industries that use Finite Element Analysis (FEA). A list of some of these commercial packages can be ANSYS, ABAQUS, ALGOR, COSMOS …etc. [Bavan and Kumar, 2013].

3.8.1. General Description of the Finite Element Software

ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. It is also suite of powerful engineering simulation programs, based on the finite element method (FEM), which can solve problems ranging from relatively simple linear analysis to the most challenging nonlinear simulations [Bavan and Kumar, 2013]. ANSYS software contains an extensive library of elements that can model virtually any geometry. It has a various list of material models that can simulate the behavior of most typical engineering materials including composites, metals, polymers and reinforced concrete.

ANSYS offers a wide range of capabilities for simulation of linear and nonlinear applications. Problems with multiple components are modeled by associating the geometry defining each component with the appropriate material models and specifying component interactions [Bavan and Kumar, 2013; Dharmadhikari et al. 2014]. In a nonlinear analysis, ANSYS automatically chooses appropriate load increments and convergence tolerances and continually adjusts them during the analysis to ensure that an accurate solution is obtained efficiently. A complete ANSYS finite element analysis (FEA) usually consists of three distinct stages: preprocessing, simulation, and post- processing.

3.8.2. Procedures of Finite Element Software/ANSYS

The following steps were used in the solution procedure using ANSYS Workbench software for transient structural Finite Element Analysis of a mechanical problem.

3.8.2.1. Importing the Model Geometry

The mechanical geometry model of the tensile and compression specimens were done by SOLID WORKS 2013 modeling software. For the finite element analysis, it was imported to

the ANSYS Workbench 17.2 in an IGES format, which is compatible with the ANSYS software package as shown in figure 3.33.

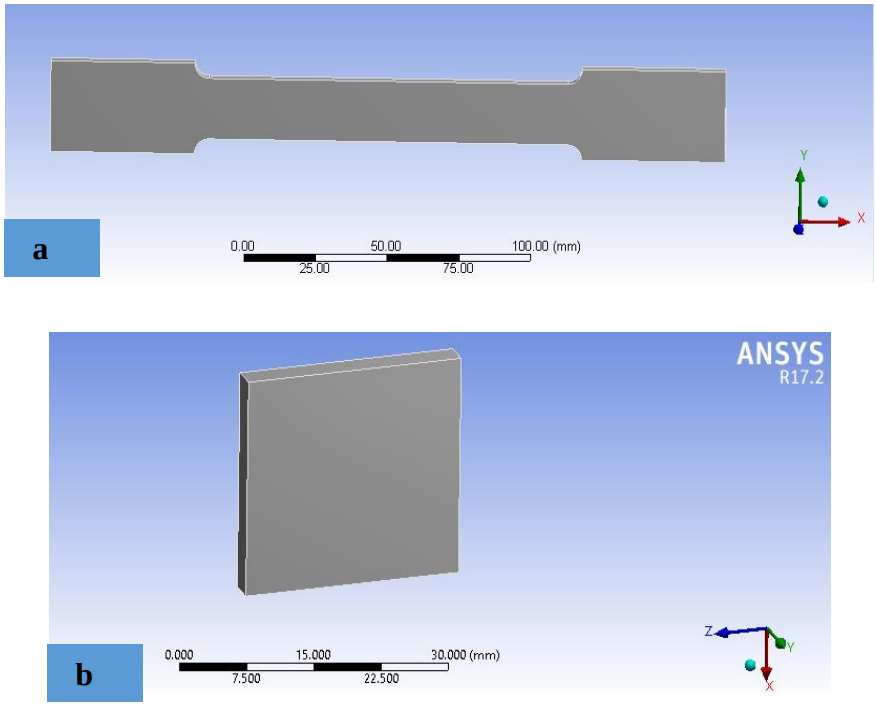


Figure 3. 33 Imported ANSYS model geometrical properties of the simulation specimen:

a) Tensile specimen and

b) Compression specimen

3.8.2.2. Input the Material Type and Properties

The material type and its properties such as density, strength, Young's modulus shear modulus and Poisson's ratio were specified under the project model geometry system. The material applied for this purpose was sisal fiber reinforced polyester composite (SFPCM) material. The engineering data helps to input the mechanical properties of the material SFPCM. The material properties can be altered or edited in this system. The important material properties were taken from the experimental results of tensile and compression specimen. Since the fibers were short and randomly dispersed, the reinforcement composite would be almost isotropic.

3.8.2.3. Meshing the Imported 3D Model

In the finite element analysis the basic concept is to analyze the structure which is an assembly of discrete pieces called elements which are connected together at a finite number of points called nodes. A network between these elements is known as meshing. This is the step that

divides the complex geometry model into small elements that become solvable in an otherwise too complex situation. The meshing of the geometry under consideration may be generated directly, i.e., generation of nodes and elements, one at a time. Solid modeling constitutes a part of the finite element analysis. Thus, the sole purpose of Solid Modeling is to create the mesh of the geometry, as conveniently and efficiently as possible. The meshing process can be performed only after the specification of element type. ANSYS offers several convenient options to assist in meshing. These include Automatic Meshing, Smart Sizing, and Mapped Meshing [Bavan and Kumar, 2013; Dharmadhikari et al. 2014].

One of the most powerful features of ANSYS is automatic mesh generation. ANSYS meshes the solid model entities up on execution of an appropriate single command. With automatic meshing, the user can still provide specific preferences for mesh density and shape. If no preferences are specified by the user, ANSYS uses the default preferences [Bavan and Kumar, 2013].

In this specific research, Meshing was done by using this automatic meshing generation method for both tensile and compression specimen models as shown in figure 3.34.

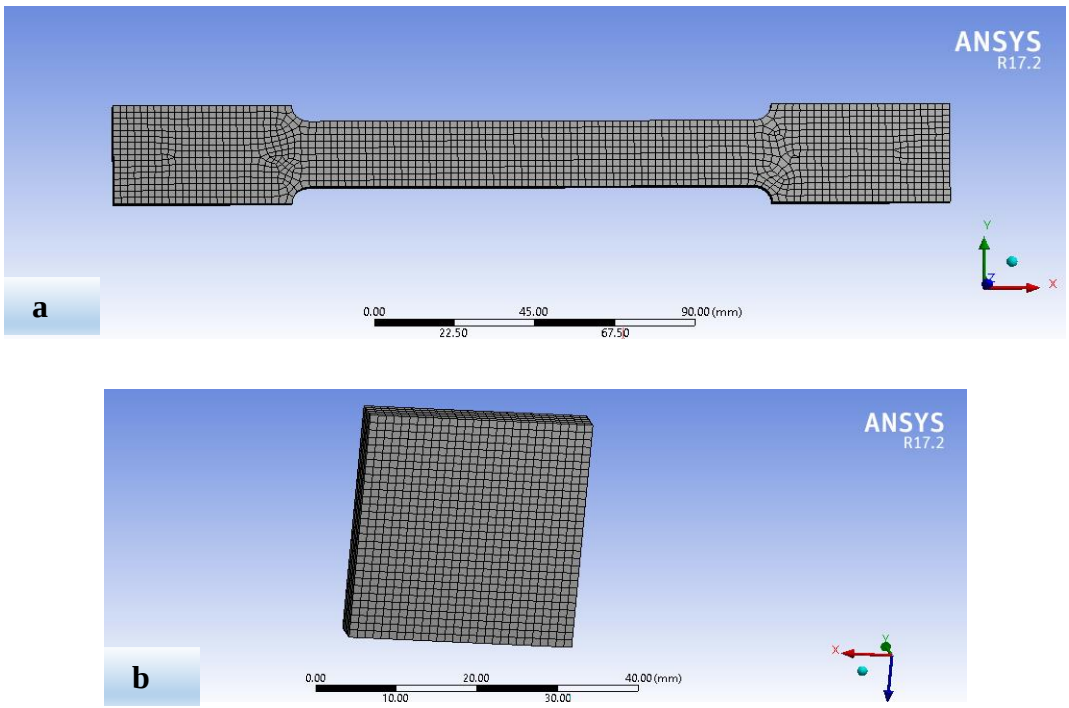


Figure 3. 34 ANSYS workbench element meshes: (a) tensile (b) compressive

3.8.2.4. Boundary Condition and Load Applied on the Specimen

The boundary condition (BC) and load must be defined and would be activated during the simulation. In ANSYS software, the term load is generally refers to anything that makes a change in the response of a structure from its initial state. In this simulation, the BC was applied at one end of the specimen. The load was applied at the other end of the specimen with type displacement of different magnitudes. Figure 3.35 shown that BC and load applied on the specimen of both tensile and compression.

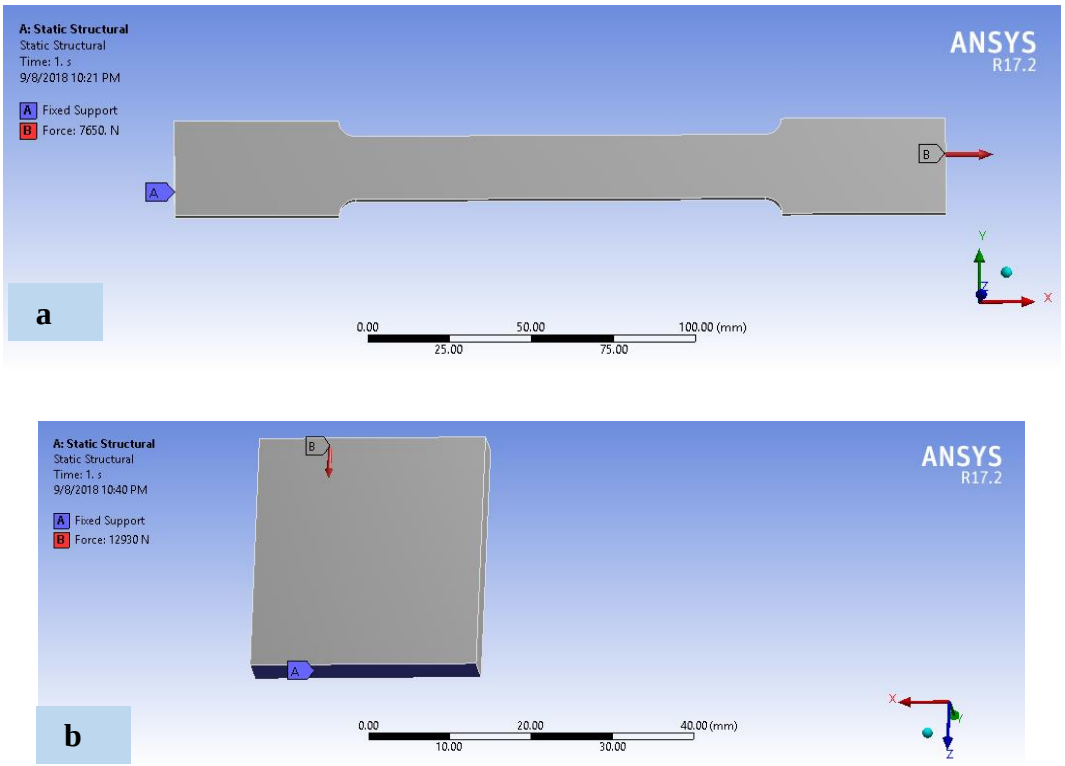


Figure 3. 35 Boundary condition and load applied for ANSYS work bench model: (a) tensile (b) compressive

3.8.2.5. Generate Solutions

The solution was generated based on the above input parameters. The equivalent (Von Mises) stress are the basic variables to be solved by this software analysis for both tensile and compression specimen.

Finally, the solution of each dependent parameter displayed one by one. Once the solution was generated, each dependent parameter was solved and ready to be seen and interpreted. This would be clearly discussed in the next chapter four.

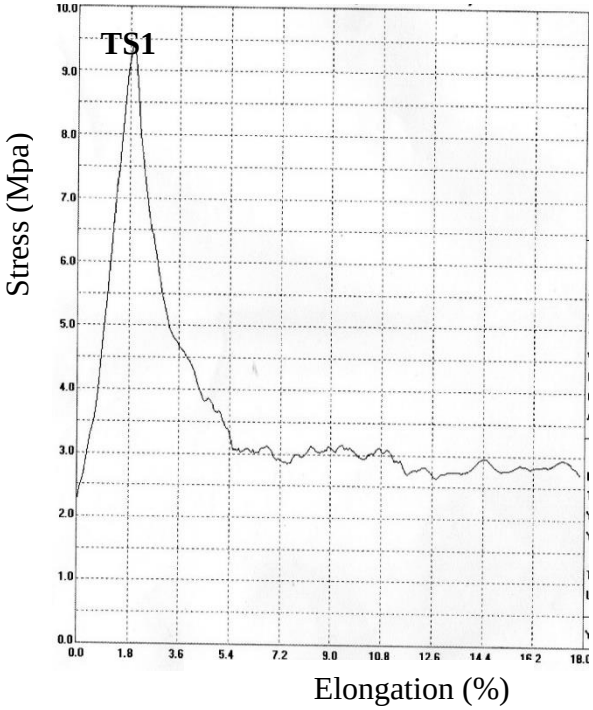
CHAPTER FOUR

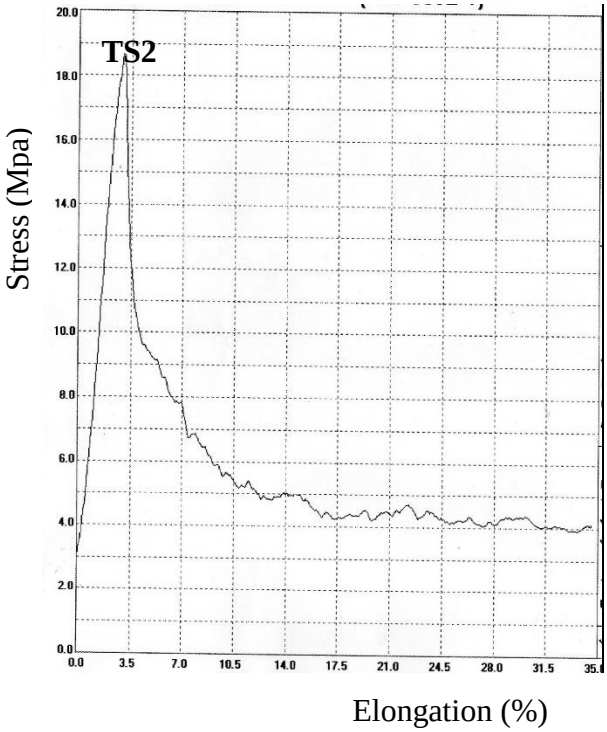
RESULTS AND DISCUSSION

4.1. Mechanical Experimental Results

4.1.1. Tensile Test Behavior of SFPCM

The tensile performance of the SFPCM with different weight and fixed chopped fiber length of 8mm was investigated. Various prepared samples TS1, TS2, and TS3 for untreated fiber and TTS1, TTS2 and TTS3 for treated fiber represented 10%, 20% and 30% fiber and 90%, 80% and 90% matrix respectively were subjected to tensile loading. The values of tensile strength and percentage elongation for corresponding fiber loadings were obtained from the post processor of UTM machine. Figure 4.1 shown some selected tensile result of SFPCM from post processor of UTM machine for both treated and untreated specimen.





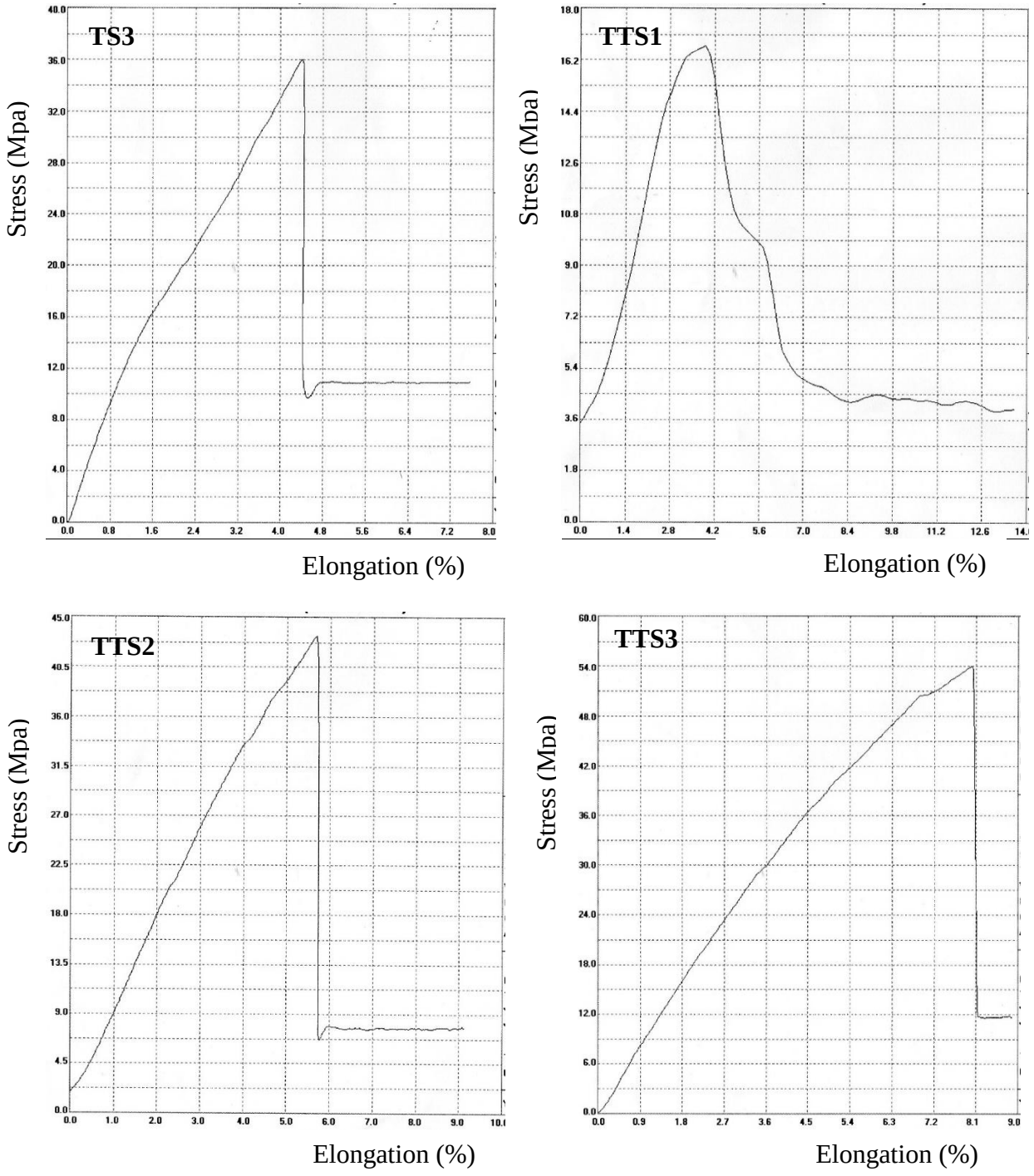


Figure 4. 1 Tensile Stress vs percentage elongation for each specimen group

The Modulus of Elasticity or tensile Modulus of the composite material is ratio of stress in Mpa to strain (uniform elongation) in millimeters per millimeter (mm/mm).

$$E = \frac{\sigma}{\varepsilon} \qquad (4.1)$$

Where σ is tensile strength and ε is uniform elongation (strain)

The experimental results of average tensile tests of composites with different weight fraction of reinforcement and calculated average elastic Modulus presented in below Table 4.1.

Table 4. 1 Experimental results for tensile testing of composites

Samples	Average tensile strength(Mpa)	Average tensile Modulus (Mpa)
TS1	12.98	487.1
TS2	26.23	519.38
TS3	37.4	733.01
TTS1	20.2	548.63
TTS2	44.8	748.18
TTS3	50.76	768.446

The experimental result properties of three-trial sample of tensile strength for each group and average tensile strength was summarized using graphs as shown in figure 4.2 and 4.3 respectively.

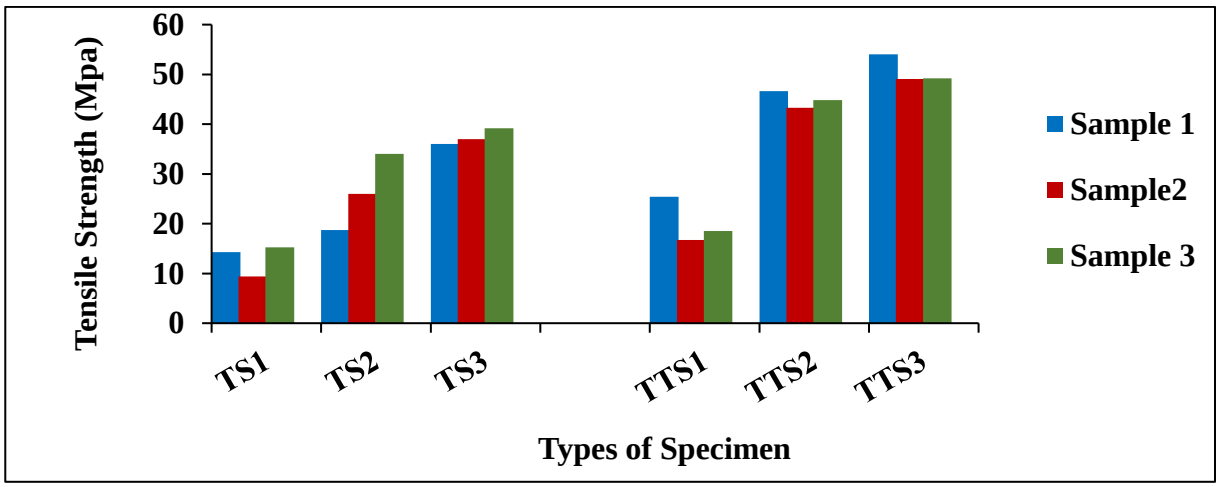


Figure 4. 2 Tensile strength comparison for all untreated and treated sisal fiber composite samples

The results from table 4.1 and figure 4.3 revealed that fiber/matrix composition did affect the tensile strength of sisal fiber reinforced polyester composite. The tensile strength value of untreated SFPCM composite shows an increase between 10/90 and 20/80, between 10/90 and

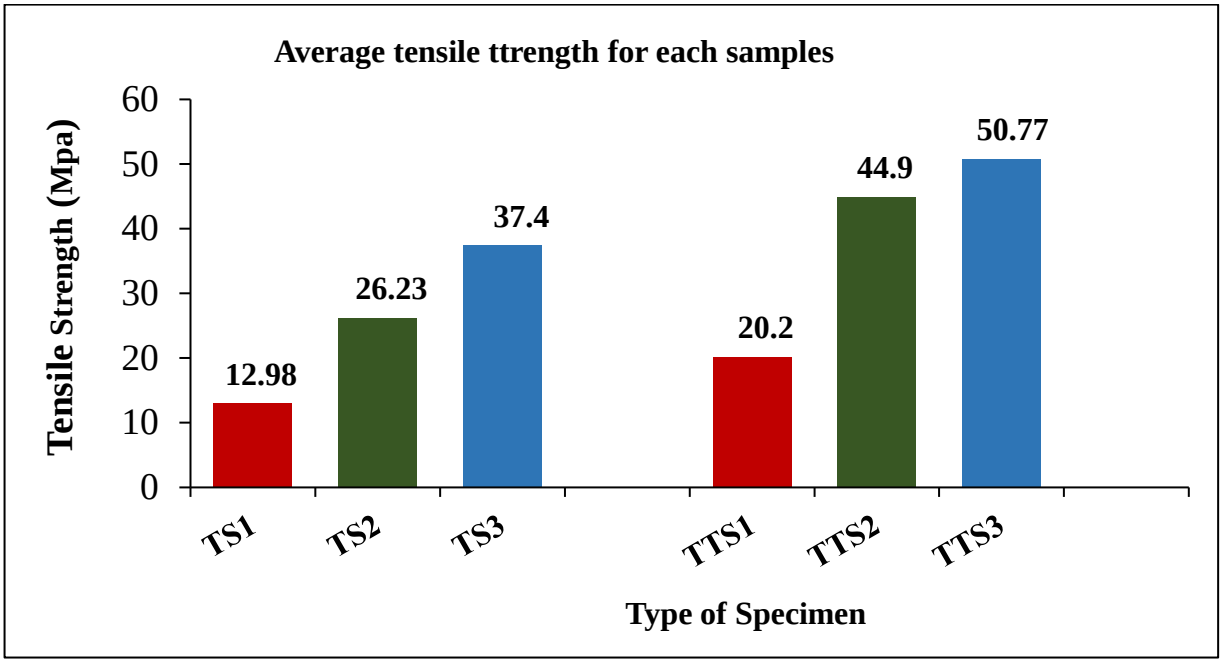


Figure 4. 3 Average tensile strength of SFPCM for treated and untreated fiber composite samples

30/70 and between 20/80 and 30/70 has been 50.51%, 65.294% and 29.866% respectively. On the other hand the tensile strength for treated SFPCM samples increase between 10/90 and 20/80, between 10/90 and 30/70 and between 20/80 and 30/70 has been 55%, 60.21% and 11.56% respectively. This showed that the fiber matrix ratio significantly affected tensile strength with increased the fiber in the SFPCM. The tensile stress decrease in the first fiber weight ratio TS1and TTS1 for both treated and untreated and then increase continuously up to TS3 and TTS3 composite samples.

Surface modification of the fiber by alkali treatment improves chemical bonding and helps to withstand high tensile load according to this reason the tensile result is better for treated samples than untreated samples. The treated TTS1 was better in tensile strength than the TS1 by 35.74% similarly TTS2, TTS3 treated samples was better than the untreated samples TS2, TS3 by 41.58%, 26.33% respectively. The tensile strength increase as the fiber content increase in the fiber matrix ratio in the alkali treated SFPCM between 20/80 and 30/70 fiber/matrix ratio the tensile strength change almost leveled. This means that the fiber content in SFPCM may have reached a saturation graph state or at least adding of more fiber in SFPCM more than 30% may decrease of tensile strength.

The graphical presentation of Young's modulus of the SFPCM for both treated and untreated composite samples shown in below figure 4.4.

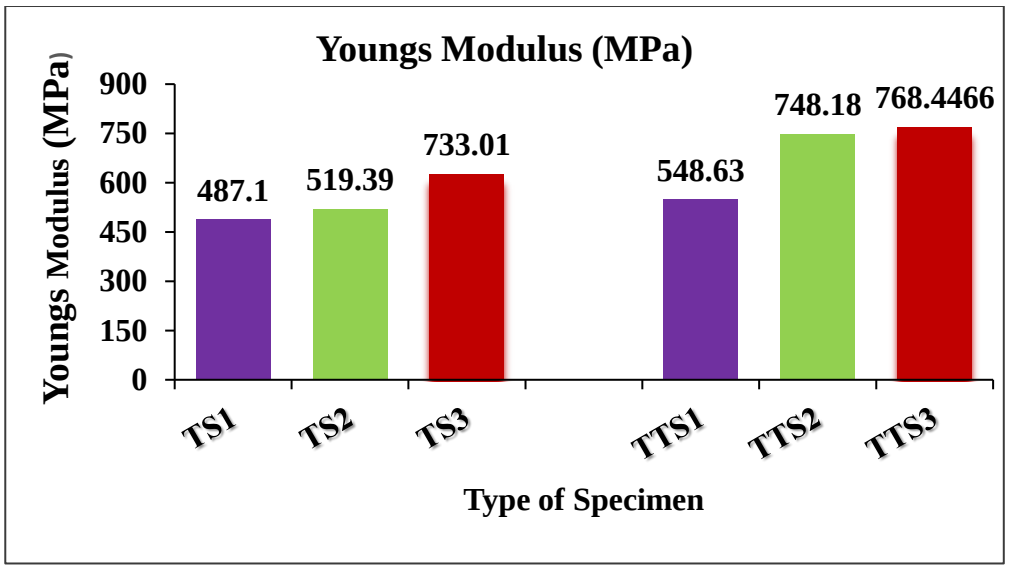


Figure 4. 4 Tensile Modulus for both treated and untreated samples

The tensile modulus results shown sample TTS3, TTS2 and TS3 gave better modulus than of the other samples ratio. Tensile modules of untreated fiber samples was increased from TS1 to TS3, but as comparing to treated samples has lower modulus because the untreated samples surface indicated that fiber/matrix interfacial failure followed by extension pulls out from the matrix. The maximum tensile modulus observed as 768.4466Mpa.

4.1.2. Compression Test Properties

The chopped random orientation compressive test specimens were prepared for both treated and untreated with the fiber/matrix ratio of 10/90, 20/80 and 30/70 %wt., three specimens were prepared and average result was taken for each composition ratio. The results of compressive strength for each specimen and average compressive strength results were tabulated in table 4.2 below. The adhesion between fiber and matrix were most important parameter in controlling the compression properties of random orientation chopped SFPCM.

The average treated and untreated sisal fiber compressive strength result were compared graphically as shown in figure 4.5.

Table 4. 2 Compressive test results

Samples specification	Compression sress trial 1(Mpa)	Compression stress trial 2(Mpa)	Compression stress trial 3(Mpa)	Compression stress Average (Mpa)
CS1	84	67.33	87.57	79.633
CS2	56.44	68.25	72.31	65.67
CS3	52.6	58.56	46.15	52.44
TCS1	139.83	165.1	129.3	144.74
TCS2	128.91	111.2	122.41	120.84
TCS3	88.96	81.7	90.61	87.09

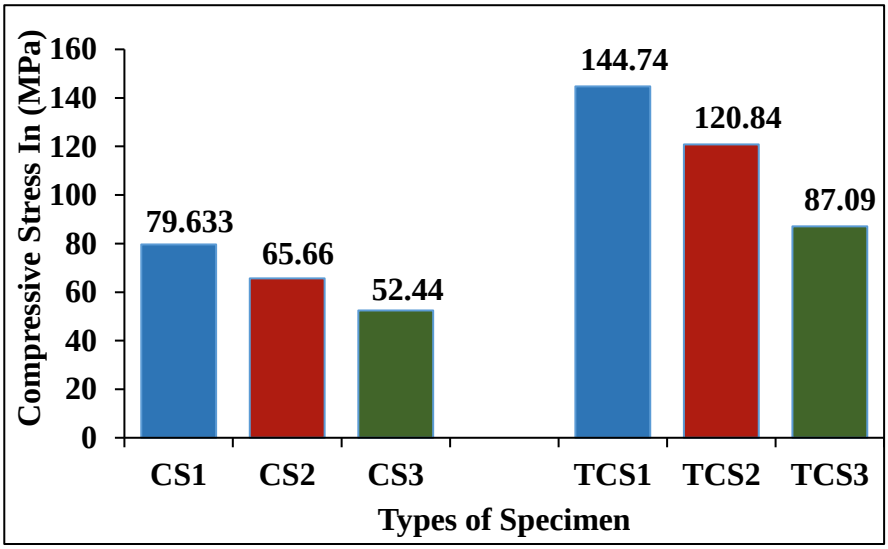


Figure 4. 5 Compressive strength comparison between untreated and treated for each fiber/matrix ratio for all weight fraction

The compressive strength of CS1, TCS1, CS2, TCS2, CS3 and TCS3 result shown in figure 4.5 compared the treated and untreated sisal fiber; the test result pointed out that the surface modification of the sisal fiber or surface treatment by NaOH solution has significant effect on the compressive properties of SFPCM. The compression strength properties of chopped fiber composite material decreased as weight of fiber increase for both treated and untreated batch of the specimen as shows in figure 4.5. The maximum compression strength for treated group was 144.74Mpa in the ratio of 10%wt (TCS1) and maximum compression strength for untreated batch 79.633Mpa in the ratio of 10%wt (CS1).

4.1.3. Impact Test Properties

Impact test were carried out using charpy impact test machine. The Impact energy for various prepared samples IS1, IS2 IS3, TIS1, TIS2 and TIS3 treated and untreated sisal fiber were obtained. There were 6 specimen groups and total 18 specimens for each fiber/matrix ratio (10/90, 20/80and 30/70) treated and untreated SFPCM three(3) samples for each weight ratio were tested and the average result was measured as shown in table 4.3 below.

Table 4. 3 Impact energy in Joule of treated and untreated composite sample

Samples specification	Trial 1 (Joule)	Trial 2 (Joule)	Trial 3 (Joule)	Average (Joule)
IS1	3.45	3.6	3.75	3.6
IS2	4.75	5.05	5.35	5.05
IS3	6.3	6.45	6.75	6.5
TIS1	4.2	4.6	4.45	4.42
TIS2	6.45	6.375	6.525	6.45
TIS3	7.45	7.6	7.75	7.6

Figure 4.6 shown the compared impact strength properties of treated and untreated sisal fiber reinforced composites on their random orientations 3 trials for each volume fraction. The average impact resistance of each volume fraction of the composite sample also shown in figure 4.7.

The result pointed out that the randomly oriented chopped alkali treated SFPCM was better in impact strength than untreated fiber as shown in figure 4.7 because evidencing increased interfacial bond exhibited by the alkali treated fiber and matrix. From the experiment it was observed that impact strength properties of TIS3 7.6J were found to maximum. Impact strength properties of TIS3 were found 111.11%, 50.495%, 16.92%, 71.95% and 17.83% more than IS1, IS2, IS3, TIS1 and TIS2 respectively.

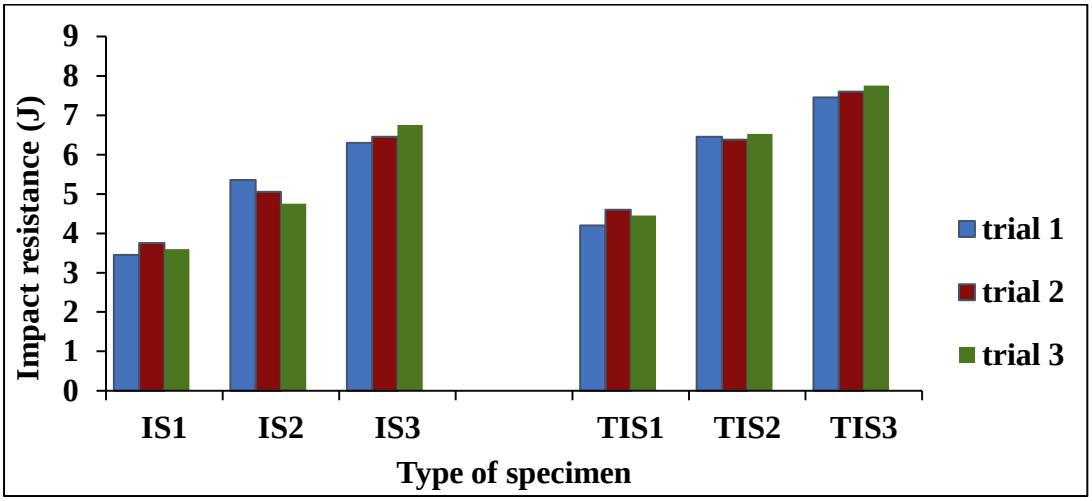


Figure 4. 6 Impact resistance for all untreated and treated sisal fiber composite samples

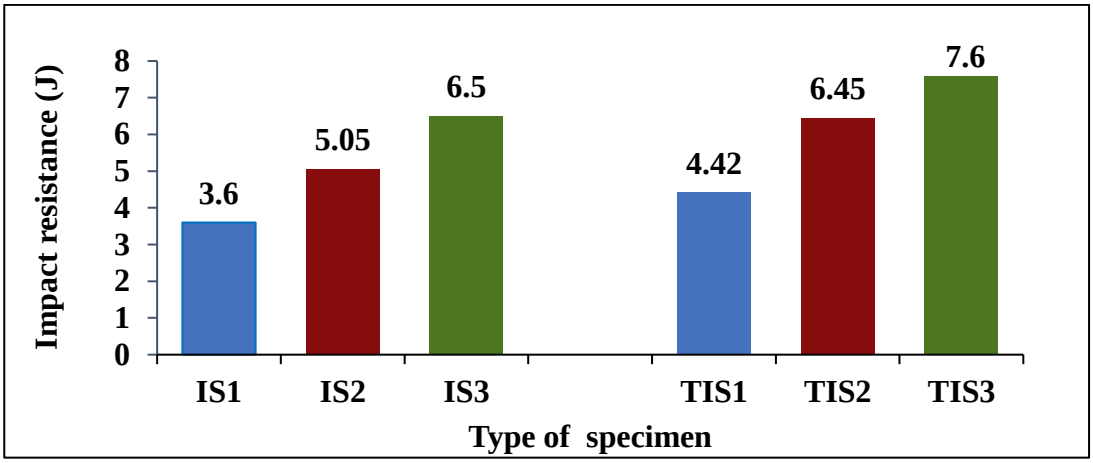


Figure 4. 7 Average impact strength of SFPCM for treated and untreated fiber composite samples

This experimental result shown the impact strength increased linearly with increasing fiber weight fraction from 10% to 30% for both treated and untreated fiber. In the alkali treated fiber composites, fiber tenacity reduced and fiber-matrix adhesion enhanced, which resulted in a significant increase in their impact strength.

4.2. Water Absorption Properties of Treated and Untreated Sisal Fiber Composites

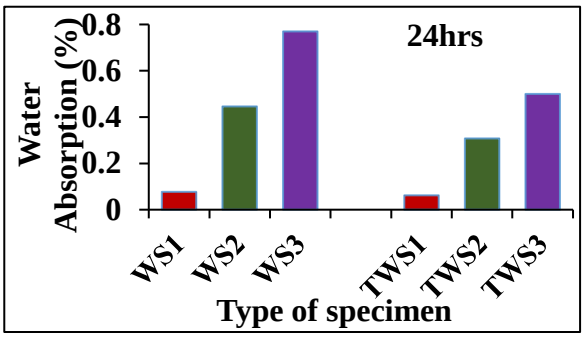
The percentage of water absorption in the composites was calculated by weight difference between the samples immersed in distilled water and the dry samples using equation (3.18). The test was carried out at 24hrs, 48hrs, 72hrs, 96hrs, 120hrs, 144hrs, 168hrs, 192hrs, 216hrs and

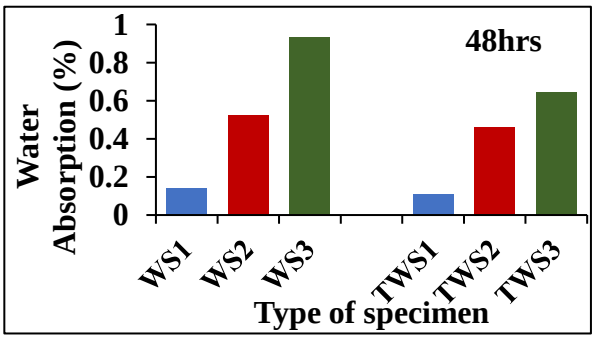
240hrs i.e. up to ten days for all treated and untreated specimen batch of WS1, WS2, WS3, TWS1, TWS2 and TWS3 at room temperature. The weight gains as function of time the result were shown in table 4.4 for all treated and untreated sisal fiber composite samples.

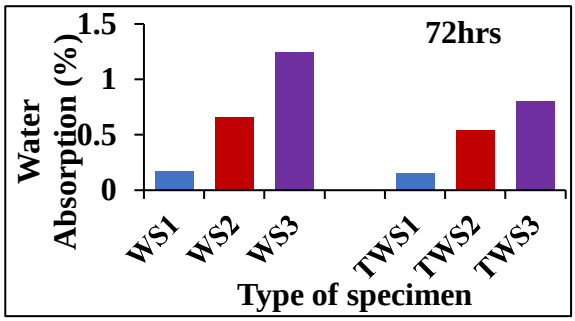
Table 4. 4 Water absorption of different batch of SFPCM with immersion time

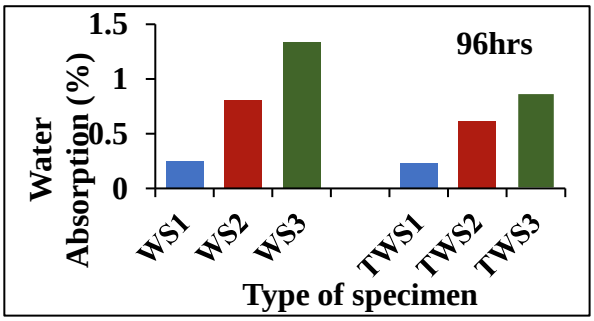
Samples	Weight gain in percent (%)									
	24h	48h	72h	96h	120h	144h	168h	192h	216h	240h
WS1	0.077	0.14	0.17	0.247	0.464	0.5	0.51	0.52	0.52	0.52
WS2	0.446	0.52	0.655	0.804	0.922	0.952	0.967	0.982	0.982	0.982
WS3	0.77	0.932	1.241	1.335	1.382	1.397	1.427	1.428	1.428	1.428
TWS1	0.062	0.11	0.156	0.233	0.28	0.311	0.343	0.358	0.358	0.358
TWS2	0.3077	0.461	0.538	0.615	0.877	0.907	0.928	0.938	0.938	0.938
TWS3	0.5	0.645	0.806	0.871	0.984	1.01	1.061	1.062	1.062	1.062

The Percentage of water absorption characteristics behavior of sisal-polyester composite for all treated and untreated samples immersed in distilled water at atmospheric temperature with time immersion interval up to ten days were shown in figure 4.8.









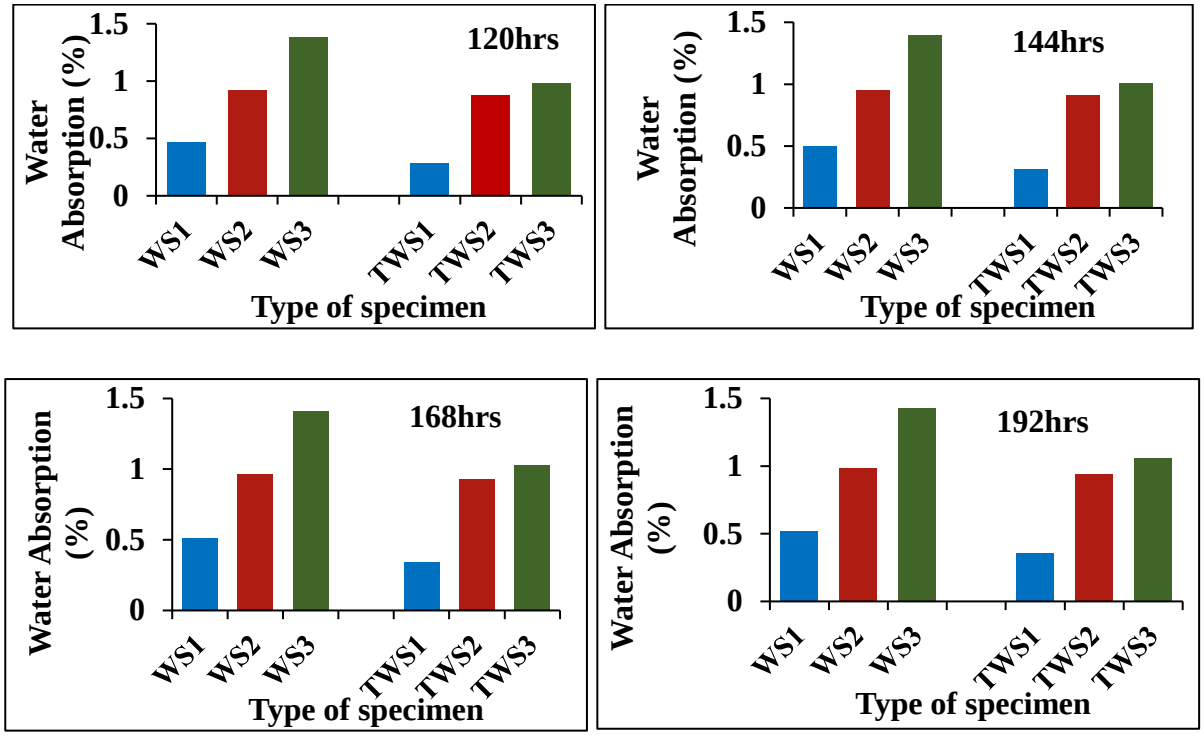


Figure 4. 8 Effect of water absorption at difference time interval, immersed for all samples

From the graph It was observed that the water absorption by the composite increases with immersion time although the rate of absorption decrease with increased time. Maximum water absorption was exhibited by WS3 in all samples as shown from the figure. Fiber matrix interface plays an important role in the composite properties. A good interfacial bond is required for effective stress transfer from the matrix to the fiber. In addition, it improves resistance to moisture-induced degradation of the interface and the composite properties. Similarly, WS1 composites gained maximum weight than the TWS1composites.

It was also observed that the composite attains equilibrium after 168 hours. The amount of water absorbed increases with fiber content. The result also shows that immersion of specimens for all hours at room temperature imparted a less weight gain to WS1 and TWS1 whereas WS2, TWS2, WS3 and TWS3 samples had more weight gain proportionately. The fiber content contributes to its absorptivity rate. At the beginning, it absorbs water at an increased rate before it attains the maximum, the rate drops drastically until reaches saturation point. The 30 wt.% of the fiber for all treated and un treated attains saturation earlier than the rest specimen.

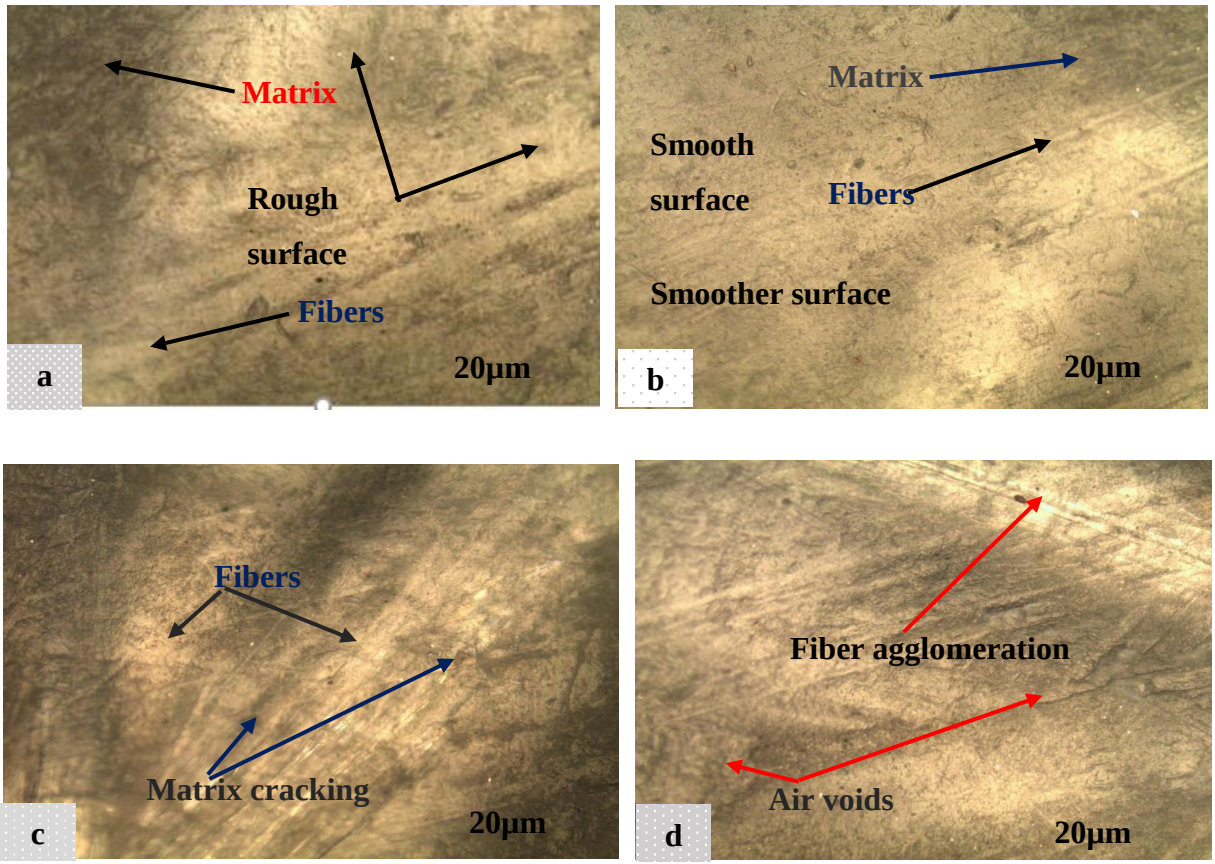
When weight gain is more, water molecules interlocked in the composites is more. Thus, the water molecules get chances to attack the interface adhesion resulting in bonding of the fiber

and the matrix internally in the composite. Thus, it evidenced clearly that the immersion time influence the absorption behavior of the sisal fiber reinforced polyester composites variedly.

4.3. Microstructure Analysis of the Composites

The structure of the fractured surfaces due to the mechanical loading was observed through optical microscope analysis. The optical microscope micrographs are to be used to observe the internal cracks, fractured surfaces and internal structure of the tested samples of the composite materials. In most of fiber composite, the micro object has fiber, matrix air voids and fiber agglomeration [Gassan and Bledzki, 1999].

Optical microscope at 1000-X magnification was employed to examine the microstructural surface of untreated and treated fibers and would expect that the untreated fiber should be differing to the treated fiber, in the terms of their level of smoothness and roughness. It showed that, NaOH treatment remove the impurities of sisal fiber because the impurities were observed on the surface of untreated fiber. Figure 4.9 shown some optical microscope images of treated and untreated SFPCM specimen.



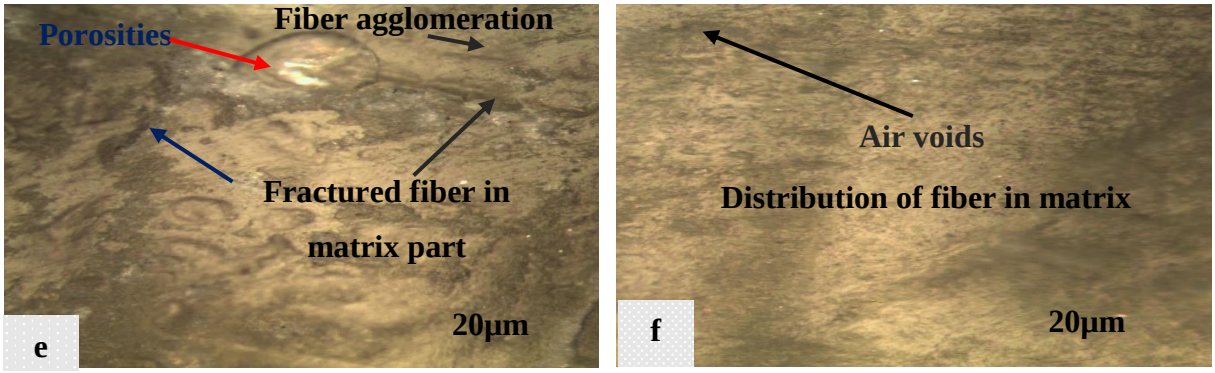


Figure 4. 9 Optical microscope micrographs of the fracture surface of SFPCM composites reinforced with: (a) untreated 10% SF (b) treated 10% SF (c) untreated 20% SF (d) treated 20% SF (e) untreated 30% SF (f) treated 30% SF

The fiber dispersion is clearly visible in the optical microscope images provided. Specimen 10% and 20%wt of both treated and untreated has little air voids (air gaps) in both batch. These air gaps reduce the strength of the composite the fiber distribution and orientation was also visible is in the Figure 4.9 (c). Similarly, for 30% of sisal fiber image shown more fiber agglomeration. The extensive fiber pullout of under load side which means fractured part of fracture is visible in the figure 4.9 (e) from which it can be deduced that there is no trace of matrix resin sticking to the fiber which indicates a poor fiber- matrix adhesion as a result of which the composite strength gets reduced by a considerable amount. Also indicates fiber agglomerations as well as fiber pull out.

4.4. Comparison of Results with Previous Works

4.4.1. Tensile Strength Comparison

The tensile strength properties of sisal fiber polyester composite of present paper work has to be compared with some other previous researchers work concerning tensile properties. The tensile strength, which is found in the present paper, was higher than to the journal paper by [Madhusudhana et al. 2014], which was found 26Mpa for 20/80 fiber/matrix. The tensile strength of 20/80 fiber/matrix ratio of the present paper work is 44.9Mpa of treated sisal fiber 20/80 fiber/matrix ratio, which is higher than Madhusudhana results; with the same hand lay-up fabrication technique, polyester resin as a matrix and random sisal fiber orientation. It can conclude that the result getting from the present paper work is 72.7% higher in tensile strength

than Madhusudhana work. In similar way the present work comparison with other previous journal papers were tabulated in table 4.5.

Table 4. 5 Tensile strength properties comparison of sisal fiber composite with previous works

Fiber type	Matrix type	Fiber orientation	Fiber/matrix ratio (wt. %)	Fabrication method	Tensile strength(Mpa)	References
Sisal treated	Polyester	Random short fiber	20/80	Hand lay-up assist by HAVBT	44.9	Present work
Sisal	polyester	Random short fiber	20/80	Hand lay-up	26	[Madhusudhana et al,.2014]
Sisal treated	Polyester	Random short fiber	30/70	Hand lay-up assist by HAVBT	50.77	Present work
Sisal	Epoxy	90º	30/70	Hand lay-up	38.84	[Kumaresan et al.,2015]
Glass	Polyester	Mat form	30/70	Hand lay-up	42	Gupta(2016)in2
Hybrid Sisal/ Coir	Epoxy	Uni-Directional for sisal short for coir	40/60	Hand layup	56	[Girishna et al., 2012]

4.4.2. Compression Strength Comparison

The compressive strength of present work was also compared with previous work as shown in table 4.6 below. The compressive strength of treated 30/70 sisal/matrix ratio of present work is 87.09Mpa much higher as compared with previous work by [Dinesh et al.,2013] fabricated through hand lay-up with treated 30/70 sisal/matrix ratio that found 64.66 Mpa . The compression strength result of the present work is higher than Dinesh's, by 34.69% at 30%wt.

Table 4. 6 Compressive strength comparison of sisal fiber composite with previous works

Fiber type	Matrix type	Fiber orientation	Fiber/matrix ratio (wt. %)	Fabrication method	Compression strength(Mpa)	References
Sisal treated	Polyester	Random short fiber	30/70	Hand lay-up assist HAVBT	87.09	Present work
Sisal treated	epoxy	Random short fiber	30/70	Hand lay-up	64.66	[Dinesh et al.,2013]

4.4.3. Impact Strength Comparison

The impact resistance of the sisal fiber polyester natural fiber composite present work also compared with another previous worked papers and the comparison result was shown in table 4.7 below. The impact energy of the present work at 30/70 sisal/matrix ratio also higher than the selected other researchers work.

Table 4. 7 Impact strength comparison of sisal fiber composite with previous works

Fiber type	Matrix type	Fiber orientation	Fiber/matrix ratio (wt. %)	Fabrication method	Impact energy (Joule)	References
Sisal treated	Polyester	Random short fiber	30/70	Hand lay-up assist by HAVBT	7.6	Present work
Sisal	Epoxy	90^{o}	30/70	Hand lay-up	7.3	[Kumaresan et al..2015]
Hybrid Sisal/ glass	epoxy	Random short fiber	30/70	Hand lay-up	5	[Kumre et al.,2017]
E-glass	polyester	Random short fiber	30/70	Hand lay-up	6.5	[Wazery et al.,2017]

4.5. Results of Tensile Stress from ANSYS 17.2

Tensile testing is also known as tension testing is a fundamental materials science test in which a sample is subjected to controlled tension until failure. The equivalent (Von Mises) stress values of all batch as shown in figure 4.10 was posted after the process of modeling solid composite specimen, apply boundary conditions load and solve the model finally evaluate solid model results in ANSYS.

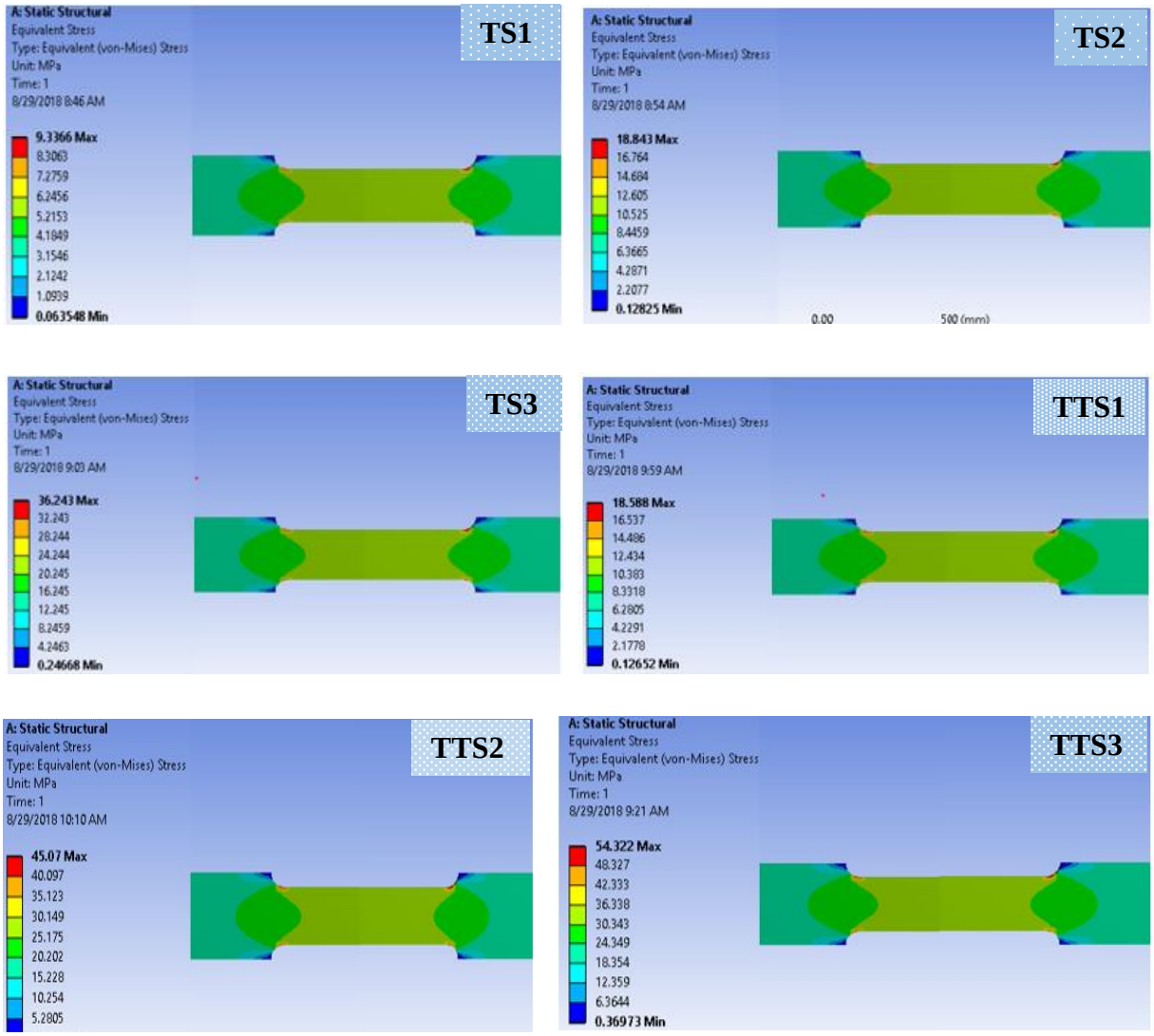


Figure 4. 10 Some tensile stress ANSYS result of treated and untreated SFPCM

The tensile stress result for all mass composition of chopped sisal fiber reinforced polyester composite of both experiment and ANSYS test results were shown in table 4.8.

Table 4. 8 Tensile test results for both experiment and ANSYS test

samples	TS(Mpa) Trial1 from experiment	TS(Mpa) Trial1 from ANSYS	Error (%)	TS(Mpa) Trial2 from experiment	TS(Mpa) Trial2 from ANSYS	Error (%)	TS(Mpa) Trial3 from experiment	TS(Mpa) Trial 3 from ANSYS	Error (%)
TS1	14.3	14.395	0.66	9.4	9.33	0.75	15.25	15.312	0.40
TS2	18.7	18.843	0.75	26	26.34	1.29	34	34.189	0.55
TS3	36	36.243	0.67	37	37.177	0.47	39.2	39.784	1.45
TTS1	25.4	25.463	0.25	16.7	16.84	0.83	18.5	18.588	0.47
TTS2	46.6	47.373	1.63	43.3	43.627	0.75	44.8	45.07	0.60
TTS3	54	54.322	0.59	49.1	49.614	1.03	49.2	49.4	0.41

The percentage error from table 4.8 was calculated in comparison between experimental and simulation results and it measures up to 1.63%, this signifies the validity of the experiment. Furthermore, both experimental and simulation results justify that all compositions of chopped sisal fiber and polyester resin matrix has robust tensile strength.

4.6. Compression Stress Results of ANSYS 17.2

ANSYS Workbench was also used to study the compressive behavior of the composite sample. Specific standard of ASTM D3410 were used to modeling the compression test samples and imported to ANSYS program. The Finite Element Analysis for compression test was also conducted on the samples of both treated and untreated batch to study the effect of reinforcement under different load conditions as shown in figure 4.11.

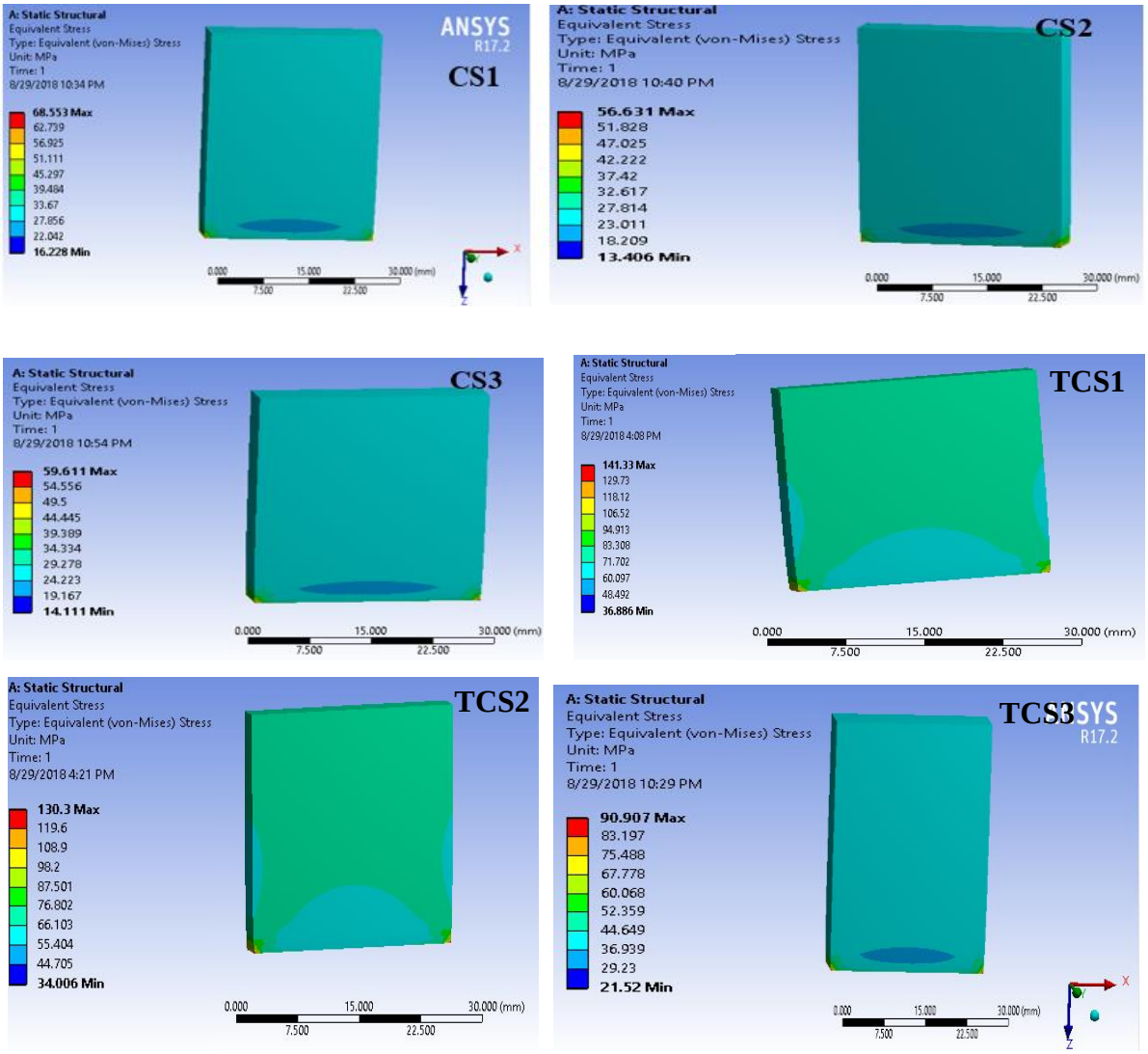


Figure 4. 11 Some compression stress ANSYS result of treated and untreated SFPCM

The compressive stress result of both experimental and ANSYS simulation of treated and untreated SFPCM also shown in table 4.9

Table 4. 9 Compression test results for both experiment and ANSYS test

samples	CS(Mpa) trial1 from experiment	CS(Mpa) trial1 from ANSYS	Error (%)	CS(Mpa)trial2 from experiment	CS(Mpa) trial2 from ANSYS	Error (%)	CS(Mpa)Trial3 from experiment	CS(Mpa) Trial 3 from ANSYS	Error (%)
CS1	84	84.946	1.11	67.33	68.553	1.78	87.57	89.417	2.06
CS2	56.44	56.631	0.34	68.25	69.596	1.93	72.31	73.471	1.58
CS3	52.6	53.65	1.96	58.56	59.611	1.76	46.15	46.199	0.10
TCS1	139.83	141.33	1.06	165.1	167.83	1.63	129.3	129.47	0.13
TCS2	128.91	130.3	1.07	111.2	113.07	1.65	122.41	126.44	3.18
TCS3	88.96	90.907	2.14	81.7	83.486	2.13	90.61	90.907	0.33

From table 4.10 the compression strength of both experiment and simulation was examined for all SFPCM batch and maximum percentage error were found 3.18%, this shown that good correlation between experiment and simulation result.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Now a day the attention to natural fiber reinforced polymer matrix composites has been increasing due to their high strength to weight ratio, environmentally friendliness, sustainable and recyclability. This can be used as a valuable marketing tool by the automotive industry, in the current situation of environmental concern. In this research work, sisal fiber was used as reinforcement and an investigation was carried out to make use of sisal fiber fabricated by polyester resin matrix composite. Sisal fiber reinforced polyester composite was manufactured and its mechanical properties such as tensile, compression and impact properties for each treated and untreated weight ratio of 10/90%, 20/80% and 30/70% was determined using experiment. Tensile and compressive strength results for all batch were validated using FEM/ANSYS software. In addition, water absorption test and microstructure of the composite has been investigated. From the obtained results of the experimental test the following conclusion was drawn.

- The sisal fiber reinforced polyester resin composite material was successfully manufactured using hand lay-up assisted by vacuum bagging technique (HAVBT).
- Mechanical property characterization of SFPCM were determined from different sisal to polyester resin percentage.
- Alkaline treatment has been found to be effective in removing the deleterious constituents such as lignin, hemicelluloses and remains, which affect the bonding strength between sisal fiber and polyester resin matrix.
- 8% NaOH alkali treatment was an effective chemical treatment that improved interfacial adhesion between sisal fibers and polyester resin. As compared with the untreated sisal fiber, the alkali treated sisal fiber were bonded better with polyester matrix.
- The comparison of tensile strength reveals that the treated random orientation sisal fiber has better tensile strength than the untreated sisal fiber in all composition. In this 30% treated random orientation fiber and 70% polyester matrix composite has 50.77Mpa exhibit higher tensile strength than 20% treated sisal fiber 44.9Mpa.whereas 10% treated sisal fiber random orientation found that 20.2Mpa. In other hand the tensile strength of

untreated random oriented sisal fiber for 30/70%, 20/80% and 10/90% is 37.4Mpa, 26.23Mpa and 12.98Mpa respectively.

- From the Compression test it was found that compressive strength of sisal fiber reinforced polyester composite were decreasing with increase in the fiber percentage.
- The maximum compression strength is 144.74 Mpa that is observed at TCS1 ratio for the treated SFPCM.
- This result of tensile and compressive strength was also compared and validated using FEM analysis and the percentage error from the experiment was measured up to 1.63% for equivalent tensile stress and 3,18% for equivalent compressive stress that signified the validity of the experiment.
- Generally, sisal fibers possess good impact absorbing properties and the impact strength was increasing with increase in sisal fiber percentage.
- The charpy impact strength of treated sisal fiber reinforced composites yield the maximum impact strength of 7.6J at TIS3.
- The water absorption property decreased on the treated SFPCM as compared with untreated SFPCM.
- The water absorption property increases with increase in fiber percentage for treated and untreated and the maximum percentage weight gain was observed 1.428g of 192hrs immersion by WS3 at ratio of 70/30.
- The morphological study reveals that fibers pull out are occurred on various percentages of treated and untreated chopped fibers. From the figures polyester resin were well bonded in treated sisal fibers than the untreated sisal fiber. Also on fiber percentage 10/90 of WS1which results in weak interfacial bonding.
- From all experimental mechanical test and water absorption results, it can be concluded that the treated 30/70 fiber/matrix sisal fiber reinforced polyester resin composite materials has a capacity to be used in different automotive application such as door trim panel which does not need a very high mechanical performance.

5.2. Recommendation

In the way of extracting this fiber used decortications method has its own impact on the fiber length, strength, diameter, time consuming …etc. It is recommended to study a better way of extracting the fiber to make the fiber having good strength, and the diameter of the fiber uniform through the length of the fiber.

The density of sisal fiber was found to be lower than that of the synthetic fibers available and so sisal fiber can be preferred to manufacture lightweight composite materials in the near future. It is recommended that the composite material are a good replacement for synthetic fibers.

5.3. Future Work

From different aspects, into the application of SFPCM for automotive application the possibility of finding the appropriate SFPCM for Automotive body application depends on the precise knowledge of the fabrication and proportion of sisal fiber and the matrix material. The following recommendations for future work can be noted:

- Finding of different sisal fiber extraction and treatment processes for the better sisal fiber surface texture.
- Characterization can be done by using different types Natural fibers to improve the strength.
- In this research, the mechanical experimental property characterization is done using only the universal testing machine. However the experimental testing should be done using appropriate universal testing machine that strain gauge was installed on it in order to attain a precise results.
- From the mechanical property of SFPCM further study based on, different fiber length, ratio and reinforcement orientation arrangement of fiber on flexural, thermal, hardness property is necessary to knowing the rest mechanical property of sisal fiber.

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APPENDIX

Appendix I Tensile strength experimental data for treated and untreated batch

Samples	Tensile strength(Mpa) sample 1	Tensile strength(Mpa) sample 2	Tensile strength(Mpa) sample 3	Average Tensile strength(Mpa)
TS1	14.3	9.4	15.25	12.98
TS2	18.7	26	34	26.23
TS3	36	37	39.2	37.4
TTS1	25.4	16.7	18.5	20.2
TTS2	46.6	43.3	44.8	44.8
TTS3	54	49.1	49.2	50.76

Appendix II Unsaturated general purpose polyester resin properties

Property	Unit
Density	1200(kg/m^3)
Thermal Conductivity	0.17(W/m ^{o}C)
Tensile Strength	(70.3 -103) (MPa)
Modula's of Elasticity	(2.06 – 4.41)(GPa.)
Fracture Tautness 0.6(MPa.M0.5)	0.6(MPa.m0.5)

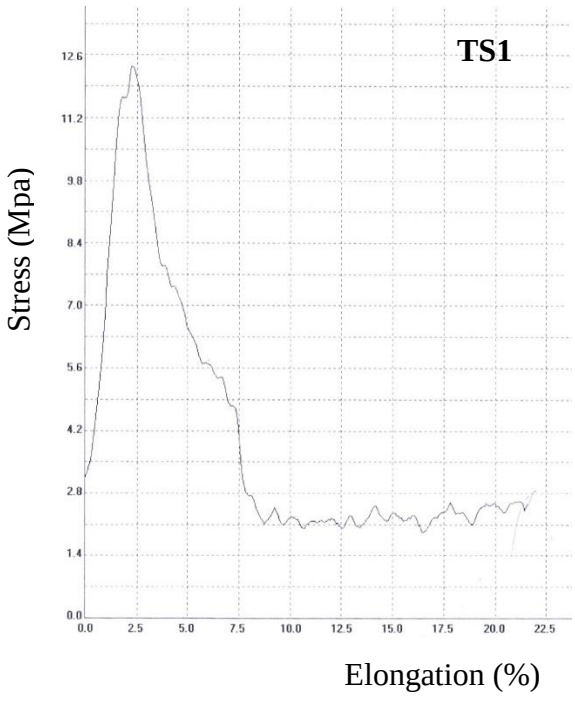
Appendix III Physical property of sisal fiber

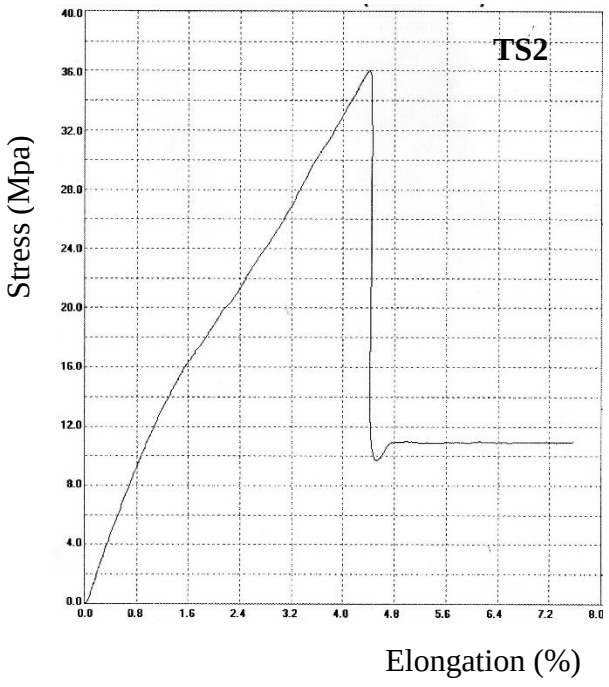
Physical Property Sisal Fiber	
Density (g/cm^3)	upto1.45
Specific Modulus (Gpa)	6-15
Cellulose Content (%)	67-78
Young's Modulus (Gpa)	9-22
Diameter of Ultimate (m)	18.3-23.7

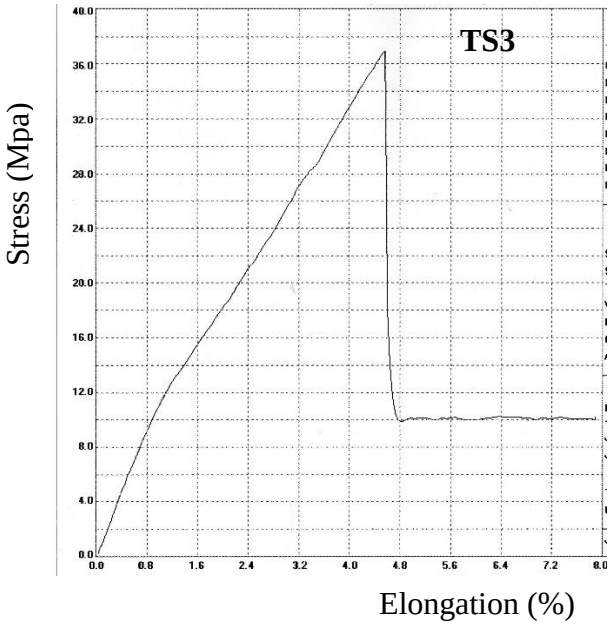
Appendix IV Physical and chemical Properties of Hardener

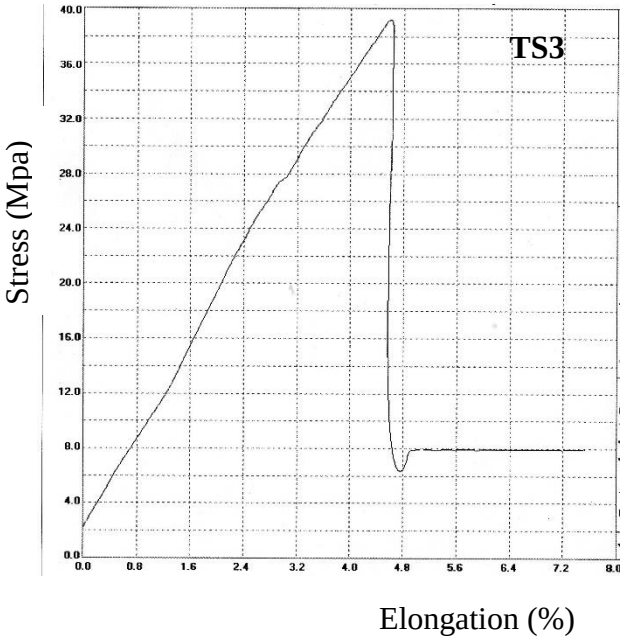
Physical and chemical properties of W 1900 HARDNER	
Appearance:	Liquid
Color:	Clear and colorless
Odor:	Mild
Melting Point/Range	: > -10ºC
Flash Point:	52ºC
Auto Ignition Temperature	218ºC
Relative Density (20ºc):	= 1.18g/cm^3
Solubility (Water):	Partly miscible g/l miscible
Viscosity (20ºc):	20 mPa.s

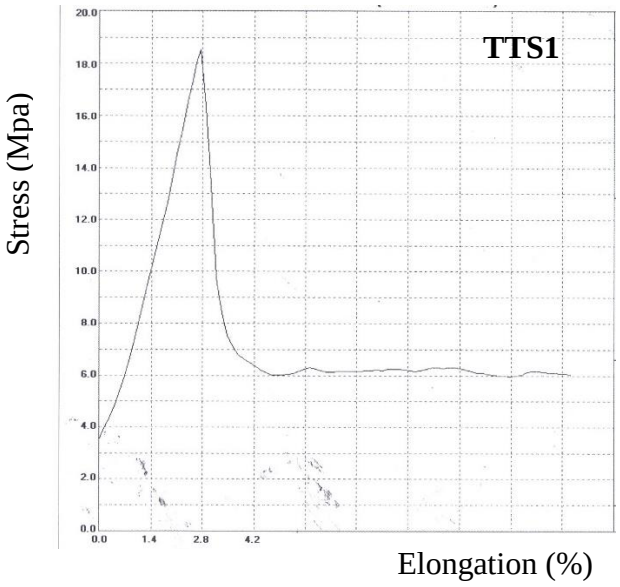
Appendix V Tensile Stress vs percentage elongation graph for each specimen group

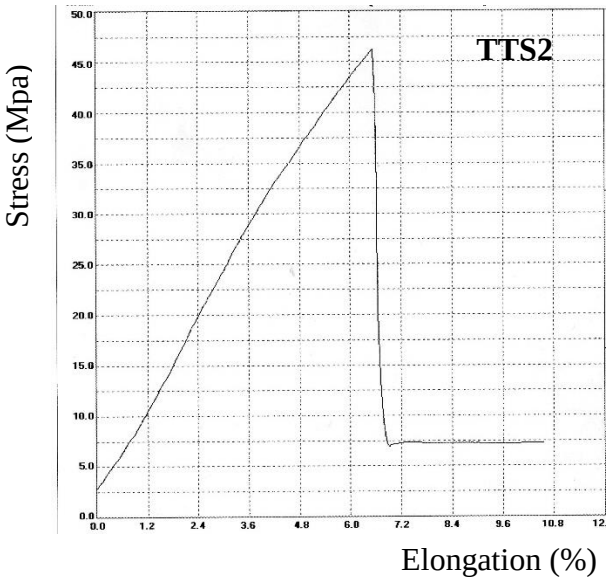


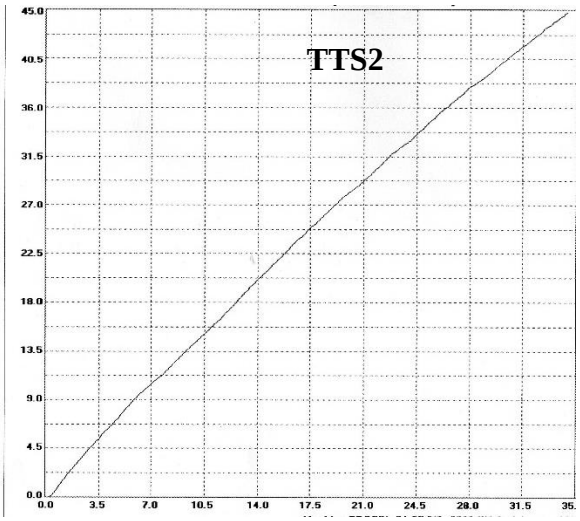


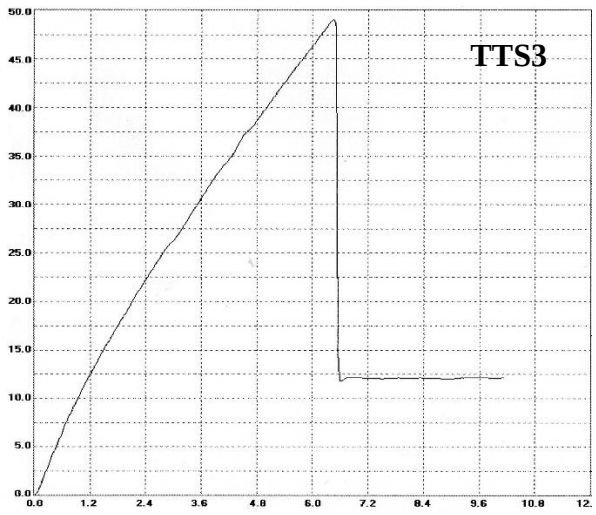

TS3
Stress (Mpa)
Elongation (%)


TS3
Stress (Mpa)
Elongation (%)

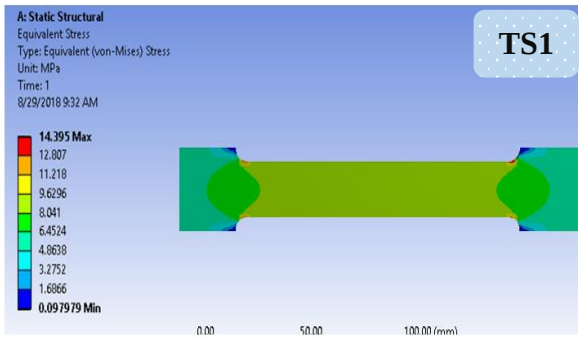

TTS1
Stress (Mpa)
Elongation (%)

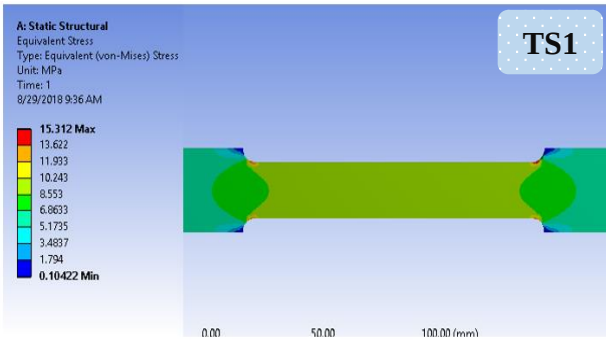

TTS2
Stress (Mpa)
Elongation (%)

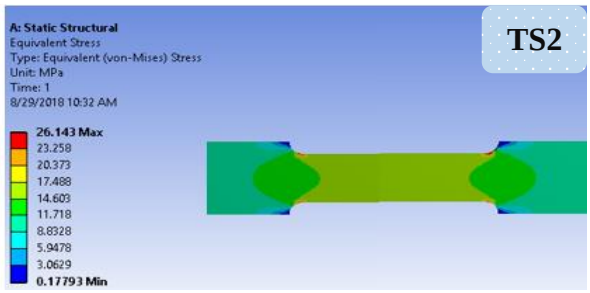

TTS2

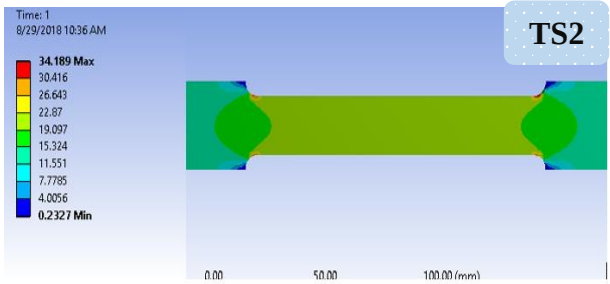

TTS3

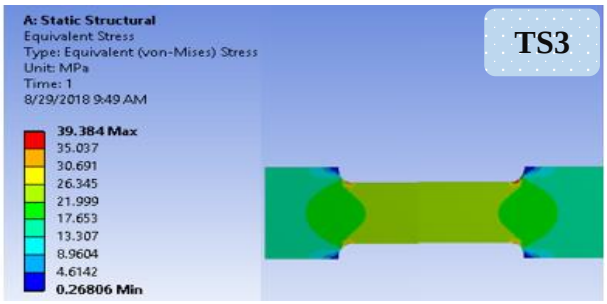
Appendix VI Tensile Stress result of ANSYS workbench for treated and untreated samples

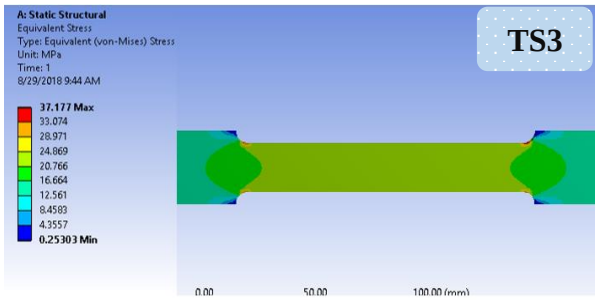


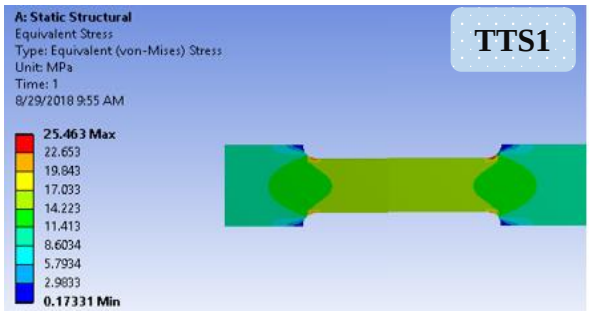


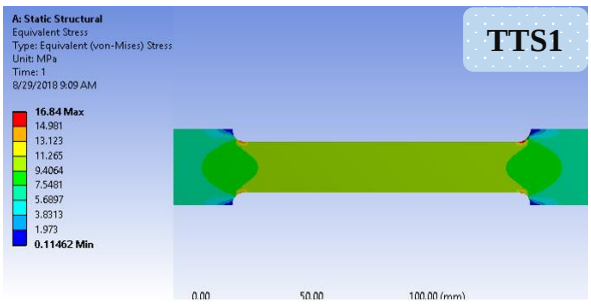


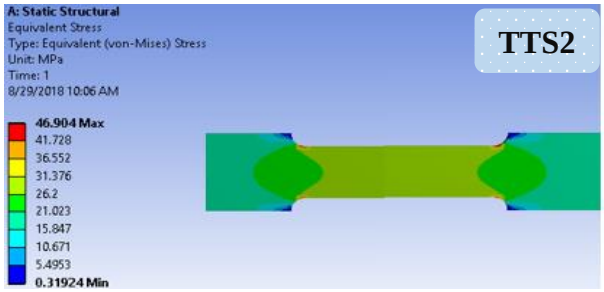


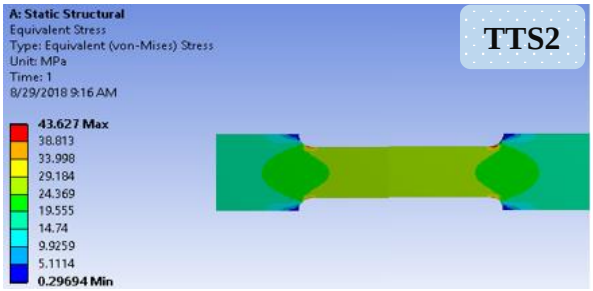


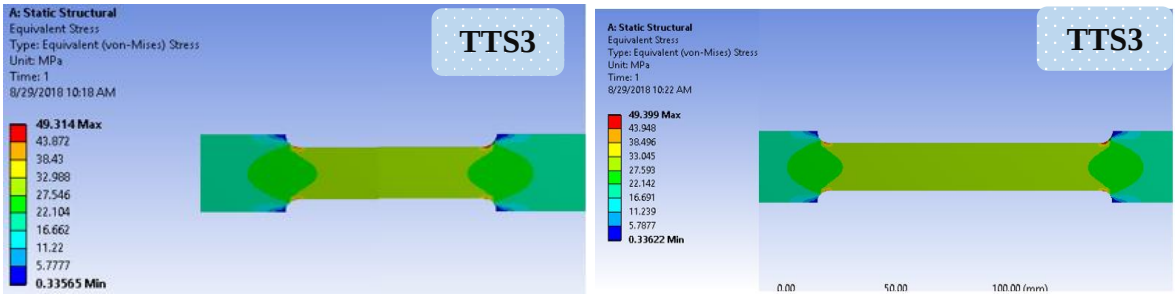




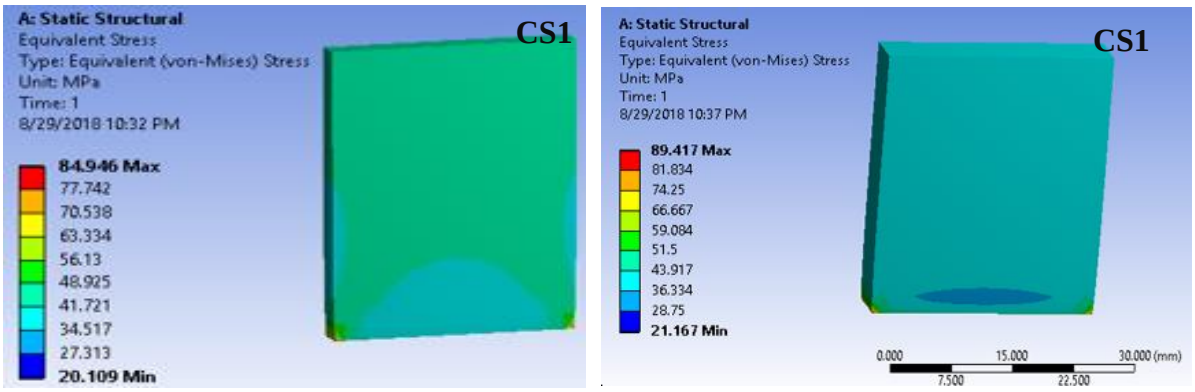


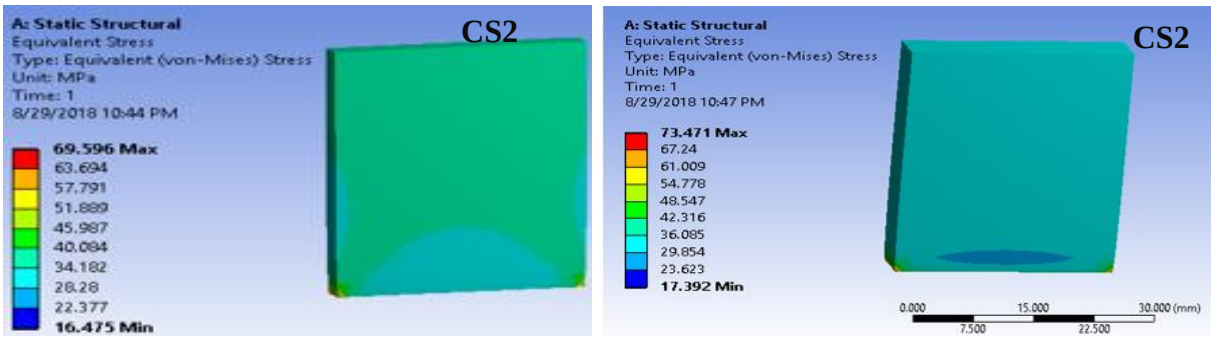


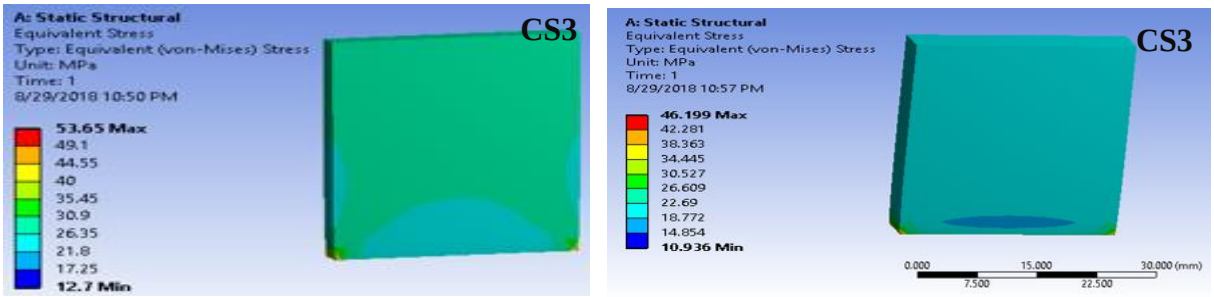


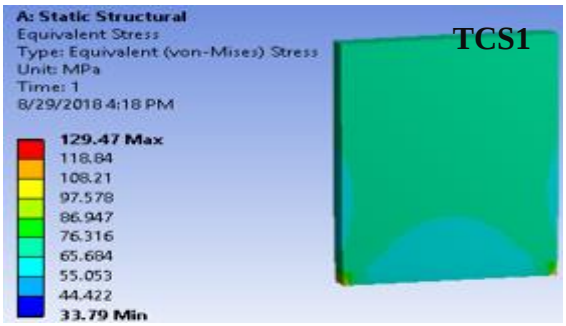


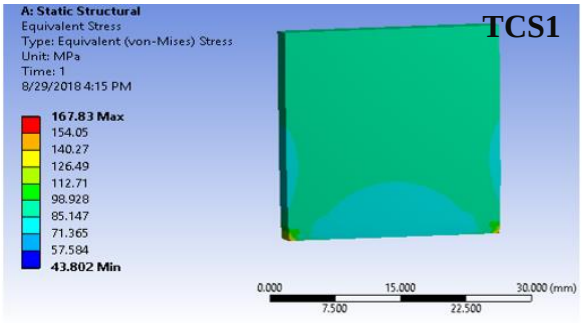
Appendix VII Compressive Stress result of ANSYS workbench for treated and untreated samples

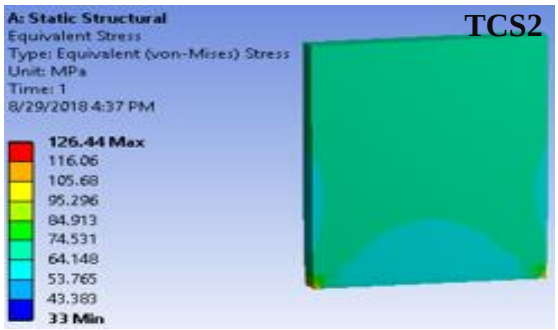


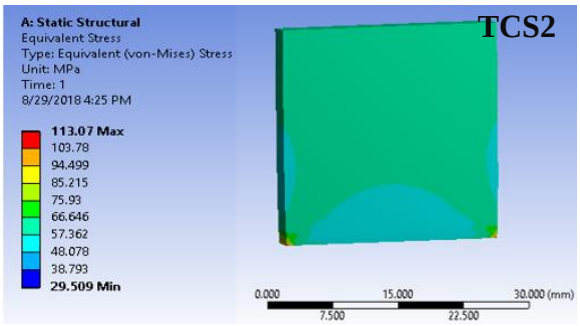


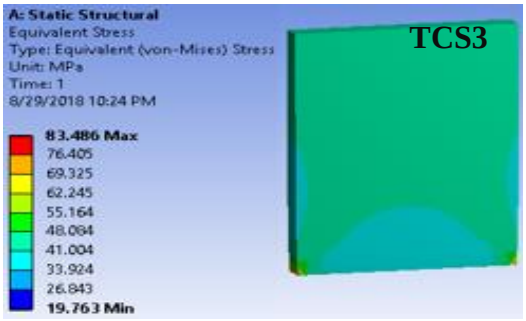


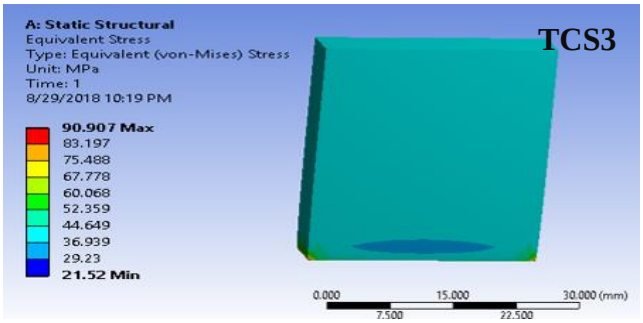

A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
8/29/2018 4:18 PM
129.47 Max
118.84
108.21
97.578
86.947
76.316
65.684
55.053
44.422
33.79 Min
TCS1


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
8/29/2018 4:15 PM
167.83 Max
154.05
140.27
126.49
112.71
98.928
85.147
71.365
57.584
43.802 Min
TCS1
0.000
15.000
30.000 (mm)
7.500
22.500


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
8/29/2018 4:37 PM
126.44 Max
116.06
105.68
95.296
84.913
74.531
64.148
53.765
43.383
33 Min
TCS2


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
8/29/2018 4:25 PM
113.07 Max
103.78
94.499
85.215
75.93
66.646
57.362
48.078
38.793
29.509 Min
TCS2
0.000
15.000
30.000 (mm)
7.500
22.500


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
8/29/2018 10:24 PM
83.486 Max
76.405
69.325
62.245
55.164
48.084
41.004
33.924
26.843
19.763 Min
TCS3


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
8/29/2018 10:19 PM
90.907 Max
83.197
75.488
67.778
60.068
52.359
44.649
36.939
29.23
21.52 Min
TCS3
0.000
15.000
30.000 (mm)
7.500
22.500

Appendix VIII Water Absorption Testing Result of Treated and Untreated SFPCM

Batches	**Water absorption weight gained results in gram**																			
	24h		**48h**		**72h**		**96h**		**120**		**144h**		**168h**		**192h**		**216h**		**240h**	
	before	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**	**before**	**after**
WS1	6.47	6.475	6.47	6.479	6.47	6.481	6.47	6.486	6.47	6.5	6.47	6.502	6.47	6.503	6.47	6.504	6.47	6.54	6.47	6.55
WS2	6.72	6.75	6.72	6.755	6.72	6.764	6.72	6.774	6.72	7.782	6.72	6.784	6.72	6.785	6.72	6.786	6.72	6.81	6.72	6.82
WS3	6.44	6.49	6.44	6.5	6.44	6.52	6.44	6.526	6.44	5.529	6.44	6.53	6.44	6.531	6.44	6.532	6.44	6.54	6.44	6.547
TWS1	6.42	6.424	6.42	6.427	6.42	6.43	6.42	6.435	6.42	6.438	6.42	6.44	6.42	6.442	6.42	6.443	6.42	6.48	6.42	6.49
TWS2	6.5	6.52	6.5	6.53	6.5	6.535	6.5	6.54	6.5	6.557	6.5	6.559	6.5	6.56	6.5	6.561	6.5	6.566	6.5	6.568
TWS3	6.2	6.231	6.2	6.24	6.2	6.25	6.2	6.254	6.2	6.261	6.2	6.262	6.2	6.264	6.2	6.266	6.2	6.284	6.2	6.286