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SCHOOL OF GRADUATE STUDIES

Fabrication and Mechanical Property Characterization of Sisal fiber Reinforced Epoxy Resin Composite Material for Automotive body Application

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science

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School of Mechanical and Industrial Engineering

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by

Mesfin Kebede

Submitted in accordance with the requirements for the degree

MASTER OF SCIENCE(M.Sc.)

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ABSTRACT

Fabrication and Mechanical Property Characterization of Sisal fiber Reinforced Epoxy Composite Material for Automotive Body Application

Mesfin Kebede

Addis Ababa University, 2015

The present Research work has been carried out to make use of Local Ethiopian Sisal fiber extracted from Ethiopian highlands. The goal of this paper is to fabricate and describe the processing techniques of specimen preparation conducting experiment to obtain and Characterize the Mechanical Property of sisal fiber reinforced epoxy composite Material The sisal fiber were extracted from Ethiopian highland sisal plant by retting and combing process manually after extraction 18% sodium hydroxide was used for further lignin, hemicelluloses and other fiber remnants removal for the improvement of bond & interfacial shear strength of the sisal fiber The tensile, compression and flexural properties of sisal fiber reinforced epoxy composite material were carried out using sisal fiber reinforced epoxy composite samples According to the ASTM standard the specimen is fabricated by using the epoxy resin (system 2000) as a matrix and the hardener(2060) and the sisal fiber as a reinforcement material with the 15%,25% and 35% fiber weight fraction, random oriented chopped fibers by using hand layup fabrication technique the specimen is prepared. 35% treated SFREC was found a higher tensile strength, 25% untreated SFREC was found a higher compressive strength and 15% treated SFREC was found a higher flexural strength furthermore the results of this study indicate that using sisal fibers as reinforcement in polymer matrix could successfully develop a composite material in terms of high strength and rigidity for light weight Automotive body interior panel.

Key Words: sisal fiber reinforced epoxy composite, interior panel, Hand layup fabrication technique, tensile. compression and flexural properties

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NOMENCLATURE

Symbol:	Property:
ρ_c	density of composite
m_c	mass of composite
m_r	mass of resin
v_r	Volume fraction of resin
V_{Epoxy}	Volume of Epoxy
V_{Sisal}	Volume of Sisal
m_{Epoxy}	mass of epoxy
ρ_{Epoxy}	density of epoxy
m_{Sisal}	mass of sisal fiber
ρ_{Sisal}	density of sisal fiber
W	width of specimen
σ	Normal stress
ε	Strain
L	Specimen Free Length
ReH	upper compressive yield strength
ReL	Lower compressive yield strength
Rmax	ultimate compressive strength
σ_{bf}	calculated fracture stress (flexural strength), MPa
P	load at a given point on the load- deflection curve, N
E_c	maximum deflection at the center of the specimen (camber distance)
m	slope of the tangent to the straight-line portion of the load-deflection beam.
L	support span of specimen
b	width of the specimen tested
d	depth of the specimen
r	strain

LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	America Society for Testing and Material
UTM	Universal Testing Machine
m	meter
mm	millimeter
nm	nanometer
FRP	Fiber Reinforced Polymer
TPO	Thermoplastic Olefins
SFREC	Sisal fiber reinforced epoxy composite
min	minute
hr	hour
cc	cubic centimeter
Eq.	Equation
PE	polyethylene
NR	Natural rubber
UP	Unsaturated Polyester
EP	Epoxy Resin
METEC	Metal and Engineering Corporation
DAVI	Dejen Aviation Industry
SNT(T)	untreated Sisal fiber reinforced epoxy composite sample for tensile test
SNT(C)	untreated Sisal fiber reinforced epoxy composite sample for compression test
SNT(F)	untreated Sisal fiber reinforced epoxy composite sample for flexural test
ST(F)	NaOH treated Sisal fiber reinforced epoxy composite sample for flexural test
ST(T)	NaOH treated Sisal fiber reinforced epoxy composite sample for Tensile test
ST(C)	NaOH treated Sisal fiber reinforced epoxy composite sample for Compression test

SNT15	15%wt percent of untreated sisal fiber reinforced epoxy composite
SNT25	25%wt percent of untreated sisal fiber reinforced epoxy composite
SNT35	35%wt percent of untreated sisal fiber reinforced epoxy composite
ST15	15%wt percent of NaOH treated sisal fiber reinforced epoxy composite
ST25	25%wt percent of NaOH treated sisal fiber reinforced epoxy composite
ST35	35%wt percent of NaOH treated sisal fiber reinforced epoxy composite

CHAPTER 1: INTRODUCTION

1.1 Background

The requirement for energy saving in the automotive industry has risen dramatically over the years. One of the options to reduce energy consumption is weight reduction. A new invention in technology material was introduced with polymeric based composite materials, which offer high specific stiffness, low weight, corrosion free, and ability to produce complex shapes, high specific strength, and high impact energy absorption.

Substitution of polymeric based composite material in automotive components was successfully implemented for fuel and weight reduction. [1]

Fiber reinforced composite materials have been widely used in various transportation vehicle structures because of their high specific strength, modulus and high damping capability. If composite materials are applied to vehicles, it is expected that not only the weight of the vehicle is decreased but also that noise and vibration are reduced. In addition to that, composites have a very high resistance to fatigue and corrosion.[2]

Traditionally, the materials used in the construction of vehicle bodies are mainly various grades of steel. Although aluminum-intensive body concepts were used starting from executive class cars, and then later on applied to other car classes. Plastics mainly dominate the vehicle interior, their external application being chiefly limited to non-load bearing components even though recently some innovative plastic materials are being implemented on some vehicle parts such as engine sub-frame and frontal bumpers subsystems to reduce the vehicle weight and improve the occupant and pedestrian safety, [3, 4].

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes, [3]. Due to rise in demand of lightweight vehicle and better mechanical performance of materials in automotive applications, different material combinations such as composites, plastic and light weight metals are implemented on primary and secondary structural parts of vehicles. Applications of composite materials in automotive industries already include

some primary and secondary structures such as dashboard, roof, floor, front & back bumper, passenger safety cell, and rarely, A-pillar and B-pillar, [3,5].

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, [3].

In order to estimate strength and stiffness, structural materials are subjected to mechanical testing such as tensile, compression, shear and flexural tests. Tests aimed at evaluating the mechanical characteristics of fibrous polymeric composites are the very foundation of technical specification of materials and for design purposes, in order to develop numerical and experimental models. The mechanical testing of composite structures to obtain parameters such as strength and stiffness is a time consuming and often difficult process. It is, however, an essential process, and can be somewhat simplified by the testing of simple structures, such as flat coupons. The data obtained from these tests can then be directly related with varying degrees of simplicity and accuracy to any structural shape, [6].

In this study, fabrication of composite with different fiber/matrix ratio and mechanical property characterization of the sisal fiber reinforced epoxy composite is the key issue to have the alternative materials for automotive industry.

1.3. Problem of the Statement

In recent years, a significant change occurred in automotive industry in Ethiopia which incorporates assembling of different types of automobile cars most of the government institution and city buses including Addis Ababa light weight city bus are assembled by Bishoftu Automotive and Locomotive Industry under Metal and Engineering Corporation (METEC) Based in Bishoftu, Ethiopia. The parts to be assembled are not manufactured here rather imported from other car manufacturing industry outside Ethiopia among this China is the main supplier But, some of the fiber composite body parts are manufactured here in Ethiopia by Dejen Aviation Industry (DAVI) but the inputs for these industry depends heavily on imported synthetic fibers for the fabrication of light weight automotive body parts, However these synthetic fiber can lead the company to extra expense, deny the country's resource to be used and also cause Environmental pollution during the Disposal of the used Composite Material.

Thus, the paper tries to fill the gap which occurs on the composite manufacturer here in Ethiopia by the use of Sisal fiber reinforced Epoxy composite material for the production of Automotive body parts in Bishoftu Automotive and locomotive industry which contributes directly to the Automotive industry and indirectly to Ethiopia's ability to generate or save hard currency and provides expanded opportunities for the rural people as the sisal fiber can be produced domestically in Ethiopia.

1.4. Objective of the Study

The general objective of this thesis is the fabrication and mechanical Property characterization of sisal fiber reinforced epoxy composite for automotive body application and utilizing the advantages offered by the local sisal fiber from Ethiopia on automotive composite material. . This is achieved by conducting different experimental tests on the above mentioned materials. In this research the consideration local sisal fiber for the fabrication of composite material will be the most important things.

The specific objective of this thesis include :

1. Extraction of sisal fibers from Ethiopian highland sisal plant.
2. Determination of fiber and matrix contents of the natural fiber composite and select Proper sisal fiber and epoxy resin with better mechanical characteristics that give better sisal fiber reinforced epoxy composite.
3. Chemical treatment of sisal fibers to improve its stiffness & interfacial adhesion
4. Fabrication of sisal fiber reinforced epoxy composite material.
5. Characterization of mechanical properties such as tensile test, flexural test, and compression test etc of fabricated composite material.
6. Comparing the Fabricated sisal fiber reinforced epoxy composite material Mechanical properties against the previously done sisal fiber reinforced composite material by using literature.

1.5 Scope of the Study

This study experimentally explores the feasibility of using sisal fiber reinforced epoxy composite in automotive industry. the mechanical properties like tensile strength, compressive strength and bending strength of SFREC were characterized. It was determined that the use of SFREC provided a reduction in cost of Material and let Ethiopia save and generate hard currency and

also local Ethiopian farmers can grow sisal plant easily and then generate money . Therefore, a study on the use of SFREC in automotive industry of Ethiopia is valid.

1.6 Limitation

Among the many, major obstacles while conducting this work were the followings;

First, it is hard to find the journal and book about Sisal fiber reinforced epoxy composite used as Automotive Body Application materials in AAit Library of Addis Ababa University . The whole literature review journals are searched in internet.

Second, there is no aready to use and highly competitive testing laboratory setup for the characterization of natural fiber composite and there is no ready to use workshop for the fabrication of composite material .

Third, since only three Mechanical Properties are investigated towards the use of SFREC for Automotive body Application; it seems not to provide enough evidence of SFREC to use as interior Body panel.

1.7 Thesis Organization

This report focuses on the fabrication and mechanical property characterization such as tensile, compression and flexural property of sisal fiber reinforced epoxy composite , and results discussion. The manuscript comprises of Six chapters.

Chapter 1: Introduces the background of natural fiber composite materials and this project's objectives. Problem Statement ,Scope and limitations

Chapter 2: Reviewed all relevant research papers regarding natural fiber composite materials, ranging from polymer types, fiber types, and composite's chemical, mechanical properties. Recent researches on sisal fiber reinforcement on polymers are widely and deeply reviewed.

Chapter 3: : Experimental deals with the mechanical Properties sisal fiber reinforced epoxy composite In this chapter the method materials for the preparation of test specimen discussed here. The Mechanical Properties are investigated Designs the experimental plan for investigation of flexural ,tensile and compressive properties of sisal fiber reinforced epoxy composites.

Chapter 4: Characterization of composite material ; The flexural, tensile and compression Properties are discussed in detail

Chapter 5: Is the conclusion of this thesis report. Conclusions describes the application of the validated fiber/matrix weight fraction to Automotive body Application Comparison with previous works on sisal fiber reinforced epoxy composite material.

Chapter 6: is dedicated to the recommendations and future work of this thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Composite Material

According to [7], A composite materials are generally engineered materials made from two or more constituents with different physical or chemical properties, which remain separate and distinct within the finished structure. The composite should also have properties which surpass the properties of the individual constituents that make up the composites[7, 8].

In general the composite materials consist of a matrix reinforced with particles or fibers. 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 light weight, 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 [7, 9].

According to [7, 9] generally composite materials are classified and related to constituents as depicted in *figure 2.1.*

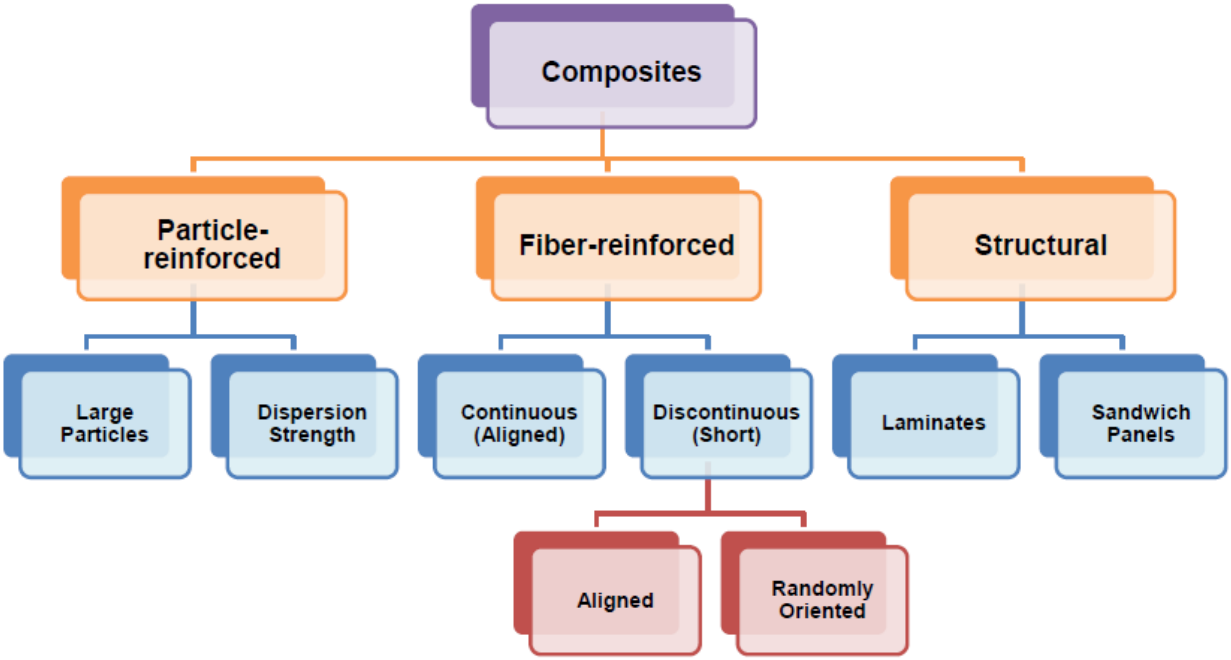

Figure 2-1 Composite materials classification

Fiber Reinforced Polymer Composite

FRP composites comprise two major constituents: the thermosetting resin matrix and the fiber reinforcement. The role of matrix resin is to keep the fibers in a desired location and orientation Similarly common matrix materials include epoxy, phenolic, polyester, polyurethane, polyetherethrketone (PEEK), vinyl ester etc. Among these resin materials, PEEK is most widely used. Epoxy, which has higher adhesion and less shrinkage than PEEK, comes in second for its high cost.The fibers must be separated from each other to avoid mutual abrasion during deformation of the composites. The load applied into the composite is distributed into the fibers through the matrix. Because fibers are mostly brittle, the resin is the source of toughness for a composite.[10]

On the basis of excessive tensile modulus, fibers can essentially enhance the mechanical features of entire compound FRP for instance tensile power and modulus.

According to [11] it is significant to disseminate the orientation directions of fibers properly while crafting the framework of FRP. However, in the orientation direction, fibers display amazing presentation, but the performance of fibers becomes much lesser in the upright position classification of fiber reinforced composite is depicted on *figure* 2.2 . A number of factors are

present for fiber to be utilized so extensively throughout the world as the fiber reinforced in Polymer composition has the potential to amplify the mechanical properties inclusive of fracture toughness and tensile strength of the composition while contrasting the fiber and the polymer [12].

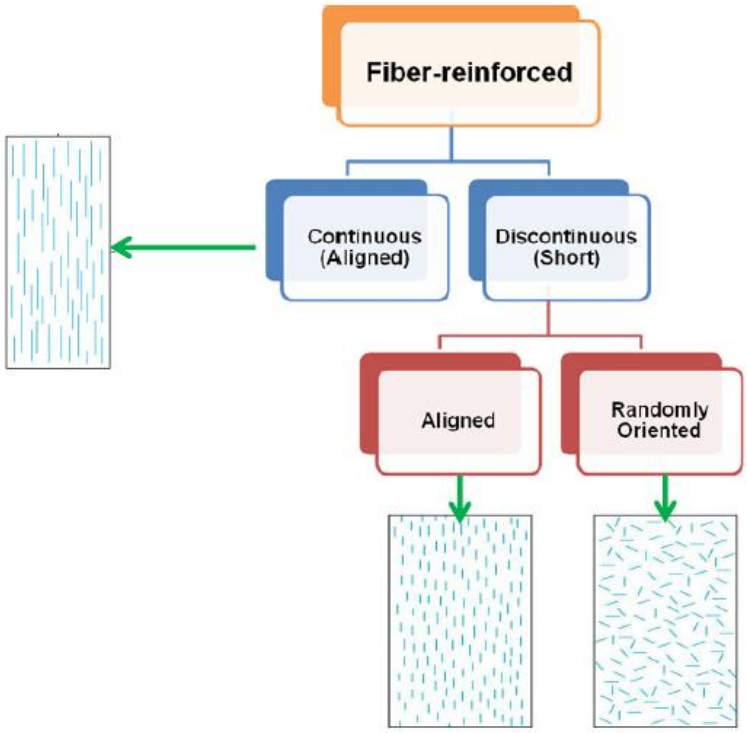

Figure 2-2 Fiber Reinforced Composite materials Sub classification

2.2 Natural Fibers

There are two kinds of fibers available i.e. natural fiber and synthetic fiber. Natural fiber, being non toxic and harmless, is composed of vegetables, minerals and animals where vegetables utilized for this purpose are: bamboo, hemp, sugarcane bagses, flax, curana, and banana while the animals' components include wool, skin, and hair According to [13] Classification of plant fiber is depicted in fig2.3. The minerals like ceramic and asbestos are required for manufacturing natural fiber. The second form, synthetic fiber is manufactured by men while it is a combination of glass fiber, carbon fiber, and aramid [14]. There is a huge market and demand for the fiber reinforced polymeric composition specifically for the synthetic fiber as it is utilized in making pipes, in tanks, sports' goods, and construction of bridges, boat hulls, automotive industry and aircraft secondary structure while thermo set matrices and thermoplastic require natural fiber[15].

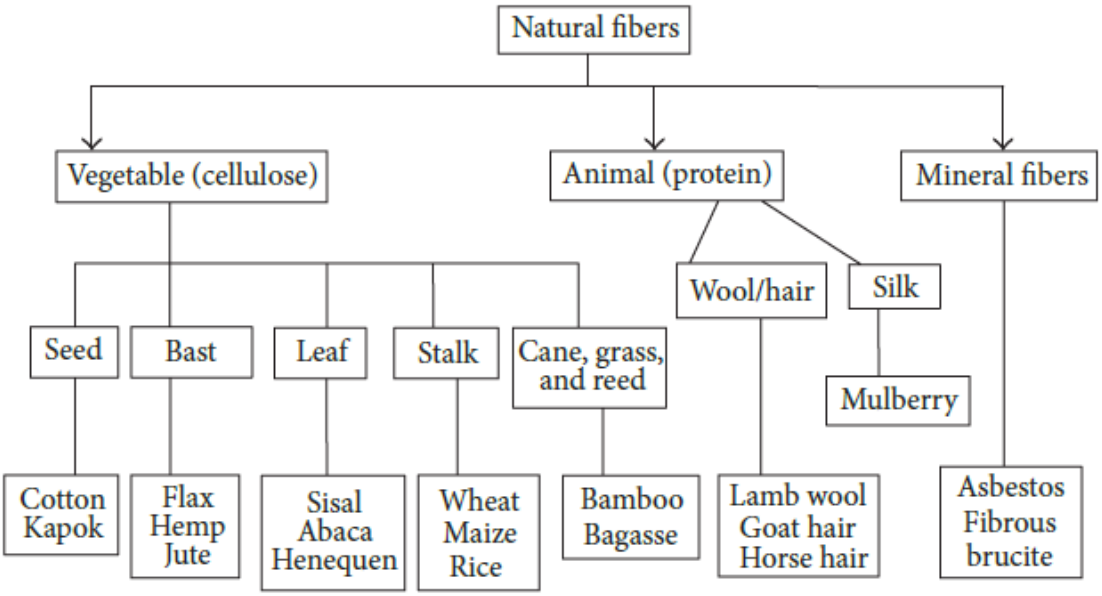

Figure 2-3 Classification of plant fiber[13]

2.2.1 Sisal plant:

Sisal or sisal hemp(Scientific name is Agave sisalana) is an agave. Agave sisalana of Agavaceae (Agave) that yields a stiff fiber used in making rope. Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East [16]. A sketch of a sisal plant is shown in *Figure 2.4* and sisal fibers are extracted from the leaves. 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 1000fibers.each leaf contains fiber bundles which is composed of 4%fiber, 0.75% cuticle, 8% dry matter and 87.25% water [18].

It is grouped under the broad heading of the "hard fibers" among which sisal is placed second to manila in durability and strength [19].

The sisal leaf contains three types of fibers [20]: mechanical, ribbon and xylem. The mechanical fibers are mostly extracted from the periphery of the leaf. They have a roughly thickened-horseshoe shape and seldom divide during the extraction processes. They are the most commercially useful of the sisal fiber. Ribbon fibers occur in association with the conducting tissues in the median line of the leaf. *figure 2.4* shows a cross-section of a sisal leaf and indicates where mechanical and ribbon fibers are obtained [20]. The related conducting tissue structure of

the ribbon fiber gives them considerable mechanical strength. They are the longest fibers and compared with mechanical fibers they can be easily split longitudinally during processing. Xylem fibers have an irregular shape and occur opposite the ribbon fibers through the connection of vascular bundles as shown in *figure 2.5* They are composed of thin-walled cells and are therefore easily broken up and lost during the extraction process.

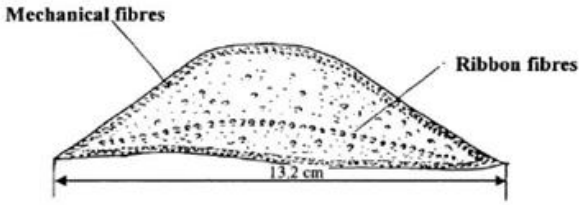

Figure 2-4 A sketch of sisal plant and the cross-section of a sisal leaf[3]; (b) photograph of a sisal plant

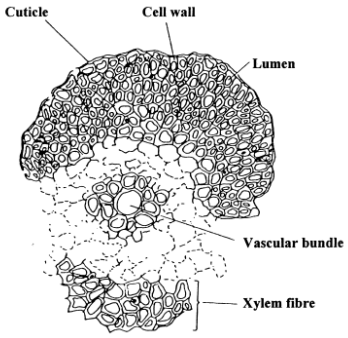

Figure 2-5 Cross-section of a ribbon fiber bundle

2.2.1.1 Sisal fiber

Sisal fiber 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 engineers all over the world. Many researchers have been done in recent years, which include 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.

The chemical compositions of sisal fibers have been reported by several groups of researchers For example, Wilson [21] indicated that sisal fiber contains 78% cellulose, 8% lignin, 10% hemi-celluloses, 2% waxes and about 1% ash by weight; but Rowell [20] found that sisal contains 43±56% cellulose, 7±9% lignin, 21±24% pentosan and 0.6±1.1% ash. More recently, Joseph et al.[23] 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 [24] 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 [20]. 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 lignocellulosic material reinforced by helical microfbrillar bands of cellulose. The composition of the external surface of the cell wall is a layer of lignaceous 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. Also, cellulose is a hydrophilic glucan polymer consisting of a linear chain of 1, 4-b bonded anhydroglucose units [25] 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 processing methods for extracting sisal fibers have been described by Chand et al. [26] and Mukherjee and Stayanarayana [27]. The methods include (1) retting followed by scraping and (2) mechanical means using decorticators. It is shown that the mechanical process yields about 2±4% fiber (15 kg per 8 h) with good quality having a lustrous color while the retting process yields a large quantity of poor quality fibers. After extraction, the fibers are washed thoroughly in plenty of clean water to remove the surplus wastes such as chlorophyll, leaf juices and adhesive solids.

2.2.1.2 Diversity of Sisal plant In Ethiopia

In Ethiopia, the production of Agave sisalana is quite minimal. Nevertheless, most part of the country semi-arid[28] and it accounts for about 71% of the entire 1.115km^2 land area about 46% with that of Agave Americana[29].Most of the areas being dry land implies that there is a fertile ground and tremendous potential to produce Agave sisalana on small scale basis(by farmers) and on large scale basis. since the crop is quite labor intensive, it could offer a great deal of job opportunities for the large rural population[30].

2.2 .3 Polymers and its type

Odian2004 [31] has described polymers as large molecule having numerous frequent subdivisions. Synthetic polymers and natural polymers are the major types of the polymers. Human life is very evident with both types of polymers, e.g., a human fabricated polymer, polyethylene (PE) is used in the supermarket shopping bag, the NR (natural rubber) is being used in the types of our cars and the NR is believed to be a natural product produced from the rubber tree [32]. Before the development of polymer science and engineering around 1900s, many kinds of polymer materials were existed, such as: Natural polymers which cover: amber, shellac, wool, silk, and cellulose. Whereas Synthetic polymers cover: Phenol formaldehyde resin, Synthetic rubber, Nylon, Neoprene, chloride, Polyvinyl , Polyethylene, Polystyrene, Polypropylene, Epoxy resin, and Polyacrylonitrile [33].

The polymer is divided into two different categories thermosets and thermoplastic and application of thermosets is mentioned below [34].

2.2.3.1 Thermosets

They are described as a polymer that transforms conclusively into an insoluble network structure through remedial measures and develops into a soft solid position. Heating or a suitable radiation

is likely to prompt the curing. A cross-linking structure will eventually be emerged through the curing procedure, by which the resin is transformed into rubber or plastic. Because, the thermosets are having 3D cross-link configuration, so they are normally robust than thermoplastics, and are desirable for high-temperature applications. But, their heavy brittleness than thermoplastics is one of the problems. Epoxy resin and unsaturated polyester are extensively used materials among all the thermosets materials[35].

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

When dibasic organic acids are reacted with polyhydric alcohols, we obtain the unsaturated polyester resins, which are applied in bulk molding compound, sheet molding compound and in the toner of laser printers [36].

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

The epoxide functional group is enclosed in the epoxy that is a preserved thermoset resin. Before use, the hardener (which cures epoxy resin) and epoxy resin are usually blended together.
Many industries observe the use of Epoxy, e.g., structural adhesives electronic and electrical components, metal coatings, fiber-reinforced plastic materials and high tension electrical insulators [37].

2.2.4 Previous Works

Automotive Body Materials in the Past

The design of vehicle body has evolved from a simple, all steel structure that meets the basic requirement of strength and functionality, to the current day complex and efficient structure.
Deep drawing steel sheets with good formability were developed in the 1950s, followed by the development of anti-corrosive steel sheets in the 1960s. In the 1970s and 1980s, low fuel consumption was a keen issue because of the two oil crises. High-strength steel sheets were developed in response to this issue and have contributed to lightening vehicles by reducing sheet thickness. In the 1990s, safety and environmental issues became primary concerns in the automotive industry, and further work was done on developing technologies for weight reductions. Aluminum alloy sheets were developed in this connection and applied to various body panels such as the engine hood, and have contributed to achieving lighter vehicles [5].

According to [5] automobile body panels consist of a double structure with an outer panel and an inner panel. For the outer panels, higher strength materials are especially required to provide

sufficient denting resistance. For the inner panels, higher deep drawing capacity materials are especially required to allow the manufacture of more complex shapes. In other words, different properties are required for the outer and inner panels, as shown in Table 2.1.
New materials for the car body have been developed to improve corrosion resistance and to reduce vehicle weight. In the 1950s and 1960s, mass production technologies were developed because of higher vehicle demand, [5].

Material technologies are also expected to contribute to improving crashworthiness. In order to achieve a safe car body in the event of a collision, deformation of the cabin structure should be minimized to protect the occupants, and the collision energy should be absorbed in a short deformation length within the crushable zones. From the viewpoint of materials, both dynamic strength and static strength are important in designing parts for greater crash safety. The average reactive force of a rectangular tube with a hat-shaped cross section is related to the k-value, i.e., the dynamic/static ratio of yield strength. In general, the k-value decreases with increasing strength. To reduce vehicle weight effectively while improving safety, new materials with a higher k-value are needed [5].

Table 2-1Important Properties required for body panels

Panel	Main Properties
Outer panel	➢ High strength after paint(Yield Strength: 200Mpa at 170^0C for 20min after 2% strain) ➢ Flat hemming property ➢ Surface condition ➢ Anti-corrosion
Inner panel	➢ Deep drawing property ➢ Joining Properties (welding, adhesion)

Lightweight composite materials, such as glass-fiber reinforced polymers, have been used to replace traditional steel and aluminum components. This is because composites offer significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction and space saving. Today, design procedures of vehicles body that ensures reliability and road worthiness is well established [4].

Mechanical Characterization of sial fiber reinforced Epoxy composite

Jackson D. Megiatto Jr. et al. studied the optimized process parameters such as pressure, temperature and time interval were varied for manufacturing thermoset phenolic composites reinforced with sisal fibers. he clearly showed that the increase in temperature decrease the time required for saturation of the composite sample, increasing of the molding pressure at the gel point of the matrix increase the impact strength of the material and also the application of higher values of the pressure at the initial stage of the cure cycle probably hindered the vaporization of the water generated as the a byproduct of the cure reaction, the improved filling of the fiber pores can be done by increasing the interdiffusion of the phenolic matrix through the sisal fibers, using higher values of pressure before the gel point of resin .

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

Sreekala et al indicated that a 10–30% NaOH solution produced the best effects on natural fiber properties. .

Padmavathi et al. presents mechanical behavior of alkali-treated with different solution concentrations (2%, 9%, 18%, 28% and 38%) of sisal-epoxy composites of different fiber weight The results clearly showed that containing optimally treated (18% NaOH) sisal fibers, using an improvised fabrication approach. An enhancement of 110% in the optimally treated fiber tensile property resulted in improvement of composite mechanical properties (compression, tensile, inter laminar shear stress and energy absorption) ranging between 18% and 158%.

bisanda et al,1991 have studied the effect of saline treatment and alkali treatment on the mechanical and physical properties of sisal epoxy composites. They have reported the treatment of sisal fiber with silane produced by mercerization provides improved wettablity mechanical properties and wear resistance, mercerization and silane treatment improve the compressive strength without significant effect on flexural property of dry sisal composite.

[sapuan et al,2003] epoxy resin are the prevalent polymer used with advanced composites. Their extensive use is primarily due to their superior mechanical properties, excellent adhesion, good possibility of utilizing adhesion type reactions, low cure shrinkage and low cost.

Paramasivam & Abdulkalam(1974) have investigated the feasibility of developing polymer based composites using sisal fibers due to the low cost production of composites and amenability of these fibers to winding, laminating and other fabrication it was found that the fabrication of these composites was fairly easy and cost production was quite low winding of cylinders with longitudinal or helical and hoop reinforcement was successfully carried out. Tensile strength of sisal epoxy composites was found to be 250-300MPa, which was nearly half the strength of fibers glass-epoxy composites of the same composition. Because of low density of sisal fiber however, the specific strength of sisal composites was comparable with that of glass composites the unidirectional modulus of sisal-epoxy composites was found to be about 8.5GPa.

2.2.5 Recent issues and recommendations

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

CHAPTER 3: MATERIALS AND METHODS

3.1. Materials

3.1.1 Matrix

Epoxy Resin

The resin used for this study is Epoxy Resin with brand name of SYSTEM #2000 EPOXY RESIN, which is purchased from the local market in Addis Ababa, Ethiopia.

Epoxy resins are the prevalent polymer used with advanced composites. Their extensive use is primarily due to their superior mechanical properties, excellent adhesion, good possibility utilizing addition-type reactions, low cure shrinkage and low cost.

Hardener (catalyst)

Epoxy resin is cured by adding a catalyst, which causes a chemical reaction without changing resin is cured by adding a catalyst,which causes a chemical reaction without changing its own composition. the catalyst initiates the chemical reaction of the epoxy resin and monomer ingredient from liquid to a solid state.

the curing agent applied in this ork for the liquid epoxy resin is hardner with brand name of SYSTEM #2060 HARDNER purchased from local market.

the typical mechanical properties of epoxy and hardener which used in this work is depicted in the appendix.

3.1.2 sisal fiber

Suitable quantity of sisal plant leaves was collected from dessie tossa mountain, Ethiopia after cutting at their base from the harvest. The fibers are extracted through hand extraction with knife. initially the leaves trimmed in longitudinal direction into strips for ease of fiber extraction The peel is clamped between the wood plank and knife and hand-pulled through in longitudinal direction gently, removing the resinous material as showed in *figure3.1* then the extracted fiber washed with pure water in order to loosen, and separate the fiber until individual fibers are obtained then The extracted fibers are sun-dried which whitens the fiber. Once dried, the sisal fibers are ready for fabrication of test pieces extracted sisal fiber is shown in *figure3.2*.

Figure 3-1: Sisal fiber extraction process a, Sisal plant b, longitudinally trimmed sisal plant c, peeling of sisal plant for sisal fiber extraction d, Extracted sisal fiber before washing and drying

Figure 3-2 Extracted Sisal fiber

3.1.3 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 [44].

Sodium hydroxide is soluble in water, ethanol and methanol. This alkali is deliquescent and readily absorbs moisture and carbon dioxide in air.

Although molten sodium hydroxide possesses properties similar to those of the other forms,

its high temperature comparatively limits its applications.

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 [44].

In this work we used NaOH in pellets form,purchased form local suppliers with the brand name and code of RANKEM,S0290 respectively and performed chemical treatment of sisal fiber

3.2 Sample Preparation Methods

3.2.1 Preparation of sisal fibers

The fibers were cut into ~ 9.0 mm using a pair of scissors chopped sisal fiber is shown in fig 3.3.

Figure 3-3 Chopped sisal fiber

3.2.2 Alkali Treatment of sisal fiber

Alkali treatment is the simplest method of chemical treatment of fibers; it leads to the increase in the amount of amorphous cellulose at the expense of crystalline cellulose. the important modification occurring here is the removal of hydrogen bonding in the network structure. The following reaction takes place as a result of Alkali treatment

$$\text{Fiber-OH} + \text{NaOH} \longrightarrow \text{Fiber-O}^{-}\text{Na}^{+} + \text{H}_2\text{O}$$

According to literature, alkali solution has a good effect on treating natural fibers. In this study, a 18% NaOH solution was used to treat the raw Sisal fibers, in order to modify their fiber structures. During this process Dried and chopped sisal fibers were taken in tray, to these trays 18% NaOH solution was added, the fibers were soaked in the for 24 hours, to remove fatty impurities . The fibers were then washed thoroughly with water to remove the excess of NaOH sticking to the fibers. Lastly, the fibers were allowed to dry in sun light for at least 4 day as shown in *figure.3.4.*

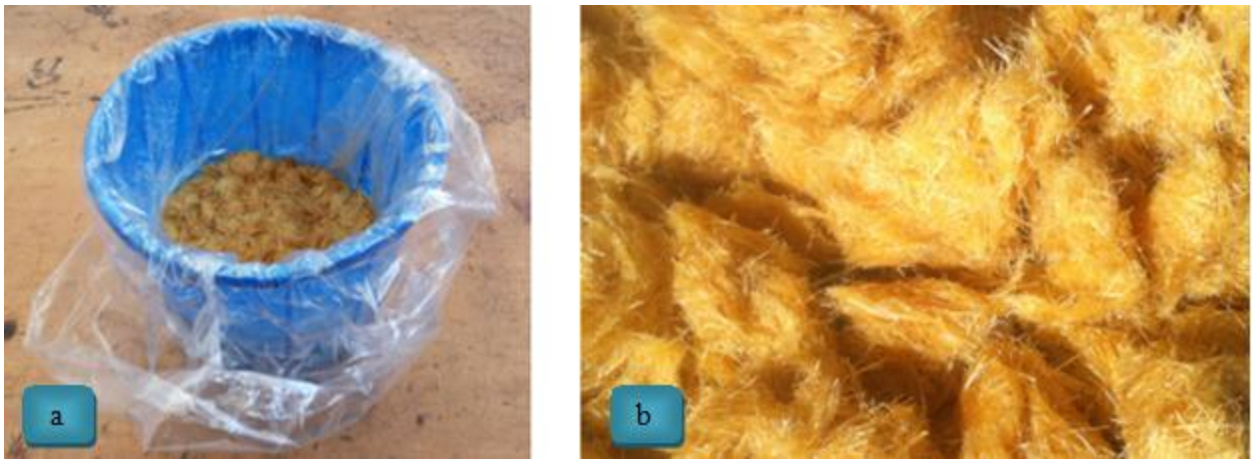

Figure 3-4: Alkaline treatment of sisal fiber

a. Sisal fiber soaked by NaOH b. Sisal fiber after soaked with sodium hydroxide

3.2.3 Weight Fraction of the Fiber and the Matrix content of the composite

The volume of the composite was calculated by multiplying the length, width and breadth of the mold prepared for molding the composite material eq(1) and the density of the composite was calculated by a method which enable the rule of law of mixture to be applied and was obtained first by adding the volume fraction of the epoxy resin and sisal fiber for each fiber/matrix ratio the density of the composite obtained as shown in eq(2) after getting the density of the composite the density of the composite multiplied by the volume of the composite eq(2) then the mass of the composite obtained then the mass of the composite multiplied by each fiber/matrix ratio then the mass of each sisal fiber and epoxy resin obtained. according to[45,46] the density of the sisal fiber and epoxy resin was taken as 1.33 g/ cm^3 and 1.2 g/ cm^3respectively.

3.2.3.1 Calculation To Find the Mass of the Fiber for Flexural Specimen

Volume of the die = 300 x195x 3.2 = 187200mm^3=187.2cm^3, ...eq(1)

Density of the Fibers/Epoxy in g/ cm^3 (Density= Mass/Volume (or) Volume=Mass/Density)

1. Sisal Fiber =1.33 g/ cm^3
2. Epoxy Resin =1.2 g/ cm^3

$V_c = V_{Epoxy} + V_{Sisal}$

$m_c/\rho_c = m_{Epoxy}/\rho_{Epoxy} + m_{Sisal}/\rho_{Sisal}$..... eq (2)

$1/\rho_c = (0.75/1)\ (1/1.2) + (1/1.33)\ (0.25/1)$

$1/\rho_c = 0.708 + 0.113 = 0.821\ cm^3/g$

ρ_c = 1.218 g/cm3 (For 15% Sisal fiber reinforced Epoxy Composite material) Similarly calculated for 25% and 35% Sisal fiber reinforced Epoxy Composite material.

$m_c = \rho_c \times V_c$……. (3)

m_c =1.218X 187.2 = 228.0096gms

Designation	Composition		Mass (gms)			No of Samples
	Epoxy(%)	Sisal (%)	sisal	Epoxy	Total	
SNT(F) 15	85	15	34.20	193.81	228.01	5
SNT(F) 25	75	25	56.9	170.6	227.45	5
SNT(F) 35	65	35	104.013	193.164	297.18	5

Table 3-1 Sample flexural specimen compositions used in this study

3.2.3.2 Calculation To Find the Mass of the Fiber for Tensile Specimen

Volume of the die = 300 x195x 2.5 = 146250mm^3=146.25cm^3,

ρ_c = 1.218 g/cm3 (For 15% Sisal fiber reinforced Epoxy Composite material) Similarly calculated for 25% and 35% Sisal fiber reinforced Epoxy Composite material.

m_c =1.218 X 146.25 = 178.1325gms

Designation	Composition		Mass (gms)			No of Samples
	Epoxy(%)	Sisal (%)	sisal	Epoxy	Total	
SNT(T)15	85	15	26.7	151.4	178.13	5
SNT(T) 25	75	25	44.98	134.92	179.9	5
SNT(T) 35	65	35	65.6	115.75	181.35	5

Table 3-2 Sample Tensile specimen compositions used in this study

3.2.3.3 Calculation To Find the Mass of the Fiber for Compression Specimen

Volume of the die = 300 x195x 3.17 = 185445mm^3=185.445cm^3,

ρ_c = 1.2151g/cm3 (For 15% Sisal fiber reinforced Epoxy Composite material) Similarly calculated for 25% and 35% Sisal fiber reinforced Epoxy Composite material.

m_c =1.218 X 185.445 = 225.87gms

Designation	Composition		Mass (gms)			No of Samples
	Epoxy(%)	Resin(%)	sisal	Epoxy	Total	
SNT(C) 15	85	15	33.88	191.99	225.87	5
SNT(C)25	25	75	55.024	171.075	228.1	5
SNT(C)35	35	65	80.612	149.708	230.32	5

Table 3-3 Sample Compression specimen compositions used in this study

3.2.4 Volume Fraction of the Fiber and the Matrix content of the composite

Fiber and matrix volume fraction (VF,VM)

Volume of fibers, matrix and composite is given by

$$Vf=\frac{Wf}{\rho f}\ ;\ Vm=\frac{Wm}{\rho m}$$

$$Vc=Vf+Vm$$

Fiber Volume fraction=$\frac{Volume\ \ of\ fiber}{Total\ Volume}$

$$Vf=\frac{Vf}{Vf+Vm}=\frac{Vf}{Vc}$$

Matrix Volume fraction=$\frac{Volume\ \ of Matrix}{Total\ Volume}$

$$Vm=\frac{Vm}{Vf+Vm}=\frac{Vm}{Vc}$$

$$VF=VM=1$$

let ρ_f and ρ_m are density of fiber and matrix respectively then we have

$$Vf=\frac{Wf\times\rho m}{Wf\times\rho m+Wm\times\rho f}$$

Similarly,

$$Vm=\frac{Wf\times\rho m}{Wf\times\rho m+Wm\times\rho f}$$

Where,

Vc = Volume of composite (cm^3)

Vm = Volume of Matrix (cm^3)

Vf = Volume of fiber (cm^3)

ρ_f = Density of fiber (g/cc)

ρ_m = Density of Matrix (g/cc)

By using the above aforementioned equations, these values were evaluated and presented in the following tables

Designation	Composition		Volume (Cc)			No of Samples
	Epoxy(%)	Sisal (%)	sisal	Epoxy	Total	
SNT(F) 15	85	15	24.21	161.51	185.72	5
SNT(F) 25	75	25	42.8	142.2	185	5
SNT(F) 35	65	35	78.21	160.97	239.15	5

Table 3-4 Sample flexural specimen compositions by volume used in this study

Designation	Composition		Volume (Cc)			No of Samples
	Epoxy(%)	Sisal (%)	sisal	Epoxy	Total	
SNT(T) 15	85	15	20.08	126.1	146.18	5
SNT(T) 25	75	25	37.48	112.43	149.91	5
SNT(T) 35	65	35	49.32	96.45	143.77	5

Table 3-5 Sample Tensile specimen compositions by volume used in this study

Designation	Composition		Volume(Cc)			No of Samples
	Epoxy(%)	Sisal (%)	sisal	Epoxy	Total	
SNT(C) 15	85	15	25.47	159.99	185.46	5
SNT(C) 25	75	25	41.37	142.6	183.97	5
SNT(C) 35	65	35	60.61	124.8	185.41	5

Table 3-6 Sample Compression specimen compositions by volume used in this study

3.2.4 Sisal fiber reinforced Epoxy Composite preparation

ASTM D 5687/D 5687M – 95 was used as a guide line composite fabrication process the fabrication approach is depicted in *figure 3.5*

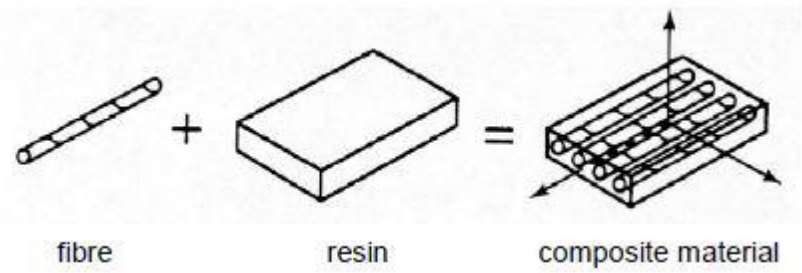

Figure 3-5:Fabrication approach

Figure 3.6 shows the scheme for the preparation of Sisal fiber reinforced Epoxy resin composites. The composite specimens were prepared in a mold cold compression method. Random fiber orientation were used to prepare the samples. Epoxy resin and hardener were taken in a steel bowl then mixed well and made ready for layup reinforced sisal fiber . The composite samples were fabricated by hand lay-up technique. At first, a plastic was placed on dried bottom part of the mould;. Then some of the prepared resin mixture spread evenly on the fiber. after that A plastic was placed on the following top part of the mold(Lid). then The prepared samples were allowed to cure under pressure at room temperature. press machine was used to develop pressure.

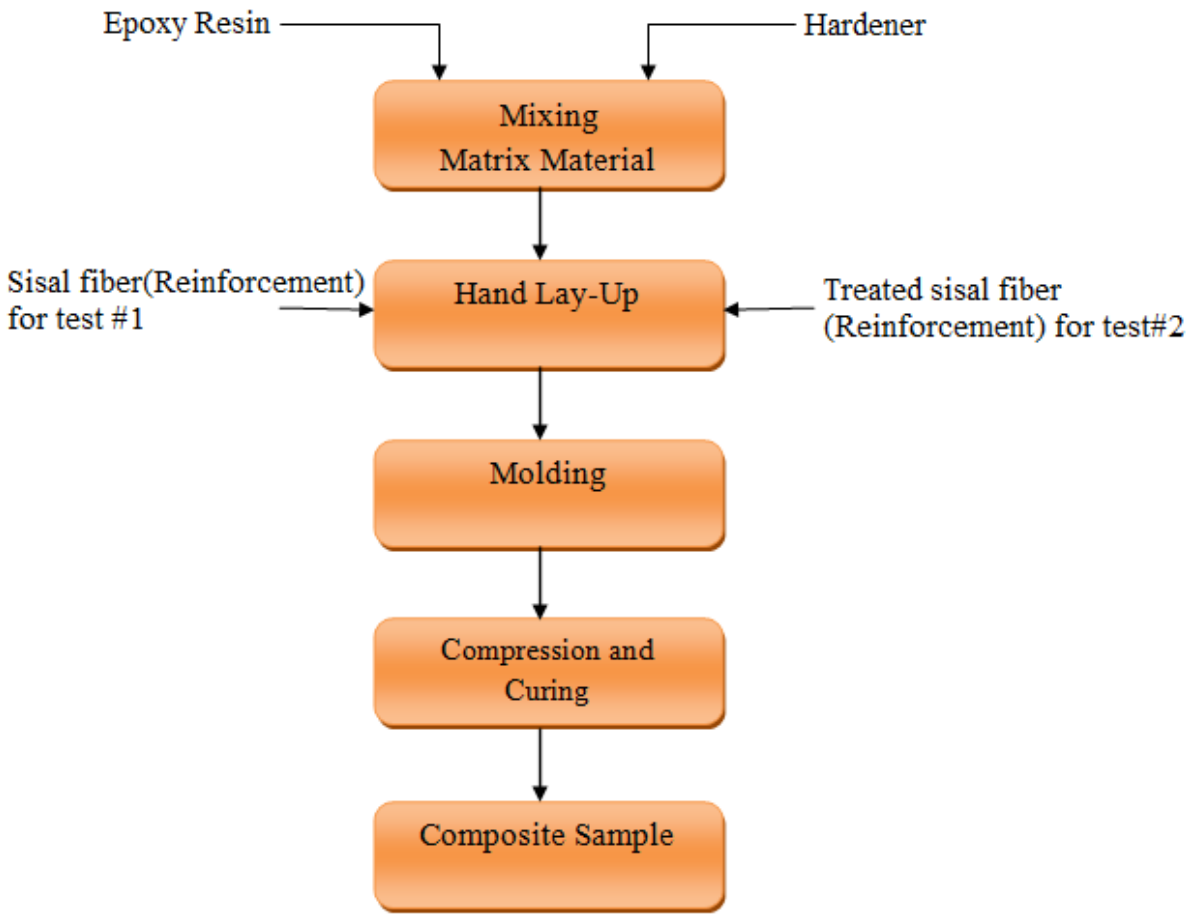

Figure 3-6 Schematic flow diagram for fabrication of sisal fiber reinforced epoxy resin composites.

3.2.4.1 Preparation of epoxy and hardener:

Epoxy of SYSTEM #2000 , mixed with hardener SYSTEM #2060 is used to prepare the composite plate. The weight ratio for mixing epoxy and hardener is 10:1. Hardeners include anhydrides (acids), amines, polyamides, dicyandiamide etc. The mixer is strewed with stirrer for about one minutes continuously The mixing is performed in the mixing containers(Bowl) the bowl is made of Nickel to prevent melting of the Bowl during the exothermic reaction with the tongue depressor the mix is done slowly so as to not entrain any excess air bubbles in the resin.

Figure 3-7 Steel Bowl and stirrer

3.2.4.2 Hand Lay-Up:

Hand-lay-up method was adopted to fill up the prepared mould with an appropriate amount of epoxy resin mixture and layers of random sisal fibers, such that starting and ending with layers of resin. The quantity of accelerator and catalyst added to resin at room temperature for curing was 1% by volume of resin each. Fiber deformation and movement should be minimized to yield good quality, random fiber composites. Therefore, at the time of curing a compression pressure of 5 MPa was applied on the mould and the air gaps formed b/n the fibers during the processing were gently squeezed out by hydraulic press to force the air present in between the fibers and resin, and kept several hours to get the perfect samples the processed wet composite were then pressed hard and the excess resin is removed and dried. Fiber configuration and volume fraction are two of the most important factors that affect the properties of the composite. In this work, configuration is limited to random, equal to the length of specimen i.e. ~ 9.0 mm in case of tensile testing, compression testing and flexural testing and the composite samples were prepared with three different volume fractions of sisal fibers. . The sisal fiber reinforced epoxy are used in varying fiber matrix ratio of 15/85, 25/75 and 35/65 respectively for both treated and untreated batch of composite.

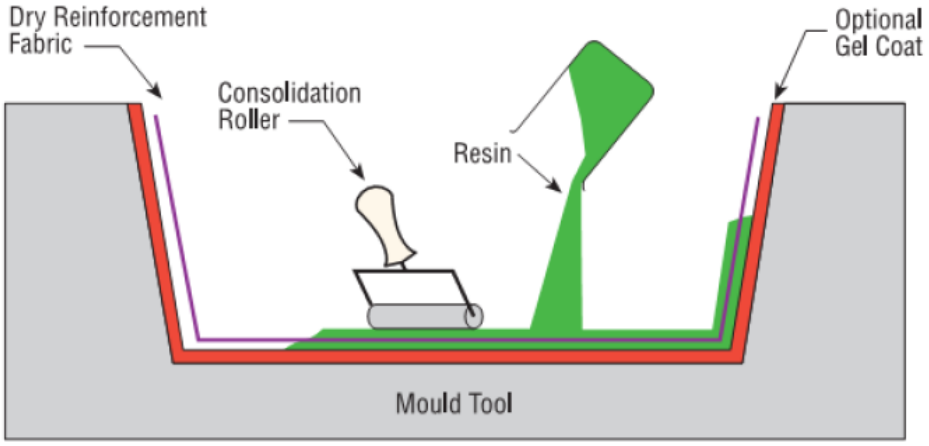

Figure 3-8 hand layup

Materials Requirements of Hand-lay-up method

- Mould
- Roller
- Mould release

i. Mould

The pattern is made up of mild steel of 300 mm X 195mm X 15mm

The pattern consist of three parts

- Base Plate
- Frame
- Mould release

The Base plate is very thin plate which is placed inside the inning. The Lid and Base Plate surfaces of the mould and the walls are coated with remover and allowed to dry. The functions of Lid and Base plates are to cover, compress the fiber after the epoxy is applied, and also to avoid the debris from entering into the composite parts during the curing time.

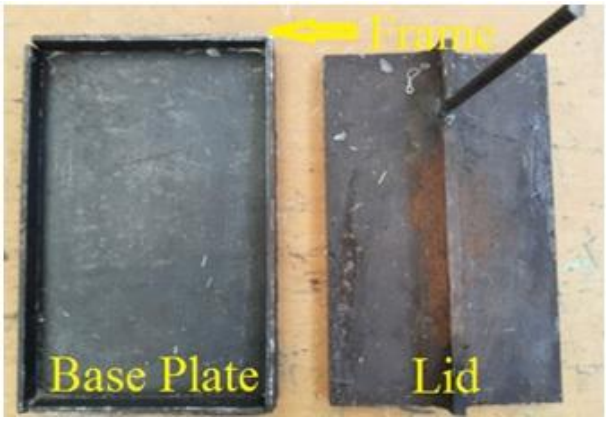

Figure 3-9 Mould

iii) Mold Release

Mold release is essential for preventing the epoxy from sticking to the mold when the composite are apart. Even though, there are several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this work is paste wax, and polyethylene plastic for better surface finish of the composite as shown *figure3.11*.

3.2.4.3 Molding:

First of all polyethylene plastic laid on the mould then mould release spray was spread overall after that we pour some mixture after that we place weighted chopped sisal according to each specific fiber/matrix ratio *figure3.11*. Above that we pour mixture of fiber polymer mixture. then we press the mold on press machine for consolidation and This sample is then left for 24 hours. The composite gets dried up in 24 hours in which the sisal fiber and the polymers adheres itself tightly in the presence of hardener. After a day we put out the mould from the press machine . Then the mold steel lower attachment(plate) is slowly and gently hammered on the boundary of its attachment when the top(lid) and the composite separate out. Then carefully plastics are removed from the steel mold. Now we have the composite.

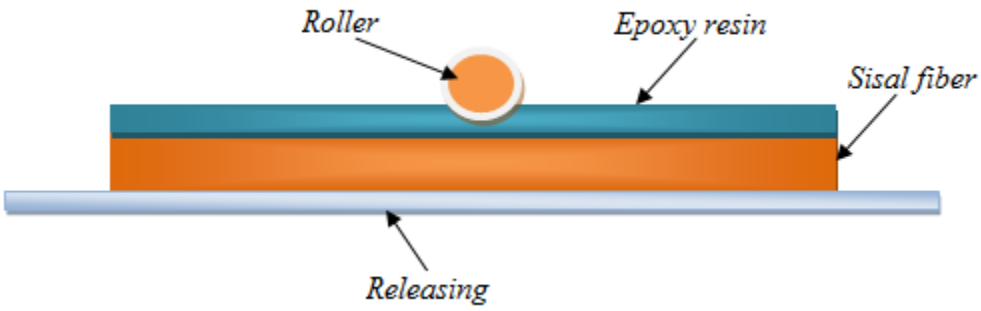

Figure 3-10 Sisal fiber reinforced epoxy composite molding sketch map

Figure 3-11 Sisal fiber reinforced epoxy composite molding at AAit Lab

3.2.4.4 Compression and Curing:

5Mpa of pressure was maintained and It requires 24 hours for curing at room temperature. after curing period the sisal fiber polymer matrix were removed from the moulds. A typical hydraulic press used for curing SFREC is shown in *figure 3.12* The prepared composite boards were post cured for 15(360 hours), 30(720 hours) days at standard laboratory atmosphere prior to preparing specimens and performing mechanical tests.

Figure 3-12 Standard Hydraulic Press for curing

3.2.4.5 Fabricated SFREC Sample:

typical treated and untreated sisal fiber reinforced epoxy composite boards is shown in *figure3.13*

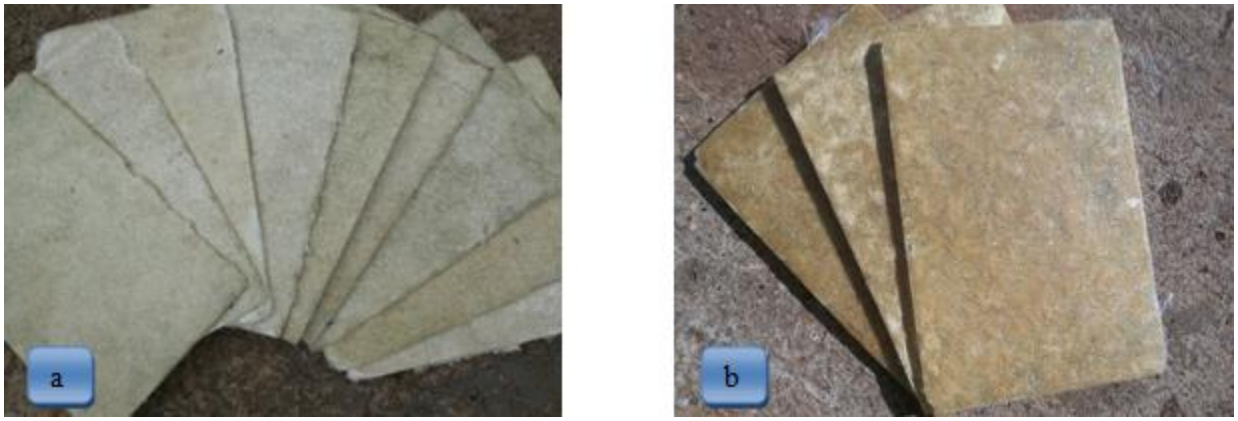

Figure 3-13 Sisal fiber reinforced epoxy composite

a. *Treated sisal fiber reinforced epoxy composite*
b. *untreated sisal fiber reinforced epoxy composite*

3.3 Experimental Procedure and Setups

3.3.1 Specimen sampling procedure

The test used in this research required a total of about 90 specimens for both treated and untreated sisal fiber. band saw blade as shown in *figure3.14* was used to cut each laminate into smaller pieces, for various experiments the cutter has a speed of 915m/minute:

Figure 3-14 Band Saw

3.3.1.1 Dimension of Test Pieces

The appropriate American Society of Testing Materials (ASTM) standards were followed while preparing the specimens for Sisal fiber reinforced epoxy composite test and their values are illustrated in *figure 3.11* [47, 48 and 49].

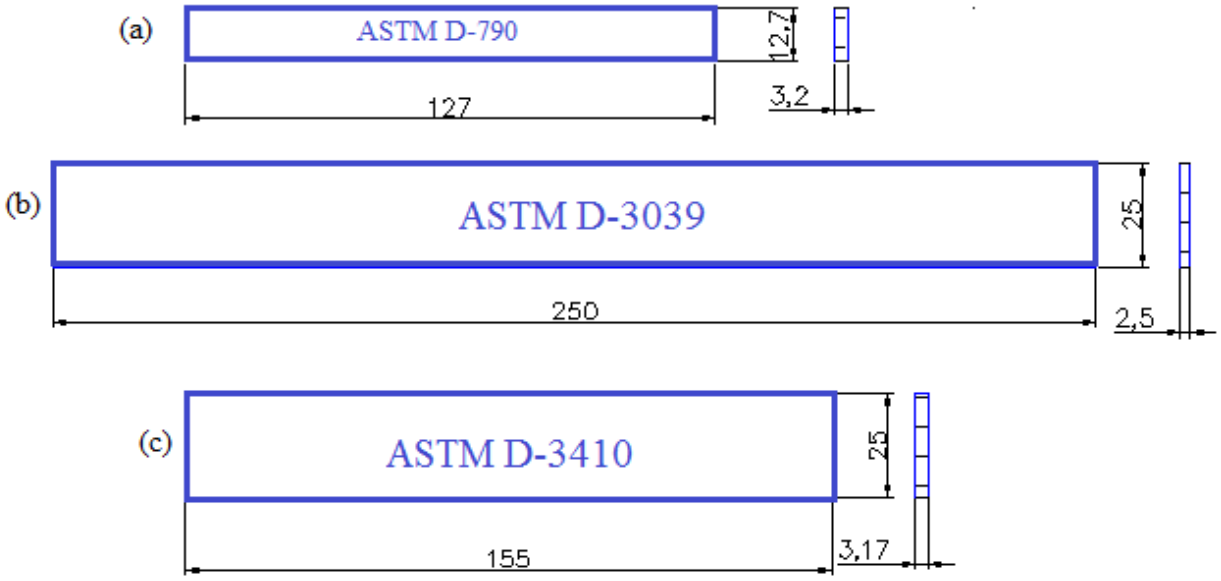

Figure 3-15Test Specimen Dimensions- (a) Bending Test Specimen (b) Tensile Test Specimen (c) Compression Test Specimen

Figure 3-16 Sample specimen after cutting

3.3.2 Specimen Testing Procedures

After the Sisal fiber reinforced epoxy composite Specimen cut in to the desired dimension based on the respective standards for each weight ratio of 15/85%,25/75% and 35/65% were tested using the three different strength testing procedures: The flexural test, compression test and tensile test for each set of specimen.

3.3.2.1 Introduction of Test Apparatus

Universal Testing Machine (UTM) Testing System

UTM Testing Systems are highly integrated testing packages that can be configured to meet different testing needs. Each includes a load unit with integrally mounted actuator and servo valves, a hydraulic power unit, and the control system, as illustrated in *figures 3-17 and figures 3-18.* The control system has three major parts: the system software running on a personal computer, the digital controller, and a remote station control panel. These functions work together to provide fully automated test control. Optional application software packages let you further tailor the system to automate most any standard or custom test procedure.

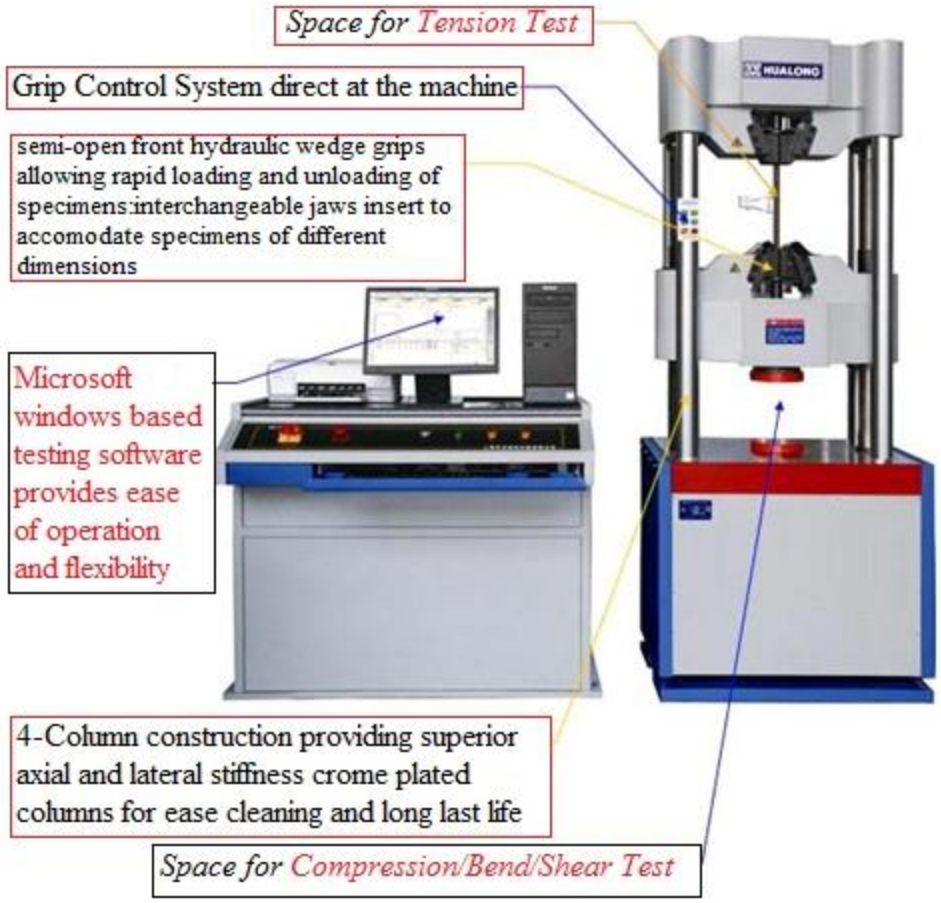

Figure 3-17 Hualong Universal testing machine testing system working sketch map.

Figure 3-18 UTM material testing system in AAiT Mechanical Testing laboratory

3.3.3 Sisal fiber reinforced epoxy Composite characterization

The composites were then characterized for tensile properties using test method ASTM D3039,compression properties ASTM D3410 and flexural properties using test method ASTM D790-2010 at least five replicate specimens were tested and the results were presented as an average of tested specimens. For each composite specimen the thickness were determined The thickness measurements were performed at 3 places along the length of each specimen. Overall sample thickness was determined by averaging measurements for five specimens the tests were conducted at a room temprature.

3.3.3.1 Flexural Strength Test(ASTM D790-2010):

Flexural strength is defined as a materials ability to resist deformation under load. The short beam shear (SBS) tests are performed on the composites samples to evaluate the value of inter-laminar shear strength (ILSS). It is a 3-point bend test, which generally promotes failure by inter-laminar shear. This test is conducted as per ASTM standard using UTM. The loading arrangement is shown in *figure3.19* . The dimension of the specimen is (127x12.7x3.2)mm. with support span-to-depth ratio of 16:1 and support span length51.2mm rate of cross head motion 0.5mm/min. The flexural strength is expressed as modulus of rupture(MR) in psi (MPa) .

Figure 3-19 Specimen under flexural testing

3.3.3.2 Compressive Strength Test(ASTM D3410)

this section of the laboratory experiment involved in subjecting SFREC specimen to axial compression loading using the UTM The dimension of the specimen is (155x25x2.5)mm the samples the samples were then placed between the compression anvils to commence compression testing During testing, the maximum load attained was recorded by the UTM

testing system after the specimen failed. Each specimen was documented (by pictures) before and after failure. A typical specimen failure is shown in *Figure 3-20*.

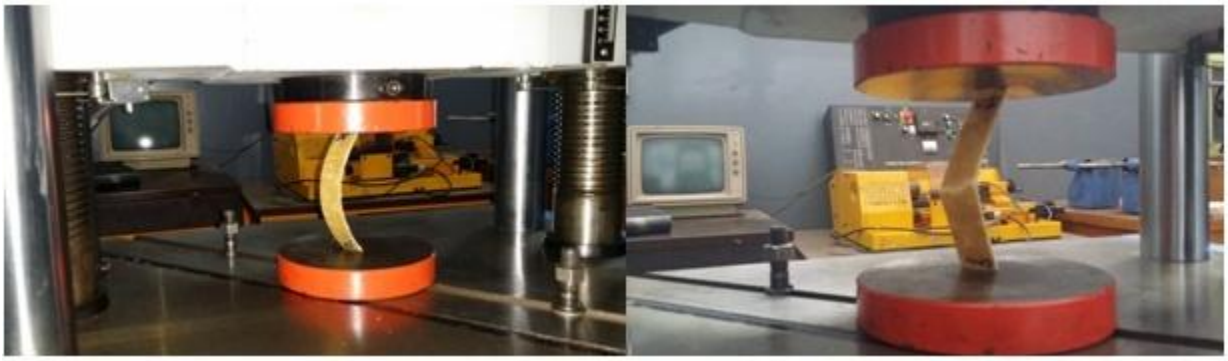

Figure 3-20 Typical specimen failure under compression loading

3.3.3.3 Tensile Strength Test(ASTM D3039/D3039M):

The primary objective of this test was to evaluate the in-plane tensile properties of sisal fiber composites. For each sample, 5 specimens were tested in each machine and cross-machine direction Each specimen was 25 by 250 mm by During the test the specimens were placed in the grips of UTM and axial load is applied through both the ends of the specimen. Typical points of interest when testing a material include: ultimate tensile strength (UTS) or peak stress; The cross-head speed used was 0.5 mm/min, and gauge length was 200 mm. Load-elongation curve, breaking load, peak stress and % strain at peak stress were acquired in real time by machine and provided at the end of each test Typical specimen under tensile strength test is shown in *figure3.21*.

Figure 3-21 Typical specimen under tensile strength test

CHAPTER 4: RESULTS & DISCUSSION

4.1 Experimental Results

4.1.1 Tensile Test

For tensile strength evaluation, there were 6 specimen groups for each fiber/matrix ratio(15/85,25/75and 35/65) treated SFREC and (15/85,25/75and 35/65) untreated SFREC total of 30 specimens while the typical stress strain curve of SFREC under tensile loading for different sisal/epoxy resin composite specimen is presented in *figure 4.1and figure 4.2* .

The initial relatively steep part of the curve represents elastic behavior and the slope of the curve defines the elastic modulus. Using a sharp pencil and a ruler, by carefully draw a straight line through as much of the straight portion of the curve as possible, extending it from the bottom of the chart (Line A-B in *figure 4.1(c)*). This straight line is referred to as the **Modulus Line**, from which the **Modulus of Elasticity** will be calculated for the material tested.

The modulus of elasticity (Young's Modulus) is the ratio of stress in Mpa to strain in millimeters per millimeter (mm./mm.) as computed from the modulus line (A-B).

$$\text{Modulus (Mpa)} = \frac{\Delta Stress\ (Mpa)}{\Delta Strain\ (\frac{mm}{mm})}$$

To find the modulus, by taking any two points (K & L) on the modulus line (A-B) , and divide the differential between their stress values in Mpa from the strain differential in mm/mm. The result of this division is the modulus of the material tested.

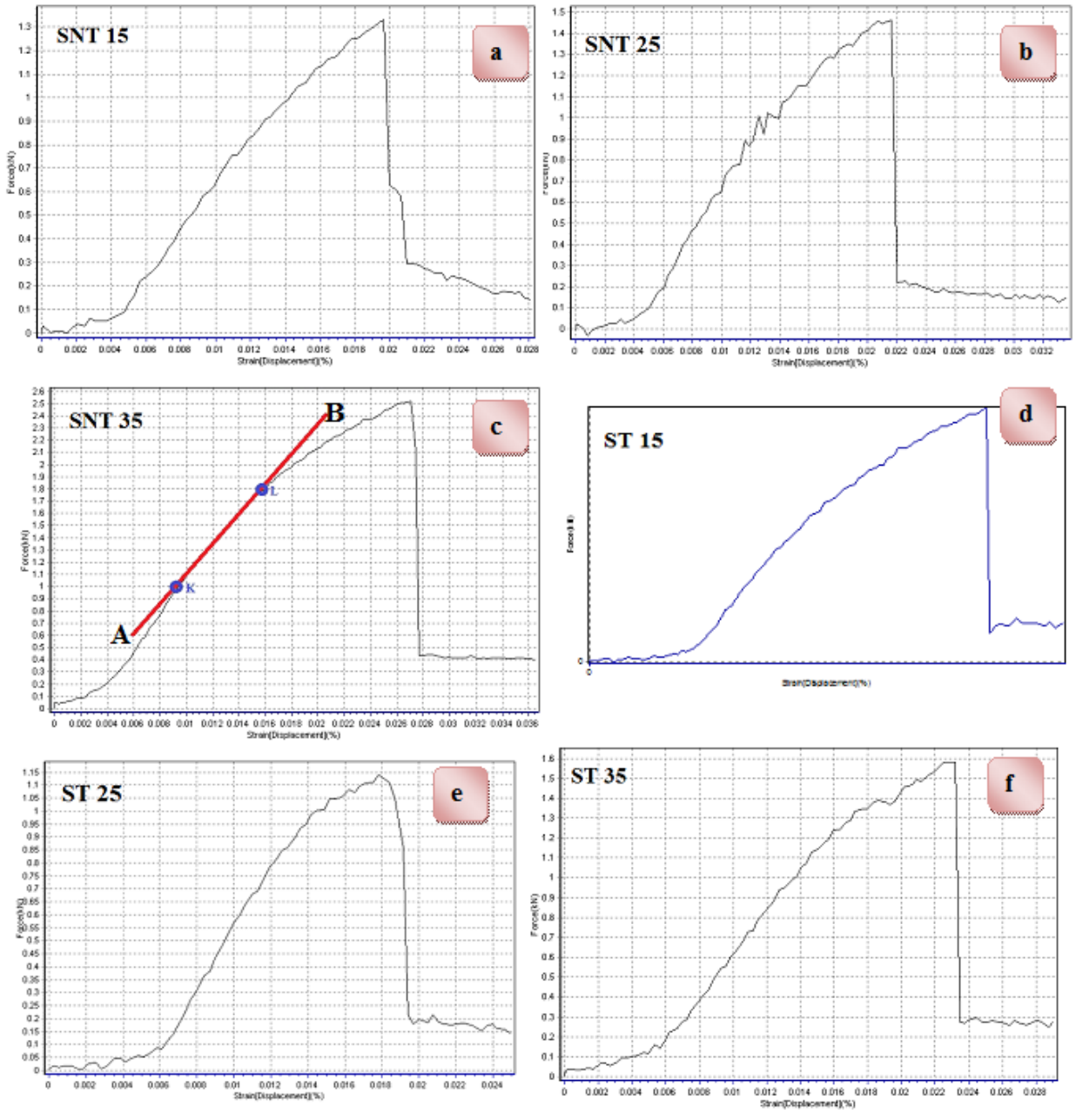

Figure 4-1 Engineering Stress vs. Engineering Strain for each specimen group

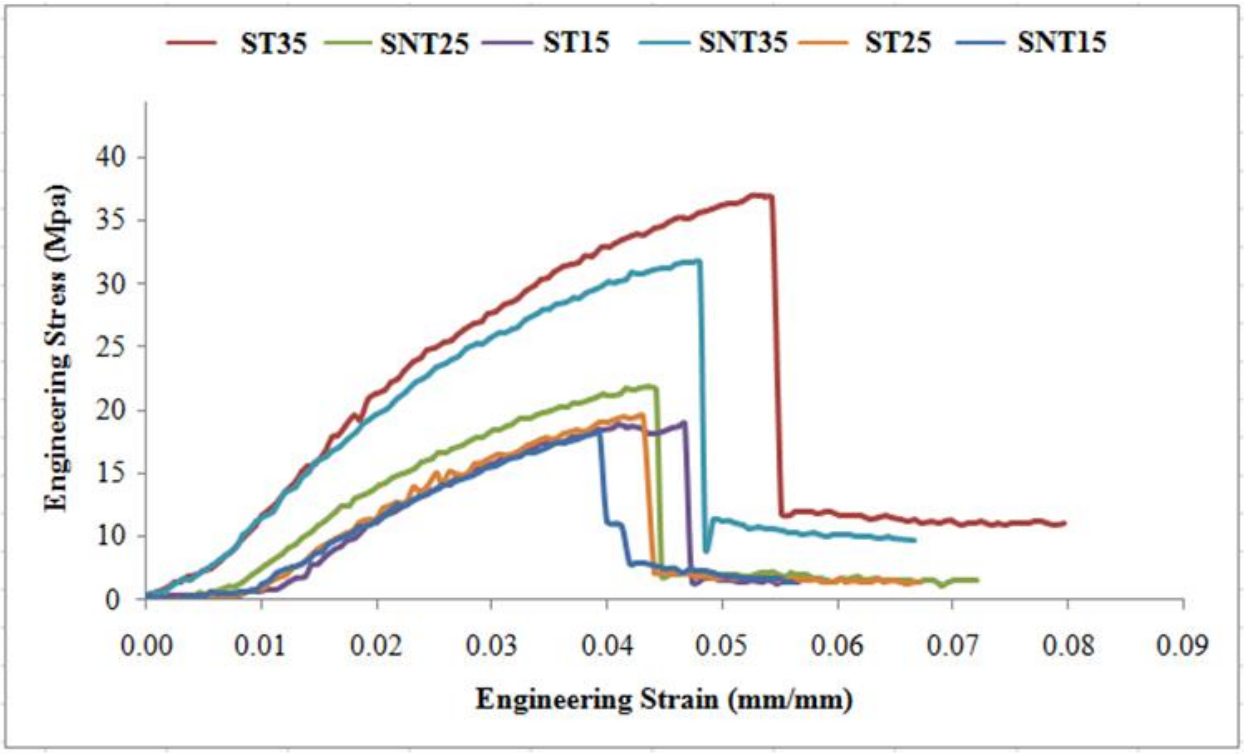

Figure 4-2Engineering Stress vs. Engineering Strain for all test groups

Engineering stress/strain are laboratory stress/strain that obtain by taking load & elongation of a given specimen as primary output from the experiment that defined the curve of stress-strain.

4.1.2 Compression Test

Compressive test specimens were prepared as Random orientation. three types of sisal/epoxy with the fiber/matrix ratio of (15/85,25/75 and 35/65) were used for both treated and untreated batch of the specimen. for each ratio, five specimens were prepared for repeatablity. The result of force vs strain graph is given in *figure 4.4* the graph indicates non linear segments (there is up and down) and the curve is not smooth,in which the jerky/stick slip behavior is responsible for this response which is discussed in the next topic. during fracture compressive stress of SFREC rapidly decreased with buckling of the specimen.

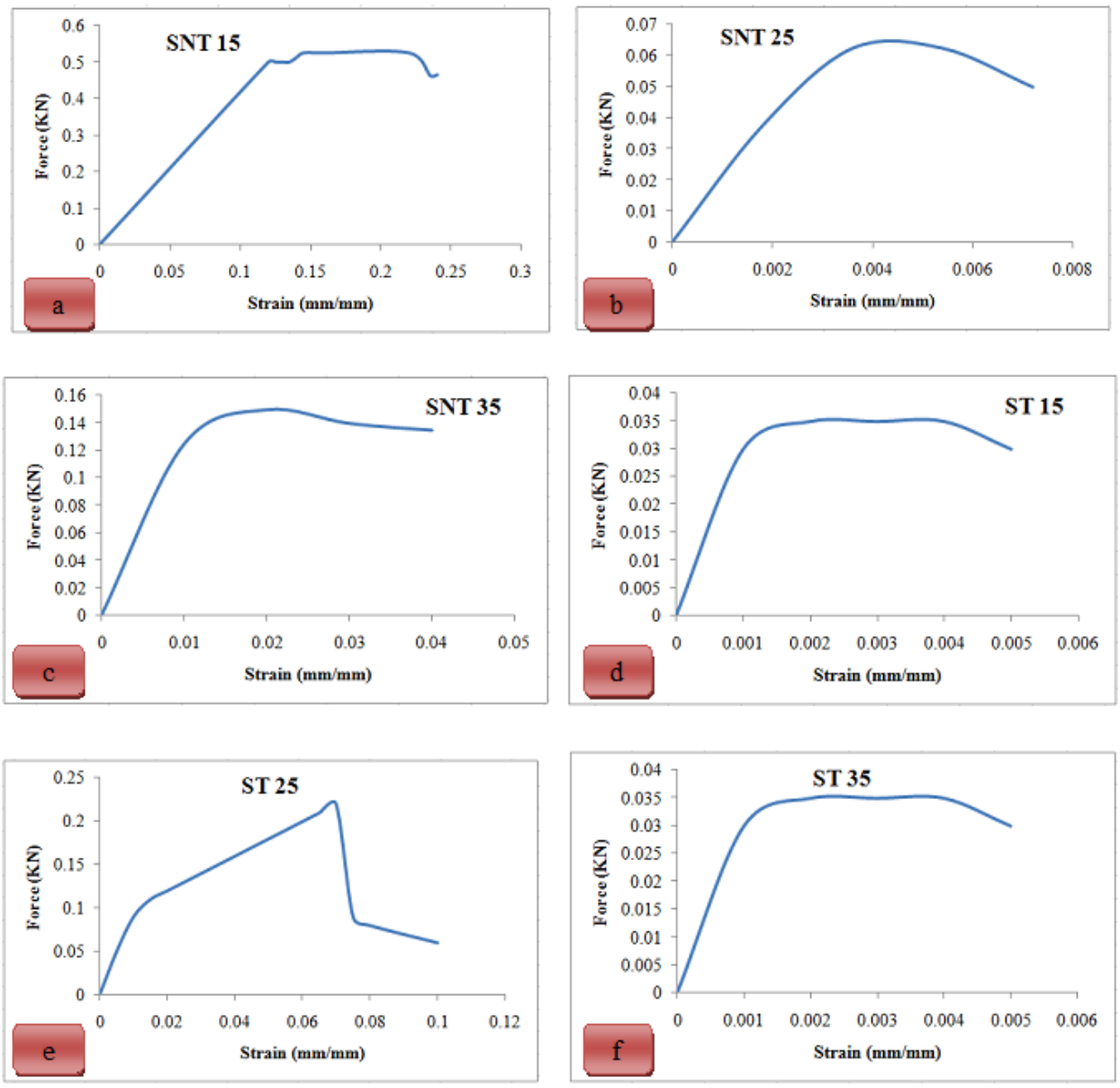

Figure 4-3 force Extension Diagrams(Compression) (a)SNT15 (b) SNT25 (c) SNT35 (d) ST15(e) ST25 (f) ST35

4.1.3 Flexural Test (three point bending test)

The flexural test measures the force required to bend a beam under three point loading situations. The data is often used to select elements for parts that will support loads without inflection Flexural modulus is used as an indication of a material's stiffness when inflection.

Three point bend test was carried out in an UTM machine in accordance with ASTM standard to measure the flexural strength of the composites.

the load was applied in the middle span of the specimen at a speed of 0.5mm/min The span length was 51.2mm as shown in *figure 4.5* and data were collected from the computer which is integrated with the standard UTM test machine.

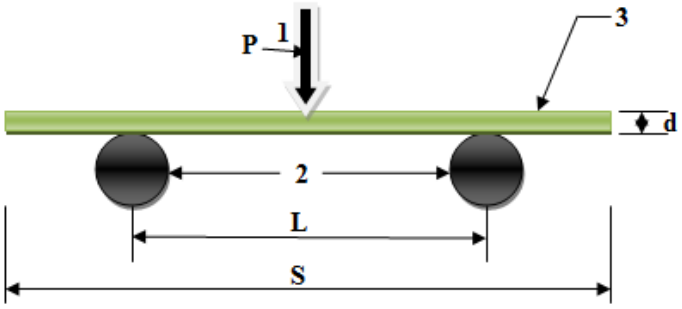

Figure 4-4 Three-point bending

1: load probe, 2: support, 3: specimen, d: depth of specimen,
L: support distance (span) and S: overall length of specimen

Atypical force displacement graph for ST15, ST25, ST35, SNT15, SNT25 and SNT35 are shown in *figure 4.6* It is observed that all curves increase linearly with respect to displacement up to the maximum force.

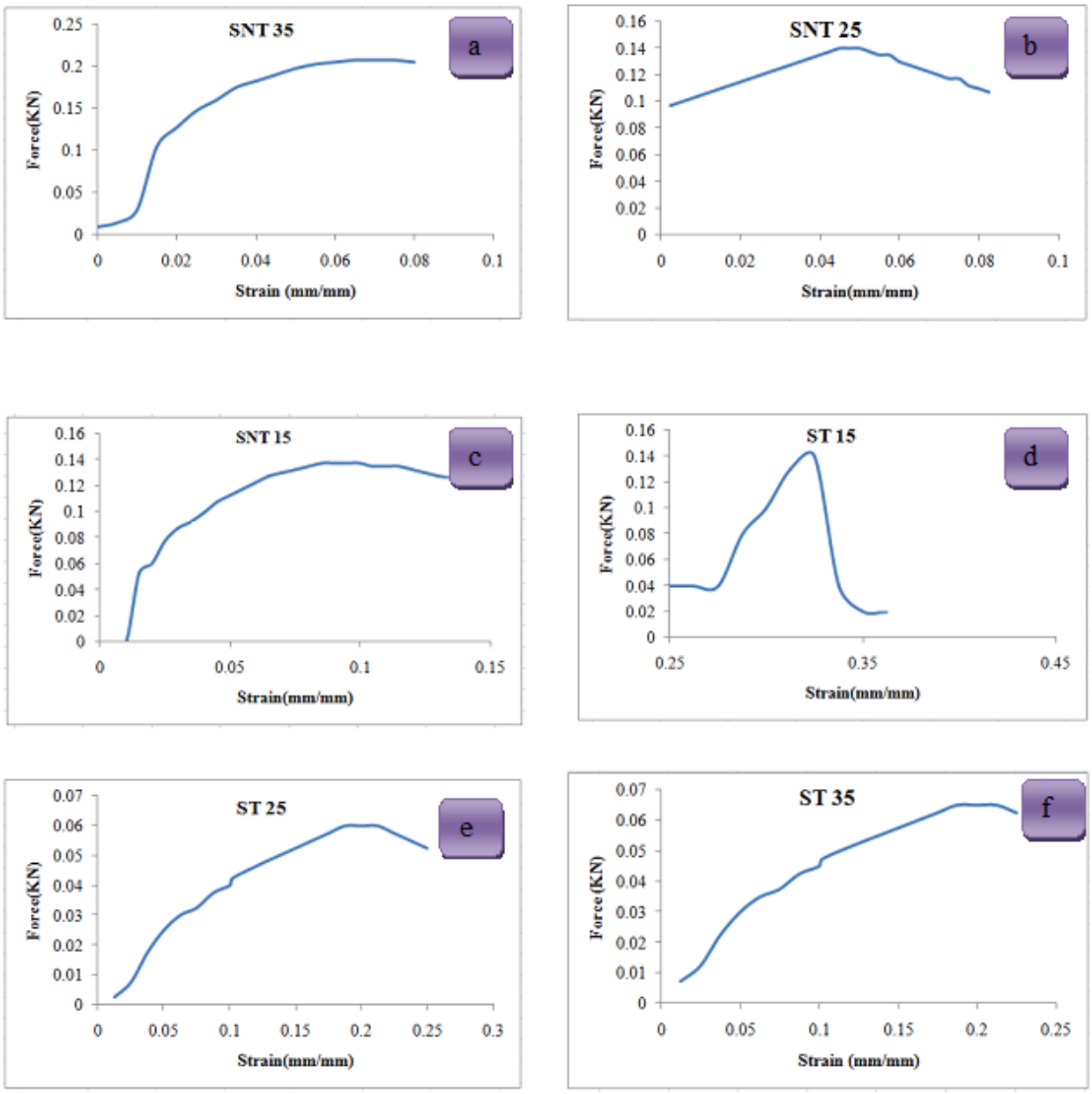

Figure 4-5 force Extension Diagrams(Flexural) (a)SNT15 (b) SNT25 (c) SNT35 (d) ST15(e) ST25 (f) ST35

4.2 Discussion

4.2.1 Tensile Test

The test results are tabulated and presented in the *table 4.1* based on the maximum values of the five specimens for each test condition.

Table 4-1 Tensile test results

Designation	Maximum Tensile strngth (Mpa)	Maximum Tensile Modulus (pa)
SNT15	26.59	2181.81
SNT25	29.23	1666
SNT35	37.12	1555.6
ST15	33.55	2638.9
ST25	39.93	2722.689
ST35	40.11	1666.7

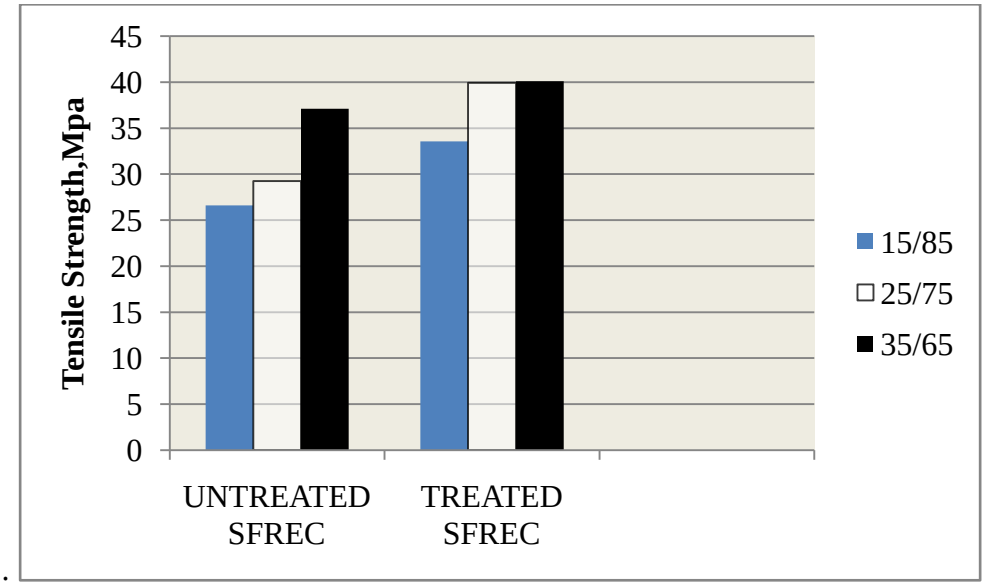

Figure 4-6 Tensile Strength comparison between two systems for each fiber/matrix ratio

Observation

1. Fiber/matrix ratio did affect the tensile strength of the sisal fiber reinforced epoxy composite. comparing the maximum strength levels for the treated and untreated batch of SFREC composite, for example the tensile strength of untreated SFREC composite shows an increase of about 9.92%,39.60%and 25.62% between 15/85and25/75, between15/85 and 35/65 and between25/85 and 35/65 respectively and also for untreated batch of SFREC composite the tensile strength of Alkaline treated SFREC composite shows an increase of about 19.02%,19.55% and 0.45% between 15/85and25/75, between15/85 and 35/65 and between25/85 and 35/65 respectively according to this and fig the fiber matrix ratio significantly affect tensile strength with increasing the fiber in the SFREC.
2. the effect of fiber content on tensile strength change was more pronounced in the SFREC between15/85 and 35/65 fiber/matrix ratio. this phenomenon can be seen in *figure4.7*
3. Though the tensile strength increase as the fiber content increase in the fiber matrix ratio in the Alkaline treated SFREC between25/85 and 35/65 fiber/matrix ratio the tensile strength change almost leveled off. this means that the fiber content in SFREC may have reached a saturation line state, or at least adding of more fiber in SFREC more than 35% may ingress decrease of tensile strength
4. Alkali treatment did affect the tensile strength of the sisal fiber reinforced epoxy composite material comparing the maximum strength values between the alkaline treated and untreated SFREC for each fiber/matrix ratio the tensile strength of fiber/matrix weight ratio of 15/85,25/75 and 35/65 shows a decrease of about 26.2%,36.6% and 8.05% respectively according to these results the alkaline treatment of sisal fiber significantly affect tensile strength.

4.2.2 Compression Test

The test results are tabulated and presented in the *table 4.1* based on the average compressive result of the five tests is given in table below.

.

Table 4-2 compressive test results

Designation	Rmax (Mpa)	ReL (Mpa)	ReH (Mpa)
SNT15	3.45	2.86	1.94
SNT25	10.9	18.6	18.04
SNT35	3.91	2.93	2.3
ST15	2.99	-	-
ST25	2.12	1.55	1.01
ST35	1.67	0.96	-

Where

Rmax- maximum compressive strength

ReH -the higher yield and

ReL-the lower yield

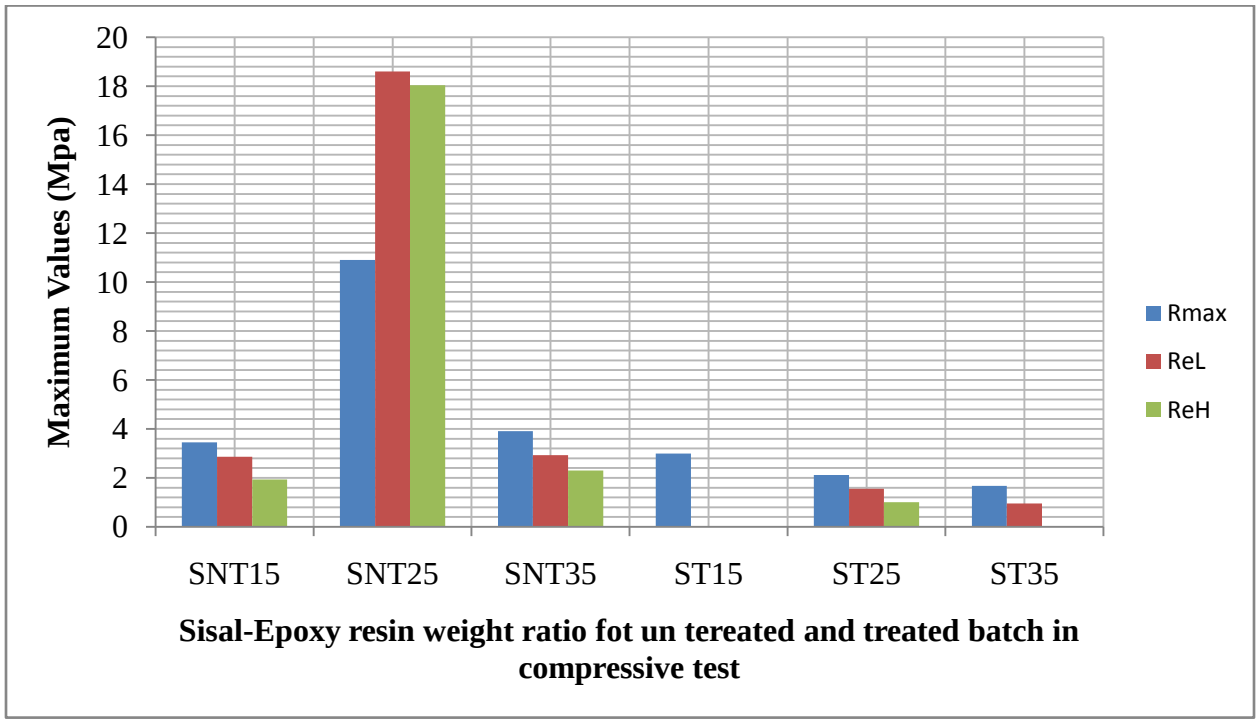

Figure 4-7 Compressive strength comparison between two systems for each fiber/matrix ratio

Observation

1. *figure4.8* compared the two systems (treated and untreated sisal) compressive strength and the test pointed out that the surface modification of the sisal fiber surface treatment has no significant effect on the compressive properties of SFREC.
2. for the untreated sisal fiber it is difficult to point out the effect of fiber/matrix ratio because the compressive strength for SNT15,SNT25 and SNT35 is 3.45Mpa,10.9Mpa and 3.91Mpa respecttively
3. for the treated sisal fiber it is clearly showed that whe the weight of the fibe is increased in SFREC there is a decrease in compressive strength this value may indicate that the result is not satisfactory and the sisal fiber fail to reinforce the epoxy resin the reason for this discussed in the following study.
4. the result getting from this test is not satisfactory as compared to other results from litrature is not satisfactory the consequence for lowering of the compressive strength result obtained would be two errors whic is disscused in the following study.

4.2.3 Flexural Test

Under three point bending in *figure 4.3* when the load P is applied at mid span of a rectangular specimen of span L between two rollers, the highest flexural strength is determined by:

$$\sigma_{bf} = \text{Smax} = \frac{3 \times L \times P}{2(b \times d^2)}$$

The deflection of the specimen by considering specimens as a beam (D_c) from the center as illustrated in *figure 4.3* can be expressed as:

$$Ec = \frac{r \times L^2}{6d}$$

The maximum flexural strain ε_f also calculated from:

$$\varepsilon_f = \frac{6 \times Ec \times d}{L^2}$$

The bending elastic modulus (E) is determined from the slope of the Load-deflection curve in alinear region and mathematically expressed as:

$$E = \frac{m \times L^3}{4 \times (b \times d^3)}$$

Where

σ_{bf} =E= calculated fracture stress (flexural strength), MPa

P = load at a given point on the load- deflection curve, N

E_c= is the maximum deflection at the center of the specimen (camber distance), mm

m= is the slope of the tangent to the straight-line portion of the load-deflection beam.

L= support span of specimen, mm

b = width of the specimen tested, mm

d = depth of the specimen, mm

r = strain, mm/mm

Smax = is the maximum strength of the material and it is also given in Mega Pascal (MPa)

The flexural test results are tabulated and presented in the *table 4.3* based on the maximum values of the five specimens and the more exaggerated result obtained from the among the five specimen from each batch were omitted.

Table 4-3 Flexural test results

Designation	Ec(mm)	Smax (Mpa)	E (Mpa)
SNT15	0.38	472.5	355.32
SNT25	0.25	448.9	145.18
SNT35	0.34	261.8	-
ST15	0.77	978	57.01
ST25	0.09	699.3	272.63
ST35	0.57	680.4	355.32

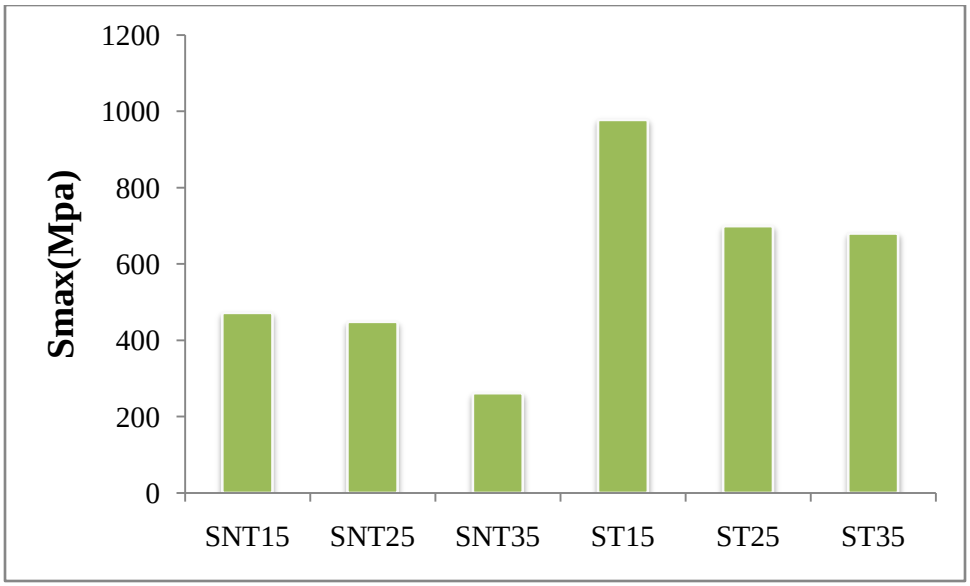

Figure 4-8 Flexural strength comparison between two systems for each fiber/matrix ratio

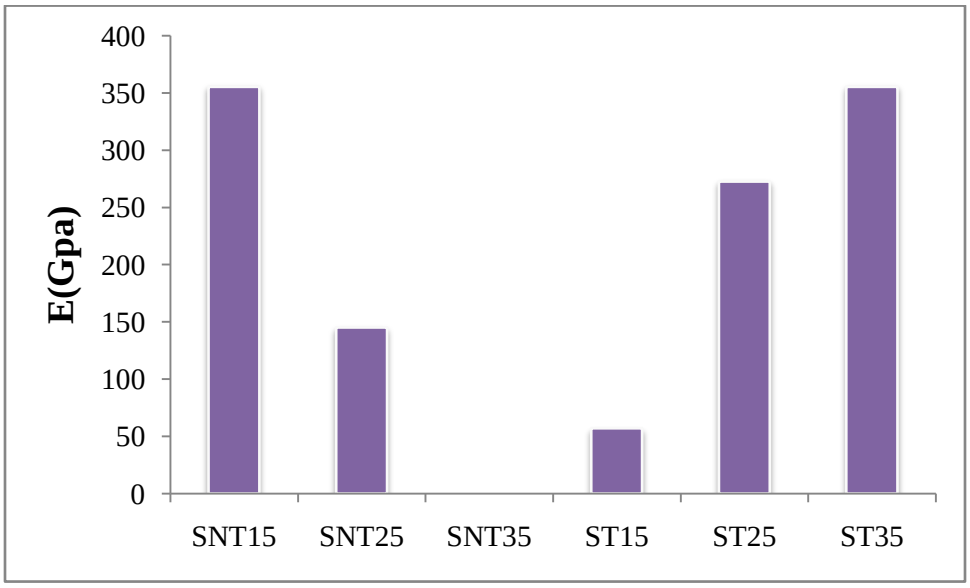

Figure 4-9 Flexural modulus comparison between two systems for each fiber matrix ratio

Observation

1. *figure4.9* compared the two systems (treated and untreated sisal) flexural strength. there is a clear phenomenon that the untreated sisal fiber epoxy composite is the lower.
2. the flexural strength of untreated sisal fiber SNT15(472.5 Mpa), SNT25(448.9 Mpa) and SNT15(261.8Mpa) but after alkali treatment the treated sisal fiber composite flexural

strength ST15(978 Mpa), ST25(699.3 Mpa) and ST15(680.4Mpa) this is due to good interfacial bonding between sisal fiber and epoxy resin and this result proved that it is crucial to chemically treat sisal fiber when using them to reinforce polymer.

3. *figure4.10* compared the two systems (treated and untreated sisal) for each fiber/matrix ratio of flexural strength. there is a clear phenomenon that the higher the fiber/matrix ratio the flexural strength decreased the reason for this is discussed in the next sub topic
4. .Regarding flexural Modulus illustrated in *figure 4.8* generally the chemical treatment failed to increase the systems flexural modulus and also when the fiber is treated there is increase of flexural modulus when weight of fiber in the fiber/matrix decreased ratio the flexural test is not very exact and there may be some error during testing the reason for this will be explained in the following study. it reaches the conclusion that when the weight of sisal sisal fiber increased in fiber/matrix ratio especially after alkali treatment greatly improved flexural strength and modulus and is able to be used in many automotive applications.

Sisal and epoxy bond revealed a strong fluctuation of force extension curve (stick-slip effect) recorded during uni-axial compression and bending test this stick-slip effect causes difficulties in interpretation of testing results obtained due to non linearity of the curve. the load oscillation happened due to the stick-slip between the granules of sisal fibers. these granules form chains of particles within the epoxy to support the applied load. when the chain becomes unstable, some granules will slide out causing the load to drop. this drop causes s sudden drop in the stresses during the compression & bending. this stick-slip phenomenon usually occurs in anisotropic materials when the particles begin to slide and roll over each other.

From relative displacement of the matrix and fiber elements at the interface, relative lipping of the cracked interface is usually expected due to the 'stick-slip' nature of frictional stress transfer. stick-slip follows a crack propagation and crack arrest behavior which indicates unstable crack growth[50] this jerky(stick-slip) behavior is related to the known physical mechanism of dislocation movements, namely the pinning (stick/slow) and depinning (slip/fast) of dislocations, stick-slip is characterized by the system spending characteristically unequal times in the stick and slip states[51,52].

The mechanical behavior of granular materials is highly dependent on the arrangement of particles, particle groups, and associated pore spaces. changes in the internal structure due to large deformation may cause changes in the mechanical behavior. these changes may include particles sliding, rolling and interaction, shear band formation; and fabric anisotropy. During tose changes, stick-slip behavior may take place between the granular particles [36].

According to[53], the stick-slip seems to disappear at large strain rates and that stick-slip is sensitive to rapid variation of deviator stress forcing to disappear, Moreover slick-slip dissapear in relatively large specimen with fast loading rates, therefore strain variations are largely affected by the stick-slip behavior of the bonds,So we can conclude that the lower value of the strain rate used for compression and flexural test responses for this jerks effect. the cross head speed for compressive and flexural testing were 0.5mm/min. strain rate is given by (Cross head speed)/(Gauge length).

Modulus of elasticity for tensile, compressive and flexural tests also determined.

the elastic moduli achieved from the tensile, compression and bend test are generally close to each other within the same material in case of isotropic material [32,40] but these values are not closer are not closer due to anisotropic characteristics. there are several factors that might affect the elastic moduli. which are:

- Elastic and plastic deformation at the rollers at the supports or the loading points might not be sufficiently small in comparison to the beam deflection.
- If a short specimen is bend tested, deformation due to shear stress may takes place, which are not ideal for the calculation according to the beam theory.
- Materials might have different elastic moduli under tension, compression and bending therefore, the elastic moduli in tension, compression and bending should be identified to an avoid confusion for the interpretation of the mechanical behavior of anisotropic materials.

Generally the flexural and compressive strength results are not pretty good the following two errors during testing may be responsible for these result

- **Sample History:** Also to consider is the sample history, which for all of the samples was largely unknown. Any number of events could have occurred in the history of the sample including stress from machining, material fatigue, or even post curing . It’s

unclear which did happen however, but we can be sure that none of them increased the tensile strength of the sample, as there are few ways to do that, and any would have to have been very deliberate. One very noticeable discrepancy with our data comes from one of the SFREC with designation of SNT25:75 sample ad found that the difference between the trials was much larger than with the other repeat trials. This suggests that the samples was very far off the norm, leading to the much larger than normal maximum compressive value .

- **Sample Preparation and Machine Compliance (Universal testing machine)** Finally we have the machine compliance for our testing rig. The most obvious form of that is the orientation of samples as there was no self-orienting appliance in the machine. Any angle off of 90º would decrease the effective stress on the sample. the UTM's compartment in AAit is not complete and accuracy of the machine is not good this will become the consequence of for lowering of the compressive strength result.

4.3 Comparison with the Previous works

4.3.1 Tensile Strength

Some of other researchers working regarding Tensile properties of natural fiber composites are compared with the Current work. From *table 4.4* the tensile strength which is found in the current work is more similar to Girishna's work which is 57Mpa for 40/60 fiber/matrix ratio and 44.78 Mpa 35/65 fiber/matrix ratio respectively with the same fabrication technique and thermosetting(epoxy and polyster resin) as matrix the sisal fiber oriented randomly it can be concluded that the result getting from the current work is pretty good and the local extracted sisal fiber from Ethiopian highland have similar tensile properties with that of India's sisal fiber . The fiber orientation is important for a composite's performance if the sisal fiber is unidirectional long fiber or in mat the composite tensile properties are high comparing to random short fiber so we cannot acquire a high performance in random short fibers when natural fiber hybrid with Glass fiber (Ariatha work) the polymer composite has much higher tensile strength this is dueto the intrinsic property of the glass fiber. but glass fiber has its drawbacks such as higher price, recyclability and higher density comparing to natural fibers so natural fibers still have a promising future in Automotive body application of fiber reinforced polymer composite.

Table 4-4 Comparison with previous works on tensile properties of sisal fiber composites

Matrix Material	Fiber	Fiber orientation	Fiber/matrix ratio(w/w)	Method of fabrication	Tensile Strength(Mpa)	Tensile Modulus(Gpa)	References
epoxy	sisal	Random short fiber	35/65	Hand layup	40.1		Current Work
epoxy	sisal	Uni directional	30/70	Hand layup	132.73	67.3	M.K Gupta (2014) [54]
epoxy	sisal	Mat form	30/70	Hand layup	89.3	395	M.K Gupta (2014) [54]
epoxy	Hybrid Sisal/ Coir (treated) [50:50]	Uni Directional for sisal short for coir	40/60	Hand layup	57	-	Girishna (2012) [55]
Polyester	Sisal (treated)	Random orientation	35/65	Hand layup	44.78	-	Kotrsh sardar (2014) []
epoxy	Hybrid sisal/ glass fiber	Uni Directional for sisal mat form for glass		Hand layup	158.167	-	Aripitha (2014) []
Unsaturated Polyester	sisal	Uni directional	20/80	Hand layup	26.0	-	Madhu sudah (2014) []

4.3.2 Compressive Strength

Some of other researchers working regarding Compressive properties of natural fiber composites are compared with the Current work. From *table 4.5* the Compressive strength which is found in the current work is lower when compared to Dr. K dinsh's work and it his work he clearly shown that sisal fiber surface treatement have significant effect on compression so more study will need on the current work K.sudah mahus's work clearly show the length of the fibers have significant effect on the compression properties of material the compressive strength property turns out to be more significant for the long fibers in comparison with the shorter ones.

Table 4-5 Comparison with previous works on Compressive properties of sisal fiber composites

Matrix Material	Fiber	Fiber/matrix ratio(w/w)	Method of fabrication	Compressive Strength(Mpa)	Compressive Modulus(Gpa)	References
epoxy	Sisal untreated	25/75	Hand layup	10.9	-	Current Work
epoxy	Sisal Treated	30/70	Hand layup	64.66		Dr. K dinish [59]
epoxy	10mm Sisal /glass	25sisal 25glass	Hand lay up	152		k.sudah madhuri [60]
epoxy	20mm Sisal /glass	25sisal 25glass	Hand lay up	160		k.sudah madhuri [60]

4.3.3 Flexural Strength

Flexural Properties of the current work compared with that of some of other researchers work. from *table 4.6* the flexural strength and the flexural modulus which is found in the current work is much higher than the other researchers work the reason for this significant change will be discussed in the following study and further study will need to figure out why this significant change happen but generally it can be concluded from the current work that the SFREC has higher flexural modulus and flexural strength and is more suitable to be used in structural parts which needs high flexural modulus. Gupta's Work relatively has equivalent flexural strength with uni-directional fiber orientation

Table 4-6 Comparison with previous works on Flexural properties of sisal fiber composites

Matrix Material	**Fiber**	**Fiber orientation**	**Fiber/matrix ratio(w/w)**	**Method of fabrication**	**Flexural Strength(Mpa)**	**Flexural Modulus(Gpa)**	**References**
epoxy	Sisal (treate	Random	15/85	Hand lay up	978	57.01	Current work
epoxy	sisal				225	18	Rong et.al [61]
Urea formaldehyde	Sisal (treated	Random	30/70	Compression molding	58.58	7.63	j.b zhong et al. [62]
Unsaturated polyster	sisal	Uni directional	20/80	Hand lay up	26.0		Madusudah [58]
epoxy	sisal	Uni directional		Hand lay up	288.6	18.21	M.K Gupta (2014) [54]
epoxy	sisal	Mat form		Hand lay up	152.12	14.8	M.K Gupta (2014) [54]

CHAPTER 5: CONCLUSSION & RECCOMENDATION

5.1. Conclusion

The sisal fiber was extracted manually from Ethiopian Highland sisal plant, and then the alkaline treatment was carried out . Next to that, sisal fiber reinforced epoxy composite was manufactured and its mechanical performance such as The tensile, compression and flexural properties is determined using laboratory experiment. All the numerous experimental test results gathered an important information about sisal fiber reinforced epoxy composite. Moreover such tests constitute fundamental confirmation of the reliability of the material and of its usage in automotive body application. Based on the tensile, compression and flexural properties experiment data studies in this work, few points can be concluded as follows:

- A polymer matrix composite contains the sisal fiber as a reinforcement was successfully fabricated.
- Different mechanical properties of SFREC were determined from different Sisal to epoxy resin percentage
- 18% NaOH alkali treatment is an effective chemical treatment in improving interfacial adhesion between sisal fibers and the epoxy. After treatment, sisal fiber are bonded better with matrix epoxy and the epoxy is able to penetrate into sisal fiber core, i.e. the interfacial adhesion has been greatly improved after 18% NaOH solution treatment in this research project . as the fiber concentration increases tensile strength also increased when fiber concentrations are less the matrix and fiber interface shows weak boding these effect clearly shown in tensile test .
- From the Tensile Experimental test results it is found that 35% alkaline treated have better tensile property anyhow from this results we suggest that as the fiber concentrations increases tensile strength also increased. When fiber concentrations are less the matrix and fiber interface shows weak bonding.
- From the Compression Experimental test results it is found that 25% treated SFREC have higher compressive tensile strength as compared to others.
- From the Bending Experimental test results it is found that 15% untreated sisal fiber has better tensile properties but treated 35% SFREC have better flexural modulus

- From the compression and tensile test results we suggest since the results is unsatisfactory and difficult to figure out the effect of surface treatment and fiber/matrix in the composite specimen so we suggest further study needed to characterize the bending and compressive properties of SFREC.
- The treated sisal fiber/epoxy composite system has a high mechanical performance especially Tensile strengths and modulus, besides its green nature. So this research muscularly gives confidence to utilize the advantages offered by renewable resources and its application in some aspects of industrial application such as automotive interior panels as substitutes.
- From all the results and comparisons we can conclude that the fabricated SFREC have some Automotive application which does not need a very high mechanical performance, but need light weight and recyclability such as interior panel.

5.2. Future work

the following study can throw more light into the application of SFREC for automotive application the possibility of finding the appropriate SFREC for Automotive body application depends on the accurate knowledge of the fabrication and proportion of sisal fiber and the matrix material .the following studies could be performed to analyse more details in this topic.

- Characterization can be done by using different types Natural fibers to improve the strength.
- Characterization of the fibers can be done by the using different fabrication techniques on SFREC's
- Characterization of the fibers can be done by the using Mat type and also with Fine powder type.
- Further we can make use of Advanced or Bio-Matrix materials (high density polyurethane or PEEK etc.).
- Finding of different SISAL fiber extraction processes.
- SEM and Finite Element Analysis can be carried out.
- Testing like Fatigue test, shear test, Impact test, Moisture content test and thermal test.
- Design of natural fibers extraction processing machine.

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APPENDIX

DATASHEETS

In this appendix, all the data have been collected during the laboratory specimens testing were provided.

Data collected during the laboratory Compression specimens testing

TableA1. Batch tensile strength statistical analysis data untreated

Fiber/Matrix ratio	1 (Mpa)	2 (Mpa)	3 (Mpa)	4 (Mpa)	5 (Mpa)
15/85	24	25.59	26.59	21.99	24.63
25/75	24.96	29.14	29.23	24.54	27.25
35/65	37.12	34.75	32.32	33.67	35.81

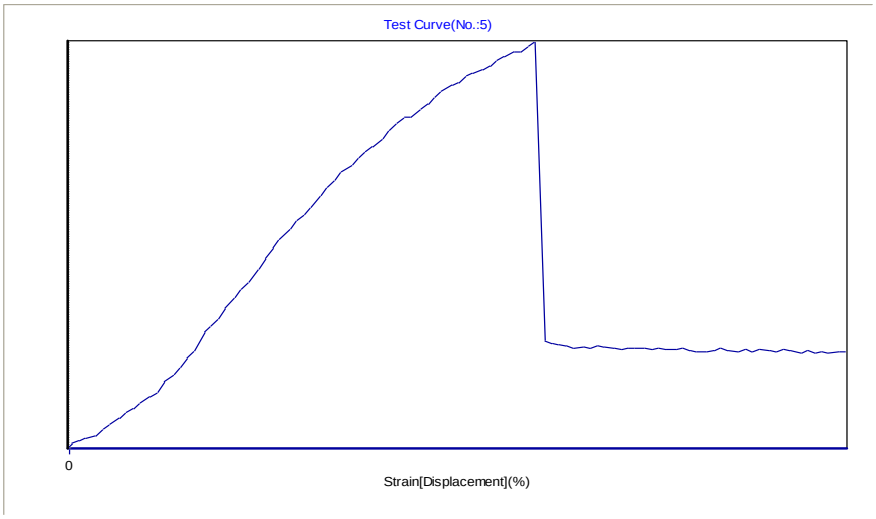
Table A2. Batch tensile strength statistical analysis data treated

Fiber/Matrix ratio	1 (Mpa)	2 (Mpa)	3 (Mpa)	4 (Mpa)	5 (Mpa)
15/85	27.52	29.6	33.55	26.40	33.34
25/75	26.83	39.93	39.87	32.92	31.17
35/65	37.08	40.11	35.61	38.67	35.49

Table A3. Batch Compressive strength statistical analysis data untreated

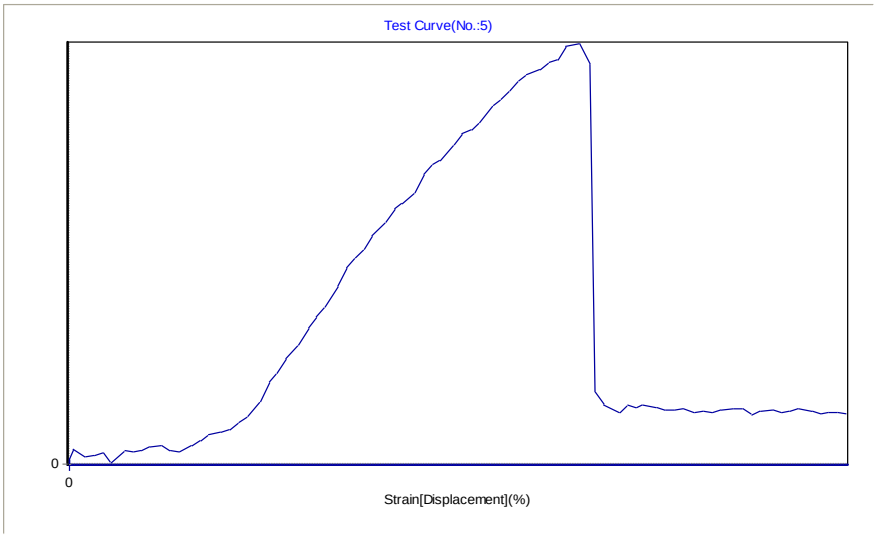
Fiber/Matrix ratio	1 (Mpa)	2 (Mpa)	3 (Mpa)	4 (Mpa)	5 (Mpa)
15/85	27.52	29.6	33.55	26.40	33.34
25/75	26.83	39.93	39.87	32.92	31.17
35/65	37.08	40.11	35.61	38.67	35.49

Figure : force vs. Strain graph for treated **ST(T) 35**



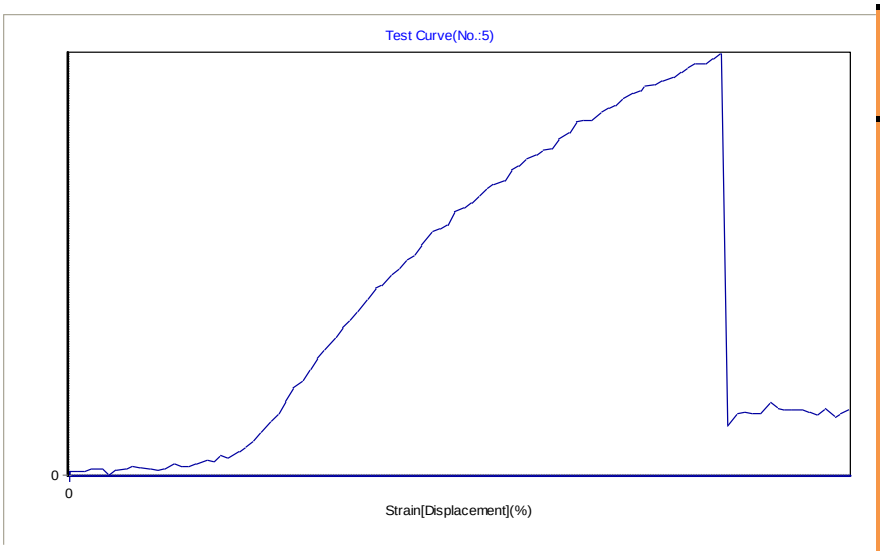
Sample No.	Fmax kN	σmax MPa
1	2.97	37.08
2	3.21	40.11
3	2.85	35.61
4	3.09	38.67
5	2.84	35.49
Average	2.99	37.39
S.D.	.159	1.994
C.V.	5.308	5.334

Figure : force vs. Strain graph for treated **ST(T) 25**



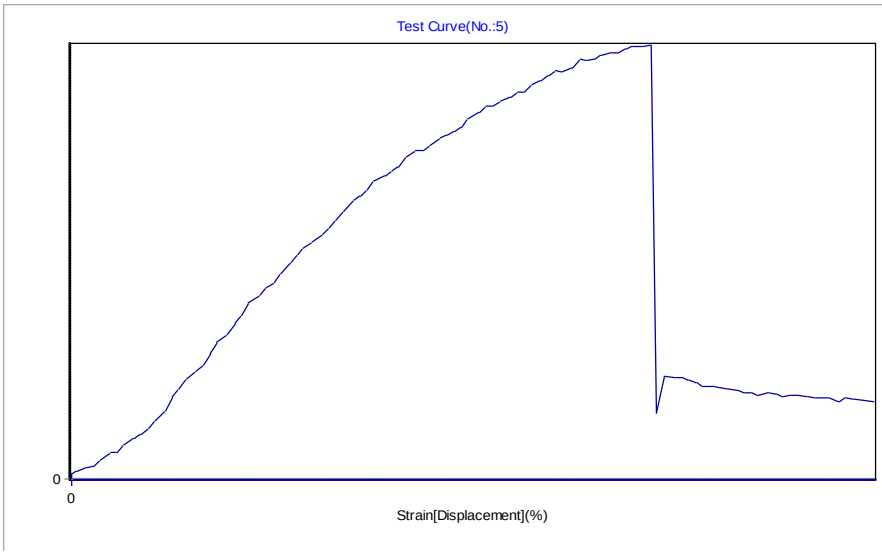
Sample No.	Fmax kN	σmax MPa
1	1.14	26.83
2	1.70	39.93
3	1.69	39.87
4	1.40	32.92
5	1.32	31.17
Average	1.45	34.14
S.D.	.243	5.703
C.V.	16.74	16.7

Force vs. Strain graph for treated **ST(T)15**



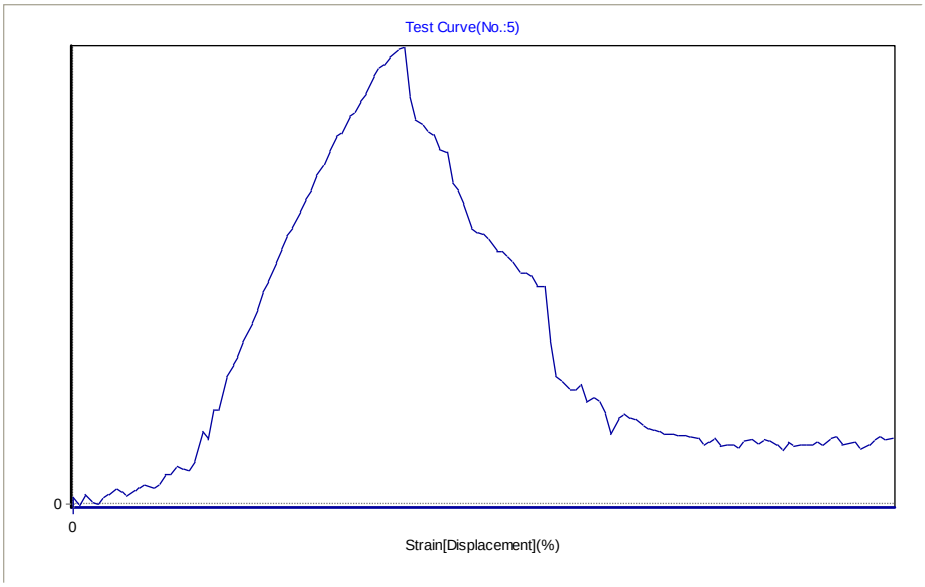
Sample No.	Fmax kN	σmax MPa
1	1.24	27.52
2	1.33	29.60
3	1.51	33.55
4	1.19	26.40
5	1.50	33.34
Average	1.35	30.08
S.D.	.147	3.279
C.V.	10.84	10.9

Force vs. Engineering Strain for untreated **SNT(T)35**



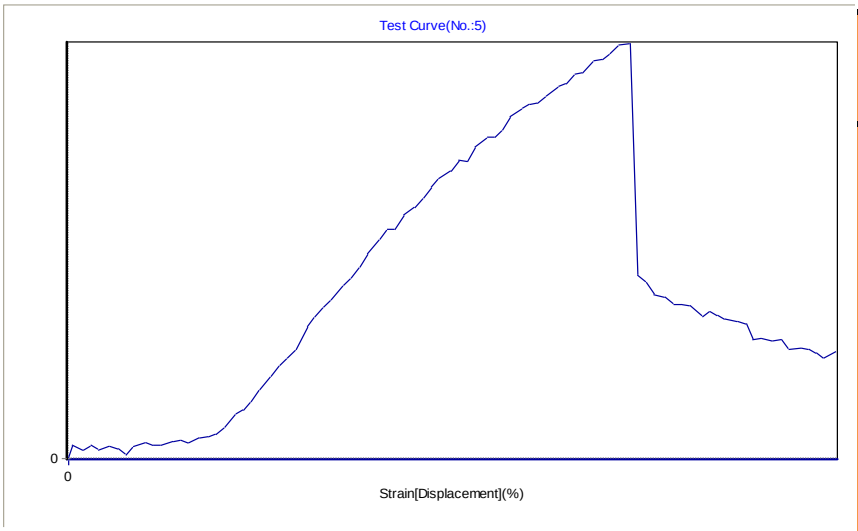
Sample No.	Fmax kN	σmax MPa
1	1.20	24.00
2	1.28	25.59
3	1.33	26.59
4	1.10	21.99
5	1.23	24.63
Average	1.23	24.56
S.D.	.087	1.74
C.V.	7.085	7.083

Force vs. Engineering Strain for untreated **SNT(T)25**



Sample No.	Fmax kN	σmax MPa
1	1.25	24.96
2	1.46	29.14
3	1.46	29.23
4	1.43	28.56
5	1.22	24.34
Average	1.36	27.25
S.D.	.119	2.394
C.V.	8.715	8.786

Force vs. Engineering Strain for untreated **SNT(T)15**



Sample No.	Fmax kN	σmax MPa
1	2.78	37.12
2	2.61	34.75
3	2.42	32.32
4	2.52	33.57
5	2.69	35.81
Average	2.6	34.71
S.D.	.141	1.873
C.V.	5.408	5.395

Data Collected during the Laboratory Compression specimens testing

Table A4 *Compressive strength testing data for* **SNT(C)-15**

Sample No.	Fmax kN	Fuy kN	Fly kN	Rmax MPa	ReH MPa	ReL MPa
1	0.06	0.05	-0.02	1.04	0.76	-0.36
2	0.56	0.48	0.47	9.28	8.04	7.88
3	0.12	0.08	-0.02	2.08	1.36	-0.32
4	0.08	0.08	0.03	1.40	1.28	0.56
Average	.21	.17	.12	3.45	2.86	1.94
S.D.	.238	.205	.238	3.911	3.464	3.983
C.V.	116.1	119.1	206.8	113.3	121.1	205.3

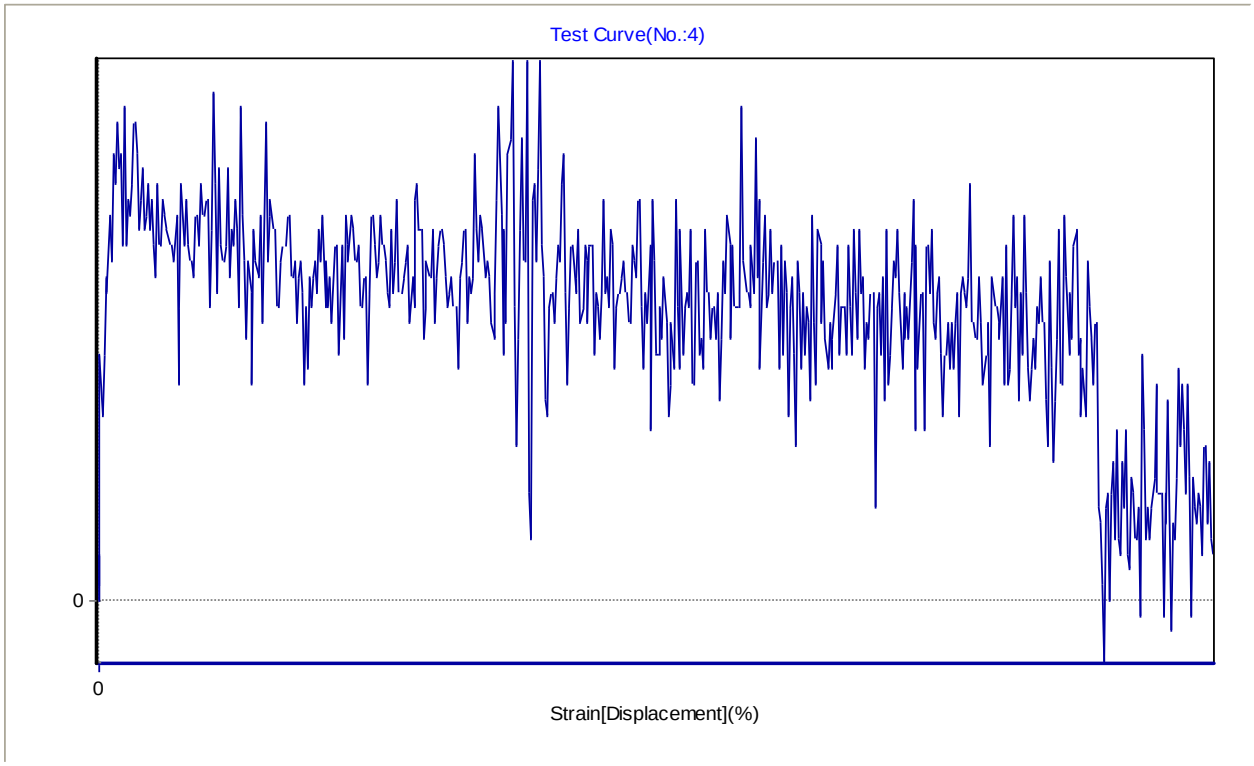


Table A5 *Compressive strength testing data for* **SNT(C)-25**

Sample No.	Fmax kN	Fuy kN	Fly kN	Rmax MPa	ReH MPa	ReL MPa
1	0.85			12.10		
2	0.04			0.62		
3	2.55	2.46	2.45	36.45	35.21	34.94
4	0.12			1.71		
5	0.25	0.14	0.08	3.63	1.99	1.13
Average	.76	1.3	1.27	10.9	18.6	18.04
S.D.	1.049	1.64	1.676	14.98	23.49	23.91
C.V.	137.6	126.2	132.5	137.4	126.3	132.6

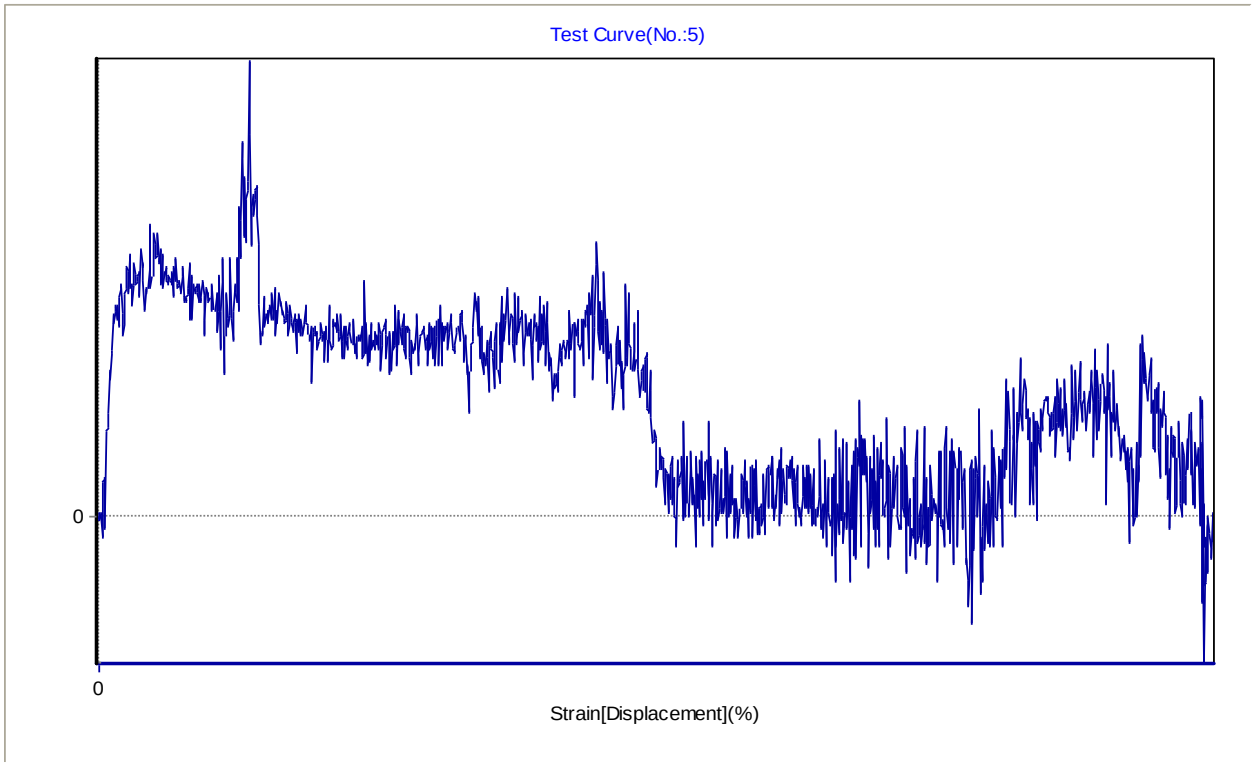


Table A6 *Compressive strength testing data for* **SNT(C)-35**

Sample No.	Fmax kN	Fuy kN	Fly kN	Rmax MPa	ReH MPa	ReL MPa
1	0.29	0.16	0.12	3.60	2.01	1.50
2	0.54	0.49	0.42	6.69	6.12	5.22
3	0.14	0.12		1.74	1.56	
4	0.28	0.22	0.12	3.54	2.73	1.50
5	0.32	0.18	0.08	3.96	2.25	0.99
Average	.31	.23	.19	3.91	2.93	2.3
S.D.	.144	.148	.158	1.78	1.83	1.96
C.V.	45.91	63.07	85.3	45.57	62.39	85.12

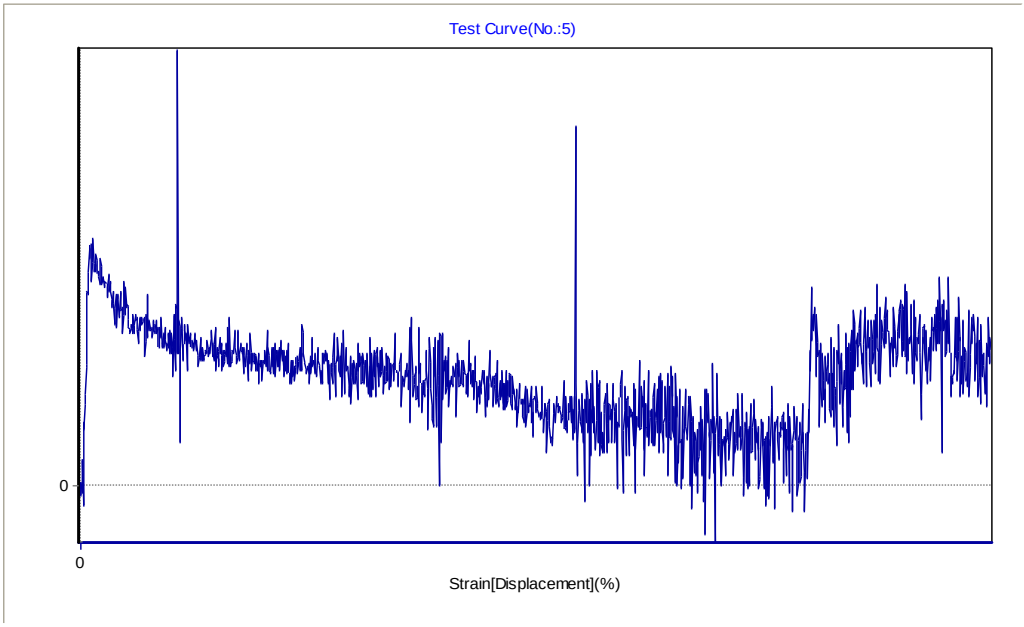


Table A7 *Compressive strength testing data for* **ST(C)-15**

Sample No.	Fmax kN	Fuy kN	Fly kN	Rmax MPa	ReH MPa	ReL MPa
1	0.37			5.91		
2	0.08			1.27		
3	0.09	0.08	-0.01	1.42	1.31	-0.12
4	0.21			3.34		
Average	.19			2.99		
S.D.	.135			2.166		
C.V.	72.13			72.56		

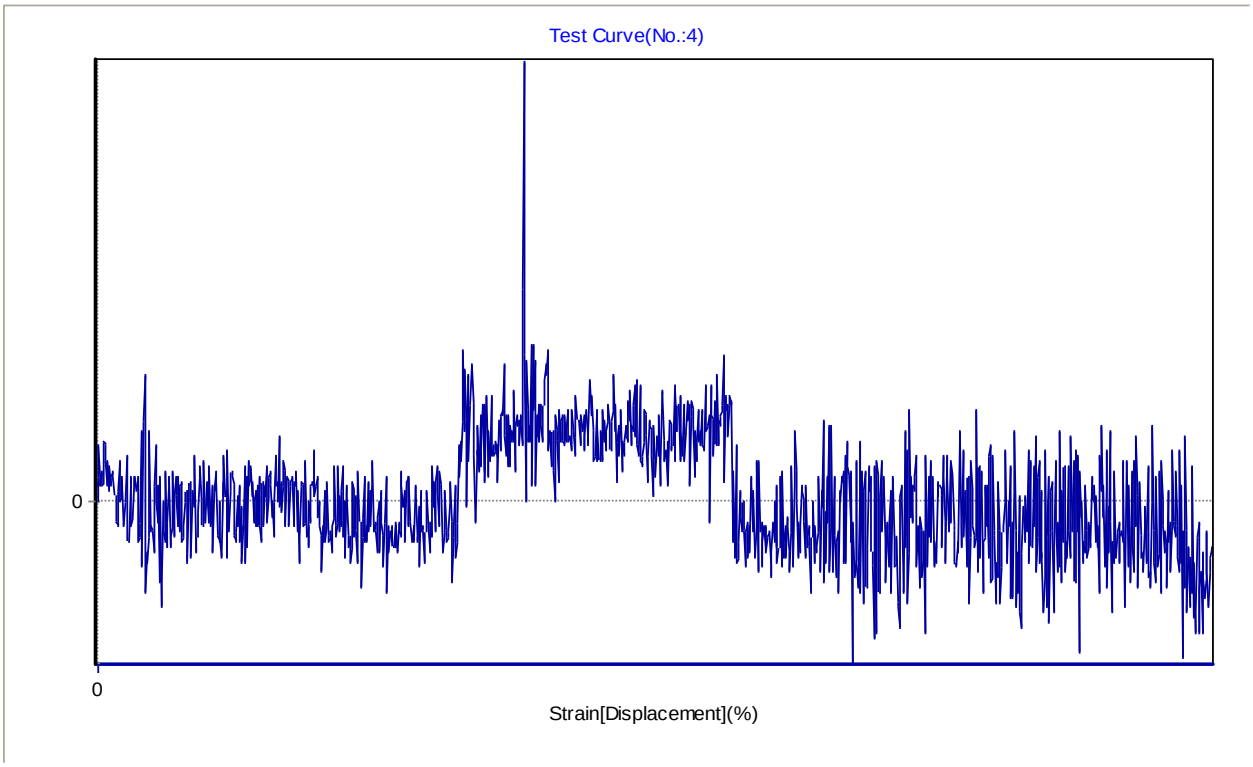


Table A8 *Compressive strength testing data for* **ST(C)-25**

Fuy kN	Fly kN	Lu mm	Rmax MPa	ReH MPa	ReL MPa
0.07			1.23	1.15	
0.09	0.02		2.50	1.50	0.35
0.08			1.34	1.31	
0.14	0.09		3.76	2.19	1.38
0.10	0.08		1.77	1.61	1.31
.1	.06		2.12	1.55	1.01
.027	.038		1.044	.398	.576
28.14	59.78		49.23	25.64	56.8

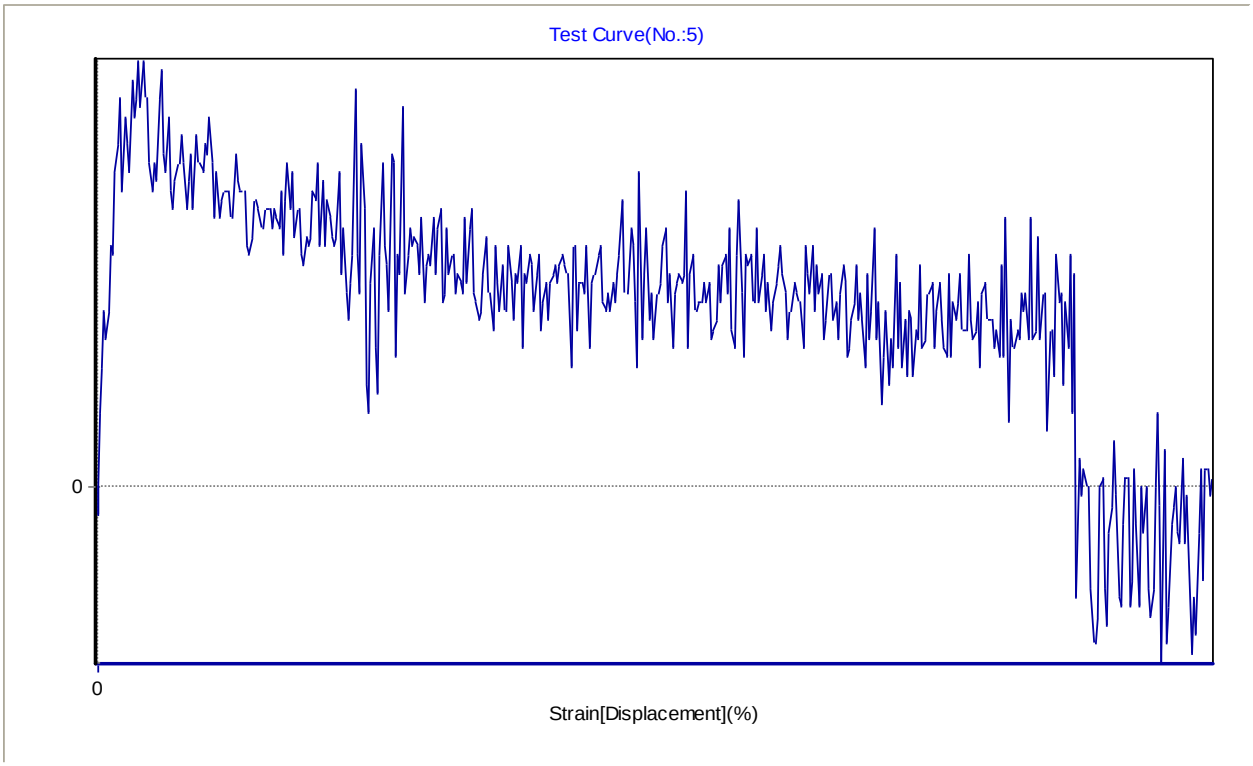
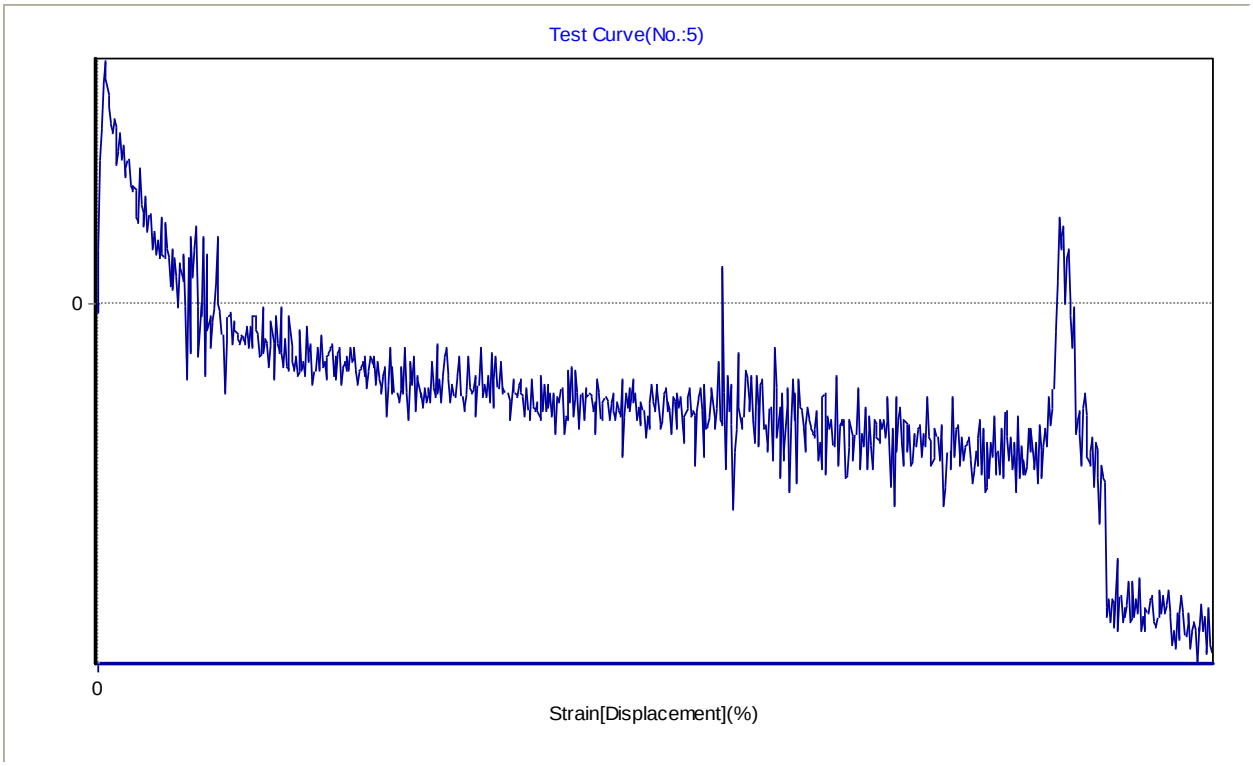


Table A9 *Compressive strength testing data for* **ST(C)-35**

Sample No.	Fmax kN	Fuy kN	Fly kN	Rmax MPa	ReH MPa	ReL MPa
1	0.21			2.76		
2	0.12			1.58		
3	0.09	0.07	-0.05	1.15	0.93	-0.62
4	0.09	0.08	-0.04	1.18	0.99	-0.46
5	0.13			1.67		
Average	.13	.08	-.05	1.67	.96	-.54
S.D.	.049	.007	.007	.653	.042	.113
C.V.	38.43	9.428	-15.713	39.16	4.419	-20.951



Data collected during the three point bend test testing

Table A10 *Flexural strength testing data for* **ST(F)-15**

Sample No.	Fmax kN	Ec mm	E GPa	Smax MPa
1	0.12	0.57	355.32	680.4
2	0.17	0.77	57.01	978.0
3	0.08	0.50	25410.30	453.6
4	0.30	0.54		1743.4
Average	.17	.6	8607.54	963.9
S.D.	.096	.12	14552	562.3
C.V.	57.13	20.19	169.1	58.34

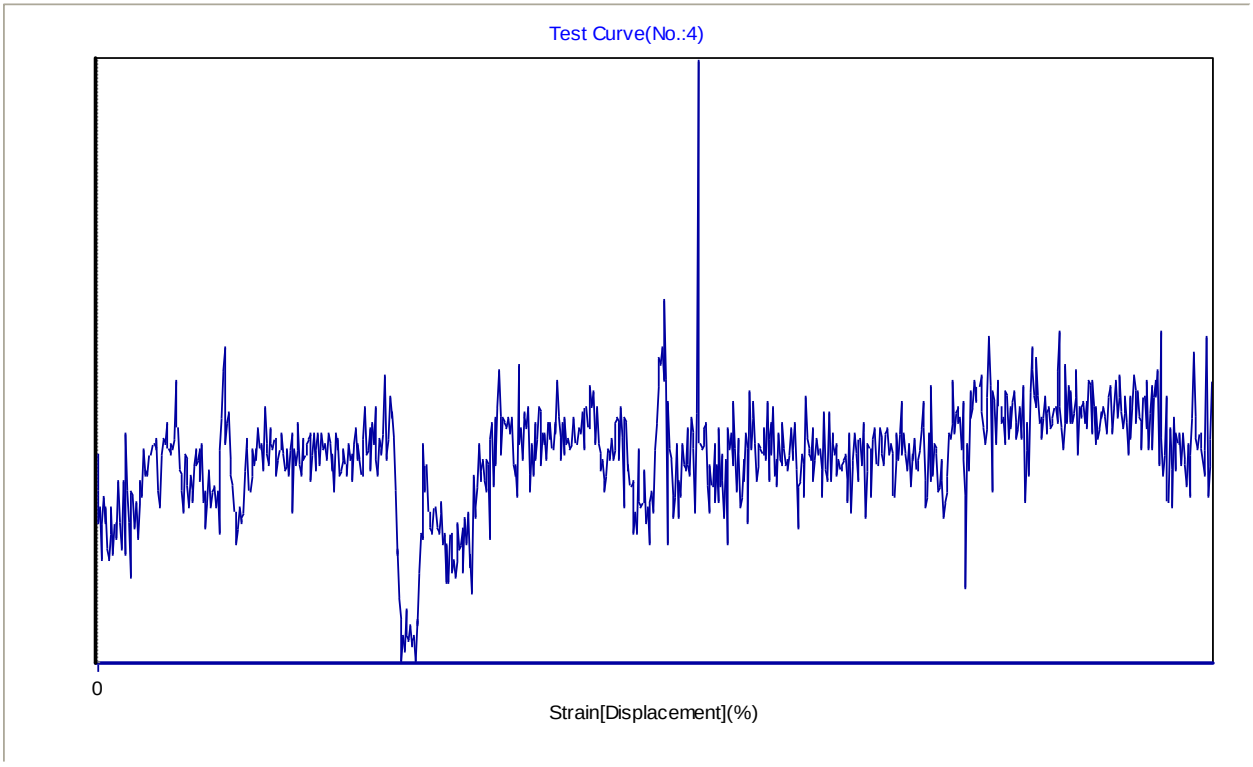


Table A11 *Flexural strength testing data for* **ST(F)-25**

Sample No.	Fmax kN	Ec mm	E GPa	Smax MPa
1	2.60	0.49		6822.5
2	0.27	0.69	272.63	699.3
3	0.08	0.48	952.98	214.2
4	0.09	0.55		239.4
5	0.09	0.69		239.4
Average	.63	.58	612.81	1643
S.D.	1.106	.104	481.1	2903
C.V.	176.7	17.92	78.5	176.7

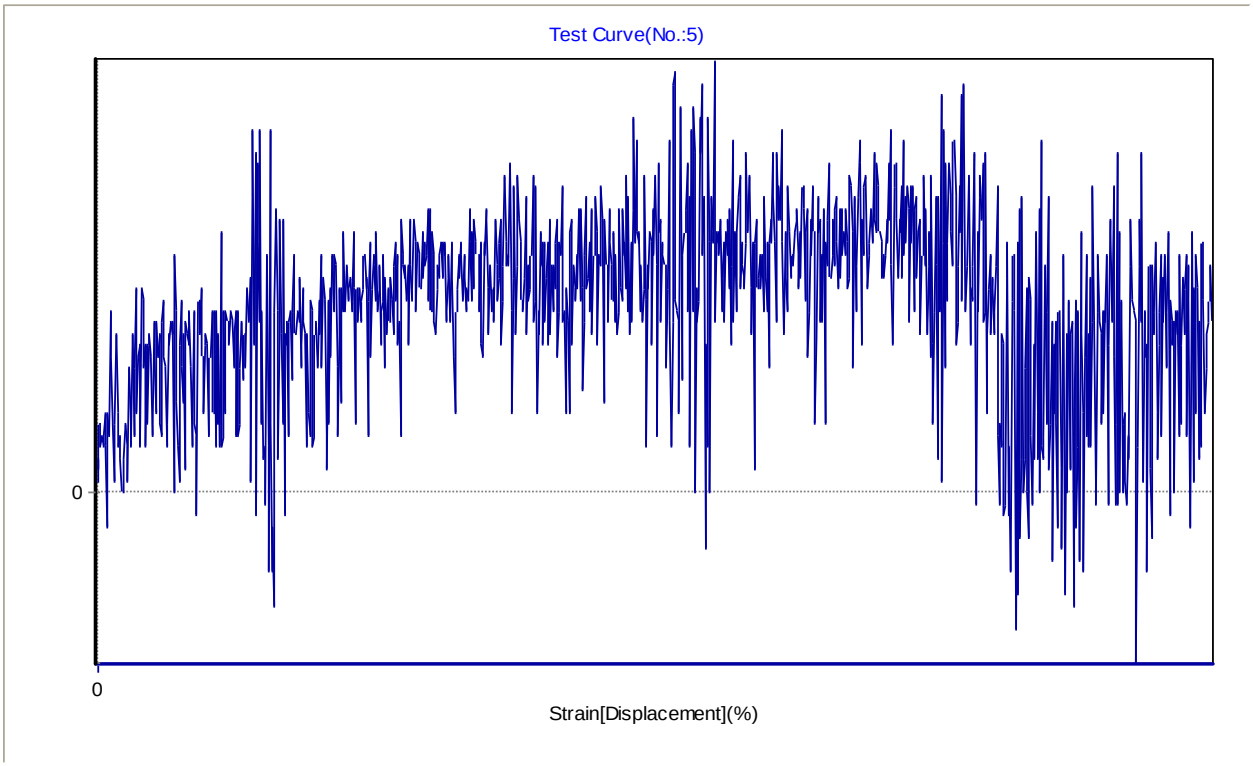


Table A12 *Flexural strength testing data for* **SNT(F)15**

Sample No.	Fmax kN	Ec mm	E GPa	Smax MPa
1	0.08	0.44		214.2
2	0.11	0.34	95569.49	277.2
3	0.09	0.28		245.7
4	0.18	0.38	457.48	466.2
5	0.18	0.38	145.18	472.5
Average	.13	.36	32057.38	335.2
S.D.	.049	.059	55003	124.5
C.V.	38.03	16.21	171.6	37.15

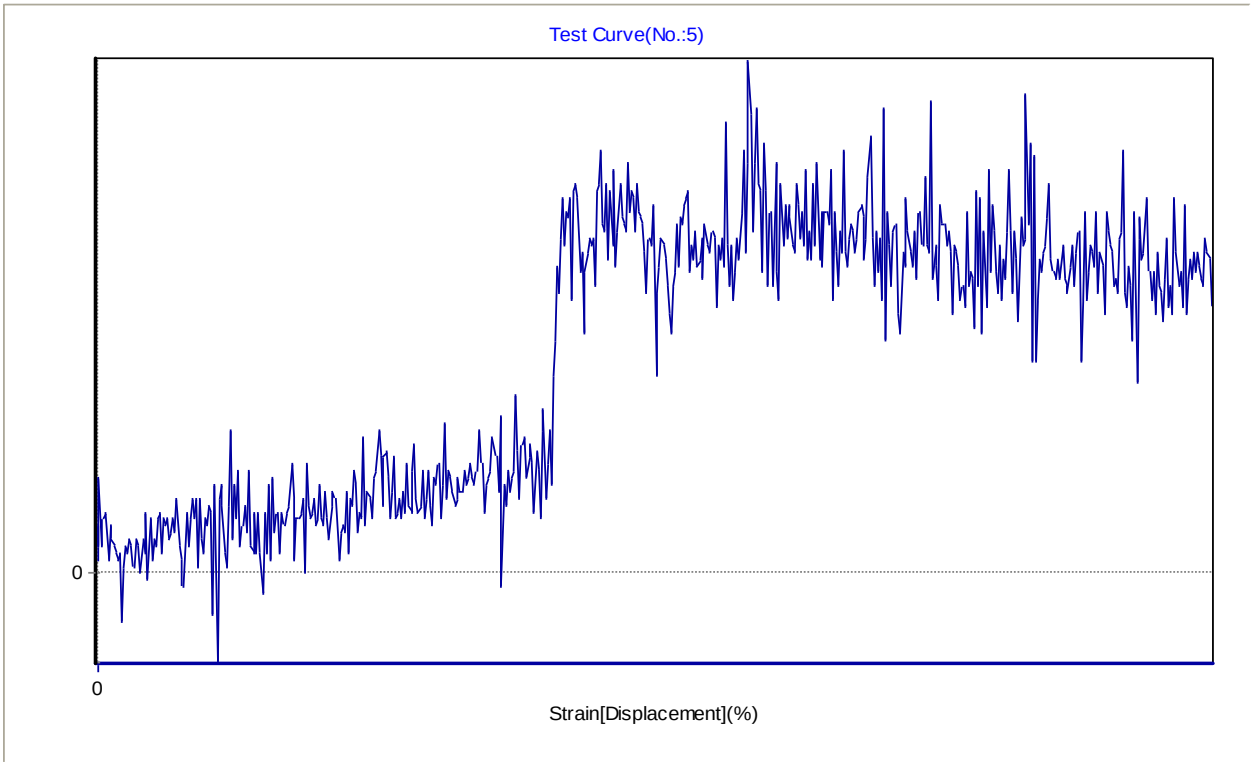


Table A13 *Flexural strength testing data for* **SNT(F)25**

Sample No.	Fmax kN	Ec mm	E GPa	Smax MPa
1	0.53	0.40	7.94	1027.5
2	0.10	0.42	111.57	185.1
3	0.07	0.48		143.5
4	0.23	0.25		448.9
5	0.05	0.33		97.2
Average	.2	.38	59.76	380.4
S.D.	.199	.088	73.28	386.6

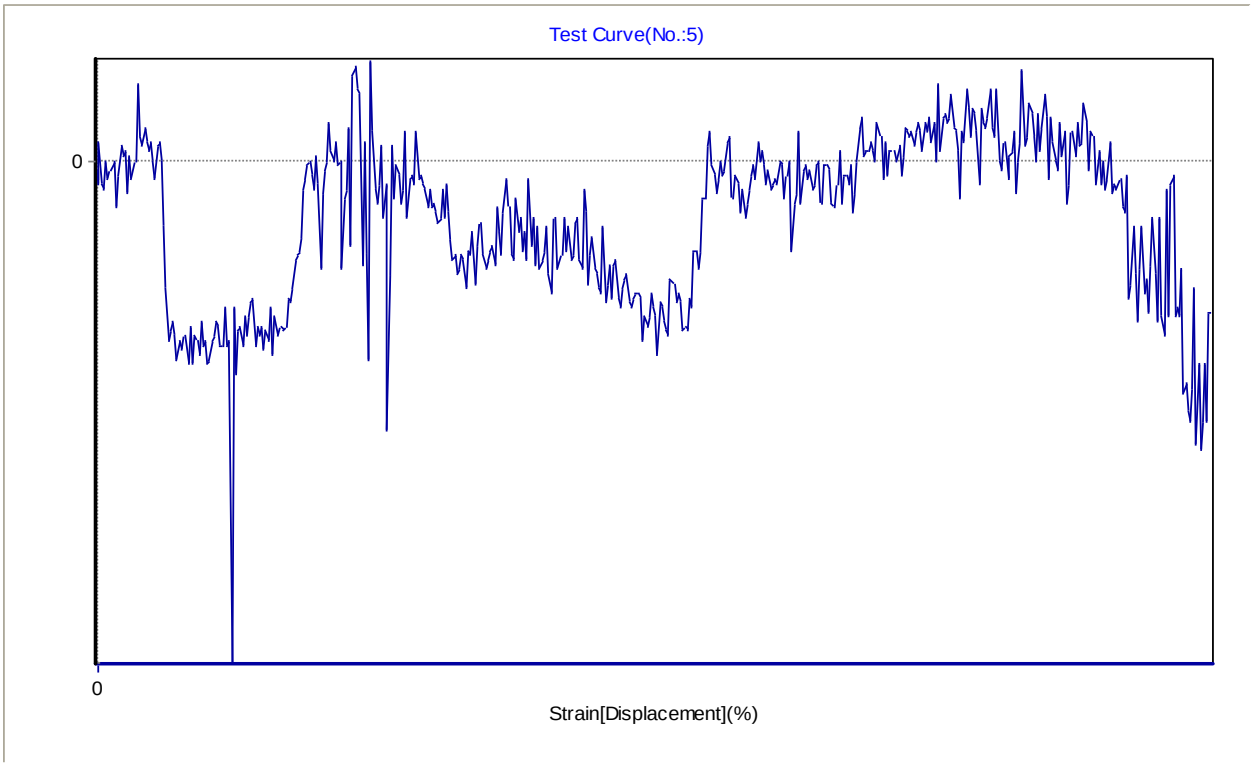
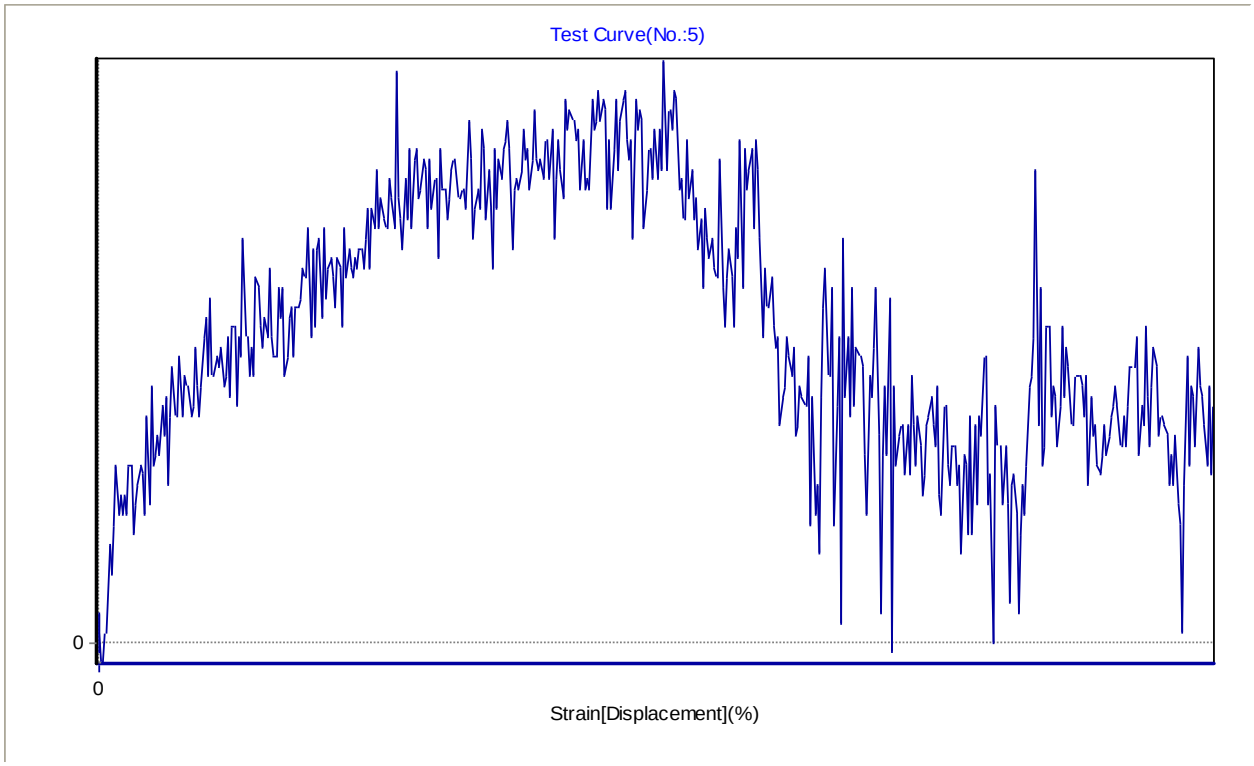


Table A14 *Flexural strength testing data for* **SNT(F)35**

Sample No.	Fmax kN	Ec mm	E GPa	Smax MPa
1	0.17	0.37	310763.00	177.1
2	0.14	0.28	280.21	148.9
3	0.24	0.34	2744.15	261.8
4	0.18	0.35	1237.71	189.9
5	0.14	0.33		151.4
Average	.17	.33	78756.27	185.8
S.D.	.041	.034	154675	45.86
C.V.	23.56	10.06	196.4	24.68



System 2000 Epoxy Resin and System 2060 hardener

Product Specifications of 2060 hardener

	2000	2020	2060	2120	ASTM Method
Color	Lt. Amber	Amber	Amber	Amber	Visual
Viscosity, @ 77° F, centipoise	1,650 cps	150-175 cps	190-200 cps	200-250 cps	D2393
Specific Gravity, gms./cc	1.15	0.96	0.96	0.95	D1475
Mix Ratio, By Wt		100 : 23 By Weight, or 4 to 1 By Volume	100 : 27 By Weight, or 3 to 1 By Volume		D2471
Pot Life, 4 fl. Oz. Mass @ 77° F		20 minutes	1 hour	2 hour	PTM&W

[Source: Fiber Glast Development Corporation, 385 Carr Drive-Brookville, Ohio 45309, USA]

Typical Mechanical Properties of system 200 Epoxy Resin with its hardener

	2000 w/ 2020	2000 with 2060				2000 w/ 2120	ASTM Method
		Neat Resin (Unreinforced)	With Fiberglass	With Carbon	With Kevlar		
Mix Ratio	100 : 27 By Weight, or 3 to 1 By Volume						PTM&W
Pot Life, @ 77° F	20 minutes	1 hour				2 hours	D2471
Color	Lt. Amber	Light Amber				Lt. Amber	Visual
Mixed Viscosity, @ 77° F, cps	950-975 cps	900 - 950 cps				925 – 975 cps	D2393
Cured Hardness, Shore D	86-88 Shore D	88 Shore D				87 Shore D	D2240
Specific Gravity, grams, cc	1.12-1.13	1.11				1.12	D1475
Density, lb./cu Inch	.0410	.0401				.0410	D792
Specific Volume, cu. in./lb.	24.4	25.0				24.4	D792
Tensile Strength, psi (1)	45,326 psi	9828 psi	45,170 psi	75,640 psi	45,400 psi	45,870 psi	D638
Elongation at Break, % (1)	1.93%	1.90%	1.96%	0.91%	1.31%	1.98%	D638
Tensile modulus, psi (1)	2,.53 x 10^6 psi	418,525 psi	2,620,000 psi	8,170,000 psi	3,770,000 psi	2,520,000 psi	D638
Flexual Strength	65,308 psi	16,827 psi	62,285 psi	96,541 psi	34,524 psi	66,667 psi	D790
Glass Transition Temp. Tg	180° F	196° F				194° F	TMA
Thermal Coef. Of Expansion Range:	3.73 x 10^{-5} in./in./° F	4.3 x 10^{-5} in./in./° F				4.15 x 10^{-5} in./in./° F	D696
Fiberglass Properties Derived with A 10 Ply Laminate, Hand Lay-up, Style 181 Glass Fabric, 55% Glass Content; Carbon Properties with a 10 Ply Laminate of 5.6 oz. 3K Fabric; and Kevlar Properties with a 10 Ply Laminate of 5 oz. Kevlar							

Table A.2: Typical Mechanical Properties of system 2000 Epoxy Resin with its hardener
[Source: Fiber Glast Development Corporation, 385 Carr Drive-Brookville, Ohio 45309, USA]