Development and Characterization of Hybrid Glass-Sisal Fiber Reinforced Polyester Composites

JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF POSTGRADUATE STUDIES

A Thesis Submitted to the Graduate Studies of Jimma University in Partial Fulfilment of the Requirement for the Degree of Master of Science in Mechanical Engineering (Manufacturing System Engineering)

By
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Approval Sheet

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DECLARATION

I hereby declare that this MSc. thesis entitled "Development and Characterization of Hybrid Glass-Sisal Fiber Reinforced Polyester Composites" is my work and this work has not been submitted elsewhere for the award of any other degree, diploma, or other requirement and all sources of material used for this thesis have been duly acknowledged. It is being submitted to the Faculty of Mechanical Engineering, Jimma Institute of Technology, in partial fulfillment of the requirement for the award of masters of sciences in Manufacturing System Engineering.

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Name of candidate	Signature	Date

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ABSTRACT

Natural fiber-reinforced polymer composite materials have high specific strength, are lightweight, non-corrosive, environmentally friendly, and low cost. Due to its attractive features, they have an involvement in some parts of the green economy. The incorporation of natural fibers with synthetic fibers hybrid composites also has enhanced economic applications.The main goal of this study is to incorporate natural fiber such as sisal and synthetic fibers (glass) to fabricate hybrid fiber composite material (HFCM) for automotive body interior panels. This HFCM was prepared by hand lay-up technique with consideration of process parameters like fiber weight ratio (30%, 35%, and 40%), fiber orientation (MMM, UMU, MUM, MRM, and RMR), and ply arrangement (SGS, GSG, and SSS). The sisal fiber surfaces were chemically treated with 10% NaOH. The treated sisal fibers and glass fibers were combined by using matrix material unsaturated polyester and the hardener (methyl ethyl ketone peroxide). Then mechanical properties such as tensile, flexural, and compressive strength and physical properties tests like water absorption and thickness swelling of prepared composite materials were conducted to characterize experimentally. From mechanical property tests, the result shows that 35% fiber weight ratio composite material with mat-mat-mat (MMM) fiber orientation and glass-sisal-glass (GSG) ply arrangement revealed the highest tensile, flexural and compressive strength when compared to other composite materials. Secondly, the physical property tests were also investigated. The results indicates that the mat-mat-mat (MMM) fiber orientation with glass-sisal-glass (GSG) ply arrangement and 30 % fiber weight fraction composite materials shows the lowest water absorption and thickness swelling characteristics. Finally, it is concluded from the results of this study the composite material prepared from the sisal-glass fiber can be used for automotive body interior panels.

***Keywords*:** Sisal fiber, Glass fiber, unsaturated polyester, Hand lay-up, mechanical properties.

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ABBREVIATION

ASTM	American Society for Testing and Materials
CM	Composite material
CMC	Ceramic matrix composite
FRCM	Fiber reinforced composite materials
GSG	Glass-Sisal-Glass
HFCM	Hybrid fiber composite material
MMC	Metal matrix composite
MEKP	Methyl ethyl ketone peroxide
METEC	Metal and Engineering Corporation
MR	Modulus of rupture
MMM	Mat-Mat-Mat
MUM	Mat-Unidirectional-Mat
MRM	Mat-Random-Mat
PLA	Polylactic acid
PP	Polypropylene
PMC	Polymer matrix composite
PE	Polyethylene
PEEK	Poly-ether-ether-ketone
PPS	Polyphenyle sulphide
PMCs	Polymeric matrix composites
RTM	Resin transfer molding

RMR	Random-Mat-Random
SSS	Sisal-Sisal-Sisal
SGS	Sisal-Glass-Sisal
SGFHC	Sisal-glass fiber hybrid composite
UTM	Universal Testing Machine
UPE	Unsaturated polyester
UMU	Unidirectional-Mat-unidirectional
UV	Ultra-violent

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The use of composite material was started with Egyptians and Mesopotamian carpenters. They have used a mixture of mud with grasses to create a strong and durable building, around 1500 B.C. [1]. The modern era of composite starts with the invention of plastic in the early 19th century that replaced metallic and timbered materials. Later in 1935, high-performance fibers like glass fibers were developed and binding with plastic polymer to get strong and rigid materials. In the 1970s the composite industry began to advance improved resins and reinforcements were developed. It can be an alternative material for many applications like transport, aerospace, civil, medical, and sports industry [2].

In the past, composites of coconut fiber/natural rubber latex were highly used by many automotive industries. However, due to its better performance newly developed synthetic fibers were substituted for cellulose fibers. For the last few years, there has been a renewed interest in using these fibers as reinforcement materials, to some extent in the plastic industry. This resurgence of interest may be attributed to the increasing cost of plastics and the environmental aspects associated with using renewable and biodegradable materials [3].

For the past three decades, researcher's and engineer's interest has been shifting from traditional monolithic materials to fiber reinforced polymer based materials due to their unique advantages of high strength to weight ratio, non-corrosive properties, and high fracture toughness. These composite materials consisted of high-strength fibers such as carbon, glass, and aramid, and low strength polymeric matrix, now have dominated the aerospace, leisure, automotive, construction, and sporting industries. Unfortunately, these fibers have serious drawbacks such as non-renew-able, non-recyclable, high energy consumption in the manufacturing process, health risks when inhaled, and nonbiodegradable. Biodegradation is the chemical breakdown of materials by the action of living organisms which leads to changes in physical properties [4].

Hybrid composite material is a mixture of two or more physically distinct and mechanically separable components, existing in two or more phases [5]. Normally, this aims at exploiting the properties of different fibers while retaining their desirable individual characteristics in the resultant product. Since time immemorial, synthetic fibers such as carbon, glass, and aramid have dominated the composite manufacturing sector because of their low cost of production and fairly good mechanical properties [6]. However, with increasing environmental concerns, studies on the possibility of replacing synthetic fibers with natural fibers for polymer composite manufacture are on the rise [7, 8].

Fiber-reinforced composite materials have been widely used in various 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 vehicles decreased but that noise and vibration are also reduced. In addition to that, composites have very high resistance to fatigue and corrosion [9]. The main issue of this study is preparing composite material from sisal-glass fiber by considering different process parameters such as fiber/matrix ratio, fiber orientation and ply arrangement, and characterizing mechanical and physical properties of the prepared composite material.

1.2 Problem statement

Presently, Ethiopia is leading to a significant change in the automotive industry in which assemblies of different models of automobiles have been conducted by Bishoftu Automotive and Locomotive Industry under Metal and Engineering Corporation (METEC) based in Bishoftu, Ethiopia. The most of car bodies, internal panels to be assembled are not manufactured here rather imported from other car manufacturing industries outside Ethiopia. But, some of the fiber composite internal panel parts are manufactured here in Ethiopia and the inputs for these industries also highly depends on imported synthetic fibers; however, these synthetic fibers can lead the company to extra expense and also cause environmental pollution during the disposal of the used composite material. Composite materials fabricated from mono fiber are also having some limitations such as limited strength. Therefore, to minimize the explained problems and reduce the weight of the automobile, composite material developed from sisal-glass fiber-reinforced is an alternative solution for the internal panels.

1.3 Motivation statement

Enhanced environmental awareness all over the world has increased a growing interest in natural fibers and their applications. Natural fiber composites are environment-friendly composites that have useable in different applications at a relatively low cost. Synthetic fiber-reinforced composites have very good specific properties, but they have main limitations such as degradability at the end of their operational life. Presently, the interest in natural fiber composites has been increased to replace synthetic fibers. Hence, in this study attempts are made to prepare sisal-glass fiber-reinforced polyester-based composites to investigate mechanical and physical properties.

1.4Objectives

1.4.1 General objective

The general objective of the study is development and hybrid glass-sisal fiber reinforced polyester composites.

1.4.2 Specific objective

- ✓ To develop glass-sisal fiber reinforced hybrid composite material by considering different process parameters such as fiber orientation, fiber weight fraction, and ply arrangement.
- ✓ To determine the effect of process parameters on the mechanical properties namely tensile strength, compressive strength, and flexural strength
- ✓ To analyze the affect of process parameters on the physical properties namely water absorption and thickness swelling
- ✓ To verify the results by comparing with the previous work

1.5 Scope of the research

The scopes of this study include developing glass-sisal fiber-reinforced composite material by considering different process parameters and experimentally investigating the mechanical properties like tensile strength, flexural strength, and compressive strength and also determining the effect of process parameters. Finally, the affect of process parameters on the physical properties of prepared composite material, namely water absorption and thickness swelling, analyzed and the results were also verified by comparing with the previous work.

1.6 Research questions

- ✓ How to develop, glass-sisal fiber reinforced hybrid composite material?
- ✓ What are the effects of process parameters (fiber orientation, fiber weight fraction, and ply arrangement) on the mechanical properties of developed material?
- ✓ How do the process parameters affect the physical properties (water absorption and thickness swelling)?
- ✓ Does the material suitable for the intended application?

1.7 Significance of the study

This study can be used to develop hybrid glass-sisal fiber-reinforced composite material with sufficient strength for automobile body, internal panel application. On the side of the community, it will be used in industries to create job vacancies for many people from fiber extraction up to manufacturing composite materials. Additionally, the industries that work in composite materials can use this research as a guide to fabricating composite materials. Researchers, teachers, and students can also use this document as teaching material and as a reference.

1.9 Thesis Organization

This thesis focuses on the fabrication of sisal-glass fiber hybrid reinforced polyester composite material and characterization of mechanical properties such as tensile strength, flexural strength, and compression strength and physical property such as water absorption and thickness swelling of prepared composite material and discussion on results. To accomplish fully the objective of this thesis, the whole studies are divided into the following five chapters.

In the ***first chapter***, the background of the study, problem statement, motivation, objectives, and scope of the thesis, research question, and significance of the study are presented in this section.

In the ***second chapter***, review of the previous work related to this work, fibers, matrix, and development of hybrid composites. Methods for fabricate composite materials and estimating their mechanical and physical properties are presented.

In the ***third chapter***, the methodology of the thesis and fabrication method to develop sisal-glass hybrid composite using polyester matrix and preparation of specimen as per ASTM standards and laboratory testing used throughout the studies are presented in detail.

In the ***fourth chapter***, discussions of results and comprises on the tensile, flexural, compression, and water absorption behavior of developed composites are discussed in detail.

In the last ***chapter five***, the conclusion of the study and recommendations for future work are presented.

CHAPTER TWO

2. LITERATURE REVIEW

Literature review reveals different previous works which help to develop enough understanding for the guidance of this work. These previous related works include journals, conference papers, and books.

2.1 Composite material

Composite material is composed of two or more distinct materials on a macro-scale with different properties to form a new material with a property that is entirely different from the individual constituents. These constituents can be reinforcing and matrix material. The reinforcing material may be fiber, particle, or layer. Its main function is supporting the load and increasing the mechanical strength of composite material, such as rigidity and flexural strength [10]. The matrix material may be polymer, ceramic, or metal. Its functions binding the reinforcement together and transfer stresses within reinforcements and fixing the material with its shape [11].

Autar K. Kaw, [12] defined 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.

Kanakaji Chittineni, [13] defined composites are a macroscopic combination of two or more distinct materials having a recognizable interface between them. Composite materials are flexible materials for multifunctional applications due to their significant properties such as high specific strength, modulus, bending stiffness, and chemical resistance.

Van Suchetclan, [14] explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can also be considered homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical properties.

Beghezan [15] presented as the composites are compound material which differs from alloy by the fact that the individual components retain their characteristics, but are so incorporated into the composites as to take advantage only of their attributes and not of their shortcoming, to obtain improved materials.

Jartiz [16] defined composite materials as it was a multifunctional material that consists of one, or more discontinuous or distributed phases embedded in a continuous phase. The discontinuous phases are usually the reinforcement with superior mechanical properties than the continuous phase is called the matrix.

Composite materials are classified based on reinforcement type and matrix type. Based on reinforcement types such as fiber-reinforced composite material and particle-reinforced composite material, whereas based on matrix type it may be polymer composite material, metal composite material, and ceramic material [16]. Based on the type of reinforcement materials, the classification is shown in Figure 2.1.

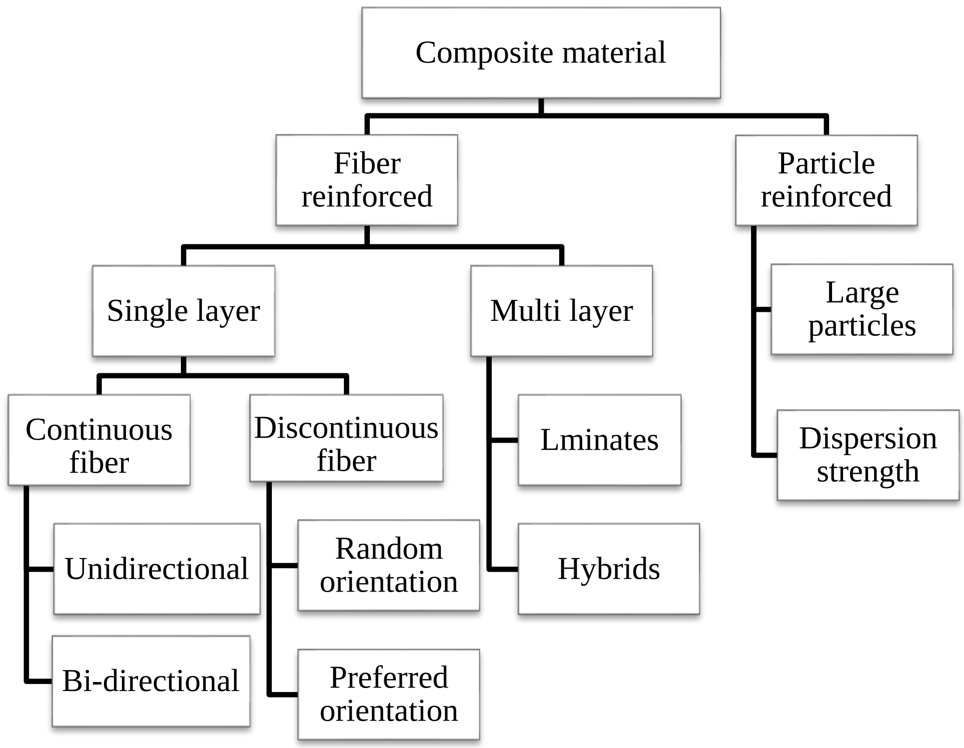


Figure 2.1 Classification of composite materials [17].

2.1.1 Reinforcement materials

Reinforcements are part of composite which provide stiffness, strength, structural endurance, good fracture resistance, and sound and shock absorbing to the composite materials. The reinforcements can be fibers (synthetic or natural fibers), particulates, or whiskers. Reinforcing fibers are found in different forms, long continuous fibers, woven fibers, and short chopped fibers. Each configuration results in different properties. The properties strongly depend on the way the fibers are laid in the composites materials [18].

Composite materials consist of fibers in the matrix structure and can be classified according to fiber length. Composites with long fiber reinforcements are termed continuous fiber reinforcement composites, while composites with short fiber reinforcements are termed discontinuous fiber-reinforced composites. Hybrid fiber-reinforced composites are those where two or more types of fibers are reinforced in a single matrix structure [18]. The reinforcement material can be either natural or synthetic fibers.

2.1.1.1 Natural fibers

Natural fibers are drawn from various parts of the plants such as leaf, stem, seed, fruitwood, and grass. Kenaf flax, hemp, and jute fibers are derived from the plant's stem. Sisal, abaca, banana, curaua, date palm, henequen, pineapple fibers are extracted from the leaves of the plants. Cotton fibers are developed using seeds, and coir kapok, oil palm, sponge gourd fibers are derived from the fruits of the plants. In the present scenario, due to growing interest in natural fibers, these fibers are extensively used in the development of composite materials for industrial applications and fundamental research [19]. The classifications of natural fibers based on their origin are shown in Figure 2.2.

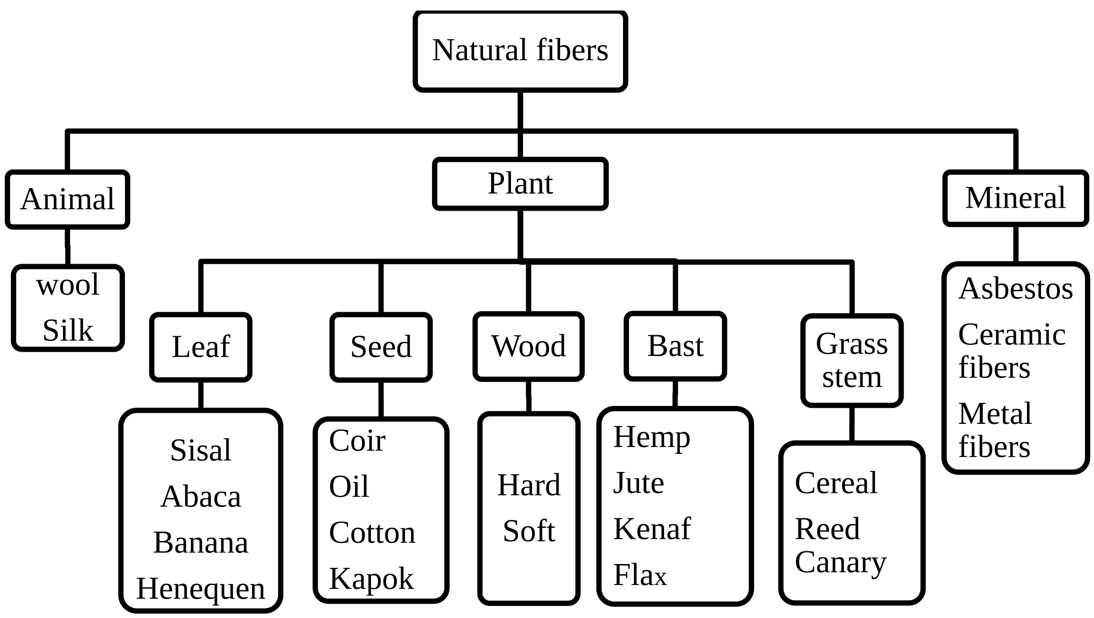


Figure2.2 Natural fibers classification according to their origin [20].

i) Sisal plant

Sisal (Scientific name is Agave sisalana) is an agave. A sisal plant is a plant that provides a stiff fiber that is used for a different type of application. The sisal plant is native to tropical and sub-tropical countries like North and South America Plant is now widely grown in tropical countries of Africa [21]. A figure of a sisal plant is shown in Figure 2.3 and sisal fibers are extracted from the leaves of the sisal plant. It has a lifespan of 7–10 years and typically produces200–250 commercially usable leaves. The stalk of the plant grows to about 90cm (3 feet) in height, with a diameter of approximately 38cm (15inches). The lance-shaped leaves, growing out from the stalk in a dense rosette, are fleshy and rigid, with a gray to dark green color. A weighing of the sisal plant leaf is about 600g will yield about 3% by weight of fiber and each leaf containing about 1000 fibers. Each leaf contains fiber bundles which are composed of 4% fiber, 0.75% cuticle, 8% dry matter, and 87.25% water [22]. The fibers are grouped among hard fibers [23].

Figure 2.3Sisal plant

ii) Sisal fiber

Sisal fiber is a kind of natural fiber and derived from the sisal plant. It is valued for cordage because of its strength, durability, ability to stretch, low price, recyclability, easy availability, and resistance to deterioration in saltwater. Scientists and engineers all over the world use sisal fiber as reinforcement to make sisal fiber reinforced polymer composites has aroused great interest in materials. Many researchers have been done in recent years, which include the study of mechanical and physical 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 instance, Rowell [24] found that sisal contains 56% cellulose, 7-9% lignin, 21-24% pentose and 0.6-1.1% ash; but Wilson [25] indicated that sisal fiber contains 78% cellulose, 8% lignin, 10% hemicelluloses, 2% waxes and about 1% ash by weight. The large variations in chemical compositions of sisal fiber are a result of its different sources, measurement methods, age, etc. Additionally, Chand and Hashmi [26] reported that the lignin and cellulose contents of sisal vary from 3.75-4.40%, and 49.62-60.95 respectively, depending on the age of the plant.

The sisal fiber is a long fiber whose length can reach up to 1.5m and thickness to 0.03m. Its size is not identical along its length. Hence, the tensile properties of sisal fibers are not uniform in the length direction [21]. The root and lower part have low tensile strength and modulus and high fracture strain. The extraction methods for extracting sisal fibers have been described by Mukherjee and Satyanarayana [27]. The method of extraction includes retting followed by scraping and mechanical means using decorticators. It is shown that the mechanical process yields about 2-4% fiber (15kg per 8hr) with good quality having a lustrous color, while the retting process yields a large number of poor quality fibers. After extraction, the fibers are washed thoroughly in plenty of distilled water to remove surplus wastes such as leaf juices and adhesive solids.

2.1.1.2 Synthetic fibers

The second form of fibers is synthetic fibers which are manufactured by men, while it is a combination of glass fiber, carbon fiber, and aramid [28]. 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 thermoset matrices and thermoplastic require natural fiber [29]. The most commonly used fiber as reinforcement is glass fiber because of its low price and is suitable for most engineering and general applications. In the present study, sisal fibers are used as natural fibers and glass fiber as synthetic in the unsaturated polyester matrix to fabricate hybrid composite. Glass fiber is commercially available in abundance and has good mechanical properties thus it is widely used in composite structures. The properties of some reinforcements (natural fibers and synthetic fibers) are presented in Table 2.1.

Table 2.1 Mechanical properties of some natural fibers and synthetic fibers [30, 31].

Fiber	*Density* ($^{g}/_{cm^3}$)	*Elongation* (%)	*Tensile strength (MPa)*	*Young's modulus (GPa)*
Sisal	1.45	2.0-2.5	349-635	35
Cotton	1.51	3.0-10	200-450	200-55
Hemp	1.48	1.6	550-900	70
Jute	1.46	1.8-3.0	400-800	10-30
Carbon	1.4	1.4-1.8	4000	230
E-glass	2.55	4.5-4.9	2500	72
Flax	1.52	1.2-5.6	800	60

2.1.2 Matrix materials

Matrix is a substance that has the role of binding the reinforcement together, which has adhesive properties. Matrixes are the continuous phase of the composite material, which has the role of binding reinforcements as its orientation and keeping the composite in its shape as designed [32, 33]. It is part of the composite material in which it surrounds the fibers and thus protects those fibers against chemical and environmental attacks. For fibers to carry the maximum load, the matrix must have a lower modulus and greater elongation than the reinforcement [13]. Based on the matrix materials used, the composite material can be divided into three types i.e. Metal Matrix Composite (MMC), Polymer Matrix Composite (PMC), and Ceramic Matrix Composite (CMC). The selection of any of the above composite materials depends upon the type of application. The most commonly used composites are polymer matrix composites. This is mainly because of their lightweight and specific properties compared to ceramics and metals matrix. Besides, polymer matrix composites can be processed at low pressure and temperature.

Polymers are materials made of long, repeating chains of molecules. The materials have unique properties, depending on the type of molecules being bonded and how they are bonded. The polymer matrix binds the fibers together to transfer the load between them and protect them from environments and handling. Polymer or resin systems are used to manufacture advanced polymer matrix composites (PMCs). There are two basic types of polymer matrixes or resins; these are thermoplastics and thermosets.

a) Thermoplastic

Thermoplastic matrices are defined as polymers that can be melted and recast almost indefinitely. They are molten when heated and harden upon cooling. However, frozen thermoplastic becomes glass-like and subject to fracture. As a result, thermoplastics are mechanically recyclable. Common thermoplastic materials are polylactic acid (PLA), polypropylene (PP), polyethylene (PE), poly-ether-ether-ketone (PEEK), and polyphenyle sulfide (PPS) [34].

b) Thermoset

The second type of thermosetting polymer, often called a thermoset polymer that is obtained by irreversibly hardening (curing) a soft, solid or viscous liquid prepolymer (resin). Curing is induced by heat or suitable radiation and may be promoted by high pressure, or by mixing with a catalyst. Thermoset matrices are found in a very low viscosity liquid state due to their chemical bonding of molecules. Due to its branched molecular chain cannot re-melt after initial curing. Thermoset resins have high thermal stability, high dimensional stability, chemical resistance and high creep properties. During composite fabrication, the liquid-state resin is converted to a hard rigid solid by chemical cross-linking during a curing process. These curing processes include heating, UV light radiation, catalyst or pressure, or a combination of these [35, 36]. Common thermoset matrices include unsaturated polyester, vinyl ester, epoxies, polyurethane, and so on [34]. Unsaturated polyester resins can be defined as a viscous liquid consisting of a linear polymeric compound. When dibasic organic acids are reacted with polyhydric alcohols, we obtain the unsaturated polyester resins, which are applied in large molding compounds, sheet molding compounds, and in the toner of laser printers. Generally, unsaturated polyester has a glassy appearance with classic advantages like good adhesion to other materials, good mechanical properties, good electrical insulating properties, good environmental and chemical resistances, etc [37]. In the present study, unsaturated polyester was used as the matrix material.

2.2 Fiber reinforced composite materials

In fiber-reinforced composites, hair-like material can be used as reinforcement in the form of filaments, thread, or textile architecture to synthesize composite material. The fibers can also be natural (plant, animal, mineral) or synthetic based on their origin. It is effective in improving the fracture resistance and shock-absorbing capability of the material [38].

Reinforced composites are popularly being used in many industrial applications because of their inherent high specific strength and stiffness. Due to their excellent structural performance, the composites are gaining potential also in tribological applications. Fiber-reinforced composites materials consist of a fiber of high strength and modulus in or bonded to a matrix with distinct interfaces between them [39]. In this form, both fibers and matrix retain their physical and chemical identities. Yet they produce a combination of properties that cannot be achieved with either of the constituents.

2.3 Mechanical and physical properties of FRCM

The mechanical properties of natural fiber-reinforced composites depend on many parameters, such as fiber strength, fiber length, and fiber orientation, in addition to the fiber-matrix interfacial bond strength.

Kaewkuk et al. [40] studied the effects of fiber weight on the mechanical properties of composite materials. It was reported that tensile strength and Young’s modulus increased as fiber content increased from 10 to 30wt%.

Padmavathi et al. [41] presented the mechanical behavior of alkali-treated with different solution concentrations (2%, 9%, 18%, 28%, and 38%) of sisal-epoxy composites of different fiber weights. The results clearly show 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, interlinear shear stress, and energy absorption) ranging between 18% and 158%.

Venkateshwaran et al. [42] reported that the mechanical performance of a hybrid composite reinforced with banana and sisal fibres in epoxy-based composites. The reported results revealed that in an increase in the mechanical properties of the composite.

Akram Khan [43] discussed the effects of fiber modification and fiber loading on the mechanical properties, morphological, and water absorption characteristics of sisal fiber/polymer composites. It can be concluded from the studies that there was an increase in mechanical properties, namely, tensile strength, Young's modulus, and elongation till 2% of alkali treatment.

Mylsamy and Rajendran [44] discussed reinforced, raw and alkali-treated chopped sisal fibers in the epoxy matrix. It is prepared 3mm, 5mm, and 7mm length raw and alkali-treated fibers. It found that the alkali-treated fiber withstood more fracture strain than the other one. Out of the three different fiber length reinforcements, alkali-treated 3mm sisal fiber reinforcement has better mechanical properties.

Betelie et al. [45] reported the maximum tensile strength and modulus were 85.5MPa and 4.5GPa respectively, observed for specimens with 30wt% fiber in a (0, 90, 90, 0) pattern. The maximum flexural strength and chord moduli were 87.1MPa and 3.6GPa, respectively which were observed in specimens with random fiber orientation and 30wt% fiber. The maximum impact strength is 24.5kJ/m2 corresponds to specimens with random fiber orientation and 40wt% fiber content.

Alwar [46] studied the properties of palm fiber, which was subjected to different types of treatment processes. 1% NaOH treatment increased the mechanical properties, whereas HCl treatment resulted in deterioration of its properties.

Kasama and Nitina [47] have connected an investigation on the effect of glass fiber hybridization on the properties of sisal fiber polypropylene composites. The obtained results showed that the incorporation of glass fiber increases the mechanical, thermal, and water resistance properties.

J. Arputhabalan et al. [48] improved the tensile strength by using chemical modification, an increase in fiber content; that time increases tensile strength, and Young's modulus of reinforced composites.

Sreekala et al. [49] have done an investigation on the performance of mechanical properties of oil palm fiber with glass fiber and used phenol-formaldehyde as resin. It was reported that maximum mechanical performance occurs at 40wt % fiber loading.

Herrera Franco and Valadez Gonzalez [50] improved the tensile, flexural, and shear properties of the short fiber laminates by using the saline treatment and matrix resin pre-impregnation process through which the tensile and flexural moduli remain unaffected.

Idicula et al. [51] done an investigation on the mechanical properties of sisal and banana fiber-reinforced polyester hybrid composites were carried out and it was reported that tensile strength 33MPa, flexural strength 70MPa, and impact strength 9 kJ/m2. The higher tensile strength was shown when both banana and sisal fibers increased the volume ratio of banana and sisal 3:1.

Braga and Magalhaes [52] have done a study on jute and glass fiber reinforced epoxy hybrid composites and have reported that the mechanical properties such as tensile, flexural, and impact properties of jute and glass hybrid fiber-reinforced composites. The results have shown that increasing the mechanical properties such as tensile, flexural and impact properties, but decrease the water absorption behavior of the resulting composite.

Kumar A et al. [53] investigated the mechanical properties of sisal and silk-fiber hybrid unsaturated polyester composites which consist of different fiber lengths. The sisal fibers were treated in 2% NaOH for 1hr. The investigation revealed that the 2cm fiber had a higher tensile property of about 24.5% higher than untreated fibers. The flexural and compressive strength were also 18.5% and 35.6% higher than untreated composites.

Athijayamani et al. [54] have prepared hybrid composite materials by adding a small amount of glass fiber to the sisal fiber and pineapple leaf fiber-reinforced polyester. The study also reported that the mechanical properties of the resulting composites improved and the water absorption tendency of prepared composites decreased because of glass-fiber hybridization.

Vikas Sahu et al. [55] studied the mechanical properties of sisal and pineapple fiber-reinforced composites with epoxy resin. The study reported that the tensile property of sisal and pineapple fiber-reinforced hybrid composite materials was higher than pine leaf fiber but lesser than the sisal fiber.

Mariotti et al. [56] have done a study on mechanical and physical properties of pandanus and banana reinforced hybrid polyester composites. The results experiments revealed pure resin composites have lesser flexural and impact strength than pandanus and banana polyester composite.

Boopalan et al. [57] have investigated the mechanical properties of jute and banana fiber-reinforced epoxy fiber composites. The study reported that the maximum flexural strength, tensile strength, and impact strength are 59.82MPa, 18.96MPa and 18.23kJ/m2. When the reinforcement was in 50/50 volumetric weight, the flexural, tensile, and impact strength was the maximum. After addition of banana fiber results in a 4.3% increase in flexural strength, 17% increase in tensile strength, and 35.5 % increase in impact strength.

Sapuan et al. [58] studied the mechanical properties of sugar-palm fiber and glass fiber hybrid reinforced unsaturated polyester composites. The study reported that the incorporation of both sugar-palm fiber and glass fiber into unsaturated polyester revealed superior enhancements in the mechanical properties.

Atiqah et al. [59] have investigated the mechanical properties of composites prepared from kenaf and glass-fiber hybrid reinforced unsaturated polyester resin (UPR) composites. The results of the experiment indicate that the highest tensile, flexural, and impact strength were obtained from treated Kenaf fibers-reinforced hybrid composites.

Ramesh et al. [60] have studied the mechanical properties of sisal fiber, jute fiber, and glass fiber fabricated composites. The results indicate that the composite fabricated from the incorporation of sisal-jute fiber with glass fiber shows improved flexural and tensile strength.

2.4 Fabrication techniques of composite materials

Composite materials can be fabricated by using different fabrication techniques. To fabricate composite with the desired specification, the selection of fabrication techniques depends on production volume, production rate, economic targets, materials availability, required skills, surface complexity, and size of the product, labor intensity, tools, and required equipment [61]. Different fabrication procedures can be used for different types of application areas. There are different fabrication techniques in the manufacturing of fiber-reinforced thermoset composites. These are

- ✓ Hand lay-up technique
- ✓ Compression molding
- ✓ Resin transfer molding (RTM)
- ✓ Injection molding

2.4.1 Hand lay-up technique

Hand lay-up technique, which is the most common and widely used open mold composite manufacturing process. Initially, fibers are placed in a mold where a thin layer of an adhesive coat is applied for easy extraction. The resin material is poured or applied using a brush on a reinforcement material. The roller is used to force the resin into the fabrics to ensure an enhanced interaction between the successive layers of the reinforcement and the matrix materials [62]. It is a very flexible process that allows the user to optimize the part by placing different types of fabric and mat materials.

This process requires less capital investment and expertise and is therefore easy to use. Composite materials for the present investigations were fabricated by using the hand layup method. In hand lay-up techniques there are four essential procedures and a typical schematic diagram for hand lay-up technique is shown in Figure 2.4.

- ✓ Mold preparation
- ✓ Demold coating
- ✓ Lay-up and
- ✓ Resin pouring and smearing

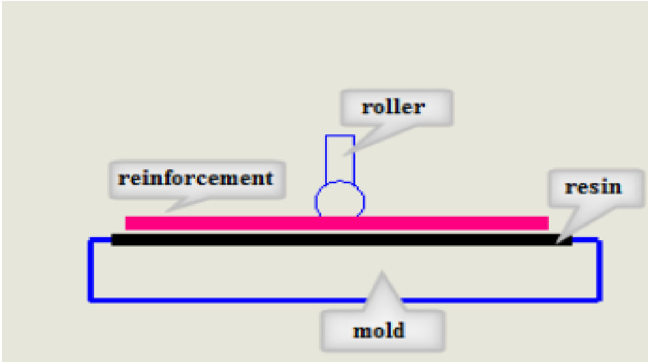


Figure 2.4 a typical schematic diagram for the hand lay-up technique [62].

2.5 Applications of FRCM

Hybrid polymer composites have been commercialized by using a wide range of applications and developments of new products. Fiber-reinforced composite materials have received much attention based on different applications because of the good properties and the advantages found over synthetic fibers. With the use of natural fibers in composites, there exist many possibilities since the number of different application possibilities is rapidly growing within many engineering fields [63]. They are highly applicable to aircraft, furniture, and construction purposes. Glass and Kenaf fiber reinforced polypropylene hybrid composites are manufactured for automotive brake levers. The design of automotive brake levers was made by the cooperation of automotive component vendors, automotive component manufacturers, and composite material experts.

Glass sugar palm fiber reinforced UPE composites are used for small boats. Boat designers work in a team comprising a designer, material experts, and boat manufacturers. Kenaf and glass-reinforced UPE resin-based hybrid composites were developed and characterized successfully for structural applications [59]. The large industrial segment uses wood fiber-reinforced polymers to manufacture door and window profiles. Other reported composites applications for natural fiber composites include flooring, walls, louvres, and outdoor and indoor furniture.

Natural fiber composites canals are very cost-effective material for application in building and construction areas (e.g. walls, ceiling, partition, window and door frames), storage devices (e.g. biogas container, post boxes, etc.), furniture (e.g. chair, table, tools, etc.), electronic devices (outer casting of mobile phones), automobile and railway coach interior parts (inner fenders and bumpers), toys and other miscellaneous applications (helmets, suitcases). It is very important to improve the strength and stiffness of these composites, as well as confront issues such as water absorption before they are used [64].

2.6 Research gap

It was observed from literature reviewed many researchers were working on the fabrication of composite material for engineering application and determine the factor that affects some mechanical properties of composite materials. But, in this study attempts are made to develop hybrid composite materials from sisal-glass fiber and unsaturated polyester resin to investigate the effect of fiber orientation, fiber weight ratio, and ply arrangement on mechanical properties like tensile, flexural, and compressive strength and physical properties (water absorption and thickness swelling) of sisal-glass fiber reinforced composite material.

CHAPTER THREE

3. MATERIALS AND METHODS

In this chapter, the explanation of raw materials, as well as tools and the research methodology for the preparation of fiber-reinforced composite materials were presented. It also covers the sample preparation and the testing procedure as well as summarizes procedures for the mechanical properties tests such as tensile, flexural, and compression tests and physical properties such as water absorption and swelling thickness tests. The general process flow chart for research methodology is shown in Figure 3.1.

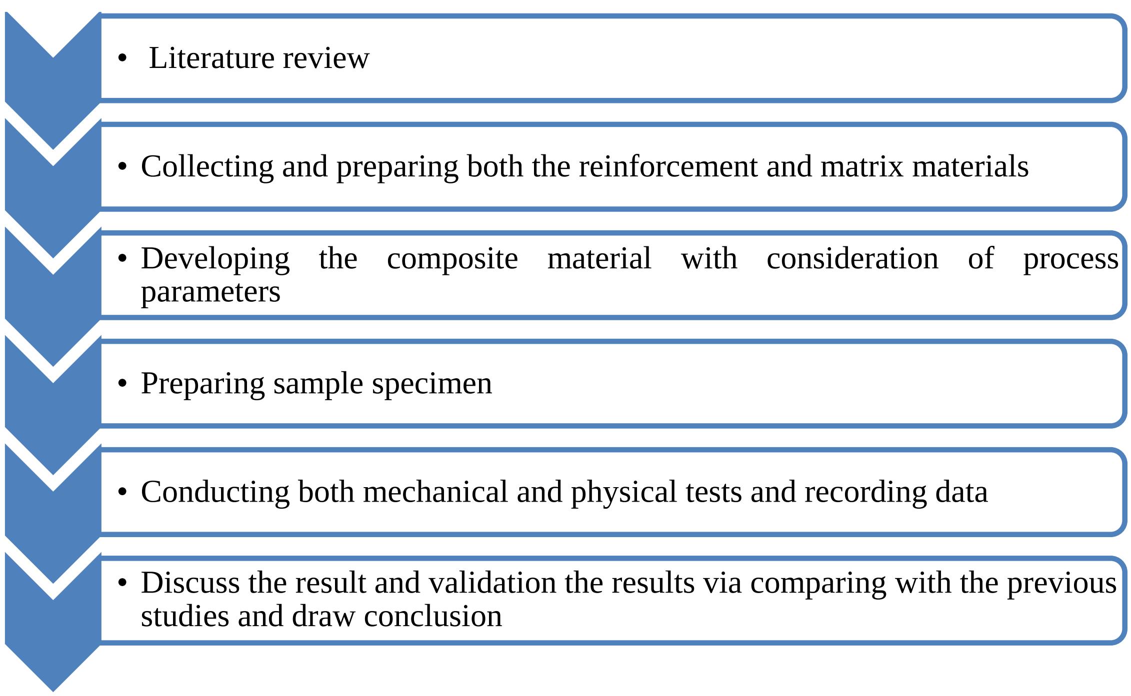


Figure3.1 Process flow charts for research methodology

3.1 Materials and Tools

3.1.1 Reinforcement material preparation

Reinforcement materials are discontinuous phases of composite materials which are a harder and load-bearing element. Its main function is supporting the load and increasing the mechanical strength of the composite material [65]. Sisal fiber and glass fiber were used as reinforcement fiber during composite preparation.

For sisal fiber, the sisal plant leaves were collected from Wolaita Sodo, an area in Ethiopia. Then fibers were extracted manually by using the sharp edges of bamboo strips. Initially, the leaves were trimmed in a longitudinal direction into strips for ease of fiber extraction. The peel is clamped between the wood plank and bamboo strip and hand-pulled through in a longitudinal direction, gently, removing the resinous material as shown in Figure 3.2. Additionally, to remove the flesh and debris from the fibers surface, the extracted fibers were washed with distilled water and sun-dried for 72 hours.

Figure 3.2 Sisal fiber extraction process a) photograph of sisal plant b) photograph of sisal fiber extraction c) photograph of extracted sisal fiber

Next to fiber extraction, the washed and dried fibers were soaked for an hour in a 10% NaOH solution. The chemical treatment by sodium hydroxide solution is used to increase the fiber surface adhesive characteristics by removing fatty impurities like lignin. Then the fibers were washed thoroughly with distilled water to remove the excess of NaOH sticking from the surface of the fibers. Finally washed fibers were dried in sunlight for 72 hours and packed to protect moisture absorption. Sisal fibers after being treated with sodium hydroxide are shown in Figure 3.3.

Figure 3.3Treated sisal fibers.

For this study, the glass fiber was purchased from the local market Addis Ababa, Ethiopia. It is the most common of all reinforcing fibers for polymeric matrix composites (PMCs). The principal advantage of glass fiber is low cost, high strength, high chemical resistance, and excellent insulating properties. The glass fiber which was used for this study is shown in Figure 3.4.

Figure 3.4Glass fiber

3.1.2 Matrix material preparation

Matrix material used for this investigation was unsaturated polyester, which was purchased from the local market in Addis Ababa, Ethiopia. It was mixed with the hardener methyl ethyl ketone peroxide (MEKP) in a proportion of 10:1 and used to cure the resin. Unsaturated polyester resin is one of the economical resins when compared to other resins, and it has very low water absorbing capability, excellent bonding tendency, good chemical, and corrosion resistance. Due to these attractive characteristics, unsaturated polyester was used.

3.1.3 Tools and Equipment’s

The basic tools and equipment’s which were used in this thesis are a universal testing machine (UTM), hydraulic pressing machine and band saw machine, and steel bowl, stirring rod, ruler, triple beam balance, digital Vernier caliper, brush, hand gloves, and goggles. Some of the tools are shown in Figure 3.5.

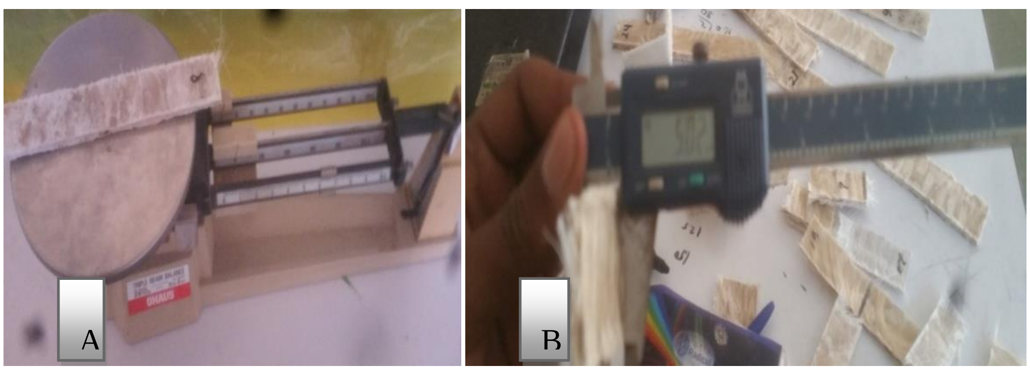


Figure 3.5 a) triple beam balance b) digital Vernier caliper

3.2 Composite development

The composite materials in this study were developed by hand lay-up technique. In this part, the mold preparation and composite preparation procedures were done respectively.

3.2.1 Mold preparation

The mold used in this work was prepared from wood with a dimension of 300mm*200mm*10mm is shown in Figure 3.6. The top, bottom surfaces of the mold and the wall side were coated with a mold releasing wax to prevent the sticking of composite to the surface of the mold. The function of top and bottom plates is to cover, compress the fiber after the unsaturated polyester is applied, and also to avoid the debris from entering into the composite parts during the curing time. A thin plastic sheet is also used between the top and bottom plates of the mold. Its function is to avoid the sticking of composite to the plate surface and to get a good surface finish.

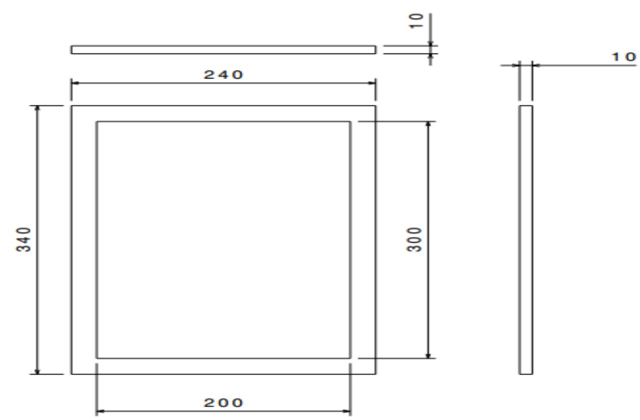


Figure 3.6 Mold

3.2.2 Composite material preparation

The composite materials were prepared by using the hand layup method. It includes the design of fiber orientation, ply arrangement, and casting of prepared composite materials. In the hand lay-up technique, the fibers were arranged in the mold by hand and the hardener mixture (10:1) was poured for every layer. After that, it was compacted with a lightweight press. For the second layer of the reinforcement, the fibers were placed on the resin surface then rolled to remove the entrapped air and to uniformly spread the mixture. The processes is repeated for all plies of the reinforcement and resin until getting the desired thick composite. The compression process was done by using the hydraulic pressing machine which is shown in Figure 3.7 by applying compression pressure of 5 MPa. Then taken out the composite material and placed outside to dry at room temperature for 72 hours. In this study, fibers were oriented in the mat, unidirectional and random continuous orientations; equal to the length of mold i.e. ~ 300 mm and the sisal-glass fiber reinforced unsaturated polyester composite samples were prepared with three different weight fractions of fiber-matrix 30/70, 35/65, and 40/60 respectively for all batch of stacking sequences (SGS, GSG, and SSS) of composite materials.

Figure 3.7Hydraulic pressing machines in Federal TVET Institute.

3.2.2.1 Prepared composite materials

The required sisal-glass-fiber-reinforced hybrid composite materials were developed with a different type of fiber orientation, ply arrangement, and fiber weight ratio as presented in Table 3.1. A weight fraction of the fibers and matrix is calculated by using Equation 3.1 [17].

$$\%W_f = \frac{W_f}{(W_{f+W_m})} * 100, \quad \%W_m = \frac{W_m}{(W_{f+W_m})} * 100 \ (3.1)$$

Where,

W_f - Fiber Wight fraction (%)

W_m-Matrix weight fraction (%)

W_m- Weight of matrix (gm)

W_f - Weight of fiber (gm)

Designation of laminates was done as per the fiber weight ratio, fiber orientation, and stacking sequence as presented in Table 3.1. Twenty-seven laminates were fabricated by using sisal and glass fibers along with unsaturated polyester matrix materials. These laminates were differentiated based on fiber weight percentages (30%, 35%, 40%) of glass and sisal fiber, fiber orientation (mat, unidirectional and continuous random), and stacking sequences such as (sisal-glass-sisal, glass-sisal-glass, and sisal-sisal-sisal).

Table 3.1 Designed sisal-glass fiber reinforced hybrid polyester composite materials

Laminates	*Orientation*	*Ply Arrangement*	*Sisal fiber weight ratio, (%)*	*Glass fiber weight ratio, (%)*	*Fiber weight ratio, (%)*	*Matrix (%)*
L_1	MMM	SGS	22.8	7.2	30	70
L_2	MMM	GSG	11.22	18.79	30	70
L_3	MMM	SSS	30	-	30	70
L_4	MMM	SGS	26.8	8.3	35	65
L_5	MMM	GSG	15.58	19.42	35	65
L_6	MMM	SSS	35	-	35	65
L_7	MMM	SGS	33.47	6.86	40	60
L_8	MMM	GSG	22.74	17.56	40	60
L_9	MMM	SSS	40	-	40	60

L_{10}	UMU	SGS	22.8	7.2	30	70
L_{11}	MUM	GSG	11.22	18.79	30	70
L_{12}	UMU	SSS	30	-	30	70
L_{13}	UMU	SGS	26.8	8.3	35	65
L_{14}	MUM	GSG	15.58	19.42	35	65
L_{15}	UMU	SSS	35	-	35	65
L_{16}	UMU	SGS	33.47	6.86	40	60
L_{17}	MUM	GSG	22.74	17.56	40	60
L_{18}	UMU	SSS	40	-	40	60
L_{19}	RMR	SGS	22.8	7.2	30	70
L_{20}	MRM	GSG	11.22	18.79	30	70
L_{21}	RMR	SSS	30	-	30	70
L_{22}	RMR	SGS	26.8	8.3	35	65
L_{23}	MRM	GSG	15.58	19.42	35	65
L_{24}	RMR	SSS	35	-	35	65
L_{25}	RMR	SGS	33.47	6.86	40	60
L_{26}	MRM	GSG	22.74	17.56	40	60
L_{27}	RMR	SSS	40	-	40	60

Typical prepared sisal-glass fiber reinforced composites shown in Figure 3.8.

Figure 3.8Prepared composite materials

3.3 Experimental procedure and setups

After preparing the composite material, the next step is specimen preparation and followed by laboratory testing and recording the data.

3.3.1 Specimen preparation

The sisal-glass fiber-reinforced composite materials were prepared with a dimension of length 300 mm width 200 mm. It was cut by using an electrical band saw machine to standard specimen dimensions.

a) Specimen preparation for tensile test

The specimens for a tensile test cut by using a band saw cutting machine and their dimensions are according to the ASTM standard D3039 for each designed composite material. In this study, a total number of about 27 specimens with dimension of 250mm*25mm were prepared for tensile test and prepared are specimens shown in Figure 3.9.

Figure 3.9 Prepared specimens for tensile test

b) Specimen preparation for flexural test

The specimens for a flexural test cut by using a band saw cutting machine and their dimensions are according to the ASTM standard ASTM D790. In this research, a total of about 27 specimens with dimension of 127mm*12.7mm were prepared for the flexural test, and prepared specimens are shown in Figure 3.10.

Figure 3.10 prepared specimen for flexural test

c) Specimen preparation for compression test

The specimens for compression test were cut using a band saw cutting machine and their dimensions are according to the ASTM standard ASTM D3410. For the compression test also, a total of about 27 specimens were prepared and the prepared specimen is shown in Figure 3.11.

Figure 3.11 Prepared specimens for compression test

d) Specimen preparation for water absorption test

Specimen for water absorption test were cut using an electrical saw cutting machine and the dimensions of the specimens are according to the ASTM standard ASTM D570. Table 3.2 show that the summery of the standard specimen preparation for different test.

Table 3.2 ASTM standards used for testing

No.	Tests	ASTM standards
1	Tensile test	D3039
2	Flexural test	D790
3	Compression test	D3410
4	Water absorption test	D570

3.3.2 Specimen testing procedures

After preparing the specimen in the desired dimension based on the respective standards, the mechanical and physical properties tests were conducted. The procedure for each test is explained as follows.

3.3.2.1 Tensile strength test

The tensile test was conducted according to the ASTM D3039 standard by using UTM, which is found in Defense University (Mechanical testing laboratory) Bishoftu, Ethiopia. Tensile strength indicates the ability of a composite material to withstand forces that pull it apart as well as the capability of the material to stretch before failure. During the test, the specimens were placed in the grips of the UTM and an axial load was applied through both ends of the specimen. The test was conducted at a crosshead speed of 5 mm/min and carried out at room temperature. A typical specimen under the tensile strength test is shown in Figure 3.12.

Figure 3.12 Typical specimens under tensile test

3.3.2.2 Flexural strength test

The flexural test was performed on the same tensile testing machine in accordance with ASTM D790 standards. The specimen hooked on the grip, then applies the load with a central grip that is fixed at the center of the specimen. When the specimen starts bending, the onboard computer generates the required data and graphs. The test tests materials' ability to withstand bending forces applied perpendicular to their longitudinal axis. It was conducted at a crosshead speed of 5 mm/min and carried out at room temperature. A typical specimen under the flexural strength test is shown in Figure 3.13.

Figure 3.13 Typical specimens under flexural test

3.3.2.3 Compressive strength test

The compressive strength test was carried out based on the ASTM D3410 standard by using UTM. The test was conducted to investigate the compressive strength of the developed composite material. It tells us the load-carrying capability of the material. The samples were placed between the compression anvils to start compression testing. It was conducted with a crosshead speed of 5 mm/min and carried out at room temperature. A typical specimen under the compressive strength test is shown in Figure 3.14.

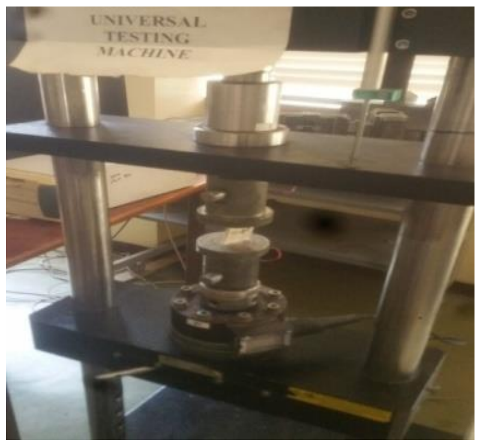


Figure 3.14 Typical specimens under compressive test

3.3.2.4 Water absorption test

A water absorption test was conducted by ASTM D570 standard. The test was carried out to determine the capability of the water absorption of prepared composite material. For this test 9 specimens were prepared with a dimension of 28mm length * 30 mm width for each factor. After preparing, the specimens were dried for a specified time and then placed to cool. The weights of the dry specimens were recorded immediately. Then the cooled material was immersed in distilled water at room temperature for 24 hours. Finally, the specimens were taken out of the water, patted dry with a dry cloth, and weighed.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

In this section, the results of the mechanical and physical tests were presented. The tests were conducted as per ASTM standards and the results were reported and discussed.

4.1Tensile strength test results

The tensile property result of developed composite materials for different fiber weight ratios, fiber orientation, and ply arrangement were presented below with tabulated form and graph interpretation.

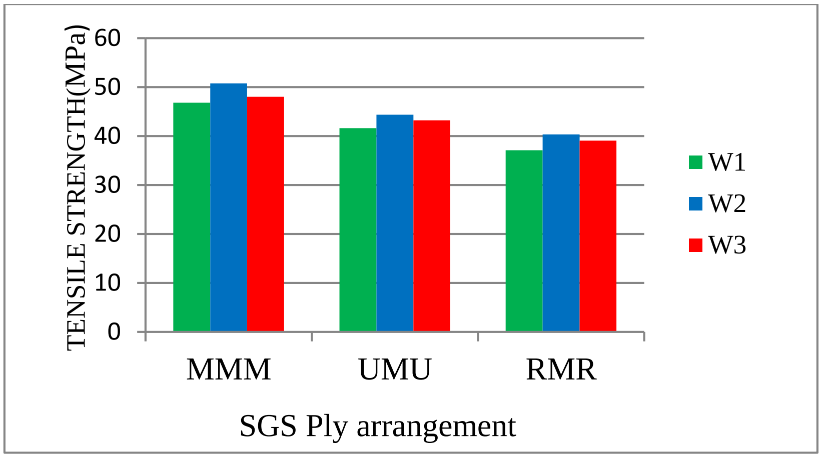
The fiber orientations which were used in this investigation are mat, unidirectional and random fiber orientations. These orientations are grouped into five levels. These are MMM, UMU, MUM, RMR, and MRM. M stands for mat or woven fiber orientation; R stands for random fiber orientation, and U stands for unidirectional longitudinal fiber orientations.

Ply arrangement is lying of respective ply in the sandwich form of HFCM. These arrangements are grouped into three forms such as Sisal-Glass-Sisal (SGS), Glass-Sisal-Glass (GSG), and Sisal-Sisal-Sisal (SSS). Whereas, the fiber matrix weight ratios for this study were 30%, 35%, and 40% of the fiber in the prepared composite and the remaining were a matrix. Further, the tensile test characteristics of the laminates are presented in Table 4.1. Similarly, to analyze the tensile characteristics of each composite laminate the tensile strength graphs are plotted in Figure 4.1.

Table 4.1 Tensile properties of the prepared composite materials

Laminates	*Fiber weight ratio, %*	*Orientation*	*Ply arrangement*	*Tensile strength (MPa)*	*Max. force (KN)*	*Young's modulus (MPa)*

L_1	30	MMM	SGS	46.82	2.23	159.091
L_2	30	MMM	GSG	92.53	5.05	351.195
L_3	30	MMM	SSS	30.87	2.11	130.3
L_4	35	MMM	SGS	50.76	2.82	188.761
L_5	35	MMM	GSG	98.26	5.67	279.853
L_6	35	MMM	SSS	32.32	2.01	142.857
L_7	40	MMM	SGS	48.04	2.31	207.552
L_8	40	MMM	GSG	94.68	5.15	264.232
L_9	40	MMM	SSS	27.28	1.94	101.804
L_{10}	30	UMU	SGS	41.61	2.15	168.79
L_{11}	30	MUM	GSG	79.2	4.01	180.469
L_{12}	30	UMU	SSS	20.52	1.32	94.1504
L_{13}	35	UMU	SGS	44.36	3.32	187.056
L_{14}	35	MUM	GSG	85.76	4.47	253.76
L_{15}	35	UMU	SSS	28.96	1.75	105.28
L_{16}	40	UMU	SGS	43.23	3.33	151.678
L_{17}	40	MUM	GSG	81.04	4.13	195.581
L_{18}	40	UMU	SSS	22.64	2.13	112.727
L_{19}	30	RMR	SGS	37.11	2.15	138.924
L_{20}	30	MRM	GSG	70.68	3.96	154.615
L_{21}	30	RMR	SSS	18.16	1.63	83.2
L_{22}	35	RMR	SGS	40.34	2.22	130.484
L_{23}	35	MRM	GSG	75.41	4.28	252.754
L_{24}	35	RMR	SSS	24.21	2.03	135.294
L_{25}	40	RMR	SGS	39.07	2.39	162.876
L_{26}	40	MRM	GSG	72.56	3.13	137.5
L_{27}	40	RMR	SSS	15.64	1.33	50.4655



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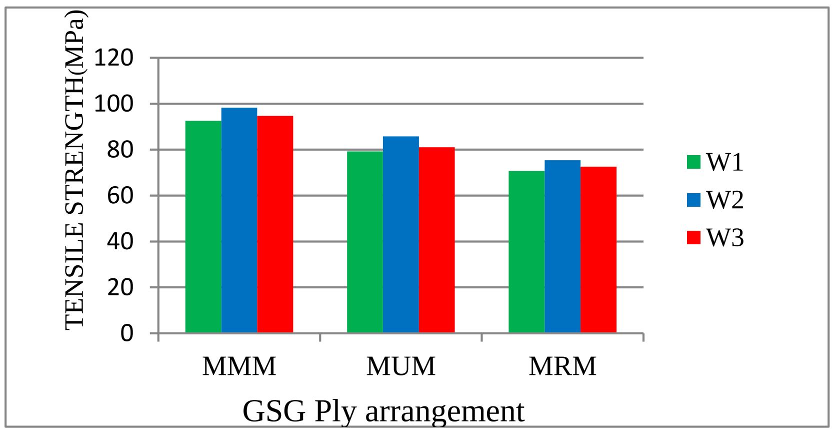

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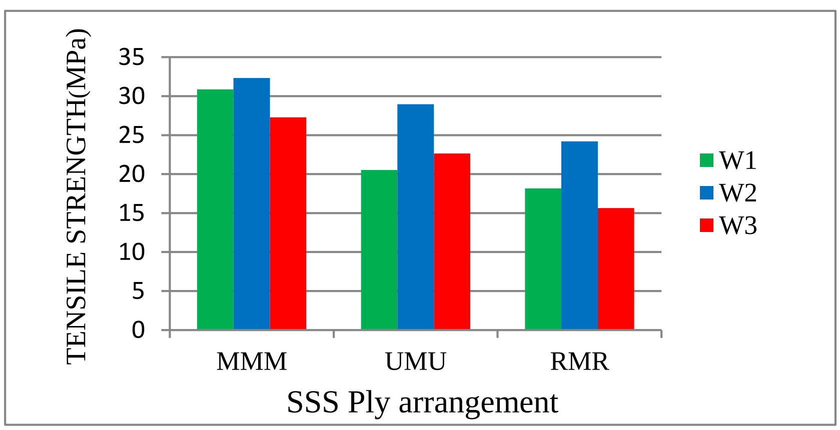


C)

Figure 4.1 Tensile strength of different laminates a) tensile strength for SGS ply arrangement b) tensile strength for GSG ply arrangement c) tensile strength for SSS ply arrangement

The tensile strength of prepared composite laminates for different fiber orientations, stacking sequences, and fiber weight ratio is shown in Figure 4.1. It is observed that the mat or woven fiber orientation with glass-sisal-glass (GSG) ply arrangement and 35% fiber weight ratio composite material reveals the highest tensile strength as compared to other composite laminates. It is revealed from the experiment that an enhancement in the tensile strength may be due to better adhesion, and uniform dispersion of the fibers in the matrix.

It is noticed that the RMR fiber orientation with SSS ply arrangement and 40% fiber weight fraction composite material shows the lowest tensile strength. It may be due to the presence of pores interface between the fiber and the matrix, and the interfacial adhesion between fiber and matrix may be too weak to transfer the load.

Figure 4.1 data implies that the tensile properties of prepared composite materials are affected by both ply arrangement and fiber orientation. HFCM with Glass-Sisal-Glass (GSG) ply arrangement shows preferable tensile strength than Sisal-Glass-Sisal (SGS) and Sisal-Sisal-Sisal (SSS) ply arrangements. Since in the case of GSG ply arrangement, more glass fiber lamina were used than SGS and SSS ply arrangement. Additionally, it reveals concentrating glass fiber in the composite gives better tensile strength than concentrating sisal fiber.

The experiment data shows fiber weight ratio also affects the tensile strength of the composite material. When the fiber ratio is increased from 30% to 35%, it shows increases in tensile strength up to a certain limit. It reveals that further addition of more fiber in composite causes a decreases in tensile strength; it may be due to poor interfacial adhesion between fiber and matrix.

To get the maximum tensile strength of the composite, the fiber weight ratio should be proportional. The GSFRC with 35% fiber weight concentration has higher tensile strength than the other fiber weight concentrations. In this case, the fiber-matrix interaction is excellent to withstand the applied load because the matrix may impregnate the fiber appropriately.

4.2Flexural strength test result

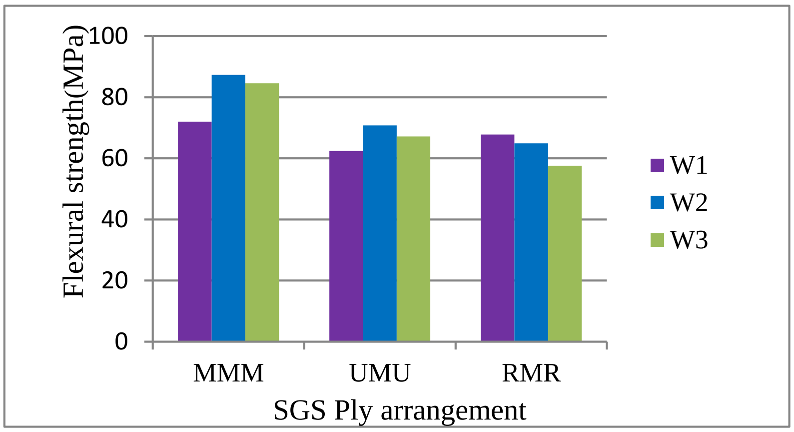
The flexural strength of all prepared composite materials for different fiber weight ratio, fiber orientation, and ply arrangements is presented in Table 4.2. The test was carried out in a UTM.

Table 4.2 Flexural properties of the prepared composite materials

Laminates	*Fiber weight ratio, %*	*Orientation*	*Ply arrangement*	*Max. force,(N)*	*Flexural strength(MPa)*
L_1	30	MMM	SGS	120	72
L_2	30	MMM	GSG	170	102
L_3	30	MMM	SSS	90	54
L_4	35	MMM	SGS	146	87.6
L_5	35	MMM	GSG	260	156
L_6	35	MMM	SSS	94	56.4
L_7	40	MMM	SGS	141	84.6
L_8	40	MMM	GSG	200	120
L_9	40	MMM	SSS	70	42
L_{10}	30	UMU	SGS	104	62.4
L_{11}	30	MUM	GSG	165	99
L_{12}	30	UMU	SSS	87.2	52.32
L_{13}	35	UMU	SGS	118	70.8
L_{14}	35	MUM	GSG	182	109.2
L_{15}	35	UMU	SSS	100	60
L_{16}	40	UMU	SGS	112	67.2
L_{17}	40	MUM	GSG	160	96

L_{18}	40	UMU	SSS	89	53.4
L_{19}	30	RMR	SGS	113	67.8
L_{20}	30	MRM	GSG	132	79.2
L_{21}	30	RMR	SSS	65	39
L_{22}	35	RMR	SGS	108	64.9
L_{23}	35	MRM	GSG	145	87
L_{24}	35	RMR	SSS	69	41.4
L_{25}	40	RMR	SGS	96	57.6
L_{26}	40	MRM	GSG	121	72.6
L_{27}	40	RMR	SSS	67.5	40.5

A)



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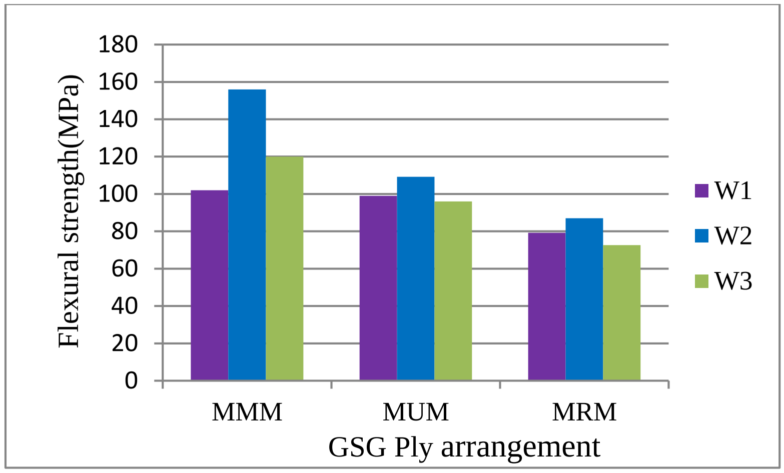

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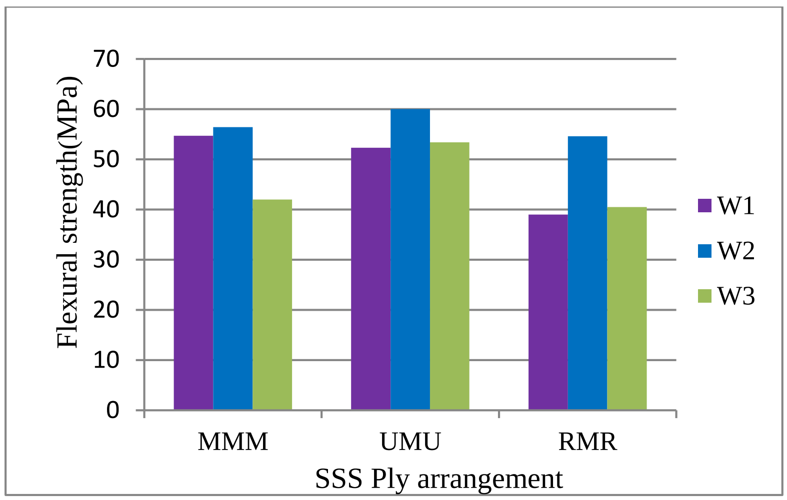


Figure 4.2 Flexural strength of different laminates a) flexural strength for SGS ply arrangement b) flexural strength for GSG ply arrangement c) flexural strength for SSS ply arrangement.

The flexural strength of prepared composite laminates for different fiber weight ratio, stacking sequences and fiber orientation is shown in Figure 4.2. It is observed that the mat-mat-mat (MMM) fiber orientation with glass-sisal-glass (GSG) ply arrangement and 35% fiber weight fraction composite material reveals the highest flexural strength. This may be due to better adhesion between fiber and matrix interfaces to a uniform load transfer.

It is observed that the lowest value of flexural strength is found on RMR fiber orientation with Sisal-Sisal-Sisal (SSS) ply arrangement composite material than other composite materials. The reason may be that the laminates are exposed to poor adhesion between the fiber and matrix interface.

Figure 4.2 data implies that the flexural properties of prepared composite materials are affected by varying stacking sequences. SGFHC with Glass-Sisal-Glass (GSG) ply arrangement shows preferable flexural strength than Sisal-Glass-Sisal (SGS) and Sisal-Sisal-Sisal (SSS) ply arrangements. Since in the GSG ply arrangement more glass fiber lamina were used than SGS and SSS ply arrangement. The data obtained from the experiment investigation shows that concentrating glass fiber in the composite gives better flexural strength than concentrating sisal fiber in HFCM.

The result shows, when the fiber weight ratio increases, the flexural strength of the composite also increases up to a certain limit. However, further addition of sisal fibers in the composite causes decreases the flexural strength. The possible reason may be that the fibers are not fully impregnated in the matrix or poor interaction of the lamina in the sandwich model.

4.3 Compression strength test result

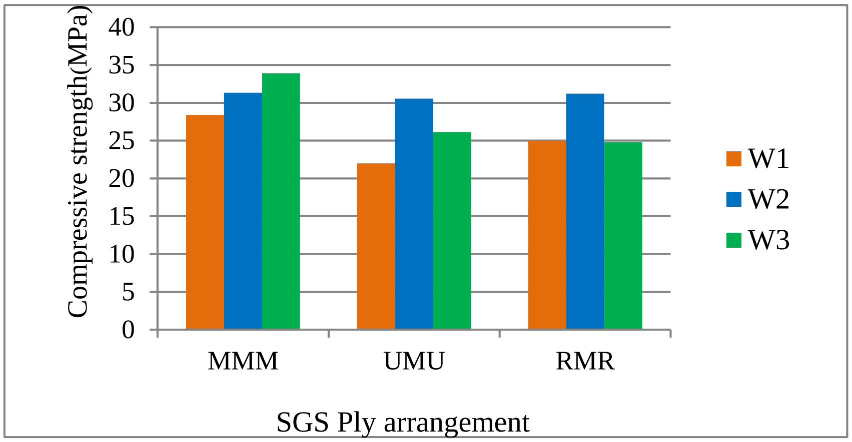
The compressive strength of prepared composite materials for different fiber weight ratio, fiber orientations, and ply arrangements is presented in Table 4.3. The test was carried out in a UTM.

Table 4.3 Compression properties of the prepared composite materials

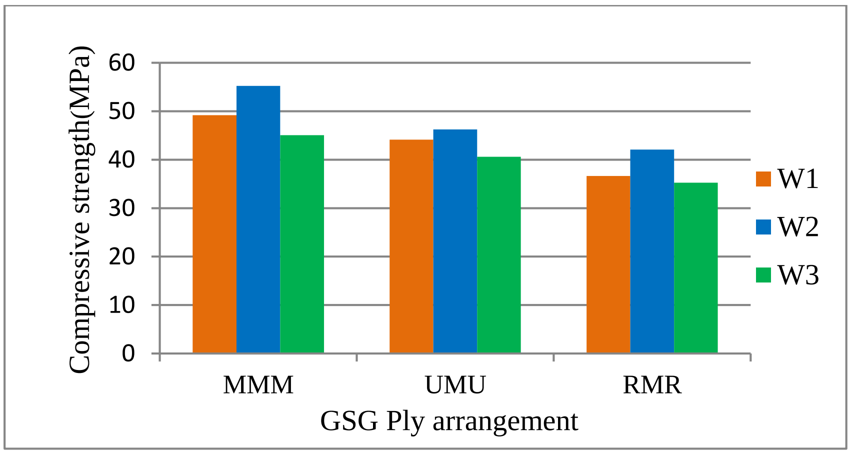
Laminates	*Fiber weight ratio, %*	*Orientation*	*Ply arrangement*	*Max. compressive strength (MPa)*	*Max. force (KN)*
$\boldsymbol{L_1}$	30	MMM	SGS	28.4	2.19
$\boldsymbol{L_2}$	30	MMM	GSG	49.2	3.31

L_3	30	MMM	SSS	16	1.21
L_4	35	MMM	SGS	31.34	2.35
L_5	35	MMM	GSG	55.32	4.37
L_6	35	MMM	SSS	17.2	1.4
L_7	40	MMM	SGS	33.91	1.57
L_8	40	MMM	GSG	45.06	3.38
L_9	40	MMM	SSS	15.03	1.13
L_{10}	30	UMU	SGS	22	1.65
L_{11}	30	MUM	GSG	44.14	3.31
L_{12}	30	UMU	SSS	14.66	1.1
L_{13}	35	UMU	SGS	30.56	1.9
L_{14}	35	MUM	GSG	46.26	3.7
L_{15}	35	UMU	SSS	12.94	0.89
L_{16}	40	UMU	SGS	26.14	1.96
L_{17}	40	MUM	GSG	40.6	3.1
L_{18}	40	UMU	SSS	13.46	1.01
L_{19}	30	RMR	SGS	25	1.95
L_{20}	30	MRM	GSG	36.64	2.7
L_{21}	30	RMR	SSS	12.54	1.3
L_{22}	35	RMR	SGS	31.2	2.3
L_{23}	35	MRM	GSG	42.1	3.14
L_{24}	35	RMR	SSS	11.68	0.81
L_{25}	40	RMR	SGS	24.8	1.86
L_{26}	40	MRM	GSG	35.26	2.63
L_{27}	40	RMR	SSS	10.42	0.82

A)



B)



C)

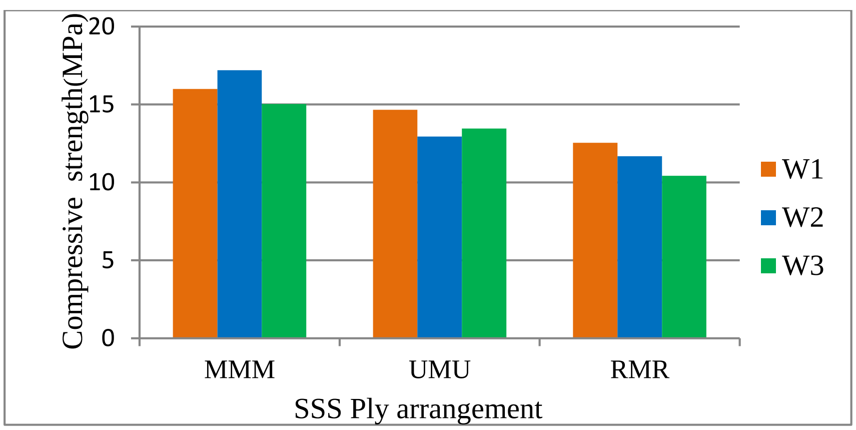


Figure 4.3 Compressive strength of different laminates a) compressive strength for SGS ply arrangement b) compressive strength for GSG ply arrangement c) compressive strength for SSS ply arrangement.

The variation in compressive strength for various stacking sequences is shown in Figure 4.3. It is noticed that the MMM fiber orientation with glass-sisal-glass (GSG) ply arrangement and 35% fiber weight ratio composite material shows the highest compressive strength as compared to other composite materials.

It is observed that the lowest values of compressive strength are recorded on RMR fiber orientation of sisal composite with sisal-sisal-sisal (SSS) ply arrangement and 40% fiber weight fraction composite material than other composite materials.

The Figure 4.3 data implies that the compression properties of prepared composite materials are affected by varying stacking sequences. The prepared composite with a glass-sisal-glass (GSG) ply arrangement shows preferable compressive strength than sisal-glass-sisal (SGS) and sisal-sisal-sisal (SSS) ply arrangements.

It is noticed from Figure 4.3 that the compressive strength was better in the GSG ply arrangement than SGS and SSS ply arrangement. It may be because more glass fiber was found in GSG ply arrangement than SGS and SSS ply arrangement. This implies that the stiffness of glass fiber is higher than that of sisal fiber. Therefore, the higher glass fiber percentage in the composite can improve the compressive strength of the material.

4.4 Water absorption test

The main advantage of this test is to determine the moisture absorption capability of the prepared composite material. The percentage of moisture absorption of prepared composite laminates for time duration of 24 hr. is presented in Figure 4.4. The moisture content is calculated by using the equation [77].

$$\%W = \frac{W_{f-w_i}}{w_i} \times 100 (4.1)$$

Where,
%W-represents percentage of water absorption

W_f-represents final weight of specimen after specified time

W_i-represents initial weight dry samples before immersion

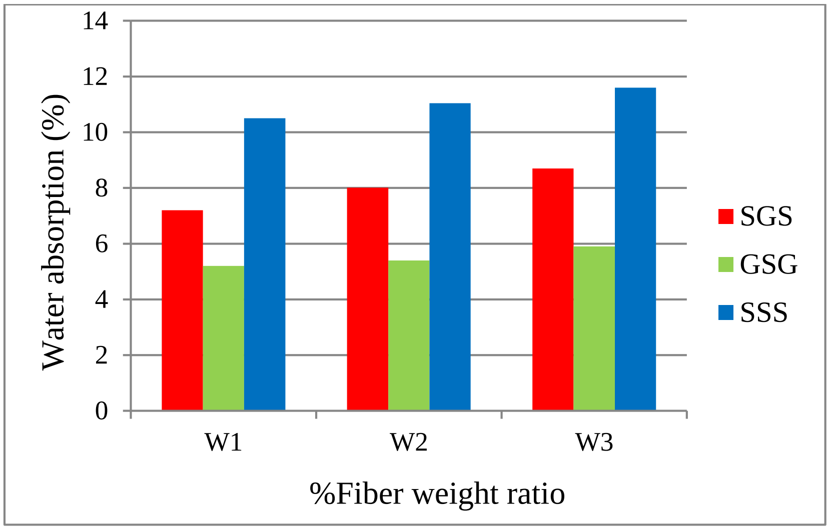


Figure 4.4 Water absorption behaviors of composite laminates with MMM fiber orientation.

It is observed from Figure 4.4 the MMM fiber orientation with glass-sisal-glass (GSG) ply arrangement and 30% fiber weight fraction composite laminates shows the lowest water absorption. This may be due to the minimum moisture absorption characteristics of glass fiber. It is noticed from the experiment investigation that composite laminates prepared with glass fiber in the outer layer do not absorb more amount of moisture.

It is noticed that, the highest amount of water absorption recorded for SSS ply arrangement with 40% fiber weight fraction composite materials. This is due to the hydrophilic nature of sisal fibers and the presence of lumens in its cellular structure, which act as voids. Additionally, it is observed from the figure that the composite with (SGS) ply arrangement shows an intermediate water uptake due to the presence of glass layers between two sisal ply.

4.5 Thickness swelling test

The thickness swelling characteristic of prepared composite materials for different ply arrangement, MMM fiber orientation with different fiber weight ratio is presented in Figure 4.5.

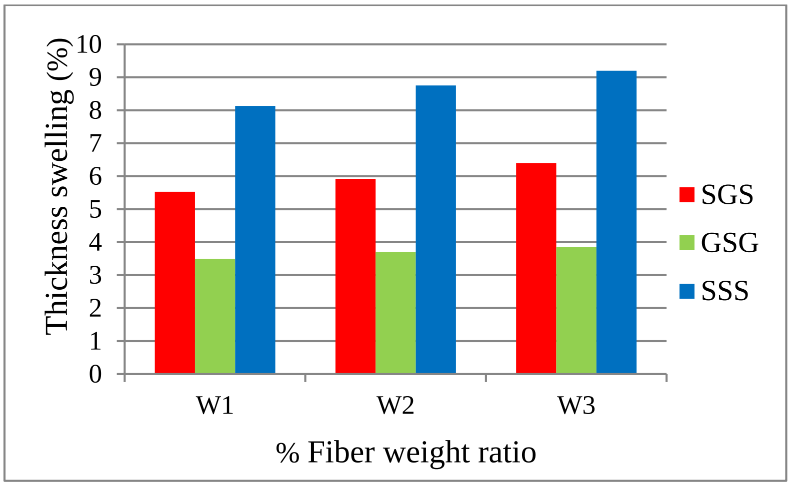


Figure 4.5 Thickness swelling behavior of composite laminates with MMM fiber orientation.

It is observed from figure 4.5 that, the hybrid composite with (GSG) ply arrangement and 30% fiber weight fraction composite laminates shows the lowest water uptake. Due to minimum amount of water absorption, the swell in thickness is also very low.

It is noticed that sisal fiber-reinforced composite material with 40% fiber weight fraction and SSS ply arrangement shows the highest swelling thickness. Due to the maximum amount of water absorption, the swell in thickness is also very high.

4.6 Comparison with previous works

4.6.1 Tensile Strength

The tensile property of the current study is compared with some of the other previous researcher's studies. From Table 4.4 the tensile strength obtained from the current work is higher when compared to [72] work, and the current work clearly shows that hybrid synthetic fibers with natural fibers and fiber orientation have a significant effect on the tensile strength of materials. It can be concluded that the results obtained from the current work are good.

Table 4.4 Comparison of tensile properties reported in this work with previous works.

Fiber	*Matrix*	*Fiber orientation*	*Fiber/ matrix ratio*	*Method of fabrication*	*Tensile strength (MPa)*	*References*
Glass/Sisal	UPR	Mat form	35/65	Hand layup	98.26	Current work
Sisal/Coir	Epoxy	Unidirectional for sisal random coir	40/60	Hand layup	57	[66]
Jute	Epoxy	Random	30/70	Hand layup	69.5	[67]
Sisal	Polyester	Random	35/65	Hand layup	44.78	[68]
Sisal	Polyester	Random	30/70	Hand layup	65.93	[69]
Sisal-Glass	Epoxy	Unidirectional	20/80	Hand layup	26	[70]
Hemp	Polypropylene	Random	50/50	Hand layup	50	[71]
Sisal	Epoxy	Random	30/70	Hand layup	83.96	[72]

4.6.2 Flexural strength

A flexural property of the current work is compared with some of the other researcher's work. From Table 4.5 the flexural strength obtained from the current work is higher when compared to [69] work, and the current work clearly shows that a hybrid synthetic fibers with natural fibers and fiber orientation has an effect on the flexural properties of materials. It can be concluded that the flexural strength results obtained from the current study are better.

Table 4.5 Comparison of flexural properties reported in this work with previous works.

Fiber	*Matrix*	*Fiber orientation*	*Fiber/ matrix ratio*	*Method of fabrication*	*Flexural strength (MPa)*	*References*
Glass/sisal	UPR	Mat form	35/65	Hand layup	156	Current work
Sisal	Urea formaldehyde	Random	30/70	Compression molding	58.58	[73]
Jute	Epoxy	Random	30/70	Hand layup	89.63	[67]
Sisal	Polyester	Long	40/60	RTM	74.5	[74]
Sisal	Polyester	Random	30/70	Hand layup	115.62	[69]
Sisal	UPR	Unidirectional	20/80	Hand layup	26	[70]
Hemp	Poly propylene	Random	50/50	Hand layup	85	[71]

4.6.3 Compressive strength

Compressive properties of the current work compared with some of the other researcher's work. From Table 4.6 the compressive strength obtained from current work is lower when compared to [76] work. It is clearly shown that the length of fiber has a significant effect on the compression property of the composite material.

Table 4.6 Comparison of compressive properties reported in this work with previous works.

Fiber	*Matrix*	*Fiber orientation*	*Fiber/matrix ratio*	*Method of fabrication*	*Compr. strength (MPa)*	*References*
Glass/ Sisal	UPR	Mat form for both fibers	35/65	Hand layup	55.32	Current work
Sisal	Epoxy	Random	30/70	Hand layup	44.66	[75]
Glass/ Sisal	UPR	Mat for glass and unidirectional for sisal	-	Hand layup	60.5	[76]

4.7 Automotive body parts-internal panel

The design of the 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 oil crisis. High-strength steel sheets were developed in response to this issue and have contributed to lightning 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 reduction. 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 [78].

According to [78] 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 4.7.

Table 4.7Important properties required for car body panels [78].

No.	Panel	Main properties
1.	Outer panel	✓ High strength after paint (Yield Strength: 200Mpa.) ✓ Surface condition ✓ Anti-corrosion ✓ Flat hemming property
2.	Inner panel	✓ Deep drawing property ✓ Joining properties (welding, adhesion)

Lightweight composite materials, such as glass-fiber-reinforced polymers, have been used toreplace 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 low oil consumption [79].

From all the results and comparisons, the current study gives the confidence to utilize fabricated composite material in some automotive body parts application which does not need a very high mechanical performance, but need lightweight like internal panel.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, sisal-glass fiber reinforced hybrid composites were fabricated successfully by using hand layup fabrication techniques with different fiber weight ratios, fiber orientation, and different ply arrangements. Also, their mechanical properties like tensile strength, flexural strength and compressive strength, and physical properties like water absorption and thickness swelling tests were investigated and from the results, the following conclusions were drawn.

- ✓ From tensile strength test results, the mat or woven fiber orientation with glass-sisal-glass (GSG) ply arrangement and 35% fiber weight fraction composite reveals better tensile strength. Enhancement in the tensile strength may be due to better bonding, adhesion, and uniform dispersion of the fibers in the matrix.
- ✓ It is obtained that the mat or woven fiber orientation with glass-sisal-glass (GSG) ply arrangement and 35% fiber weight fraction composite material reveals the highest flexural strength as compared to other composite laminates. It may be due to better bonding and improved adhesion between fiber and matrix interfaces to a uniform load transfer.
- ✓ From compressive strength test results, the mat or woven fiber orientation with glass-sisal-glass (GSG) ply arrangement and 35% fiber weight fraction composite material shows the highest compressive strength as compared to other composite materials.
- ✓ Composite laminates with glass-sisal-glass (GSG) ply arrangement and 30% fiber weight fraction show minimum water absorption characteristics due to the

presence of glass fiber. It is evident from the experiment that the composite laminates fabricated with glass fabric in the outer layer lead to minimizing moisture absorption. Additionally, it is noticed from the experiment that the moisture uptake and thickness swelling values increases with an increase in fiber loading.

From the current study, the use of natural fibers alone may not provide that much sufficient strength for a specific application, because natural fibers have relatively high moisture absorption characteristics and poor adhesion. The effective method to enhance the properties of natural fiber-reinforced composites is to combine distinct fibers to produce hybrid composites. The sisal-glass hybrid composite materials have good mechanical performance. It is possible to use sisal-glass-reinforced unsaturated polyester composites as a substitute material for automotive internal panel parts.

5.2 Recommendation for future work

From the conclusions of this research, the following studies could be performed to analyze more details on this topic.

- ✓ In this study, the hand lay-up fabrication technique was used to prepare glass-sisal-reinforced polyester composite material. By using other fabrication techniques, it can be analyzed.
- ✓ Characterization of the fibers can be done by using different fiber lengths on composite materials.
- ✓ Study on effects of water absorption on the mechanical performance of fiber-reinforced composites concerning different immersion times.
- ✓ Finding of different sisal fiber extraction processes.
- ✓ SEM and Finite Element Analysis can be carried out.
- ✓ Investigate the effect of fiber treatment and mechanical bonding of the HFCM in mechanical performance.

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APPENDIX

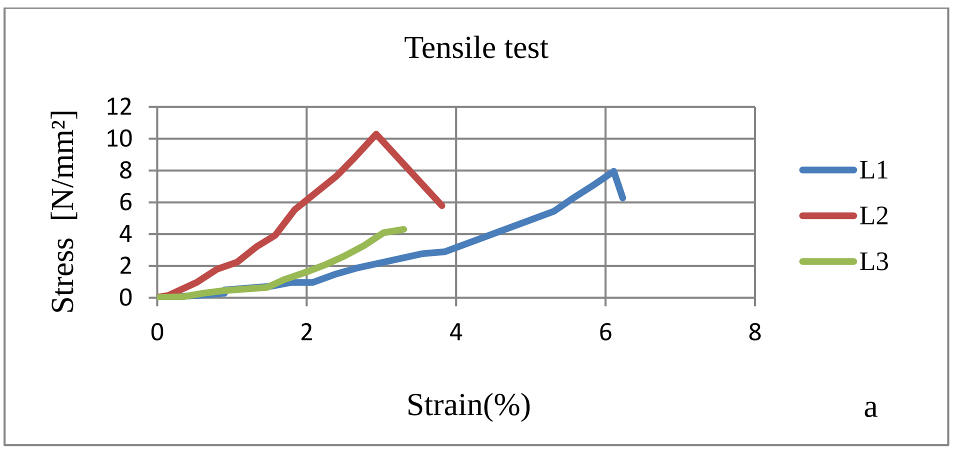
In this appendix, all the data have been collected during the laboratory specimens testing wereprovided.

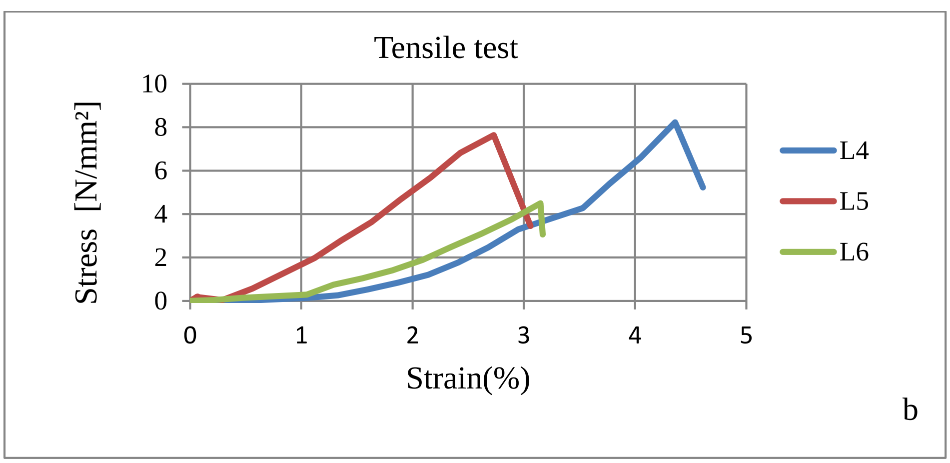
Table A1 Data collected from tensile strength test

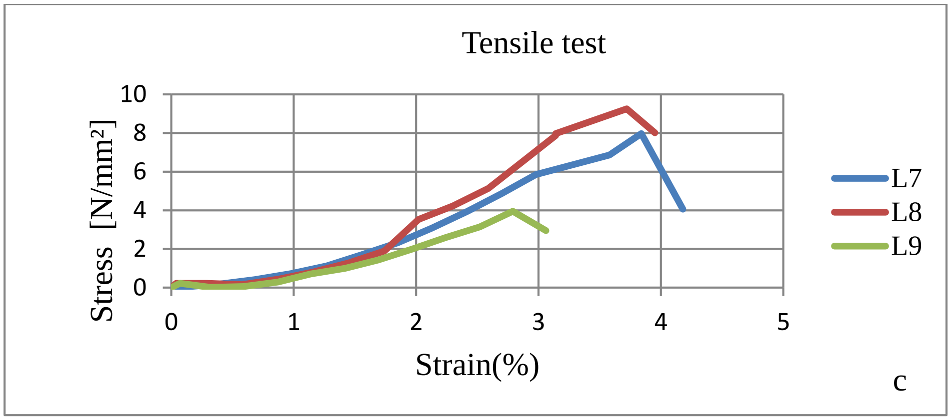
Laminates	*Fiber weight ratio, %*	*Orientation*	*Ply arrangement*	*Force @ peak, (KN)*	*Tensile strength (MPa)*	*Stress (MPa)*	*Strain*	*Young's modulus (MPa)*
L_1	30	MMM	SGS	2.23	46.82	11.55	0.0726	159.091
L_2	30	MMM	GSG	5.05	92.53	10.29	0.0293	351.195
L_3	30	MMM	SSS	2.11	30.87	4.3	0.033	130.303
L_4	35	MMM	SGS	2.82	50.76	8.23	0.0436	188.761
L_5	35	MMM	GSG	5.67	98.26	7.64	0.0273	279.853
L_6	35	MMM	SSS	2.01	32.32	4.5	0.0315	142.857
L_7	40	MMM	SGS	2.31	48.04	7.97	0.0384	207.552
L_8	40	MMM	GSG	5.15	94.68	10.49	0.0397	264.232
L_9	40	MMM	SSS	1.94	27.28	3.95	0.0388	101.804
L_{10}	30	UMU	SGS	2.15	41.61	5.3	0.0314	168.79
L_{11}	30	MUM	GSG	4.01	79.2	6.93	0.0384	180.469
L_{12}	30	UMU	SSS	1.32	20.52	6.76	0.0718	94.1504
L_{13}	35	UMU	SGS	3.32	44.36	7.37	0.0394	187.056
L_{14}	35	MUM	GSG	4.47	85.76	9.11	0.0359	253.76
L_{15}	35	UMU	SSS	1.75	28.96	4.38	0.0416	105.288
L_{16}	40	UMU	SGS	3.33	43.23	6.78	0.0447	151.678
L_{17}	40	MUM	GSG	4.13	81.04	8.41	0.043	195.581
L_{18}	40	UMU	SSS	2.13	22.64	4.34	0.0385	112.727
L_{19}	30	RMR	SGS	2.15	37.11	4.39	0.0316	138.924

L_{20}	30	MRM	GSG	3.96	70.68	6.03	0.039	154.615
L_{21}	30	RMR	SSS	1.63	18.16	2.08	0.025	83.2
L_{22}	35	RMR	SGS	2.22	40.34	4.58	0.0351	130.484
L_{23}	35	MRM	GSG	4.28	75.41	8.72	0.0345	252.754
L_{24}	35	RMR	SSS	2.03	24.21	4.14	0.0306	135.294
L_{25}	40	RMR	SGS	2.39	39.07	4.87	0.0299	162.876
L_{26}	40	MRM	GSG	3.13	72.56	6.38	0.0464	137.5
L_{27}	40	RMR	SSS	1.33	15.64	2.71	0.0537	50.4655

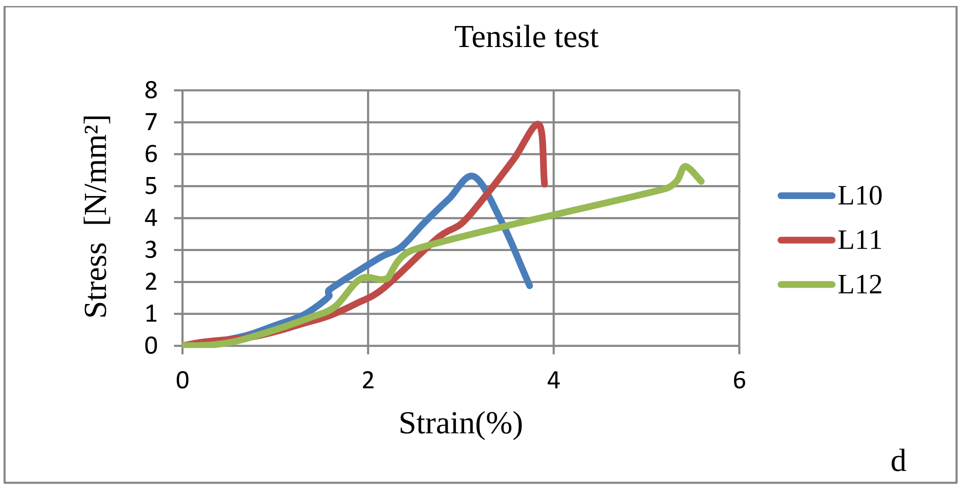
Figure A1 stress vs. strain curves for each composite laminates of tensile tests.



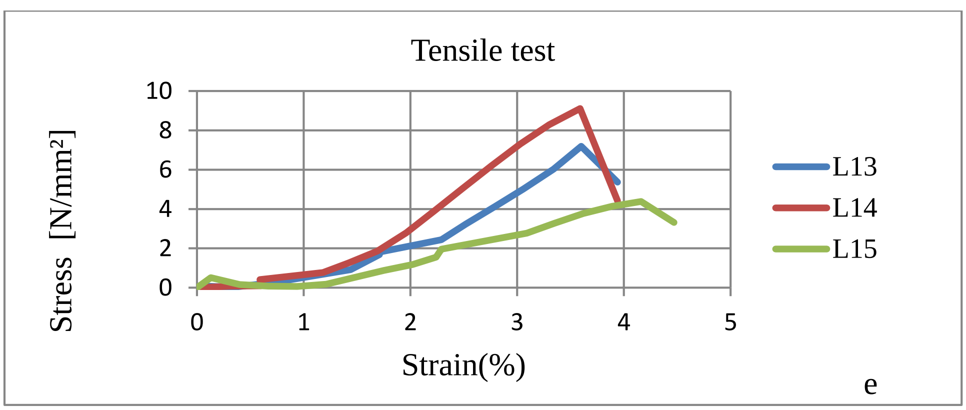




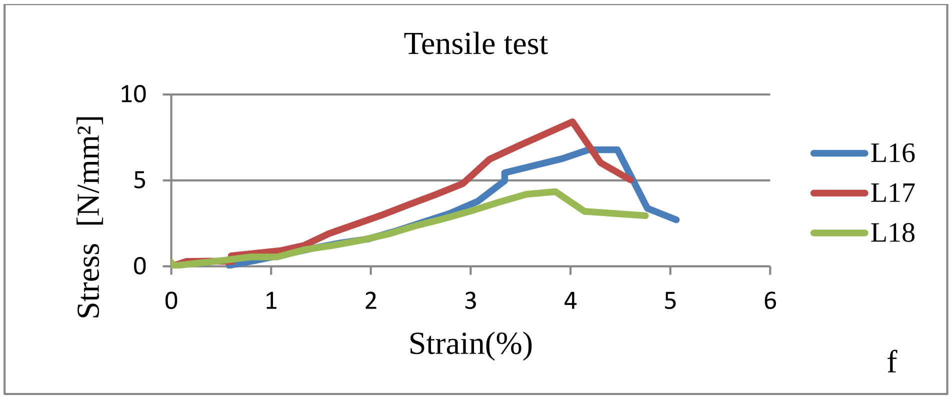
Tensile test
Stress [N/mm²]
10
8
6
4
2
0
0
1
2
3
4
5
Strain(%)
L7
L8
L9
c

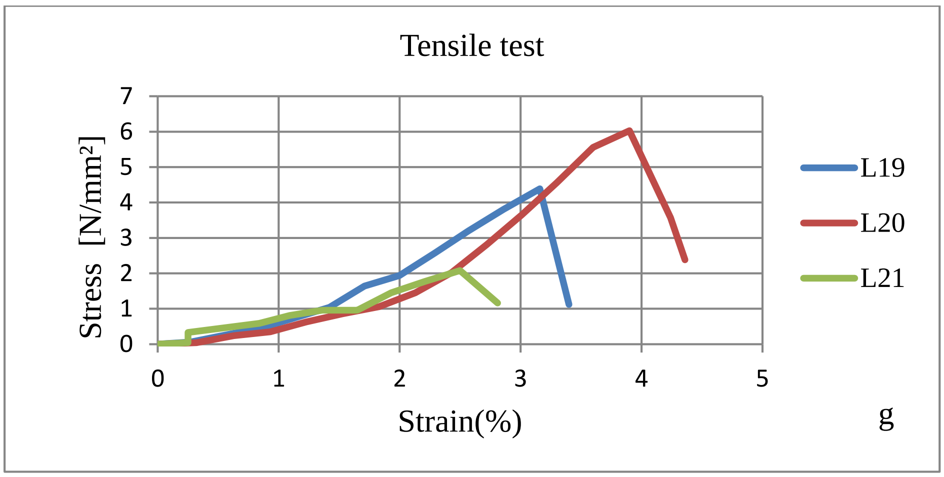


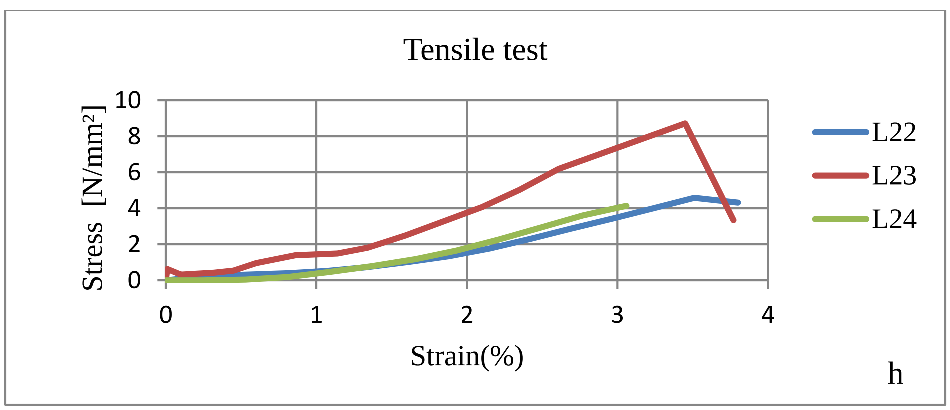
Tensile test
Stress [N/mm²]
8
7
6
5
4
3
2
1
0
0
2
4
6
Strain(%)
L10
L11
L12
d



Tensile test
Stress [N/mm²]
10
8
6
4
2
0
0
1
2
3
4
5
Strain(%)
L13
L14
L15
e


Tensile test
Stress [N/mm²]
Strain(%)
L16
L17
L18
f


Tensile test
Stress [N/mm²]
Strain(%)
L19
L20
L21
g


Tensile test
Stress [N/mm²]
Strain(%)
L22
L23
L24
h

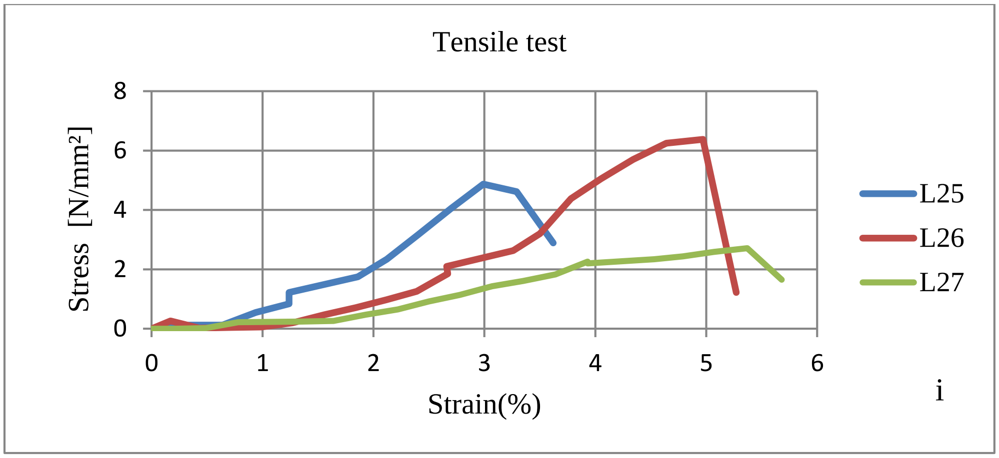


Table A2 Data collected from flexural strength test

Laminates	*Fiber weight ratio, %*	*Orientation*	*Ply arrangement*	*Force @peak, (N)*	*Flexural strength (MPa)*
L_1	30	MMM	SGS	120	72
L_2	30	MMM	GSG	170	102
L_3	30	MMM	SSS	90	54
L_4	35	MMM	SGS	146	87.6
L_5	35	MMM	GSG	260	156
L_6	35	MMM	SSS	94	56.4
L_7	40	MMM	SGS	141	84.6
L_8	40	MMM	GSG	200	120
L_9	40	MMM	SSS	70	42
L_{10}	30	UMU	SGS	104	62.4
L_{11}	30	MUM	GSG	165	99
L_{12}	30	UMU	SSS	87.2	52.32
L_{13}	35	UMU	SGS	118	70.8
L_{14}	35	MUM	GSG	182	109.2
L_{15}	35	UMU	SSS	100	60
L_{16}	40	UMU	SGS	112	67.2

L_{17}	40	MUM	GSG	160	96
L_{18}	40	UMU	SSS	89	53.4
L_{19}	30	RMR	SGS	113	67.8
L_{20}	30	MRM	GSG	132	79.2
L_{21}	30	RMR	SSS	65	39
L_{22}	35	RMR	SGS	108	64.9
L_{23}	35	MRM	GSG	145	87
L_{24}	35	RMR	SSS	69	41.4
L_{25}	40	RMR	SGS	96	57.6
L_{26}	40	MRM	GSG	121	72.6
L_{27}	40	RMR	SSS	67.5	40.5

Table A3 Data collected from compressive strength test

Laminates	*Fiber w.ratio, %*	*Orientation*	*Ply arrang.*	*Max. compressive strength (MPa)*	*Force @peak, (KN)*
L_1	30	MMM	SGS	28.4	2.19
L_2	30	MMM	GSG	49.2	3.31
L_3	30	MMM	SSS	16	1.21
L_4	35	MMM	SGS	31.34	2.35
L_5	35	MMM	GSG	55.22	4.37
L_6	35	MMM	SSS	17.2	1.4
L_7	40	MMM	SGS	33.91	1.57
L_8	40	MMM	GSG	45.06	3.38
L_9	40	MMM	SSS	15.03	1.13
L_{10}	30	UMU	SGS	22	1.65
L_{11}	30	MUM	GSG	44.14	3.31
L_{12}	30	UMU	SSS	14.66	1.1
L_{13}	35	UMU	SGS	30.56	1.9

L_{14}	35	MUM	GSG	46.26	3.7
L_{15}	35	UMU	SSS	12.94	0.89
L_{16}	40	UMU	SGS	26.14	1.96
L_{17}	40	MUM	GSG	40.6	3.1
L_{18}	40	UMU	SSS	13.46	1.01
L_{19}	30	RMR	SGS	25	1.95
L_{20}	30	MRM	GSG	36.64	2.7
L_{21}	30	RMR	SSS	12.54	1.3
L_{22}	35	RMR	SGS	31.2	2.3
L_{23}	35	MRM	GSG	42.1	3.14
L_{24}	35	RMR	SSS	11.68	0.81
L_{25}	40	RMR	SGS	24.8	1.86
L_{26}	40	MRM	GSG	35.26	2.63
L_{27}	40	RMR	SSS	10.42	0.82

Table A4 Data recorded fromwater absorption test

Laminates	*Fiber weight ratio, %*	*Fiber Orientation*	*Ply arrangement*	*Initial weight (gm)*	*Final weight(gm)*	*Water absorp. (%)*
L_1	30	MMM	SGS	44.15	47.32	7.2
L_2	30	MMM	GSG	45.09	47.43	5.2
L_3	30	MMM	SSS	48.65	53.75	10.5
L_4	35	MMM	SGS	53	57.26	8.04
L_5	35	MMM	GSG	53.2	56.07	5.4
L_6	35	MMM	SSS	57.7	64.08	11.06
L_7	40	MMM	SGS	58.5	63.58	8.7
L_8	40	MMM	GSG	60.13	63.67	5.9
L_9	40	MMM	SSS	61.1	68.09	11.6

Table A5 Data recorded from thickness swelling test

Laminates	*Fiber weight ratio, %*	*Fiber Orientation*	*Ply arrangement*	*Initial thickness (mm)*	*Final thickness(mm)*	*Thickness swelling (%)*
L_1	30	MMM	SGS	4.9	5.16	5.53
L_2	30	MMM	GSG	4.93	5.10	3.5
L_3	30	MMM	SSS	5.12	5.45	8.13
L_4	35	MMM	SGS	4.96	5.25	5.92
L_5	35	MMM	GSG	5.06	5.24	3.7
L_6	35	MMM	SSS	4.97	5.32	8.75
L_7	40	MMM	SGS	4.83	5.13	6.4
L_8	40	MMM	GSG	5.02	5.21	3.86
L_9	40	MMM	SSS	4.98	5.4	9.2