ADDIS ABABA UNIVERSITY

ADDIS ABABA INSITUTE OF TECHNOLOGY

School of Mechanical and Industrial Engineering in Mechanical Engineering

(Manufacturing Engineering)

Investigation of properties of hybrid glass-sisal fibers reinforced polyester with $Al2O3$ filler composite for wind turbine applications

A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Mechanical Engineering (Manufacturing Engineering)

By: Azeb Teklemariam

Advisor: Dr. Desalegn Wogaso

Addis Ababa, Ethiopia

June, 2024

Addis Ababa University

Addis Ababa Institute of Technology

School of Graduate Studies

School of Mechanical and Industrial Engineering

Investigation of Properties of hybrid glass-sisal fibers reinforced polyester with Al2O3 filler composite for wind turbine applications

By: Azeb Teklemariam

Approved by Board of examiners

Dr.Desalegn Wogaso __________ __________

Advisor **Date** **Signature**

__________ __________ __________

Internal Examiner **Date** **Signature**

__________ __________ __________

External Examiner **Date** **Signature**

__________ __________ __________

School chairman **Date** **Signature**

Approval

The research entitled "Investigation of Properties of hybrid glass-sisal fibers reinforced polyester with Al2O3 filler composite for wind turbine applications" set by Azeb Teklemariam, submitted in accordance with the requirements for the degree of Master of Science in Mechanical Engineering (Manufacturing Engineering) complies with regulation of the university and meet accepted standard with respect to originality, content and standard.

Name: Azeb Teklemariam

Signature:________________

Date: ________________

Advisor Signature

Dr. Desalegn Wogaso ________________ ________________

Signature **Date**

Acknowledgments

I want to sincerely thank and show my respect to everyone who has assisted me with my thesis work. First and foremost, I want to express my gratitude to Almighty God for giving me the health, strength, and chances for success.

I am incredibly grateful to my advisor, Dr. Desalegn Wogaso, for his invaluable comments, suggestions, and constructive criticisms throughout my thesis work. I especially appreciate his immense support, guidance, and supervision during the research process, and his assistance in shaping the final write-up.

Furthermore, I extend my sincere thanks to Mr. Nilsen, Mr. Israel, Mr. Manweanot, and Dr. Mesfin for their relentless advice, suggestions, and support.

Last but not least, I express a deep sense of gratitude for my entire family. Their love, encouragement, appreciation, and unwavering support have empowered me each day. I am especially grateful to my husband, Mr. Bikila A., for his unconditional love, unwavering support, insightful advice, and encouragement, which gave me the strength to complete this work.

Abstract

The purpose of this study is to examine and characterization of the mechanical and physical characteristics of glass reinforced with sisal fiber that has been filled with Al2O3. Due to their exceptional performance and customized qualities, fiber reinforced materials are extensively utilized in a wide range of engineering applications. These days, particular fillers and additives are added to composite materials to lower material prices, increase and adjust the composites' quality to some extent, and in certain situations, improve the product's performance and capacity to be processed. The creation, characterization, and examination of the mechanical and physical characteristics of a polyester hybrid composite reinforced with glass-sisal fibers and Al2O3 is the goal of this research. It also aims to evaluate the hybrid composite suitability for wind turbine blade material applications. In the present work Aluminum Oxide (Al2O3) with different weight fractions (0, 2, 4, 6, 8 and 10wt %) were studied .The HFRC samples are prepared using the hand lay-up method followed by light compression loading. The experimental results shows that the addition of Al2O3 improved the mechanical properties of the HFRC, with the optimal composition being 6% Al2O3, 22% glass fiber, 12% sisal fiber, and 60% polyester. This composition showed the highest tensile strength (93.66 MPa), flexural strength (176.29 MPa), and impact strength (22.17 kJ/m²). It also had the lowest water absorption (3.26%) and density (1.22 g/cm³).The experimental results were also analyzed using ANSYS software. The ANSYS analysis showed that the optimal HFRC composition could withstand the static loads that wind turbine blades are subjected to. Based on the experimental and ANSYS results, the HFRC with 6% Al2O3, 22% glass fiber, 12% sisal fiber, and 60% polyester has the potential to be used as an alternative material for wind turbine blades material.

Keywords: Hybrid fiber reinforced composites, Al2O3 filler, Wind turbine blades, Mechanical properties, Physical properties, ANSYS

Contents

List of figures

List of tables

List of Abbreviations and Acronomys

ASTM	American Standard Test Methods
FEM	Finite Element Method
Hrs	Hours
KPa	Kilo Pascal
MPa	Mega Pascal
NaOH	Sodium Hydroxide
MKEP	Methyl Ethyl Ketone Peroxide
Al2O3	Aluminum Oxide
HFRC	Hybrid fiber reinforced composite
ρc	Density of composite
Wm	Weight fraction of the matrix
Wf	Weight fraction of fiber
ρm	Density of the matrix
ρf	Density of fiber
m	Mass of a single specimen
Vf	Volume of the water when a specimen is immersed.
Vi	Volume of the water before a specimen is immersed.

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Instead of synthetic materials, composites can be built with natural fibers like hemp or flax. These come from plants, animals, or even rocks and act like a strengthening inner layer when combined with glues or special plastics. Other examples include things like bamboo, coconut husks, and pineapple leaves. [1].

Synthetic fibers reinforced materials are a type of composite material that is made from aramid, carbon, and glass fibers. These materials are widely used in a variety of industries, including aerospace, leisure, automotive, construction, and sporting goods [2]. Glass fiber materials are the most widely used synthetic fibers in composites, as they are relatively inexpensive and have good mechanical properties. However, they also have some negative environmental impacts, such as high density, high cost, non-renewable resources, high energy consumption, and non-biodegradability. Related to this, literature show that about 87% of the 8.7 million ton of global fiber reinforced polymer composites is based on E-glass fiber composites [3].

Natural fibers offer some potential advantages over synthetic fibers in terms of environmental sustainability. For example, natural fibers are often lighter than synthetic fibers, and they can be derived from renewable resources. Additionally, natural fibers are often biodegradable, which means that they can be disposed of without harming the environment [1].

The use of natural fibers in composite materials is a growing field of research. As the technology continues to develop, natural fibers may become a more viable alternative to synthetic fibers in a variety of applications.

Hybrid composite materials are becoming increasingly popular in engineering fields like aerospace, cars, and medicine. This is because they offer several advantages, including being strong and stiff while still being lightweight, and being able to withstand repeated stress better than traditional materials. [4]

Both natural and synthetic fibers are used to strengthen hybrid composites. While each type has its perks, they also come with downsides. Synthetic fibers can be tricky to recycle and reuse, and don't break down naturally. Natural fibers, on the other hand, tend to absorb a lot of moisture and might not be as strong. By combining these two types of fibers, engineers can create a material that benefits from the strengths of both, while minimizing their weaknesses. This way, they get a high-performing composite with fewer drawbacks. [4]

Generally, this study focuses on developing Al_2O_3-filled hybrid composites and investigating mechanical and physical properties. In addition, it the aim is to assess their suitability for wind turbine blade applications. In a way, the study aims to select appropriate work parameters to make it feasible with the existing subject matter in our country and all over the world. The study endeavors to develop a composite along with seeking ease of manufacturing, strength, environmentally friendly, job opportunity and cost. Besides, the study was limited to comparing the newly developed composite physical and mechanical properties with previous related Al_2O_3 filler containing research works.

1.2 Statement of the Problem

Engineering is turning towards natural fiber composites for a good reason. These materials are eco-friendly superstars –biodegradable, affordable, and lightweight. This is a big improvement over traditional synthetic composites, which is non-biodegradable and cause soil pollution. [5]

While natural fibers are great for the environment, using them alone can be tricky. They tend to soak up water, weaken in heat, lose strength over time, and can't handle impacts very well. That's where combining them with synthetic fibers comes in. By blending these two types of fibers, engineers can create a material that overcomes the weaknesses of each individual type. This hybridization leads to better performance in terms of wear, mechanics, and overall properties compared to using natural fibers on their own. [6].

Fiber-reinforced materials are superstars in engineering because they're so versatile. To make them even better, engineers sometimes add special ingredients called fillers or additives. These can help lower costs, improve the overall quality of the material, and even make them easier to work with during manufacturing. Some popular fillers include things like calcium carbonate, clay, and even bone powder, Alumina .These extras help the final product perform even better., In the present work Aluminum Oxide (Al_2O_3) at different weight fractions (0, 2,4,6 ,8and 10wt%) were studied because Al_2O_3 is known with its unbeatable wear and corrosion resistance, thermal and chemical stability, comparatively better strength, accessibility in abundance, low cost and has no open porosity. This property of $Al2O3$ will helpful to enhance the property of the reinforcing fiber and the whole composite to a greater extent [7].

On the other hand, Weaning ourselves off fossil fuels is a global priority, and that means ramping up renewable energy sources like wind power. This requires building more wind farms, both onshore and offshore, with ever-larger turbines. But keeping these massive machines, especially those far out at sea, running smoothly for decades is a challenge. That's where advanced composite materials come in. By making wind turbine blades stiffer, stronger, and more resistant to wear and tear from the environment, these materials can ensure reliable operation for 20 years or more. Lighter weight blades are a bonus too, making them all the more efficient. So, developing and using advanced composites is crucial for the future of wind energy. While synthetic fibers are common in wind turbine blades, they raise environmental concerns throughout their lifecycle, from production to disposal. This, along with the high cost of wind turbines, can sometimes make other energy sources more attractive. To address these issues, researchers are looking closely at hybrid composite materials. These materials combine natural and synthetic fibers, aiming to leverage the benefits of both. This could lead to more eco-friendly and potentially more affordable wind turbine blades [8].

This research took a hands-on approach to creating and testing new wind turbine blade materials. They focused on hybrid composites made with a mix of glass and sisal fibers, combined with a polyester base. To overcome limitations of both natural and synthetic fibers, alumina ($Al2O3$) filler added and treated the fibers themselves. This helped improve the overall strength and physical properties of the final composite material.

1.3 Objective of the study

1.3.1 General Objective

The main objective of this research is investigate the mechanical and physical properties of $Al2O3$-filled glass-sisal fiber reinforced polyester hybrid composites for wind turbine blade applications.

1.3.2 Specific Objectives:

1. Fabricate glass-sisal hybrid composites with varying weight percentages of $Al2O3$ filler.

2. Analyze the mechanical properties (tensile, flexural, and impact strength) of the developed composites using ASTM standard tests.
3. Analyze the physical properties (water absorption capacity and density) of the developed composites using ASTM standard tests.
4. Compare the performance of the developed hybrid composites with findings from previous related studies.
5. Evaluate the suitability of the developed hybrid composites for wind turbine blade applications.

1.4 Research Questions

1. Will adding alumina filler (Al2O3) improve the strength and overall performance (mechanical properties) of the composite made with glass and sisal fibers and polyester resin?
2. Will adding alumina filler (Al2O3) affect how much water the composite absorbs and its overall weight (physical properties)?
3. Is there a specific amount of alumina filler that creates the strongest and most functional (with best mechanical and physical properties) composite material?
4. Can the composite we create with these materials (glass, sisal, polyester, and alumina) be used effectively in wind turbine blades?

1.5 Scope of the study

The scope of this research was to develop an Al2O3 filled Glass-Sisal fiber Polyester composite (HFRC) and to characterize its mechanical and physical properties, as well as its structural properties using ANSYS software. The research aim was also to select appropriate work parameters and to develop an HFRC that is easy to manufacture, strong, environmentally friendly, and cost-effective.

1.6 Significance of the study

- **Sustainability and Cost Reduction:** Glass fibers are the dominant material for wind turbine blades, but they have a high embodied energy and environmental impact. Sisal fibers, a natural and renewable resource, can offer a more sustainable alternative. Aluminum oxide is also be a more abundant and potentially lower cost filler compared to some alternatives. This study could assess the feasibility of using this combination to create a more eco-friendly and potentially lower-cost wind turbine blade material.

- **Improved Mechanical Performance:** Wind turbine blades experience significant mechanical stress due to wind and gravity. The addition of Aluminum oxide filler might improve the strength, stiffness, or fatigue resistance of the composite compared to using just glass and sisal fibers. This could lead to blades that are lighter yet able to withstand the demanding operational loads.
- **Moisture Resistance:** Wind turbine blades are exposed to various weather conditions, including rain and humidity. Sisal fibers are susceptible to moisture absorption, which can weaken the composite. Aluminum oxide filler might help to reduce moisture uptake, leading to a more durable blade with better long-term performance.
- **Weight Reduction:** Lighter wind turbine blades require less material and reduce the overall weight of the turbine. Depending on the density of the Aluminum oxide compared to the neat resin, it might offer a way to reduce the weight of the composite while maintaining or improving other properties. This can lead to taller and more efficient wind turbines that capture more wind energy.
- **Potential for Broader Application:** The findings from this study might be applicable beyond wind turbine blades. The knowledge gained on how Aluminum oxide filler affects the properties of the Glass-Sisal fiber polyester composite could be valuable for developing other lightweight and high-performance composites for various applications in the transportation, construction, and marine sectors.

Overall, this research can contribute to the development of more sustainable, cost-effective, and high-performance wind turbine blades, with potential benefits for the wind energy industry and the environment.

1.7 Motivation of the research

Motivation for this research is overcoming limitations of single-fiber (Glass fiber) composites for wind turbine blades. This research explores hybrid composites with fillers for wind turbine blades. Single-fiber composites struggle under the varied stresses these blades experience. Hybrid composites offer a solution by combining different fibers to address each other's weaknesses. Fillers further enhance this approach, allowing to create a customized material perfectly suited for the demanding needs of wind turbine blades.

1.8. Organization of the Thesis

Chapter 1: Introduction

This chapter introduces the overall background of the topic, including its significance and current understanding. It also outlines the research question or objective that motivates the investigation.

Chapter 2: Literature Review

This chapter delves into the scientific principles behind natural, hybrid composite, filler, and wind turbine blade materials. It comprehensively reviews relevant literature, highlighting existing knowledge and potential research gaps.

Chapter 3: Methodology

This chapter details the materials used in the research. It explains the preparation methods, processes, and specific conditions employed to create the test specimens.

Chapter 4: Results and Discussion

This chapter presents the findings obtained from the experimental tests. The results are thoroughly discussed, with explanations and interpretations. Followed by a detailed discussion of the simulation results.

Chapter 5: Conclusion and Recommendations

This chapter summarizes the key findings of the research and presents the main conclusions drawn from the investigation. It also offers recommendations based on the obtained results. Finally, the chapter proposes potential avenues for future research in this field.

CHAPTER TWO

2. LITRETURE REVIEW

2.1 Introduction

In this portion of the study, the overview of composite materials, natural fibers and synthetic fiber and their classifications were discussed. Next, literature related to sisal plant, sisal fiber and glass fiber production were addressed. The thesis goes beyond the basic material explanations. It also dives into the structure and chemical makeup of sisal fibers, one of the key components. Additionally, it explores the findings of previous research on glass-sisal fiber reinforced polyester composites, focusing on mechanical properties, physical properties, and water absorption.

2.2 Composite material

Composite materials are like teams - they combine different components, each with its own strengths, to create something even better. These components include a base material (matrix) and reinforcing fibers or particles. In the mid-20th century, natural fibers became popular choices for this reinforcement. Since then, the use of natural fibers in composites has exploded in construction, transportation, and even aerospace. Because compared to traditional materials like metals, natural fiber composites offer some unbeatable advantages: they are stronger, lighter weight, and have a lower density. [9]

There are two main types of fiber-reinforced composites: short and continuous. Short fibers are chopped up into small pieces and randomly mixed in. How well the composite performs depends on how well these fibers stick to the base material (matrix).Continuous fiber-reinforced composites, on the other hand, often have a layered structure. While this can be a benefit, it also has downsides. Continuous fibers can limit the types of shapes the composite can be formed into, and they can clump together during molding. [10] There are two main ways to categorize composite materials based on the fibers used: natural and synthetic. Natural fibers come from plants, animals, or minerals, while synthetic fibers are man-made. [11]

2.2.1 Matrix material

Matrix connects the components of the reinforcement. The reinforcement is shielded from chemical and structural harm by the matrix. It gives the composite its shape and form, hardness, stability against buckling, and stress distribution. [12]

There are three types of matrix; Ceramic Matrix Composite, Metal Matrix Composite and Polymer Matrix Composite.

Polymer Matrix Composites (PMC): These utilize polymers like epoxy, polyester, or vinyl ester as the matrix. PMCs offer good formability, corrosion resistance, and are lightweight. [13]

Metal Matrix Composites (MMC): As the name suggests, MMCs use molten metals like aluminum, magnesium, or titanium as the matrix. These composites excel in high-temperature applications due to their excellent thermal properties and strength. [14]

Ceramic Matrix Composites (CMC): These employ ceramic materials like silicon nitride or carbide as the matrix. CMCs are known for their exceptional high-temperature strength, wear resistance, and dimensional stability. [15]

In modern composites, matrices from polymers are categorized into thermoplastic and thermosetting matrices and thermosetting type matrix was used for this study with glass-sisal fiber reinforcement and Al_2O_3 filler. Thermosetting matrices comprise; epoxies, vinyl esters, polyesters, polyimides, cyanate esters, bismaleimides, and phenolics. Among these, polyester is selected and used as a matrix for this study.

2.2.2 Reinforcements Materials

The secret weapon of composite materials is reinforcement! These reinforcements are like tiny building blocks added to strengthen the material and prevent cracks from growing during use. They give the overall composite a major boost in terms of mechanical strength, often making it much stronger, stiffer, and harder than the base material (matrix) on its own. The reinforcement materials are classified into four elementary categories: Fibers, fillers, particulates, and flakes [16].

Thin, flat flakes can be used to strengthen plastic or glass. These flakes, like aluminum, mica, and silver, are strong and stiff in two directions. In general, tiny particles (think dust-sized or smaller) called fillers are added to materials to improve their strength and other properties. These fillers can be various shapes, like cubes or platelets. Fillers made from metals like copper, tungsten, or chromium are often used to create strong composite materials. The plastic or glass that holds the flakes or particles together is called the matrix. Both the fillers and the matrix are important for the final properties of the composite material.

Composites can also be reinforced with long, thin strands called fibers. These fibers come in various shapes like squares, circles, or cylinders. They can be made from natural materials like sisal or cotton, or synthetic materials like glass, aramid, carbon, and even boron or silicon carbide. The presence of fibers significantly improves the strength and stiffness of the composite, especially when aligned in a particular direction. [17]

2.3 Classifications of Composite Materials

Composite material can be classified based on matrix material and reinforcement material.

2.3.1 Classify composites by the type of matrix

Ceramic matrix composites: the glue holding everything in place is a ceramic material. This ceramic matrix is reinforced with strong fibers scattered throughout it, like raisins in a cookie. These fibers can also be ceramic, making this type of composite unique [13, 16].

Another type of composite uses a metal as the glue, or matrix. This is called a metal matrix composite. Common metals used for the matrix include magnesium, aluminum, iron, and copper. Just like with ceramic composites, these metal matrices are strengthened by scattering strong fibers throughout them. These fibers can be made from various materials to give the composite the desired properties. [13, 16]

Polymer Matrix: The most common type of composite uses plastic as the glue, or matrix. These plastics are large molecules built by linking many smaller molecules together, kind of like a long chain. There are three main types of plastics used in composites: thermoplastics, thermosets, and elastomers. In the world of composites, plastic used as a matrix is often called a resin. [13, 16].

2.3.2 Classification of Composite Based on Reinforcement Material

Particle Reinforced Composite: These bits are the reinforcement in a particle reinforced composite. They can be various shapes, like cubes, ovals, spheres, or even irregular, but none are long and slender like fibers. These particles help strengthen the overall material [18].

Whisker Reinforced Composite: Unlike regular fibers which can be made of many tangled strands, whiskers are like perfect single crystals. This special structure makes them incredibly strong for their size. [18]

Structural Reinforced Composite: There are two main ways to build up strong composite structures:

Laminar composites: Imagine stacking thin, flat sheets on top of each other, like sheets of plywood. In this type of composite, the layers are carefully arranged in a specific direction to get the most strength possible [18].

Sandwich composites: These are like double-decker cookies! They have strong, stiff outer layers (like the cookies) with a lighter, thicker core in the middle (like the cream). The core can be a honeycomb structure or a foam, and its thickness can be adjusted depending on the needs of the project [18].

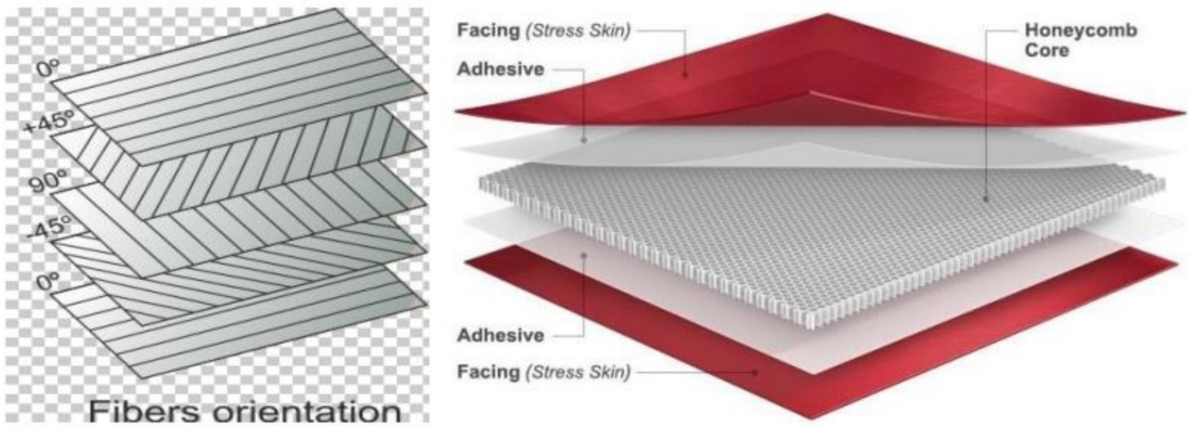


Figure 1structural reinforced composite, [18] (a) Laminar composite (b) sandwich composite

Fiber Reinforced Composite: The most common type of composite is built with fibers. These fibers can be long and continuous strands, or chopped up into shorter pieces. The way these fibers are arranged (their orientation), how much fiber is used (loading), and how evenly they're spread out (distribution) all play a big role in how strong the final composite will be. Interestingly, using shorter, randomly oriented fibers allows the material to resist forces coming from any direction. This kind of versatility in fiber length and arrangement is why fiber reinforced composites are so popular compared to other strengthening materials. [19]

2.4. Fiber Reinforced Composites

Fiber-reinforced composites are taking over industry. These new materials are winning favor for a whole suite of reasons. They're practically invisible to electromagnetic waves, which makes them ideal for certain applications. They also allow designers to create complex shapes with fewer parts, saving time and money. Plus, they're incredibly tough, lasting a long time and holding their shape well. And here's the kicker: they're lightweight yet strong, making them perfect for applications where weight matters. On top of that, they can be customized for specific needs, offering superior resistance to chemicals, heat, corrosion, and wear. No wonder they're becoming the go-to material for so many industries. [20]

2.4.1 Types of Fiber-reinforced Composites

The key ingredient that separates different fiber-reinforced composites is the type of fiber used, not the glue (matrix). Following this logic, there are two main categories:

Natural Fiber-Reinforced Composites (NFRC): These composites use reinforcements made from natural materials like plants or wood.

Synthetic Fiber-Reinforced Composites (SFRC): Here, the strengthening fibers are man-made materials like glass or carbon fibers.

2.4.1.1 Natural Fibers Reinforced Composite

These renewable resources are becoming increasingly popular replacements for synthetic fibers in composite materials. They're a dream for eco-conscious manufacturers because they're biodegradable, recyclable, and don't release harmful pollutants. Plus, they're lightweight, non-toxic, and surprisingly tough. This winning combination of properties makes them a great choice for a variety of applications, from military gear and building materials to cars, trains, airplanes, and even packaging. No wonder the demand for natural fibers is skyrocketing! They offer a sustainable and effective alternative to synthetic fibers [21].

Natural fibers in composites love water a little too much. The problem is, this fondness for water can weaken the bond between the fibers and the surrounding material (matrix). When exposed to a humid environment, water molecules get attracted to the natural fibers, forming connections that compete with the bond between the fiber and the matrix. This can lead to a weaker overall composite [20, 22].

The good news is there are ways to improve this situation. By treating the fiber surface with alkaline solutions, scientists can strengthen the bond between the fiber and the matrix. Think of it like creating a stronger handshake between the two components. This improved adhesion helps the composite resist the weakening effects of moisture and maintain its strength and water resistance [23].

Sisal plant

Sisal is a tough plant that produces long, stiff fibers ideal for various uses, like making ropes. Growing sisal is relatively easy, and it can thrive in many environments [24, 25, 26]. A single sisal plant can live for 7-10 years, producing around 200-250 leaves during its lifespan [27]. Each hefty leaf (around 600 grams) yields roughly 1,000 fibers with an average length of 1.5 meters and a width of 15 centimeters [28, 29]. The individual fibers themselves are quite fine, with a diameter ranging from 100 to 300 micrometers [29].

Ethiopia has the potential to become a major sisal producer. Regions like Amhara, Oromia, Tigray, and SNNPRS boast fertile land perfect for sisal cultivation, on both small and large scales. However, despite this potential, sisal production in Ethiopia currently remains limited. Farmers primarily grow sisal for their own needs, using the fibers to make ropes and other basic necessities [30, 31].

Sisal fiber

Sisal plants are the source of a strong, eco-friendly fiber. Special machines are used to extract these fibers, which have a nice shine [26, 32]. Washing removes impurities from the fibers [24, 33]. Sisal is a good choice for many reasons: it's affordable, lightweight, breaks down naturally, and is relatively strong and stiff. It also holds its shape well, doesn't cause harm, and can be recycled. Plus, sisal grows fast and is readily available. Traditionally, it's been used to make ropes, carpets, clothes, and other strengthening materials [33]. Sisal fibers contain more lignin than other natural fibers like jute or pineapple [34].

2.4.1.2 Synthetic Fibers Reinforced Composite

Unlike natural fibers, synthetic fibers are man-made for strengthening purposes. Common types include carbon fiber, glass fiber, and aramid fiber. Glass fiber is the most popular due to its availability and affordability. These reinforcing glass fibers come in two forms: continuous (used for weaving, winding, and braiding) and discontinuous (made by chopping up continuous fibers). Woven glass fabrics are used to create laminates for applications like boats, sporting goods, and marine equipment. Special multidirectional fabrics offer reinforcement in various directions. [35, 36].

Synthetic fiberglass composites have a downside: they're tough to recycle, reuse, and break down naturally at the end of their lifespan. However, they do resist moisture better than natural fibers. This is why combining these two types of fibers can be a great strategy. By blending them, you can get the best of both worlds: the beneficial properties of each fiber, with the strengths of one making up for the weaknesses of the other.

Glass fiber

There are two main types of synthetic fibers: organic and inorganic. Fiberglass, an inorganic fiber, is a popular choice for strengthening composite materials [37]. It's known for being strong, affordable, resistant to chemicals, and lightweight. Here's a breakdown of different fiberglass types and their uses:

C-glass: This type is ideal for strengthening chemical plant barriers against corrosion and improving surface finish.

D-glass: When low strength is sufficient for the application, D-glass is a good option.

E-glass: The most versatile type, E-glass is used for various applications including decoration, structural support, electrical insulation, and more.

S-glass: With its high silica content and exceptional fatigue strength, S-glass is the go-to choice for demanding applications in the aerospace industry [38].

An advantage of fiberglass over materials like Kevlar or carbon fiber is that it's isotropic. This means its properties stay consistent regardless of the direction it's loaded in, preventing a loss of strength. [39]

2.4.1.3 Comparison of Natural with Synthetic Fiber

The comparison of the physical and mechanical properties of natural fibers against synthetic fiber is illustrated in table 1.

Table 1 Mechanical properties of synthetic and natural fibers [40]

Fiber	Density (gm/cm3)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elastic elongation limit (%)
Jute	1.3	393 - 773	26.5	1.5-1.8
Sisal	1.5	511 - 635	9.4 – 22	2.0-2.5
Flax	1.5	500 – 1500	27.6	2.7-3.2
Hemp	1.47	690	70	2.0-4.0
Pineapple	1.56	170 – 1627	60-82	2.4
cotton	1.5-1.6	400	5.5-12	7.0-8.0
kenaf	1.45	930	53	1.6
E-glass	2.55	3400	71	3.4
Aramid	1.4	3000 – 3150	63-67	3.3-3.7
Carbon	1.4	4000	230-240	1.4-1.8

2.5. Chemical Treatment of Fibers

Chemical treatments can improve fiber-matrix interface adhesion and reduce fiber water absorption [40]. As a result, chemical treatments can be used to alter the qualities of natural fibers. Some chemicals, such as sodium hydroxide, acetic acid, acrylic acid, melting coupling agents, isocyanates, potassium permanganate, and peroxide, are known to improve adhesion by chemically coupling the adhesive to the substance. Alkali treatment of fibers is one of the most popular and effective ways of chemical modification and it has been successfully applied to practically all -natural fibers. [41]

Alkali treatment: One of the most common chemical treatments for natural fibers is alkaline treatment, often known as mercerization. When paired with additional chemical alterations, this treatment can also be utilized as a pre-treatment. The amount of amorphous cellulose increases at the expense of crystalline cellulose as a result of alkali treatment. The hydrogen bonding in the network structure is removed with this treatment. [42].

Sodium hydroxide (NaOH) is the chemical used in alkaline treatment. This method removes the hydrogen bonding in the network structure of the fiber's cellulose. The following is the chemical reaction of fiber hydroxyl with sodium hydroxide.[42]

$$\text{Fiber-OH} + \text{Na OH} \rightarrow \text{Fiber-O-Na+} + \text{H2O}$$

2.6 Hybrid Composite Materials

When a composite material has two or more types of reinforcement fibers, or two or more types of matrix (the binding material), it's called a hybrid composite. A common and effective technique is to combine natural fibers with synthetic fibers. This hybridization creates a composite that's stronger and stiffer than natural fibers alone. It also improves heat resistance, fatigue resistance, and moisture resistance. [43] Hybridization provides combination of properties that cannot be realized by an individual composite component [44]. Commonly, hybridization of natural with synthetic fibers offers a technique to improve properties of materials over natural fibers alone [45]. The hybridization of synthetic fibers with natural ones will provide a balance between reasonable costs and the finest mechanical properties compared with those of single fiber materials [46]. One drawback of natural fibers is their love for water (hydrophilic) due to their many tiny holes. This can cause natural fiber composites to swell up when they absorb a lot of moisture. A clever solution is to create hybrid composites. These combine specially treated natural fibers (often modified to be less water-loving) with synthetic fibers. By adding hydrophobic (water-resistant) synthetic fibers to the mix, the overall composite becomes much better at resisting moisture. This helps prevent the natural fibers from degrading and keeps the composite strong. [47].

Combining natural and synthetic fibers in a hybrid composite is a winning strategy for a few reasons. First, it delivers superior mechanical properties, meaning the resulting material is stronger and more durable. Second, it can be more cost-effective. By blending the fibers, you can take advantage of the affordability of natural fibers while still achieving the desired performance. This plays to another benefit: sustainability. Hybrid composites can potentially replace traditional materials that rely solely on expensive and non-renewable synthetic fibers. This reduces environmental impact as well. Basically, hybrid composites offer the best of both worlds: excellent performance, affordability, and a greener footprint. [48, 49]

2.7 Effect of filler addition on the properties of composite

Modern material development is buzzing with the potential of nanotechnology. Researchers are using it to create innovative materials with all sorts of improved properties. One exciting technique involves using tiny fillers derived from nanotechnology. These fillers are scattered throughout a polymer base (matrix) to enhance the material's strength, heat resistance, electrical properties, and even how well it resists moisture. [50] The concept of adding fillers to composites isn't new, it's been around since the 20th century. Their job is to act like glue, holding the matrix (the binding material) and the reinforcing fibers together tightly. The idea of using nanoparticles as fillers came about later, but it's a game-changer. Here's why: nanoparticles have a massive surface area compared to their size. This translates to a much stronger bond between the filler and the matrix when they're evenly distributed throughout the material. The stronger this bond, the better the mechanical properties of the composite become. In short, adding fillers improves the adhesion between the different parts of the composite, preventing it from failing prematurely. [51]

Effect of fillers on mechanical properties

Tensile strength: The addition of fillers can improve the tensile strength of composite materials. Zhang et al. found that the tensile strength of a high-density polyethylene (HDPE) composite was increased by up to 20% with the addition of silica nanoparticles [52].

Compressive strength: Fillers can also improve the compressive strength of composite materials. Kontou et al. Found that the compressive strength of a low-density polyethylene (LDPE) composite was increased by up to 30% with the addition of nano-fibrillated cellulose [53].

Flexural strength: Fillers can also improve the flexural strength of composite materials. Dorigato et al. found that the flexural strength of a polypropylene (PP) composite was increased by up to 40% with the addition of glass fiber [54].

Effect of filler addition on other properties

Stiffness: Fillers can also increase the stiffness of composite materials. Zhang et al. found that the stiffness of a HDPE composite was increased by up to 50% with the addition of silica nanoparticle [52].

Hardness: Fillers can also increase the hardness of composite materials. Kontou et al. found that the hardness of a LDPE composite was increased by up to 60% with the addition of nano-fibrillated cellulose [53].

Wear resistance: Fillers can also improve the wear resistance of composite materials. Dorigato et al. found that the wear resistance of a PP composite was increased by up to 70% with the addition of glass fiber [54].

2.8. Fabrication Techniques of Composite Materials

There are many ways to make composite materials, from simple to complex, using just one material or many. Each method has its own pros and cons. The best way to make a composite depends on several factors: the type of fiber and matrix used, how much pressure is needed to move the thick resin through the fibers, the curing temperature needed for the matrix, the final shape of the product, and of course, cost. Some popular techniques include resin transfer molding, compression molding, vacuum molding, and hand lay-up. [55]

Hand Lay-up: Hand lay-up is an open forming method for the manufacture of composite materials. It is the easiest and oldest form of composite manufacturing technique which can be considered particularly suitable for large components in lamination methods [56]. Resins are added through the hand into fibers in the form of mats or chopped form. Rollers or brushes are generally used for the application of resin in the fiber and the removal of voids or impurities. In normal atmospheric conditions, the composite is left to cure. The major drawback of hand layup is the lack of consistency; the quality of the product depends heavily on the ability of the worker. Resins are required to be low in viscosity to be workable by hand for the laminator.

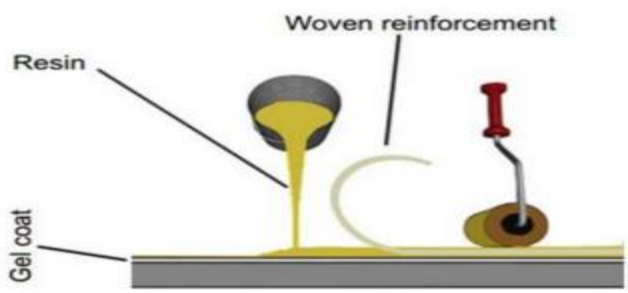


Figure 2 Hand lay-up processes [59]

Vacuum bag molding: Vacuum bag molding is a more sophisticated manufacturing process than hand lay-up. It uses vacuum pressure to compact the laminate and eliminate voids. Vacuum bag molding can be used to produce high-quality parts, but it is more expensive than hand lay-up [57].

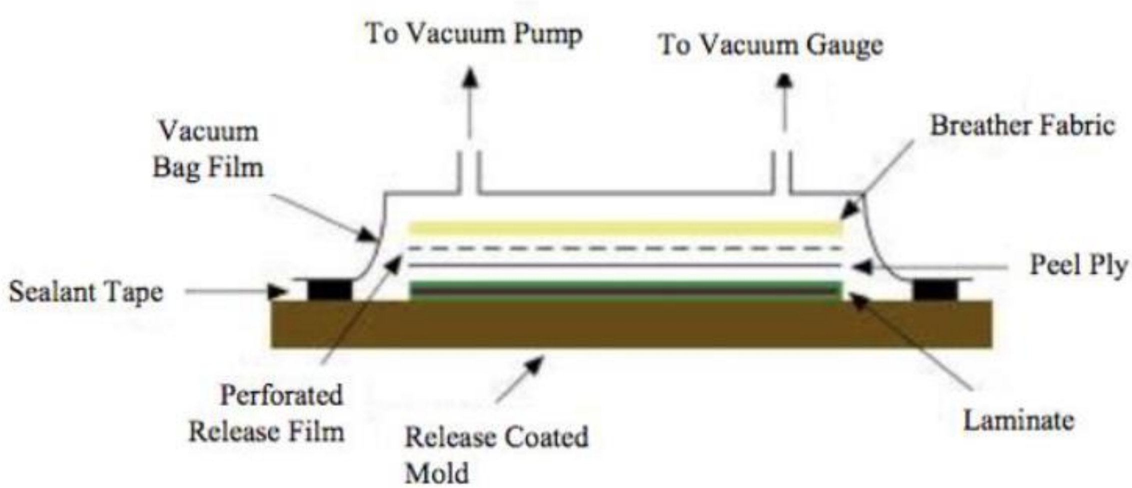


Figure 3 Vacuum bag configuration [60]

Pressure bag molding

The key difference between pressure bag molding and vacuum bag molding is how pressure is applied. Vacuum bag molding uses a vacuum sealed between the plastic bag and the composite layers to create pressure. In pressure bag molding, on the other hand, positive air pressure is used.

This is achieved by inflating an elastic bag that sits on top of the composite layers on the open mold. [58]

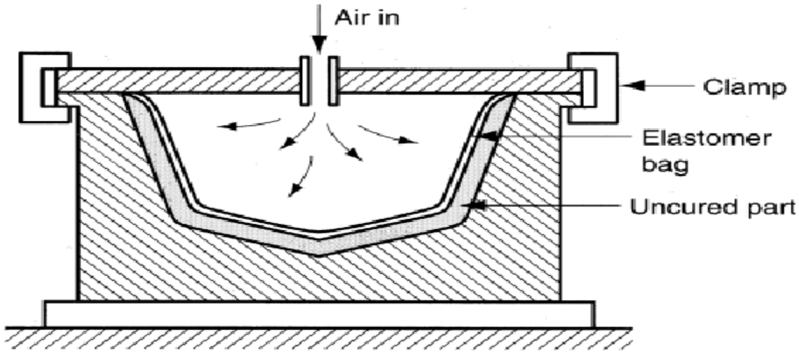


Figure 4 Pressure bag molding [63]

This study uses the hand lay-up technique because it requires less equipment and is successful in producing a small number of fabrications.

2.9. Applications of fiber reinforced composites

There's a surge in demand for FRP composites as a powerful engineering material for all sorts of applications. This has given a big boost to many industries. But there's a catch: crude oil reserves are running low, and we need a good replacement for traditional synthetic composites (which aren't renewable). This has led to a focus on research and development of FRP composites made from natural, renewable materials. [59] FRP composites are already used in a wide range of consumer and industrial products, and the list is still growing. With booming technological advancements, the need for even stronger and more dependable engineering materials is rising. While keeping costs down is important, it shouldn't come at the expense of what truly matters: reliability, environmental friendliness, and the ability to reuse or recycle the materials. [60] In fields like aerospace, where cutting-edge technology reigns, engineers need top-notch materials that are lightweight, super strong, and resist bending (have high flexural rigidity). While some traditional materials might tick a few of these boxes, they often come with limitations that hinder their use in these demanding applications. Ultimately, these limitations lead to them being replaced with better options. This makes choosing the right material for an engineering project a complex task that requires careful evaluation of all the factors involved. [61, 62] As a result, they are very challenging and useful, based on a detailed understanding of FRP composites' excellent mechanical, thermal, and physical properties. Here are some of the applications of fiber-reinforced polymer composite materials**:**

- **Automotive:** These versatile materials are finding their way into three main parts of a car: the body, frame, and engine (though body and frame components are more common than engine parts currently). A key driver for using FRP composites in cars is weight reduction. By using them for parts like seats, the overall weight of the vehicle goes down, which improves fuel efficiency. Here are some specific examples of FRP composite parts you might find in a car: structural panels, fuel and water tanks, spoilers, axle shafts, and even body panels and bearings. [63, 64, 65]
- **Aerospace:** The aerospace industry is a leader in using these materials for structural parts because they're lightweight. This translates to faster airplanes and more cargo space. Airbus, for instance, incorporated FRP composites extensively in their A310 model (designed in 1987), and both the A310 and A320 aircraft used composite tail sections.

  But FRP composites in airplanes go far beyond tails. They're used for a wide range of components including wings, stabilizers, seats, and even helicopter blades. They're also found in the fuselage (body), landing gear, fuel tanks, and tail structures. Even more, FRP composites are used to build truss structures, payload bay doors, manipulator arms, and remote pressure vessels for aerospace applications. [63, 66, 67]
- **Defense industry:** Military uses of FRP composites have a long history, dating back to World War II. This widespread adoption was driven by the benefits they offered. FRP composites can improve fatigue and corrosion resistance, which means less maintenance and repair costs for military vehicles. Additionally, with careful fiber design, they can enhance the flexibility, aerodynamics, and aeroelasticity of aircraft wings, tails, and airfoils, all crucial for performance. [63]
- **Marine industry:** These materials are popular for building warships and ship hulls because they're highly resistant to corrosion - a major concern in saltwater environments. FRP composites also offer weight-saving advantages, allowing for smaller, faster ships with better acceleration and cruising speeds. This translates to improved fuel efficiency and maneuverability. Roughly 90% of all recreational boats today are made from FRP composites, typically using glass fiber combined with polyester or vinyl ester resin. [63]

- **Building bridges (literally) with FRP composites:** These materials are becoming a promising alternative to traditional concrete in construction projects for several reasons. First, they're lighter, which can be beneficial for certain structures. Second, they're strong and resistant to corrosion and vibration, making them durable choices. This combination of properties makes FRP composites a viable option for building components like floor beams and even entire bridges [64].
- **Domestic appliances:** From furniture like desks and chairs to railings, toilet panels, and even internal building components, FRP composites are showing up in a variety of household applications. They're even used in some furniture springs. [64]
- **Electrical and electronics industries:** FRP composites are also used throughout the electrical industry. They're a key component in building electrical equipment like frames, cables, and insulators. You'll also find them in transformer housings and various other electrical products. [65]
- **Sports, leisure, and recreation products:** FBR are a favorite in sports and leisure products because they offer three key benefits: lighter weight, more design flexibility, and excellent vibration absorption. From fishing rods and vaulting poles to bicycle parts, swim fins, and even sports equipment like baseball bats, skis, and golf clubs, FRP composites are everywhere. They're also used in tennis rackets, surfboards, and skateboards, thanks to their design possibilities, vibration dampening properties, and well-known weight reduction advantages. [64]
- **Medical Science:** FRP composites are used in implantable devices, such as bone plates for fracture fixation and prosthetics. This highlights the biocompatibility and suitability of FRP composites for certain medical applications. [64]

2.9.1 Material Requirements for Wind Turbine Blade

When designing rotor blades, there are three key factors to consider based on how the blades will be used: stiffness, density, and how well they hold up over time (fatigue life). [65]

Stiffness: The blades need to be very stiff to maintain their aerodynamic performance, which means they can handle air resistance effectively.

Density: Lighter blades are better because they experience less force from gravity, making the whole system more efficient.

Fatigue life: The blades need to last a long time without breaking down or wearing out. By considering these three properties, engineers can narrow down their choices of materials for rotor blades. A good starting point is to look at all possible materials and see which ones offer the best combination of stiffness, low weight, and long fatigue life. [66] Figure 6 provides a simplified way to visualize this selection process based on stiffness and density. This initial selection can then be further refined based on the specific design of the rotor blade, which typically functions like a beam.

Mb = E 1/2/ρ,

A beam with Mb = E 1/2 /ρ has a merit index that is illustrated by sloping lines with an upper line equal to 0.006 and a lower line equal to 0.003. The horizontal line (4) denotes the absolute stiffness criteria, which is E = 15 GPa.

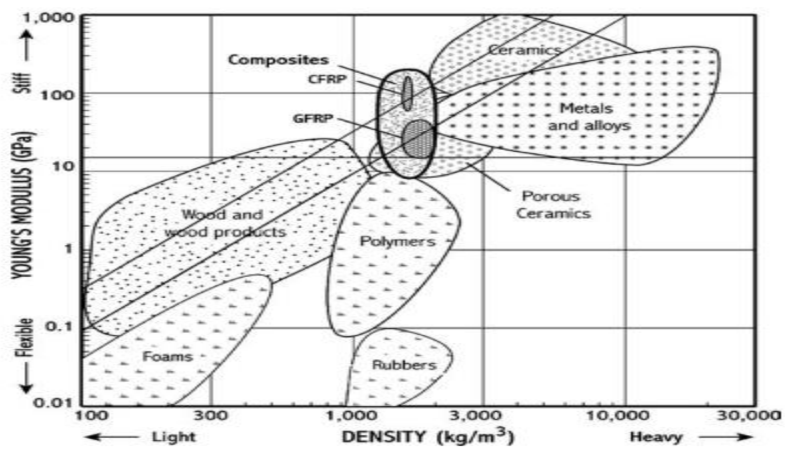


Figure 5 Stiffness versus density of all material [67]

Where ρ is the material density and E is the stiffness of the material. Materials that meet the criteria (fully or partially) are on the line and to the upper-left of the line where lines of constant Mb are superimposed on the diagram. The two arbitrary lines in Figure 4 depict materials that are equally suitable for a cantilever beam in terms of density and stiffness. The materials of probable candidates are indicated by the lower of the two lines as being composed of wood, composites, porous ceramics, metals, and ceramics. With units of E in GPa and ρ in kg/m3, the lower line's merit index is Mb = 0.003. The upper line is valid if the merit index is doubled to Mb = 0.006. This line states that composites, wood, and ceramics are examples of possible materials. A second requirement is absolute stiffness; a cantilever beam will be less deflected by a stiff material than by a flexible one. A horizontal line in Figure 4's illustration represents a stiffness criteria. The general design of the tower and rotor, as well as the rotor blades geometry and dimensions—specifically, the blade deflection as it passes the tower all play a role in deflection considerations. A material stiffness of 10–20 GPa is necessary for a reasonable deflection; Figure 4 shows the line for E = 15 GPa as an example. The majority of woods, certain composites, and certain porous ceramics are evidently excluded from materials on or above this line, which meets the criteria. It's crucial to take materials fracture toughness into account when evaluating a material's strength, or its ability to withstand large loads and extended fatigue. The merit index indicates that woods and composites are good candidate materials because to their high fracture toughness and low density.

2.9.2 Application of Fiber Reinforced Composite for Wind Turbine Blade

Selecting the appropriate reinforcing material is essential for creating robust and effective wind turbine blades. Fortunately, there are numerous choices to choose from, each having advantages and disadvantages of their own. Glass fibers (E-glass and S-glass): These have long been the mainstay, providing a nice mix of qualities at an affordable price. [65, 66] Carbon fibers, both HS- and IM-type: Carbon fibers are thought to be a suitable substitute because of their improved rigidity and reduced density. This means that lighter, thinner blades that are able to harness more wind power will result. They are more expensive than E-glass and have disadvantages such as a lower compressive strength, a lower damage tolerance, and a lower overall cost. [67]

The pure glass or pure carbon reinforcements are attractive alternatives, as are hybrid reinforcements (E-glass/carbon, E-glass/aramid, etc.). According to research by Ong and Tsai [68], utilizing carbon fibers in place of all conventional materials could result in a significant 80% weight reduction. But there's a steep 150% cost rise associated with this. Even with a more balanced strategy that replaces only 30% of the carbon fiber, there could be major advantages. In this case, an 8-meter turbine blade would have a weight reduction of about 50% and a more tolerable cost rise of 90%. Made of carbon/glass hybrid composites, the 88.4 m long blade from LM Wind Power is now the largest wind turbine rotor blade in the world [69].

Natural fibers can also be utilized in specific circumstances. The affordability, accessibility, and eco-friendliness of natural fibers such as sisal, flax, hemp, and jute are their advantages. High moisture absorption, limited thermal stability of the raw fibers, and quality variability are the drawbacks [70]. Research is still being done to enhance the usage of natural fibers in wind turbine blades in spite of these obstacles. A novel material called bamboo-poplar epoxy laminate was investigated in studies by Holmes et al. [71, 72]. This novel material produced encouraging findings, exhibiting great stiffness and strength, indicating that it might eventually replace conventional composites in wind blades.

Thermosets: vinylesters, polyesters, and epoxy with almost 80% of the market, these resins are currently the workhorses [73, 74]. Among their benefits are: Curing at room temperature or at moderate temperatures facilitates handling and lowers viscosity, enabling quicker processing and simpler infusion into the fibers. Composite blades were first made with polyester resins. Epoxy resins have taken the place of polyester as the most common material for wind blade composites as a result of the growth of huge and extra-large wind turbines. Nevertheless, new research (such as that conducted by the Swiss company DSM Composite Resins) backs up the case for going back to unsaturated polyester resins, citing improved energy efficiency and a quicker cycle time as reasons. The newly created polyesters also satisfy all strength and durability requirements.

2.10. Previous Works on Effects of Addition of Filler on Composite Material

In order to assess and reduce the wear rate,.Ghazaly et.al [75] concentrate on employing hybrid filler made of Al_2O_3 and TiO_2 NPs with different loading contents . A reciprocating tribometer was used to assess the nano composites' tribological properties. SEM and 3D microscopic pictures were also used to evaluate the wear resistance. To compare to an empty sample, PMMA nano composite samples with filling contents of 0.4%, 0.8%, 1.2%, 1.6%, and 2.0 weight percent of hybrid Al_2O_3 and TiO_2 NPs were created. Using a Shore D durometer, the nano composites' hardness was determined. Experimental methods were used to determine the XRD, density, modulus of elasticity, compressive yield strength, and fracture toughness. The addition of hybrid Al_2O_3 and TiO_2 NPs improved the mechanical and tribological characteristics of PMMA composites, according to the results. The experimental findings demonstrated that, in comparison to other filler concentrations, the nano composites containing 0.8 weight percent of filler exhibited a unique performance. Up to 20% and 28%, respectively, less COF and wear rate are observed.

The heat conductivity of epoxy/Ai103 composites was studied by Asutosh Panda [77]. This work focuses on creating epoxy composites that contain up to 22.1 vol% of micro filler (Al_2O_3). Every specimen underwent evaluations of experimental thermal conductivity tests, and the results were compared with the suggested model. The primary focus of this work was on the usage of spherical alumina particles as a useful means of improving both heat conductivity and adequate voltage endurance. It was explained that the thermal conductivity of epoxy composites filled with 11.3 vol% micro-alumina is 0.7 Wm-1k-1 in numerical analysis, but it is 0.82 Wm-1k-1 in testing with 22.1 vol%, which is somewhat higher than that of raw epoxy resin. The findings demonstrate that at this volume fraction (16 vol%), when a sharp increase in thermal conductivity is observed, the Al_2O_3particles exhibit a percolation activity.

The main goal of this study was to examine the mechanical properties of a hybrid composite made of bagasse fibers reinforced with Al_2O_3 and SiC for use in automobiles. The method used for the creation of composites was called the hand layup method. The Taguchi L9 orthogonal array design served as the foundation for the experiment. The maximum tensile and flexural strengths, according to the data, were 39.9 and 56.1 MPa, respectively. The values for hardness and impact strength were 14 J and 75.05 HV, respectively. The findings showed that the tensile strength increased with increasing Al_2O_3 and SiC weight percentages, and that the tensile strength declined once bagasse fiber weight percentage reached optimal values. Flexural strength increases with increasing Al_2O_3wt%; nevertheless, flexural strength decreases after bagasse fiber and SiC wt% reach their optimal values. The hardness of the composite increases with increasing bagasse fiber weight percentage, and it also increases with increasing Al_2O_3 and SiC weight percentage. However, the hardness decreased after achieving optimal values. Impact strength decreases with increasing Al_2O_3wt% after the optimal values, but impact strength increases with increasing bagasse fiber and SiC wt%. After SiC and Al_2O_3 powder were added as filler materials, it was discovered that the created hybrid composite material improved the composites' characteristics. This thesis suggests that research be done on how to make use of this plentiful resource of waste bagasse fiber by higher education institutions, automakers, manufacturers, building businesses, and the government [77].

The impact of alumina contents on the mechanical properties of polyester composites reinforced with alumina (Al_2O_3) is studied by Latief et al. [78] In this study, polyester-based composites with different alumina (Al_2O_3) contents—0, 1, 5, and 10 vol%—have been created. The composites' mechanical and physical characteristics have also been examined. The findings of the research demonstrated that the polyester/alumina composites' experimental density was lower than their theoretical density, which was likely caused by voids that formed during the composites' manufacture. As the alumina content of the composites grew, the strain-at-break of the materials reduced while the tensile strength, stiffness, and hardness of the materials improved.

The composites with the best tensile strength, stiffness, and hardness were found to include 5 vol% alumina. The improvement in mechanical characteristics was probably caused by the uniform distribution and dispersion of alumina particles. Conversely, a minor reduction in the composite's tensile strength, stiffness, and hardness was seen in the composites containing 10% alumina. The primary cause of the decline in both characteristics was thought to be the creation of agglomerates and vacancies.

A comparative analysis of the mechanical characteristics of epoxy/e-glass composite materials including PBO, Al2O3, CaCo, and SiO fillers was carried out The goal of this study is to compare the mechanical properties of epoxy/glass composite materials with fillers (Al2O3, CaCo3, SiO2, and PbO) and determine whether adding materials to the matrix can enhance the composite's mechanical performance. The mechanical properties of these composite materials are assessed using the Vickers Hardness Testing Machine, UTM Tensile Strength Test, Torsion Strength Test, Charpy Test, and Impact Testing Machine. This paper presents the findings from a variety of mechanical characterisation experiments. The results clearly show that Lead Oxide (PbO), when added as a filler material to resin and fiber composites (52% Resin + 13% PbO + 35% Fibre), has superior mechanical tensile properties compared to others; that Silica Oxide (SiO2), when added as a filler material to resin and fiber composites (52% Resin + 13% SiO2 + 35% Fiber), has superior mechanical torsion properties and hardness properties compared to others; and that resin and fiber composite without filler (65% + 35% Fiber) has superior mechanical energy absorbed properties[79].

The impact of Al2O3 nanofillers on the mechanical, wear, and hardness properties of epoxy laminate composites made of basalt was studied [80]. With varying percentages of Al2O3 nano fillers, basalt/epoxy composite laminates were created using the hand layup technique. In accordance with ASTM guidelines, mechanical properties such as hardness, flexural strength, impact strength, inter laminar shear strength (ILSS), and tensile strength were examined. Wear experiments were conducted while maintaining a constant sliding distance for various loads and sliding velocities. It was found that while tensile strength decreased and hardness increased as the percentage of fillers increased, flexural strength and ILSS increased for modest percentages of nanofillers. According to the wear data, basalt/epoxy composite wear loss is greatly decreased by the use of Al2O3 nanofillers. Scanning electron microscopy pictures were used to assess worn and fractured surfaces, and the results show good agreement with the analysis.

Devaraj et.al. [81] study on the mechanical behavior of Al2O3 filler: epoxy composites examines the tensile and compression strengths of epoxy composite materials reinforced with 2%, 4%, and 6% aluminum oxide filler and 20% chopped E-glass fibers (3 mm in length). In accordance with ASTM D638 type IV Standard and ASTM D-1621, an effort has been made to create 2%, 4%, and 6% of aluminum oxide filler addition with 20% (constant) chopped E-glass fiber (3mm in length) reinforcement epoxy composite materials with low density and economical. Employing a hand layup construction approach with resin (LY556) as the matrix material and hardener (HY 951) with 20% chopped E-glass fiber (3 mm in length) as the reinforcement material and varying percentages of aluminum filler addition. When 6% of aluminum oxide filler is added along with 20% (constant) chopped E-glass fiber (3mm in length) fibers reinforced epoxy composites, there are noticeable improvements in tensile strength, hardness, and compression properties of strength as compared to 4% and 2% of aluminum oxide filler addition.

Study by Chidambaram et.al [82] on adding Al2O3 to improve the mechanical properties of glass fiber-reinforced polymer composites. This work shows the mechanical behavior of a novel class of multi-phase composites made of polyester composite reinforced with glass fiber and loaded with Al2O3 particles. Alumina particles were added to glass fiber-reinforced polyester composites at three different filler contents 1, 3, and 6% and the mechanical characteristics of the resulting materials were assessed. By adding alumina particles, the mechanical characteristics of the glass fiber-reinforced polyester composite, such as impact energy and hardness, were enhanced. However, it was observed that the impact energy decreased while the hardness value increased as the filler concentration increased. A brief analysis is conducted on the macroscopic fracture surfaces of tensile specimens of all types of composites. It was found that the Al2O3-filled glass fiber polyester composite had a slightly lower tensile strength and modulus than the bare glass fiber-reinforced polyester composite. This is because the tensile properties are more sensitive to the way the particles present as a network in the matrix.

2.11 Overview of Related Previous Works on Glass-Sisal Hybrid Composite

A Araújoon et.al [83] studied mechanical properties glass-sisal reinforced-epoxy hybrid composite. The fibers underwent tensile testing in a universal testing machine in compliance with ASTM D3039 and D790 standards after being treated in a 10% by weight sodium hydroxide solution. With 86% tensile strength and 64% elastic modulus, the sisal + fiberglass hybrids were the best-performing composites. The hybrid composites performed well in the bending tests, with a maximum stress of 119% and a greater breaking stress of 138%.

The treated and untreated characteristics of jute-sisal-fiber reinforced epoxy composites were investigated by Boopalan et al. [43]. The study looked into and contrasted the raw and treated properties of an epoxy composite reinforced with jute sisal fiber. The fibers were treated with 20% NaOH for two hours prior to being added to the epoxy matrix. The acquired result demonstrated that compared to the raw, the treated composite had better tensile and flexural strength.

The mechanical characteristics of hybrid glass-sisal fiber and hybrid glass-jute fiber reinforced epoxy composites were assessed and compared by Ramesh et al. [1]. There were tensile, flexural, and SEM tests performed. The outcome demonstrated that whereas jute and GF together provide greater flexural qualities, sisal and GF integration provides superior tensile properties.

The mechanical properties of an epoxy composite reinforced with glass sisal were examined by Rana et al. [84]. Glass fiber and sisal were used to strengthen the epoxy matrix. Acetylene was used as a chemical treatment on sisal fiber to improve the interfacial interaction between the fiber and matrix. Epoxy matrix composite was used to reinforce two fixed layers of glass fiber that had varying weight percentages of sisal fiber (0%, 2%, 4%, and 6%). Tensile and flexural strength increased by 4% as a result of the sisal fiber mix decreased.

The impact of flax, sisal, and glass fiber-reinforced composites' surface treatment on their mechanical, thermal, and water absorption was examined by Meenakshi et al. in [85]. Following examination of the manufactured specimens, The glass-flax fiber reinforced hybrid's tensile strength rose by 58%, its flexural strength by 36%, and its impact strength by 51%. following 5% NaOH surface alkaline treatment. The interfacial bonding characteristics were examined using

SEM. According to the study's findings, surface treatment enhances natural fiber's performance in hybrid fiber-reinforced composites.

The impact of nanoZnO particles on the mechanical and bioactivity qualities of a 40 vol% woven flax fabric (((0/90)2) s)/UPR composite was studied by Shaker et al. [86]. The composite was created using a vacuum molding approach. The challenge of achieving a consistent distribution of nanoZnO particles within the composite was overcome by combining methanol and UPR/ZnO. Accordingly, the results of the tensile test demonstrate that the modest amount of nanoZnO particles—which was less than that of the glass fiber reinforced polyester resin composite—means that the incorporation of nanoZnO particles has no discernible effect. However, increased ZnO particle quantity resulted in increased tensile modulus and enhanced bioactivity with 0.02wt% of ZnO.

Balasubramanian [87] conducted a thorough analysis of the use of nano and micro fillers in electronics applications. The filler arrangement was shown to be a critical component in the analysis of the manufactured composites' thermal and electrical conductivity. Together with the mechanical qualities, the use of nano fillers improves the composites' thermal conductivity. Additionally, they came to the conclusion that the reason for the rise in all attributes was the addition of Nano fillers, which boosted the compatibility with the matrix.

The impact of micro/nano fillers on composites produced with polyamide 66 and polypropylene was examined by Suresh et al. in 2016 [88]. After the produced composites underwent mechanical and tribological performance investigations, it was found that the filler effect boosted the composites' tensile, flexural, and hardness strengths. On the other hand, filler-based composites also have a very low wear rate. Because of its many good qualities, graphene is a good choice for creating nanofiller-based composites, which may then be widely applied in a variety of industrial settings when combined with polymer matrices. With grapheme acting as a nano filler in polymer matrices, sophisticated composites were also created for electrical purposes.

2.12. Gaps Identified

According to the examination of the literature, composites' mechanical and hydrophobic qualities could yet be improved for usage under a range of operational circumstances. Although these qualities have been improved through chemical treatment and filler additives, the outcomes have not been substantial enough for high-load applications.

Theoretically, Al_2O_3 filler which has never been tested on a hybrid composite when combined with chemical treatment of sisal fiber for glass-sisal fiber reinforced polyester composites will further enhance the mechanical and hydrophobic properties by reducing voids, fiber degradation, and fibrillation,. This will be accomplished by a mechanism that interlocks the polymeric chains of the reinforcement and matrix to prevent movement [89].

CHAPTER THREE

3. RESEARCH METHODS AND MATERIALS

3.1 Introduction

The materials used to conduct the research were polyester resin, alumina, chopped sisal fiber, glass fiber, NaOH, and curing agent. The equipment's used were (digital balances, molds, mixer and machines (universal testing machine) identified with their clear specification. The sisal fiber treatment with NaOH used to improve the weak property of sisal fiber was done. Next, the density, volume and mass of the composite, matrix reinforcement and filler were calculated and tabulated in tables using the rule of mixture. Finally, composite manufacturing process by hybridizing sisal fiber and glass fiber, test specimen preparation and property test characterizing methods of the developed composite were conducted, clearly identified and documented.

3.2. Methodology of the Research

The methodology flow chart 6 clearly shows the methods that have been adopted in this study to develop and characterize the mechanical and physical properties of composite.

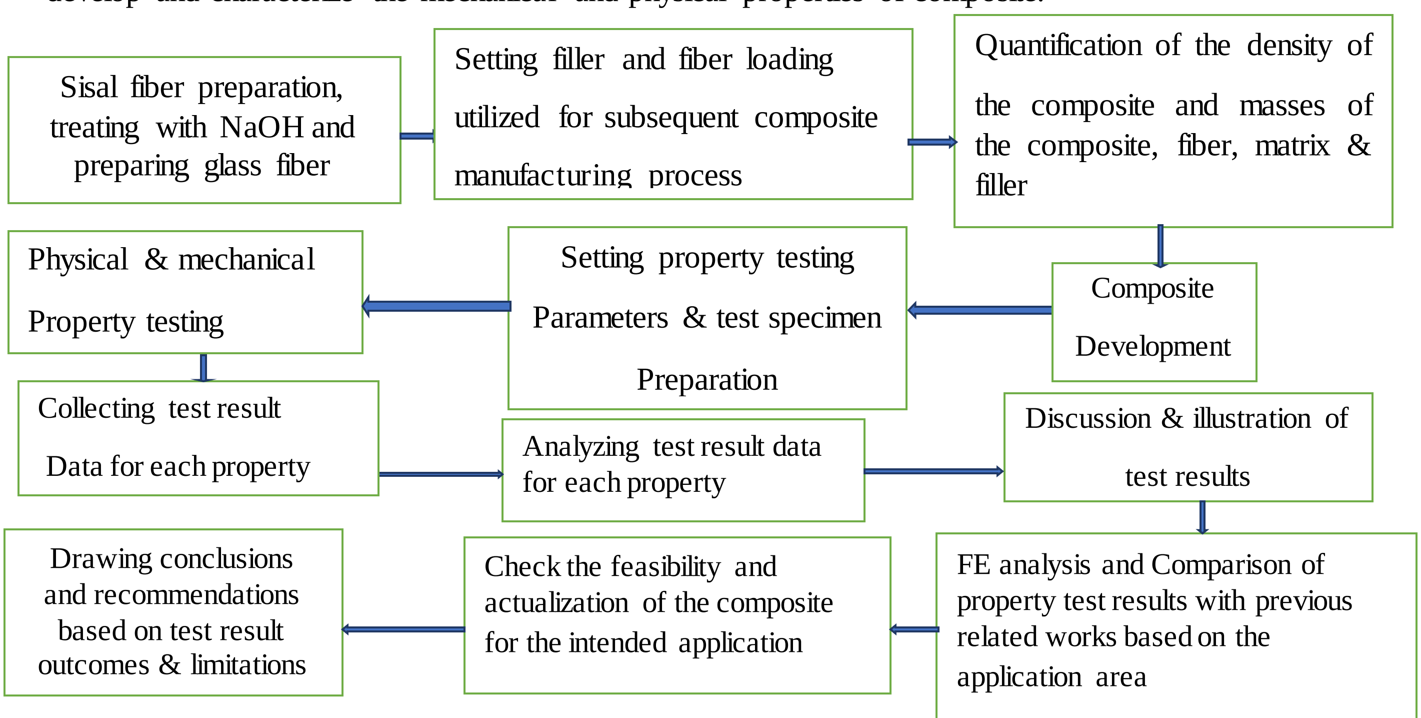


Figure 6 Methodology flow chart

3.3. Materials Used

I. Glass fiber

Because E-glass fibers have high mechanical, insulating, and chemical resistance qualities, they are frequently employed in the fabrication of composite materials. E-glass fiber exhibits superior strength and impact resistance, low thermal conductivity, low susceptibility to moisture, good electrical insulator characteristics, high resistance to chemical agents, and dimensional stability at high temperatures when compared to other forms of glass fibers [90]. They do, however, have certain drawbacks, including low stiffness, a short fatigue life, and a high temperature sensitivity [68]. Because of the aforementioned property, E-glass fiber is chosen for this study. From World Fiber Glass and Waterproofing Works in Addis Ababa, Ethiopia, randomly oriented E-glass fiber was acquired with properties of density 2.54g/cm3, Tensile strength 3450MPa, Young's modulus 72.40 Gpa, Poisson's ratio 0.2.

Figure 7 Glass fiber

II. Sisal fiber

The sisal plant was used to obtain the sisal fibers. Fibers with a glossy color and good quality are obtained by mechanical extraction techniques. To get rid of extra trash including sticky solids, leaf juice, and chlorophyll, extracted fibers were cleaned with clean tap water. High specific qualities, low cost and density, biodegradable and environmentally friendly, reasonably stiff and robust, good dimensional stability, harmlessness, recyclability, short growth cycle, and high availability are only a few of the benefits of sisal fiber [85]. Due to mentioned good characteristics sisal fiber was selected with e-glass fiber to manufacture hybrid composite. Sisal fiber was obtained from the Addis Ababa, Ethiopia market with properties of density (g/cm3) 1.5, Tensile strength (MPa) 550,Young's modulus (GPa) 23.5,Poisson's ratio 0.32 and combined with an A12O3 filler and polyester matrix to create the composite that was later developed.

Figure 8 Sisal fiber

III. Polyester resin

Polyester is a polymerizable thermosetting resin type that is frequently used in polymer matrix composites. It has low shrinkage and doesn't release reaction products during curing. It has good chemical qualities, good resilience to chemicals and the environment, good adherence to other materials, and good insulating capabilities [85]. Unreinforced polyester resin material has a tensile strength ranging from 10.0 MPa to 123 MPa, with an average of around 51.8 MPa [91] The polyester resin is chosen for this research because of these beneficial characteristics. In order to do this, commercial polyester resin was bought from World Fiber Glass & Waterproofing Works, which is based in Addis Ababa, Ethiopia with properties of density 1.2g/cm3, young's modules72.4 Gpa and, Poisson ratio 0.2.

IV. Alumina (Al2O3)

Alumina ceramic was employed to create the composite as a filler.. Alumina has attractive physical and mechanical properties which makes it preferable for a variety of engineering tasks. Al2O3 is known with its unbeatable wear and corrosion resistance, thermal and chemical stability, comparatively better strength, accessibility in abundance, low cost and has no open porosity [82, 83]. Also, it is reported that the toughness of Al_2O_3 was sufficiently more than required [83]. This property of Al_2O_3 will be expected to enhance the weak impact resistance property of the reinforcing fiber and the whole composite to a greater extent.

For this work laboratory reagent grade Al_2O_3 with particle size of 63- 210 microns , 101.96 g/m molecular weight young's modules 314Gpa and Poisson's ratio 0.27 has purchased from Rofino chemical trading PLC located in Addis Ababa, Ethiopia. To fabricate the composite samples, Al_2O_3 with different weight percentages has used which will help to characterize the composite's physical and mechanical characteristics.

Figure 9 Laboratory grade Aluminum Oxide (Al_2O_3)

V. NaOH

It is also called caustic soda which is applicable in various manufacturing industries. It was used here to treat flax fiber; releases the lignin and hemicelluloses from the fiber's surface while reactivating the hydroxyl groups bonded to the cellulose. By increasing the amount of cellulose exposed on the fiber's surface, this will strengthen the bond between the fiber and the binding matrix and ultimately improve the composite's properties.

Analytical reagent grade standard NaOH, having 98% purity with 40 g/mol molecular weight have been purchased from Rofino chemical Trading PLC Addis Ababa for this research.

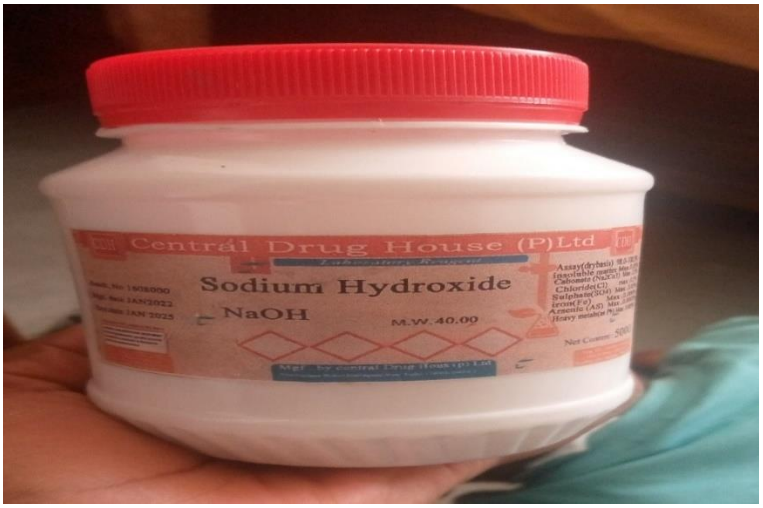


Figure 10 Laboratory reagent grade sodium hydroxide (NaOH)

VI. **Mold Release Agent (Wax)**

Wax is a chemical agent which assists to avoid the contact between the processed composite and the mold that the composite sample is removed easily. Composite mold release wax was acquired from World Fiber Glass & Waterproofing Work, an Ethiopian company with a location in Addis Ababa.

Figure 11 Mold release wax

VII. Methyl Ethyl Ketone Peroxide (MKEP) /Curing Agent

MKEP was used in composite manufacturing processes as a catalyst in polyester resin and gel coats. It changes or cures the liquid unsaturated resin to solid following the reaction.. For this work, MKEP catalyst purchased from World Fiber Glass & Waterproofing Works was used to cure the composite**.**

3.4 Equipments Used

3.4.1. Digital Balance

Digital balances; Ohaus model 1g minimum readability and 32000g maximum readability was used to measure the masses of chemicals, fibers, matrix and Al_2O_3 filler during treatment and composite manufacturing and the weight gain of the samples during water ageing processes respectively**.**

3.4.2. Mixer

Digital Mixer was used to mix the Al_2O_3powder with the polyester matrix.

Figure 12 Digital mixer

3.4.3. Wooden Molds

Rectangular wooden mold was prepared to manufacture composite samples with the desired size. The dimensions, quantity of test specimens, and number of tests were taken into consideration when designing the mold. To achieve a consistent 3 mm ply composite thickness for various testing in compliance with ASTM guidelines, the mold volume was set up. To obtain a 3 mm composite thickness, the mold's dimensions should be 27.15 cm by 27.15 cm by 0.5 cm. In accordance with this dimension, the 271.5 mm x 271.5 mm x 5 mm mold was made to obtain the required composite dimension.

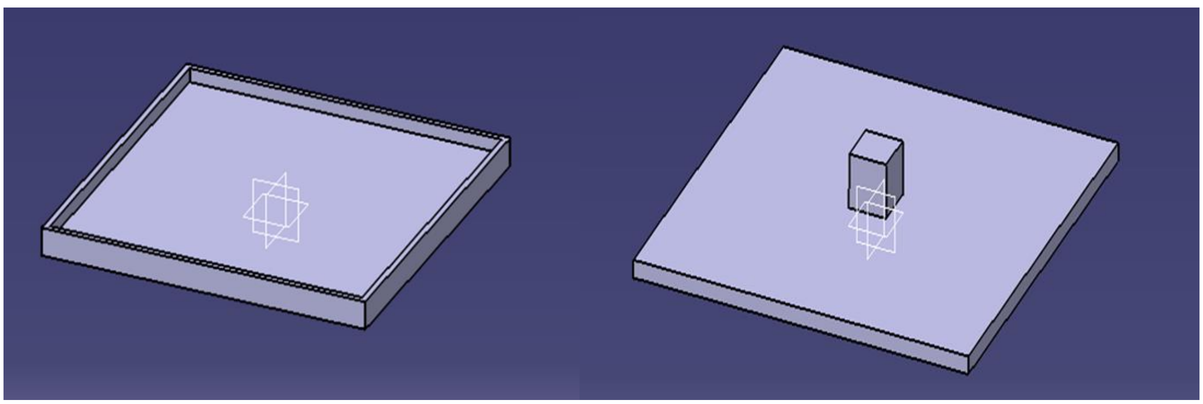


Figure 13 Design of mold by Catia software

Figure 14 Prepared wooden mold to fabricate the composite

3.4.5. Manual cutter

The ordinary manual grinder was employed to get ready both physical and mechanical property test specimens based on their conformance standards.

Figure 15 Hack saw

3.5. Chemical treatment of sisal fiber

Alkali treatment was used to treat the fiber. In particular, alkaline treatments improve the mechanical interlocking between the fiber and matrix, promoting the interfacial adhesion between fibers and matrices [41]. The literature review indicates that sisal fibers can be effectively treated with the alkali solution. Initially, the sisal fiber in this investigation was repeatedly cleaned with water to get rid of dust particles from the fiber's surface. Next, water and the appropriate amount of NaOH were combined in a plastic tub. Here, 5% NaOH was used, taking into account [92]. The study found that a 5% NaOH treatment improved the tensile and flexural strengths. The proportion was taken into account when mixing 250g of NaOH with 5L of water.

Following mixing, the cleaned sisal fiber was submerged for a full day in a NaOH solution. After that, the fiber was removed and repeatedly cleansed and washed with water to get rid of the chemical and achieve a neutral pH level. The cleaned fibers were then spread out and allowed to dry in the sun. Finally, the fiber that had been dried and processed was removed to be fabricated on the intended composite.

Figure 16 Washed sisal fiber *Figure 17 Drying washed sisal fiber with sunlight*

Figure 18 Soaked sisal fiber in NaOH solution and cover by plastic cover

3.6. Chopped Glass and Sisal Fiber Preparation

The kind of reinforcing material, matrix, filler, composition, processing method, and condition all have a significant impact on the mechanical and physical properties of natural fiber composites. However, the orientation and arrangement of the reinforcing fiber have its own impact on the physical and mechanical performance and processing cost of the composite.

Long chopped fibers (approximately from 30 to 40mm length) sisal and glass fibers cut with scissor was used. This is because long chopped fiber reinforcements combined with thermosetting resins manufactured by compression molding route are capable of producing a composite with improved strength with minimal manufacturing cost than other fiber orientation types [93]

3.7. Density, Volume and Mass Calculation of the Composite, Fibers, Matrix and Fillers Based on Rule of Mixture

To build the composite according to the variation of reinforcing fiber, matrix, and filler, the density, volume, and masses of the composite, reinforcement, and fillers should be determined. The weight percentages of the filler, reinforcement, matrix, and mold volume are used in this computation. Additionally, Table 6 lists and tabulates the proportions and weight % fluctuation.

Based on previous investigation in this research work, the total fiber and matrix weight percentages is40/60%percenta selected, for the two fibers (sisal and E-glass) 15% sisal and 25% glass selected. The variations of filler contents have utilized for subsequent composite development and property analysis processes that optimum mechanical properties were gained in these filler loading ranges (2, 4, 6, 8% and 10%) [94].

This ratio were for testing the effect of Al2O3 filler material on the properties of glass/sisal fiber reinforced polyester hybrid composite. By keeping the polyester matrix ratio constant and varying the filler content from 0% to 10%, used to assess the impact of filler addition on the composite's properties. Additionally, by reducing the weight percentage of both glass and sisal fibers equally as the filler content increases, maintain a consistent fiber-to-fiber ratio, were allowing to isolate the effects of filler addition.

In specific case, the addition of Al2O3 filler was likely to affect mechanical characteristics of the composite, including density, tensile and flexural strength, impact resistance, and water observation capacity. By conducted experiments with varying filler content, filler percentage for achieving the desired properties were determined.

Table 2 Weight percentage of fabricated composite for property test

Samples	Glass fiber wt %	Sisal fiber wt%	Polyester resin wt%	Al2O3 filler wt%
1	25	15	60	0

2	24	14	60	2
3	23	13	60	4
4	22	12	60	6
5	21	11	60	8
6	20	10	60	10

Using these proportions, the effect of fiber and Al2O3 filler was analyzed on the Glass-Sisal/Polyester composite. These values have utilized to design and calculate the density, volume and mass of the composite and the contents of Glass and Sisal fiber, Polyester matrix and filler which are used to manufacture composite samples.

3.7.1 Density and Mass of the Composite and Mass Proportions of Fibers and matrix for 40/60-0 filler Composition

To calculate the total mass of the composite; and the masses of polyester matrix, reinforcement and filler, the density of 40/60-0 composite should be determined first. The density of composite was calculated based on the rule of mixture provided in equation (3.1) [95], using the weight fractions of the matrix and chopped fibers only.

$$\rho c = \frac{1}{Wm/\rho m + Wf/\rho f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$pc = \frac{1}{0.6/1.2 + 0.25/2.54 + 0.15/1.5}$$

$$= 1.43 \mathrm{g/cm3}$$

Where,

ρc is the density of Glass- Sisal/Polyester composite

Wm is the weight fraction of the matrix=0.60

Wf is the weight fraction of fiber =0.40

ρm is the density of the matrix=1.2g/cm3, from table and

ρf is the density of sisal fiber, based on Table is found to be 1.5g/cm3.

To determine the mass of the composite, the volume of mold was calculated and it was determined using equation 3.2

Dimension of the sample=l× w × t ……………………………… (3.2)

= 27.15 x 27.15 x 0.3

= 221.14cm3

where l, w, and t stand for the sample respective lengths, widths, and thicknesses.

Mass of composite = (density of composite (ρc)) × (mold volume) ……………. (3.3)

= 1.43 g/cm3 x 221.14 cm3 = 315.91 g

Based on equations 3.1, 3.2 and 3.3, density and mass of 40/60 composite and the masses of chopped Glass and Sisal fiber and polyester were calculated and tabulated in Table 7.

Table 3 Density and mass of composite, fiber and matrix of sample one

Composite density	Mold volume	Composite mass	Glass fiber mass	Sisal fiber mass	Polyester mass	Al2O3 mass
1.43g/cm3	221.14cm3	315.91 g	78.98g	47.39g	189.55g	0

3.7.2. Density and Mass of the Composite and Mass Proportions of Fiber, matrix and Al2O3 for 40/58-2Composition

Also, the rule of mixture was utilized to determine the density of the 40-2/60 which is provided in equation 3.4**.**

$$\rho c = \frac{\mathbf{1}}{Wf/\rho f + Wm/\rho m + Wa/\rho a} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

$$= \frac{1}{0.24/2.54 + 0.14/1.5 + 0.6/1.2 + 0.02/3.95}$$

= 1.44g/cm3

Where;

Pc is the density of 40-2/58composite

Wf is the weight fraction of Glass- Sisal fiber =0.25 & 0.15

Pf is the density of glass and sisal fiber, based on Table

Wmis the weight fraction of the matrix (0.58)

$\rho m$is the density of the matrix (1.2g/cm3)

Wais the weight fraction of filler (0.02)

ρa is the density of filler. And, based on the work of [91] density of Al2O3, 3.95g/cm3has used for this calculation.

Based on equations 3.2, 3.3 and 3.4, the density and mass of 40/58-2composite and the masses of chopped Glass and Sisal fiber, polyester and Al2O3 have all calculated and tabulated in table 8.

Table 4Density and mass of sample two

Composite density	Mold volume	Composite mass	Glass fiber mass	Sisal fiber mass	Polyester mass	Al2O3 mass
1.44g/cm3	221.14cm3	319.15g	76.60 g	44.68g	191.49 g	6.38g

3.7.3. Density and Mass of the Composite and Mass Proportions of Fiber, matrix and Al2O3 for 40-4/60Composition

Using equations 3.2, 3.3 and 3.4, the density and mass of 40-4/60composite and the masses of glass and sisal fiber, polyester and Al2O3 were calculated and tabulated in Table 9.

Table 5 Density and mass of sample three

Composite density	Mold volume	Composite mass	Glass fiber mass	Sisal fiber mass	Polyester mass	Al2O3 mass
1.46g/cm3	221.14cm3	321.85g	74.02g	41.84 g	193.11 g	12.87g

3.7.4. Density and Mass of the Composite and Mass Proportions of Fiber, matrix and Al2O3 for 40-6/60Composition

Using equations 3.2, 3.3 and 3.4, the density and mass of 40-6/60 composite and the masses of glass and sisal fiber, polyester and Al2O3 have calculated and tabulated in Table 10.

Table 6 Density and mass of sample four

Composite density	Mold volume	Composite mass	Glass fiber mass	Sisal fiber mass	Polyester mass	Al2O3 mass
1.47g/cm3	221.14 cm3	324.25 g	71.34 g	38.91g	194.55 g	19.46g

3.7.5. Density and Mass of the Composite and Mass Proportions of Fiber, matrix and Al2O3 for 40-8/60Composition

Using equations 3.1, 3.2 and 3.3 density and mass of 40-8/60 composite and the masses of glass and sisal fiber, polyester and Al2O3 have calculated and tabulated in Table 11.

Table 7 Density and mass of sample five

Composite density	Mold volume	Composite mass	Glass fiber mass	Sisal fiber mass	Polyester mass	Al2O3 mass
1.48g/cm3	221.14 cm3	326.99 g	68.67 g	35.97g	196.19g	26.16g

3.7.7. Density and Mass of the Composite and Mass Proportions of Fiber, matrix and Al2O3 for 40-10/60 Composition

Using equations 3.2, 3.3 and 3.4, the density and mass of 40-10/60 composite and the masses of glass and sisal fiber, polyester and Al2O3 have calculated and tabulated in table 12.

Table 8 Density and mass of sample six

Composite density	Mold volume	Composite mass	Glass fiber mass	Sisal fiber mass	Polyester mass	Al2O3 mass
1.49g/cm3	221.14cm3	329.42g	65.88 g	32.94 g	197.65 g	32.94g

3.7.8 Total mass needed for six composites are listed as follows;

The total mass needed for six composite40-0/60, 38-2/40, 36-4/60, 34-6/60, 32-8/60 and 30-10/60 were calculated and tabulated in table 13.

Table 9 List of total mass of six composite samples to fabricate the samples

Composite specimen	Mass of Glass fiber (gm)	W% Glass fiber	Mass of Sisal fiber (gm)	W% Sisal fiber	Mass of Polyester (gm)	% Polyester	Mass of Alumina (Al2O3) (gm)	% Alumina
1	78.98	25	47.39	15	189.55	60	0	0
2	76.60	24	44.68	14	191.49	60	6.38	2
3	74.02	23	41.68	13	193.11	60	12.87	4
4	71.34	22	38.91	12	194.55	60	19.46	6
5	68.67	21	35.97	11	196.19	60	26.16	8
6	65.88	20	32.94	10	197.65	60	32.94	10
TOTAL	**435.49**		**241.57**		**1,162.54**		**97.81**	

3.6. Fabrication of Composite

The composites were manufactured at the Mechanical Engineering workshop at AAIT at room temperature. They were manufactured using a conventional hand layup procedure, then compression molding (with subsequent weight addition during curing for a specified period of time).

First, the fibers were chopped into 30 mm lengths. This length was used for all six composites. A hand stirrer was used to measure and combine the two fibers. The two fibers were evenly distributed throughout one another thanks to the swirling. Then, the mixed fibers were manually spread out to form layers of a specific thickness. This was done by uniformly dispersing the mixed fibers and then adding weight over them inside the mold.

The prepared wooden molds were polished and cleaned, and then a composite mold releasing agent/wax was applied. The wooden molds were manually lubricated with wax, which helps to separate the cured composite from the mold easily.

A predetermined amount of polyester was weighed and poured into the stirrer. The designed weight percentage of Al2O3 was then weighed and added. The polyester and Al2O3 mix were stirred intermittently at high speed for 2 minutes to ensure that the Al2O3 was uniformly distributed in the polyester. After this, the polyester and Al2O3 mix was allowed to outgas bubbles for 5 minutes, this could have an impact on the ultimate characteristics of the composite. Next, 2 wt% of MKEP catalyst was added to the polyester and Al2O3 mix and stirred manually for 2 minutes to accelerate curing process.

The polyester and Al2O3 mix were then blended with the designed weight percentage of mixed fibers layers in the wax-lubricated wooden mold. The fibers were manually spread out until they were fully and uniformly impregnated with the polyester-Al2O3 mix. The wooden mold containing the glass-sisal fiber/polyester-Al2O3 mix was then closed with a wax-lubricated wooden cap.

The mold was subjected to a uniform load of 10 tons (1 MPa) using a hydraulic press machine for the compression and curing procedure. This made it easier to remove extra glue and keep the thickness consistent. At room temperature, the composite was subjected to the load for a whole day. The mold was opened 24 hours later, and the manufactured composite material was carefully removed.

Repeating this process resulted in 6 composites. They were all produced and allowed to cure at room temperature.

a) Chopped glass fiber

b) Chopped sisal fiber

b) Mixed glass and sisal fibers

d) Mixing Al2O3 and polyester resin

e) Placing fiber and matrix in the mold

f) Compression and curing

g) Final product

Figure 19 Fabrication process of composite (a) Chopped glass fiber (b) chopped sisal fiber (c)Mixed glass and sisal fibers (d)mixing Al2O3 and polyester resin (e) placing fiber and matrix in the mold (f) compression and curing (g) Final product

3.7. Test Specimen Preparation

The specimen created for this thesis complied with the requirements set forth by the American Society for Testing Materials. The specimens were ready for surface morphology, tensile, flexural, impact, and water absorption tests. The manufactured composites were cut in accordance with ASTM requirements using a normal hand grinder.

Table 10 ASTM standards for specimen preparation

Test	Standards	Specimen dimension in mm
Tensile Test	**ASTM D3039**	**250 x 25 x3**
Flexural Test	**ASTM D790**	**125 x 13 x 3**
Impact test	**ASTM D256**	**64 x 13 x 3**
Water absorption test	**ASTM D570**	**76 x 25 x 25**
Density test		**40x20x3**

3.8. Experimental Testing, Result and Discussion

3.8.1. Tensile Test

3.8.1.1. Tensile test procedures

The tensile test was carried out at room temperature at Ethiopian Technical Institute in accordance with ASTM D3039 using a Balreo Universal testing machine moving at a speed of 60 mm per minute along the composite's longitudinal direction. The specimen sample was inserted vertically into the testing apparatus's jaws. A minimum of five specimens were made and tested for every composite specimen. Three were chosen, and each was examined. Both the lower and upper jaws could move. When a fracture occurs, the machine stops and shows the results on a computer.

Figure 20 Specimen for tensile test

Figure 21 Tensile testing machine

Figure 22Test specimen under tension

Figure 23Specimen after braking

3.8.1.2 .Tensile Test Result

Composite specimen with no Al2O3 filler material and have hybrid fiber with composition of 25% Glass fiber, 15% sisal fiber and 60% polyester matrix have its stress-strain diagram is shown in Figure 39. For this composite three specimens were tested according to ASTM D3039.

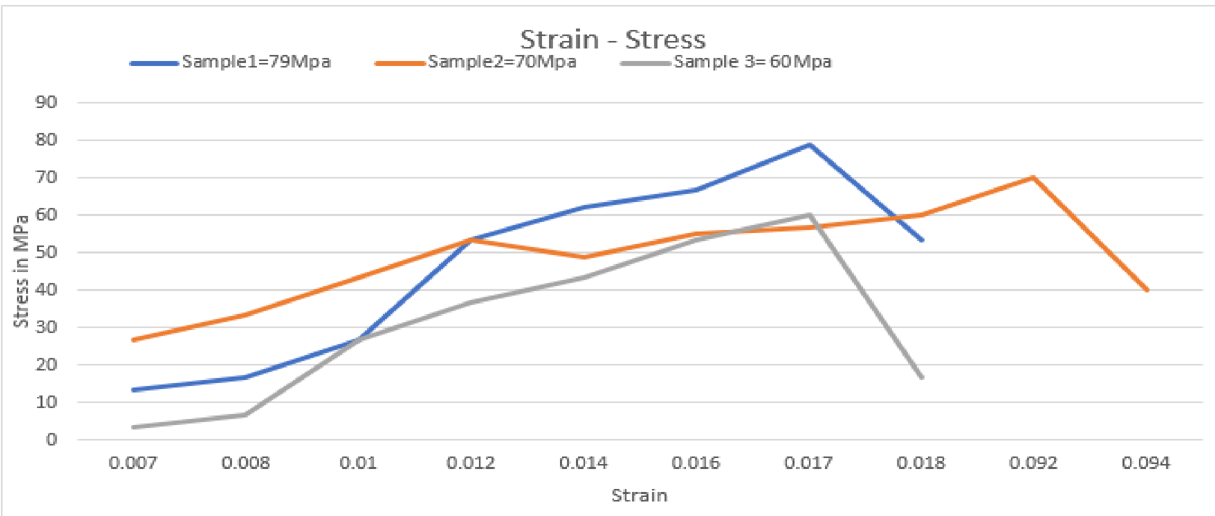


Figure 24 Tensile stress -strain curve for sample 1

The tensile strengths of the three specimens and their average of sample with addition of 0% filler are shown in figure 40.

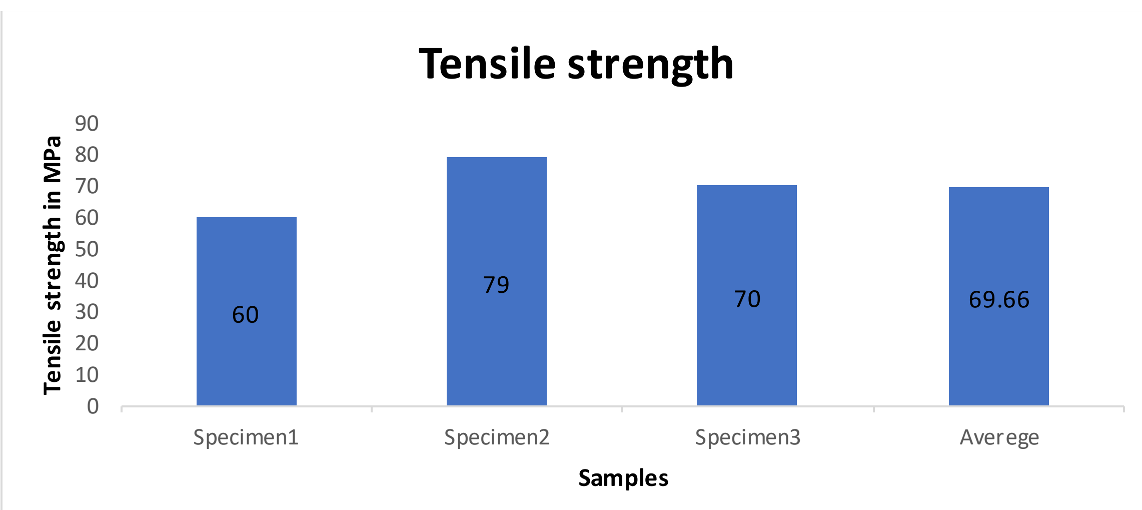


Figure 25 tensile stress for each specimen and their average for composite1

Three specimens were examined in accordance with ASTM D3039 for treated composites with chopped reinforced hybrid fibers composed of 24% glass, 14% sisal, 60% polyester, and 2% Al2O3.On figure 41, the highest tensile stress and its average from the samples were displayed.

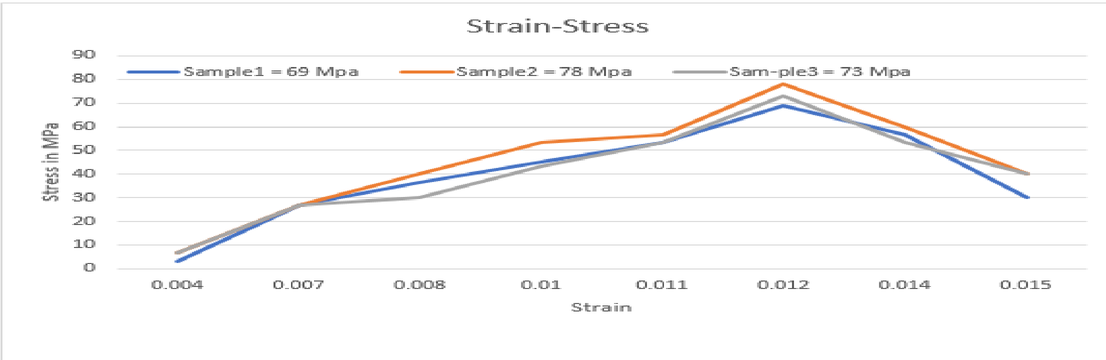


Figure 26 Tensile stress - strain curve for sample 2

The tensile strengths of the three specimens and their average of sample with addition of 2% filler are shown in figure 42.

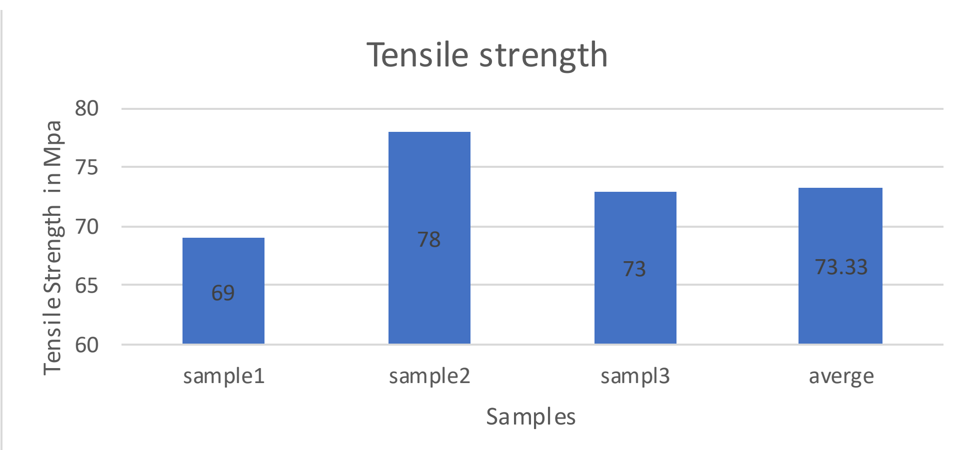


Figure 27 tensile stress for each specimen and their average for composite 2

Three specimens were examined in accordance with ASTM D3039 for treated composite with chopped reinforced hybrid fibers composed of 23% glass, 13% sisal, 60% polyester, and 4% Al2O3. On figure 43, the highest tensile stress and its average from the samples were displayed.

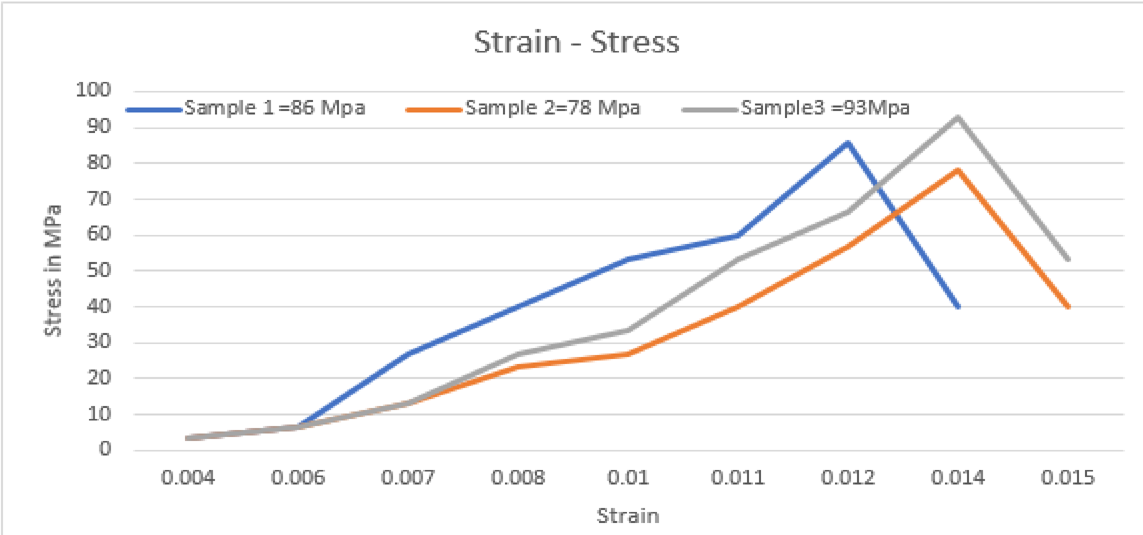


Figure 28 tensile stress - strain curve for composite 3

The tensile strengths of the three specimens and their average of sample with addition of 4% filler are shown in figure 44.

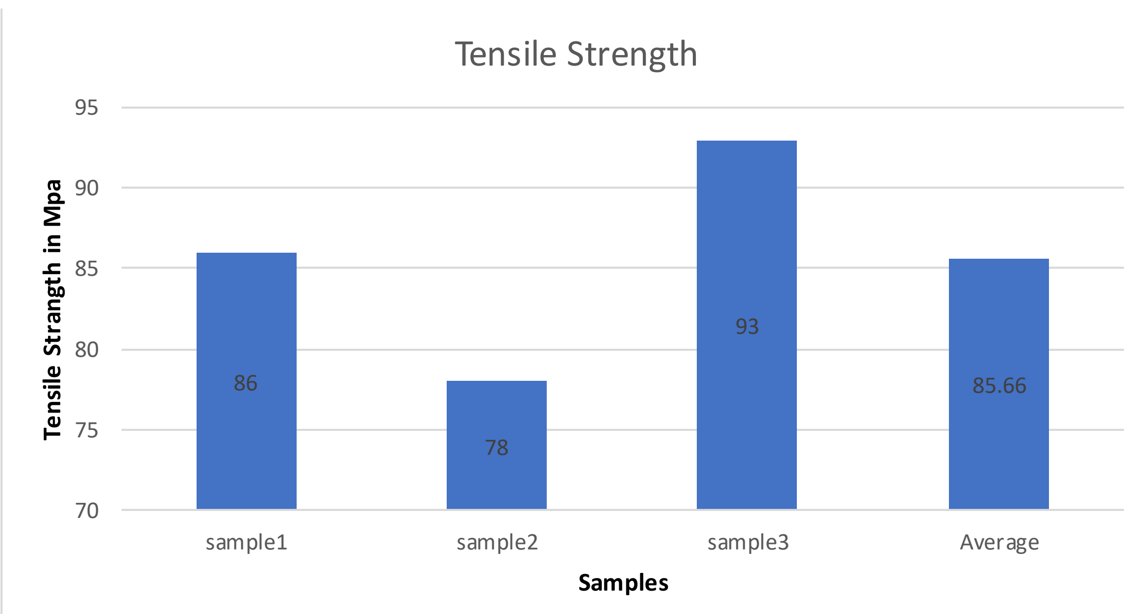


Figure 29 tensile stress of each specimen and their average for composite3

Three specimens were examined in accordance with ASTM D3039 for treated composites with chopped reinforced hybrid fibers composed of 22% glass, 12% sisal, 60% polyester, and 6% Al_2O_3. On figure 45, the highest tensile stress and its average from the samples were displayed.

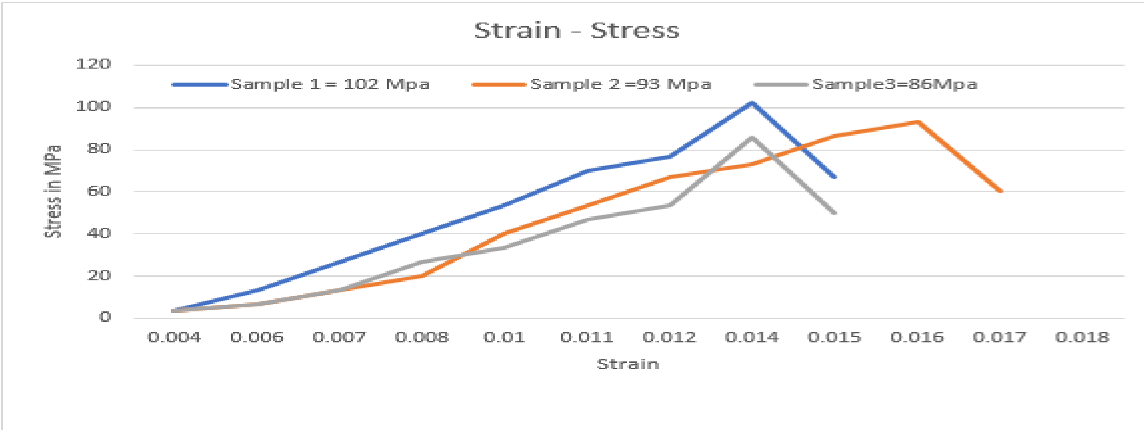


Figure 30 tensile stress - strain curve for composite 4

The tensile strengths of the three specimens and their average of sample with addition of 6% filler are shown in figure 46.

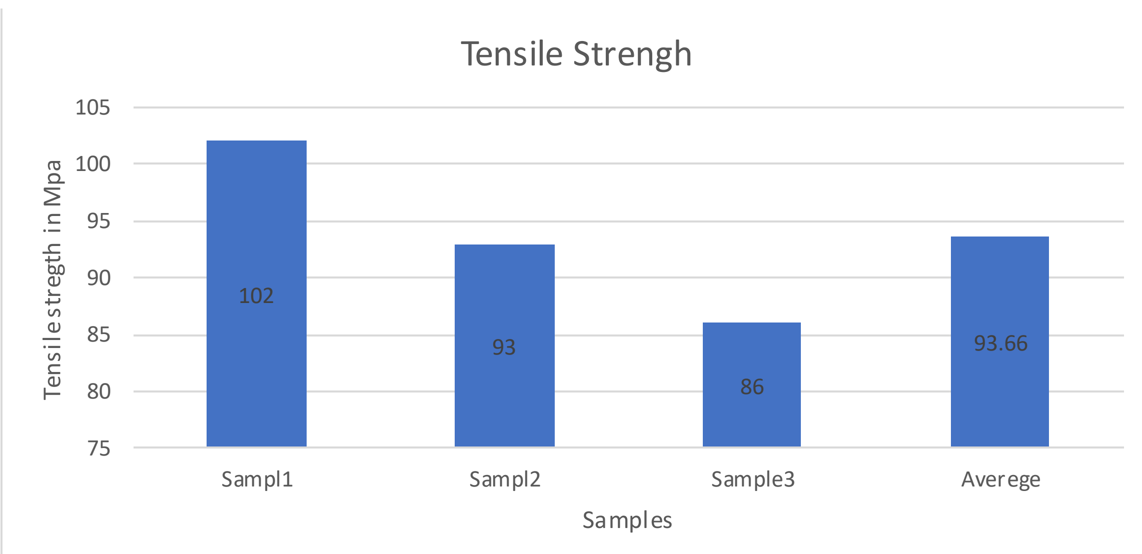


Figure 31 Tensile stress of each specimen and their average for composite 4

Three specimens were examined in accordance with ASTM D3039 for treated composites with chopped reinforced hybrid fibers composed of 21% glass, 11% sisal, 60% polyester, and 8% Al2O3. On figure 47, the highest tensile stress and its average from the samples were displayed.

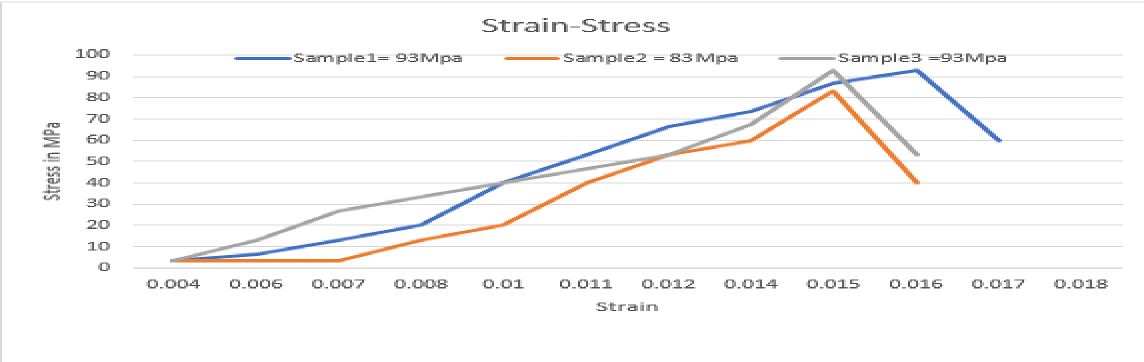


Figure 32 Tensile stress - strain curve for composite 5

The tensile strengths of the three specimens and their average of sample with addition of 8% filler are shown in figure 48.

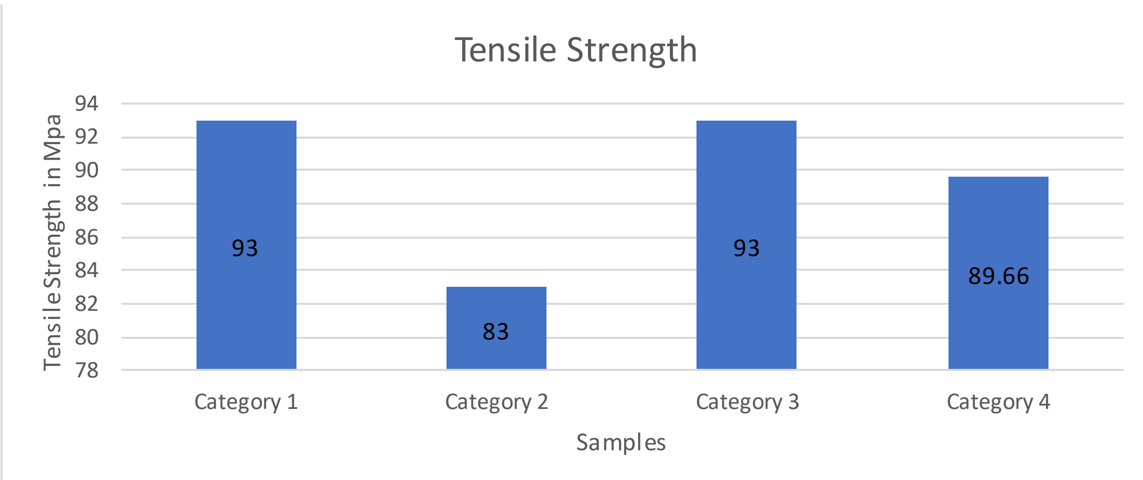


Figure 33 Tensile stress for each specimen and their average for composite 5

Three specimens were examined in accordance with ASTM D3039 for treated composite with chopped reinforced hybrid fibers composed of 20% glass, 10% sisal, 60% polyester, and 10% Al_2O_3. On figure 49, the highest tensile stress and its average from the samples were displayed.

.

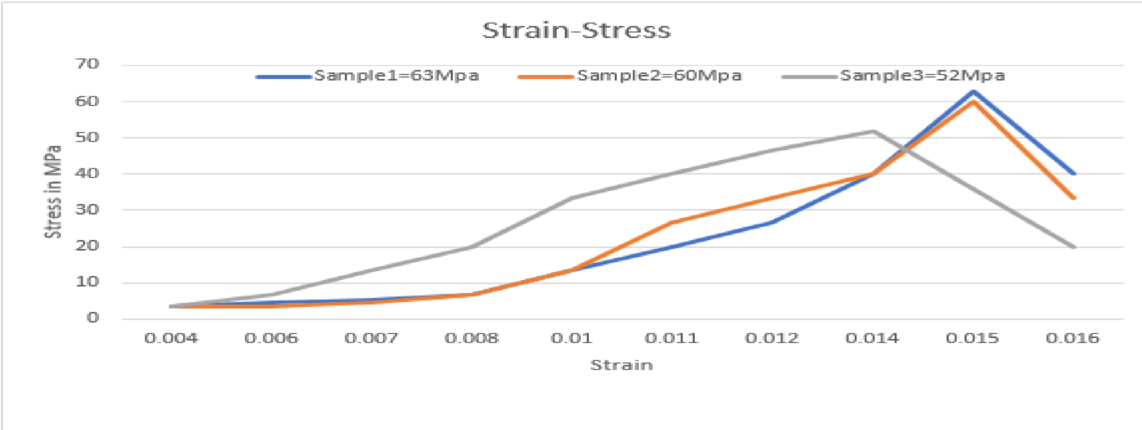


Figure 34 Tensile stress - strain curve for composite 6

The tensile strengths of the three specimens and their average of sample with addition of 10% filler are shown in figure 50.

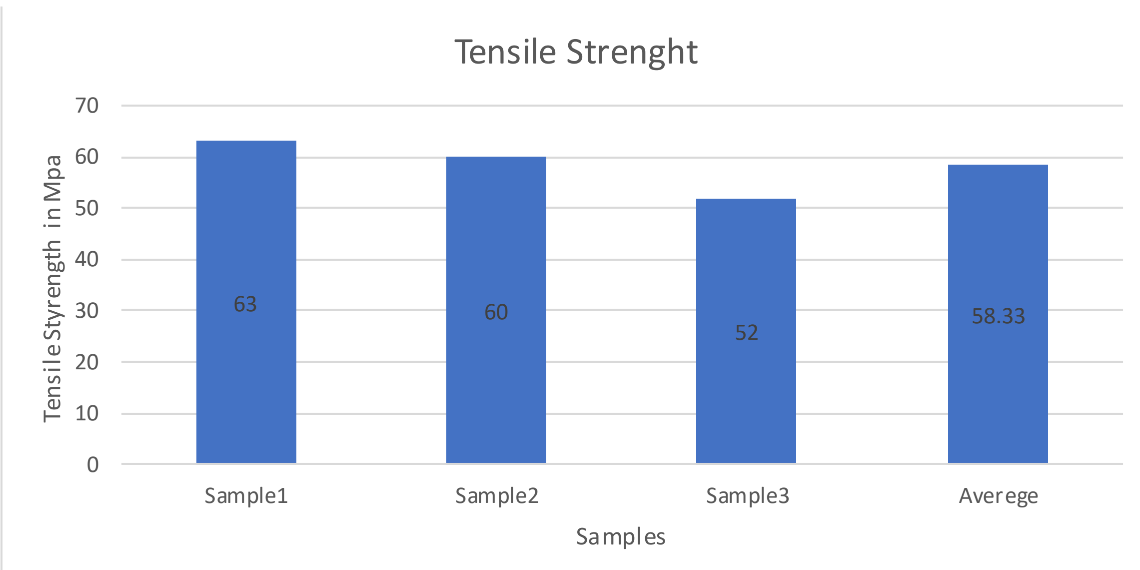


Figure 35 tensile stress for each specimen and their average for composite 6

3.8.1.3. Tensile Test result and discussion

It is uncommon for researchers to use Al2O3 filler in fiber-reinforced polymer matrix composites to improve the properties of metallic matrix materials. Instead, ceramic fillers are often used.

Figure 58 shows that adding Al2O3 as a filler has an impact on the glass-sisal/polyester composite's tensile strength.

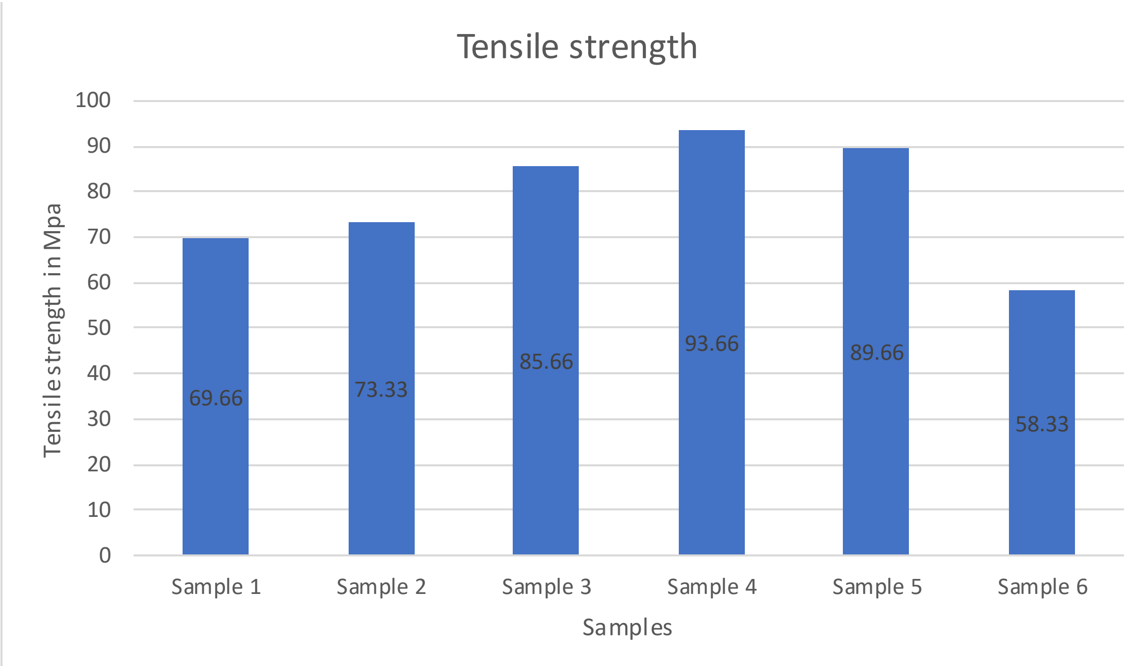


Figure 36 Tensile test result of the six composite

The study's findings demonstrated that, up until a filler level of 6%, the tensile strength of the glass fiber/sisal fiber/polyester composites increased with increasing Al2O3 content. After that, it dropped. It was discovered that 6% Al2O3 filler was necessary for the highest tensile strength.

The % enhancement of the property on each sample is as follows:

- Sample 1 (0% Al2O3): 69.66 MPa
- Sample 2 (2% Al2O3): 73.33 MPa, an increase of 5%
- Sample 3 (4% Al2O3): 84.44 MPa, an increase of 21.2%
- Sample 4 (6% Al2O3): 93.66 MPa, an increase of 34.5%
- Sample 5 (8% Al2O3): 89.66 MPa, an increase of 28.7%
- Sample 6 (10% Al2O3): 58.33 MPa, a decrease of 16.3%

The sample with 6% Al_2O_3 (sample 4) had the highest tensile strength, which was 34.5% higher than the sample with no Al_2O_3 (sample 1). This is because the 6% Al_2O_3 content was sufficient to fill in the voids between the glass fiber and sisal fiber without causing agglomeration. This resulted in a strong and uniform bond between the fibers and the matrix, which improved the tensile strength of the composite material.

The samples with 8% and 10% Al_2O_3 (samples 5 and 6) had lower tensile strengths than the sample with 6% Al_2O_3. This is because the high concentration of Al_2O_3 particles caused agglomeration and stress concentration at the fiber-matrix interface. This resulted in a weaker bond and premature failure of the composite material.

In conclusion, the Al_2O_3 filler content for maximum tensile strength of glass fiber/sisal fiber/polyester composites is 6%.

3.8.2. Flexural Test

3.8.2.1. Flexural test procedures

The Flexural Test was carried out at Defense Engineering College in compliance with ASTM D790. The flexural strength in this test was determined using the three-point bending mode. The specimen was positioned on a two-point support bed with a 125mm spread. Next, a load-bearing one-point upper jaw was placed to the specimen's middle span. Room temperature was used for the experiment. Each composite sample was tested, a minimum of three times.

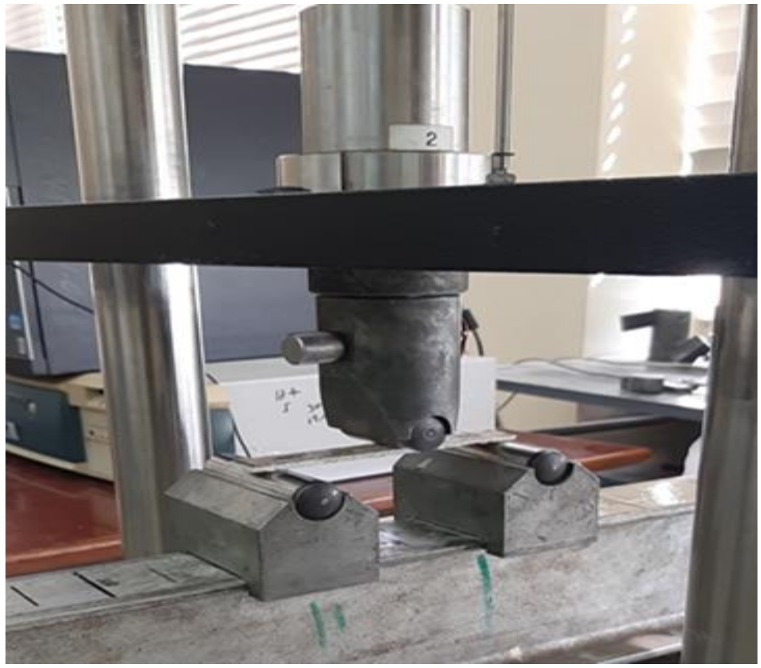


Figure 37 Specimen for flexural test

Figure 38 Specimen under flexural test

Figure 39 Specimens after flexural deformation

3.8.2.2 Flexural Test Result

The three-point bending test yielded the flexural test result. Three specimens were obtained as a result. Equation 4.1, 4.2, 4.3 was utilized by the machine to determine the flexural strength.

Section modulus (Wb) Wb = B*(HxH)/6………………………………. 4.1

Maximum bending Moment (Mbmax) $Mbmax$ =FmaxXL/4………… 4.2

From this,

Flexural Strength (δbmax) $\delta bmax = Mbmax/Wb$………………………. 4.3

Whereas B is the specimen's width. H stands for specimen thickness, the maximum applied force is Fmax. L stands for span length.

Figure 51 show how the machine calculate the flexural strength of the composites.

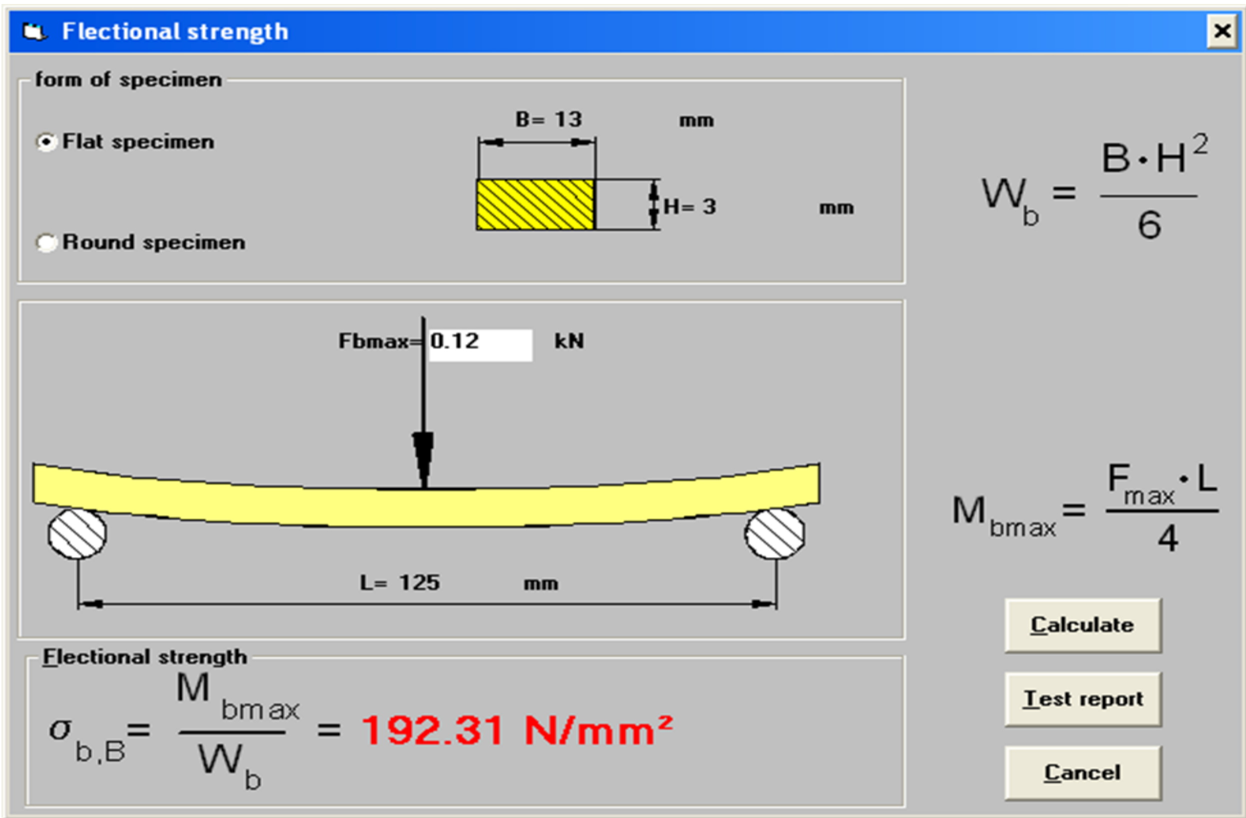


Figure 40 Computer output of flexural result

Three specimens were evaluated in accordance with ASTM D790 for treated composite with chopped reinforced hybrid fibers consisting of 25% glass, 15% sisal, 60% polyester, and 0% Al_2O_3. The results are displayed in the graph of figure 52.

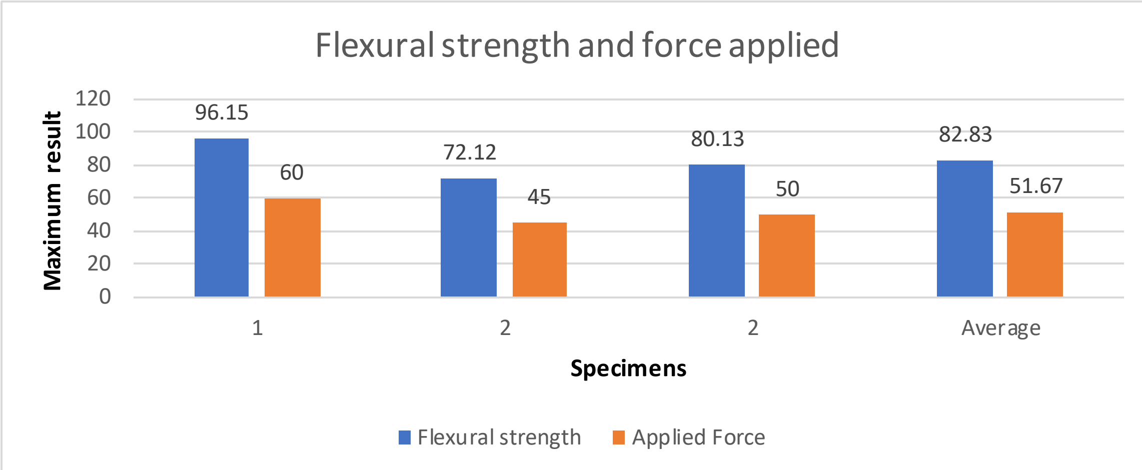


Figure 41 Flexural results of sample 1 and their average

Three specimens were examined in accordance with ASTM D790 for treated composites with chopped reinforced hybrid fibers composed of 24% glass, 14% sisal, 60% polyester, and 2% Al2O3. The results are displayed in figure 53.

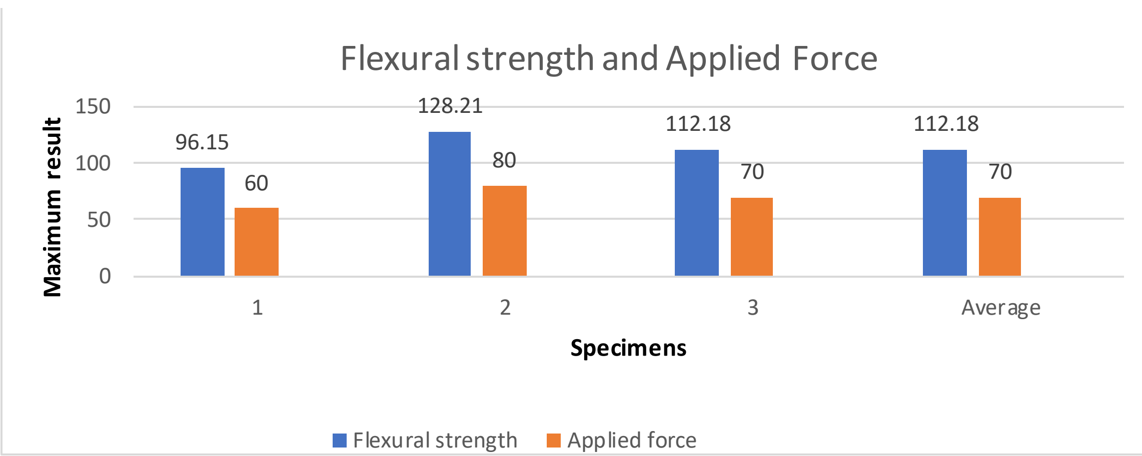


Figure 42 Flexural results of sample 2 and their average

Three specimens were evaluated in accordance with ASTM D790 for a treated composite with chopped reinforced hybrid fibers that was composed of 23% glass, 13% sisal, 60% polyester, and 4% Al2O3. The results are displayed in figure 54.

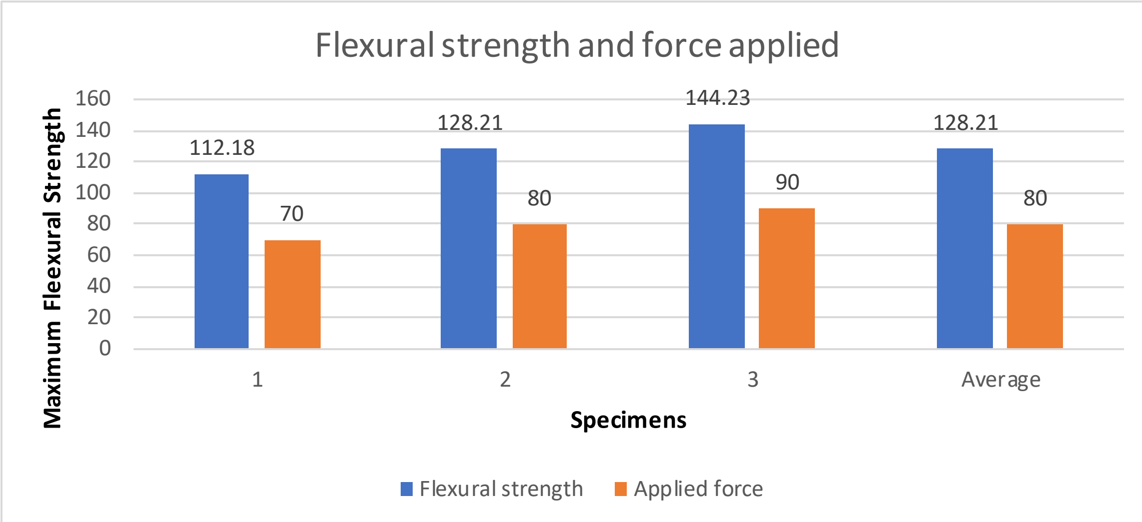


Figure 43 flexural results of sample 3 and their average

Three specimens were examined in accordance with ASTM D790 for a treated composite with chopped reinforced hybrid fibers that was composed of 22% glass, 12% sisal, 60% polyester, and 6% Al2O3. The results are displayed in figure 55.

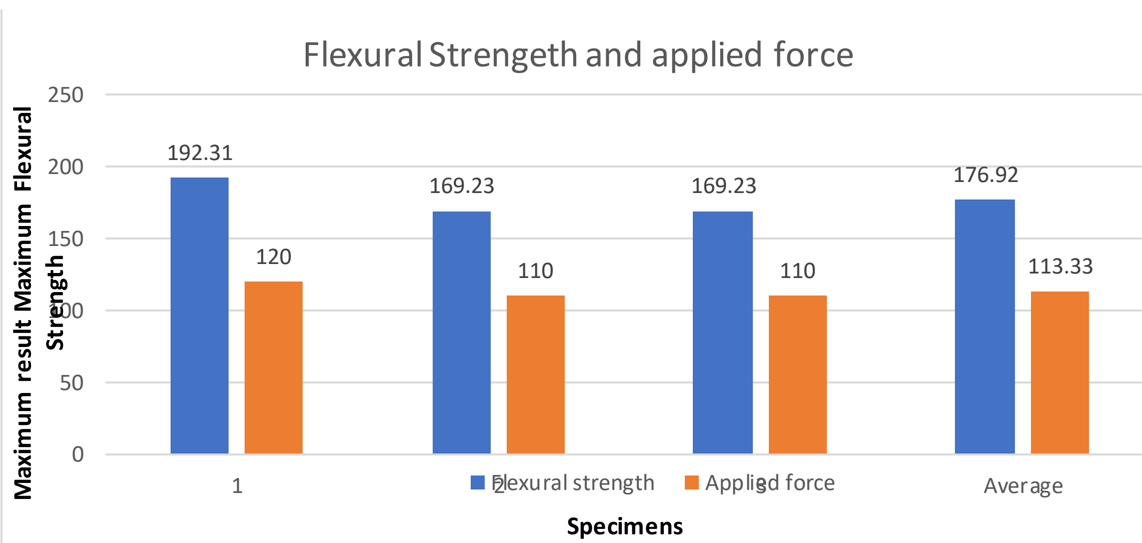


Figure 44 Flexural results of sample 4 and their average

Three specimens were evaluated in accordance with ASTM D790 for a treated composite including chopped reinforced hybrid fibers with a composition of 21% glass, 11% sisal, 60% polyester, and 8% Al2O3. The results are displayed on figure 56.

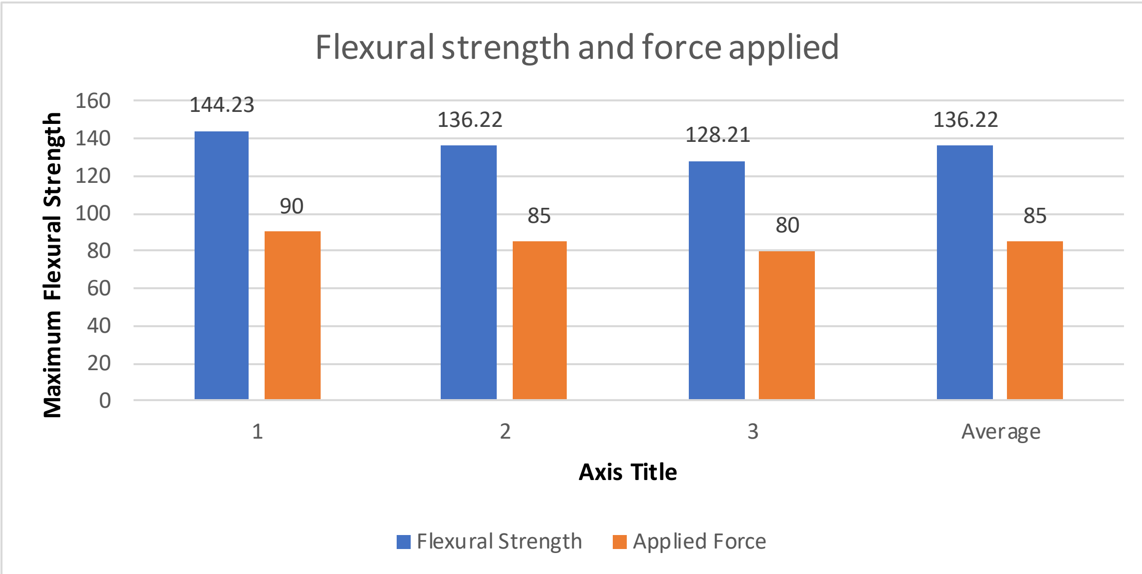


Figure 45 Flexural results of sample 5 and their average

Three specimens were evaluated in accordance with ASTM D790 for a treated composite with chopped reinforced hybrid fibers that was composed of 20% glass, 10% sisal, 60% polyester, and 10% Al2O3. The results are displayed on figure 57.

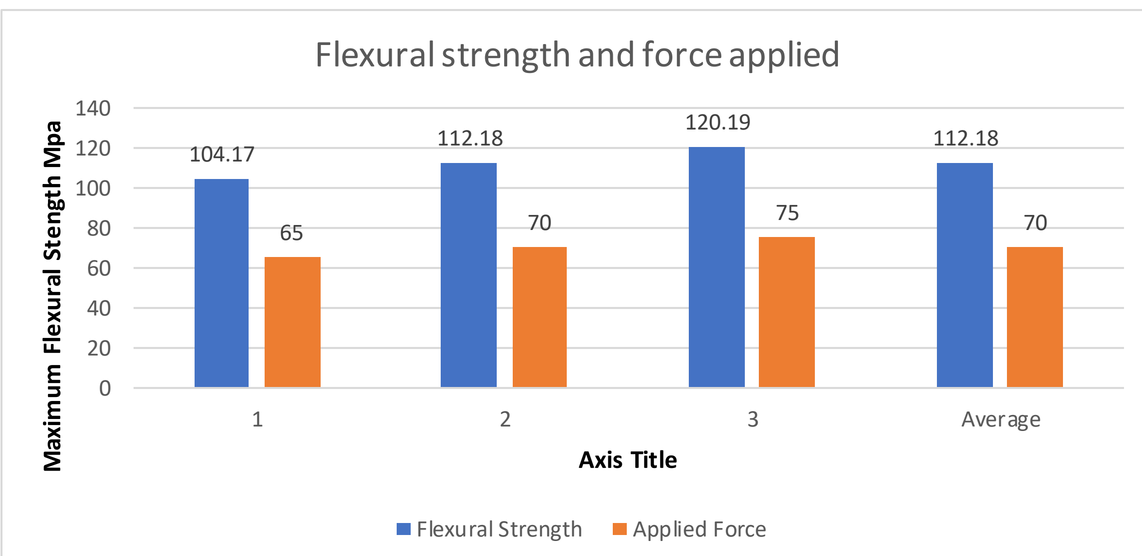


Figure 46 Flexural results of sample 6 and their average

3.8.2.3 Flexural Test result discussion

Experimental research was done to determine how Al2O3 filler affected the glass-sisal fiber reinforced polyester composite's flexural strength. Various percentages of Al2O3 filler (0%, 2%, 4%, 6%, 8%, and 10%) were used to make six samples. After that, a three-point bending test was used to determine each sample's flexural strength. Figure 59's results demonstrate that, up to a certain point, the inclusion of Al2O3 filler enhanced the composite's flexural strength. The sample with 6% Al2O3 filler had the maximum flexural strength, 2.13 times more than the control sample's flexural strength without Al2O3 filler. However, the samples with 8% and 10% Al2O3 filler showed a modest loss in flexural strength.

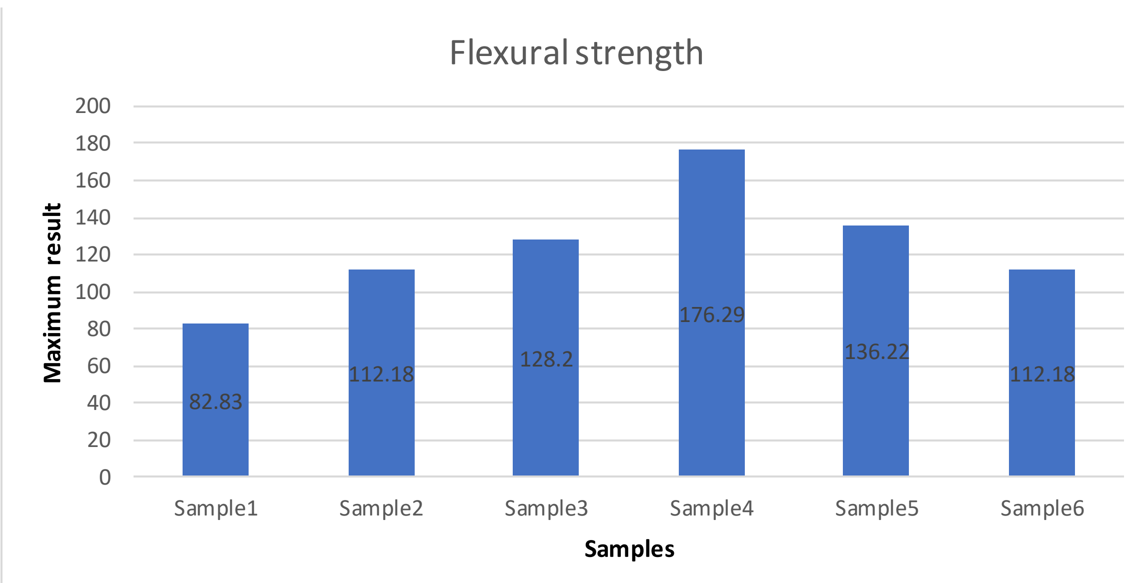


Figure 47 Flexural test results of the six composite

This trend can be explained by the following factors:

- Al2O3 filler is strong material, which can reinforce the composite and improve its flexural strength.
- Al2O3 filler can also improve the interfacial bonding between the fibers and the resin matrix, which further increases the flexural strength of the composite.

- On the other hand, agglomeration caused by an excessive amount of Al_2O_3 filler might weaken the composite and lower its flexural strength. The study's findings imply that Al_2O_3 filler can be utilized to increase the glass-sisal fiber reinforced polyester composite's flexural strength. However, in order to prevent agglomeration and guarantee the highest possible flexural strength, it is crucial to select the ideal percentage of Al_2O_3 filler.

3.8.3. Impact test

3.8.3.1. Impact test procedure

The impact test at Defense Engineering College was carried out in compliance with ASTM D256. The specimen was clamped into the tester's bed in order to measure its fracture toughness. The specimen was then dropped to cause impact fractures. All six composites were subjected to an impact strength test using Charpy impact. The dial indicator on the pendulum rod allowed observers to see how much energy the specimen absorbed during the breaking—also known as the specimen's impact strength. It displays the impact strength clearly.

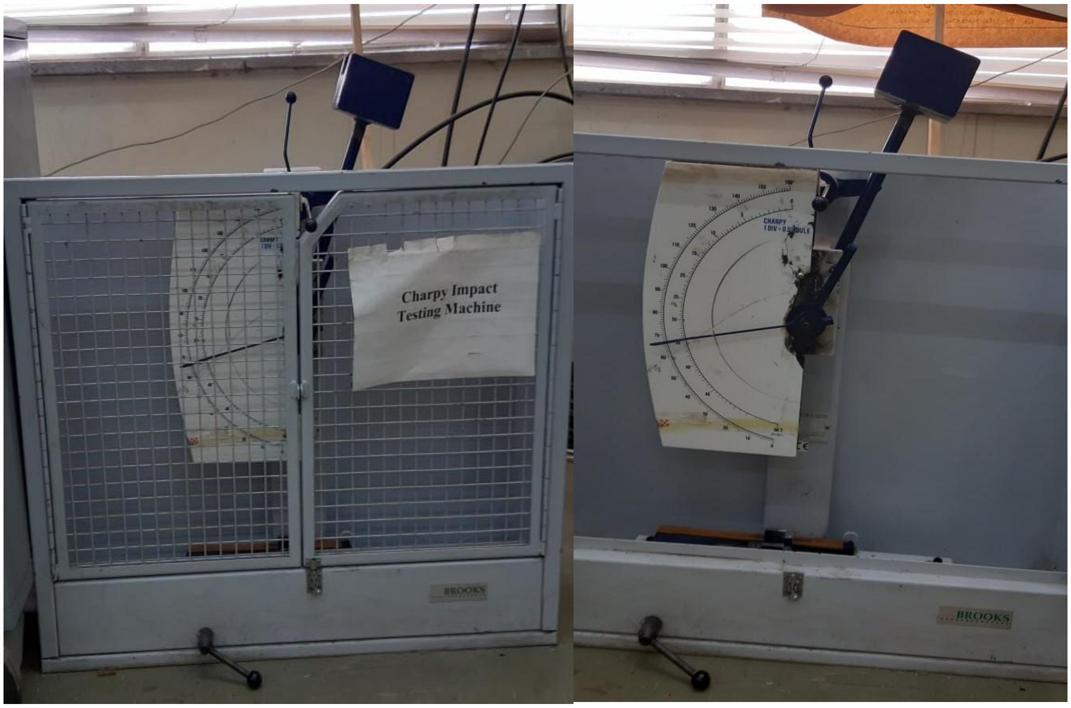


Figure 48 Impact testing machine

Figure 49 Specimen for impact test

Figure 50 Specimen after deformation

3.8.3.2. Impact Test Result

Following the impact test, the impact energy of five specimens from each sample was noted. For every sample, the impact energy average values were calculated and published. The findings of Charpy impact tests on hybrid sisal-glass polyester hybrid composites with Al2O3 filler material produced at varying filler material volume fractions are displayed in Table 17. The findings demonstrate that impact resistance qualities of the hybrid composite are improved by increasing the volume fraction of filler.

Table 11 List of impact test result of six samples

NO	Composite Composition	Sample No.	Impact Energy (J)
1	Glass fiber 25 %Sisal fiber 15%Polyester resin 60%Al2O3 filler 0%	1	16
		2	14
		3	15
		Average	15
2	Glass fiber 24 %, Sisal fiber 14%, Polyester resin 60%, Al2O3 filler 2%	1	17
		2	15
		3	16
		Average	16
3	Glass fiber 23%, Sisal fiber 13%, Polyester resin 60%, Al2O3 filler 4%	1	17
		2	18
		3	17
		Average	17.33
4	Glass fiber 22%, Sisal fiber 12%, Polyester resin 60%, Al2O3 filler 6%	1	20
		2	23.5
		3	22
		Average	21.83

5	Glass fiber 21%, Sisal fiber 11%, Polyester resin 60%, Al_2O_3 filler 8%	1	20
		2	24
		3	22.5
		Average	22.17
6	Glass fiber 20%, Sisal fiber 10%, Polyester resin 60%, Al_2O_3 filler 10%	1	19
		2	18.5
		3	17.5
		Average	18.33

3.8.3.3 Impact Test result discussion

The effect of Al_2O_3 filler on the impact energy of glass-sisal fiber reinforced polyester composite was investigated experimentally. Six samples were prepared with different percentages of Al_2O_3 filler (0%, 2%, 4%, 6%, 8%, and 10%). The impact energy of each sample was then measured using a Charpy impact test.

The results on figure 60 showed that the impact energy of the composite increased with the addition of Al_2O_3 filler up to a certain point. The highest impact energy was achieved for the sample with 8% Al_2O_3 filler, which was 1.45 times higher than the impact energy of the control sample without Al_2O_3 filler. However, the impact energy decreased slightly for the samples with 10% Al_2O_3 filler.

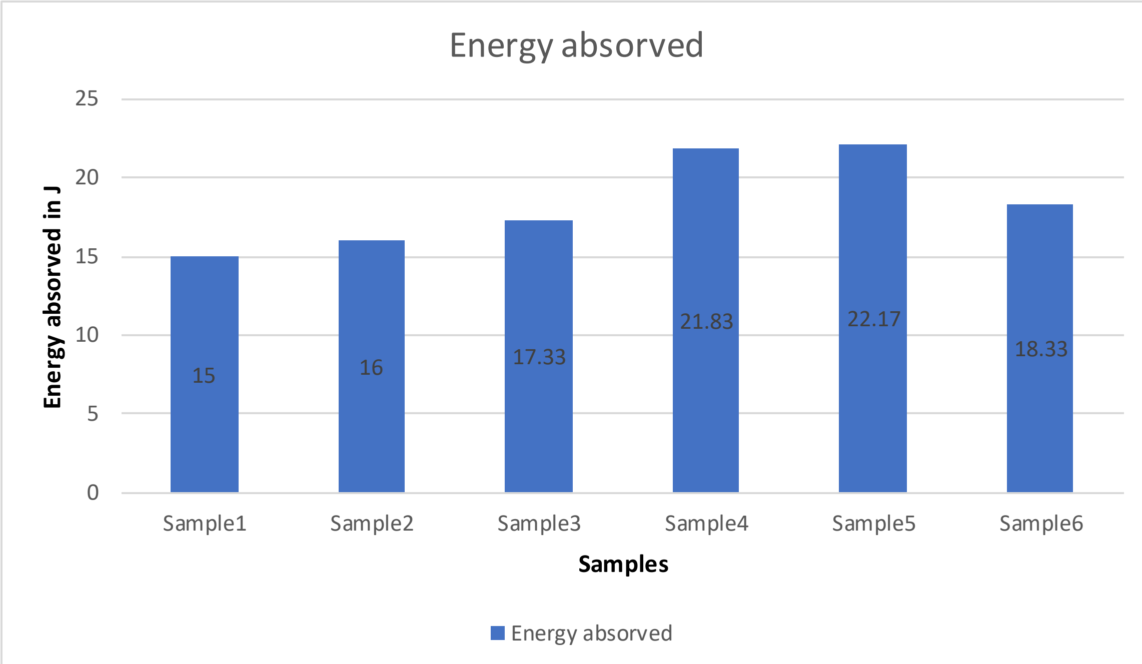


Figure 51 Impact test result of the six composites

This trend can be explained by the following factors:

- Al2O3 filler is a robust substance that can enhance the impact energy of the composite by absorbing more energy upon impact.
- Al2O3 filler can also strengthen the link between the fibers and the resin matrix, increasing the composite's impact energy even further. On the other hand, if too much is added, it can cause agglomeration, which weakens the composite and lowers its impact energy.

The results of this study suggest that Al2O3 filler can be used to improve the impact energy of glass-sisal fiber reinforced polyester composite. However, it is important to choose the optimal percentage of Al2O3 filler to avoid agglomeration and ensure maximum impact energy.

3.8.4. Water absorption test

3.8.4.1 Water absorption test procedure

In the water absorption test, which was carried out in accordance with ASTM D570, each specimen was submerged in water for a full day at room temperature. Prior to sowing, every specimen was weighed using an electronic digital balance, and the outcomes of every sample were recorded. The specimens were then taken out and cleaned to get rid of any extra water on the surface after being socked for 24 hours. The specimens were then eventually weighed one more time. Following this procedure, the following formula was used to get the mass gain as a percentage.

$$\frac{(\text{Final Weight minus Initial Weight})}{\text{Initial Weight}} \times 100 = \text{water absorption \%} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \ldots.3.5$$

Figure 52 Specimen for water absorption test

Figure 53 Specimen soaked in water

3.8.4.2 Water Absorption Test Result

Thirty composites were submerged in water for twenty-four hours as part of the water absorption test. After measuring the mass both before and after socks, the water absorption percentage was computed using formula 3.5, with the results recorded in table 16.

$$\text{Percentage of water absorption} = \frac{\text{(Final Weight - Initial Weight) x 100}}{\text{Initial Weight}} \ldots\ldots\ldots\ldots 3.5$$

Table 12 List of water absorption result

No.	Composite Composition	Sample No.	Water Absorption (%)
1	Glass fiber 25 %Sisal fiber 15%Polyester resin 60%Al2O3 filler 0%	1	4.3
		2	4.44
		3	3.96
		Average	4.23
2	Glass fiber 24 %, Sisal fiber 14%, Polyester resin 60%, Al2O3 filler 2%	1	3.75
		2	4.26
		3	4.33
		Average	4.11
3	Glass fiber 23%, Sisal fiber 13%, Polyester resin 60%, Al2O3 filler 4%	1	3.8
		2	4.6
		3	3.4

		Average	3.96
4	Glass fiber 22%, Sisal fiber 12%, Polyester resin 60%, Al2O3 filler 6%	1	3.6
		2	3.2
		3	4.25
		Average	3.68
5	Glass fiber 21%, Sisal fiber 11%, Polyester resin 60%, Al2O3 filler 8%	1	4.12
		2	3.37
		3	4
		Average	3.83
6	Glass fiber 20%, Sisal fiber 10%, Polyester resin 60%, Al2O3 filler 10%	1	2.6
		2	3.1
		3	3.5
		Average	3.06

3.8.4.3 Water Absorption result discussion

The effect of Al_2O_3 filler on the water absorption of glass-sisal fiber reinforced polyester composite was investigated experimentally. Six samples were prepared with different percentages of Al_2O_3 filler (0%, 2%, 4%, 6%, 8%, and 10%), while the percentages of glass fiber, sisal fiber reduce equally with the percentage of filler added, and polyester resin were kept constant at 25%, 15%, and 60%, respectively. The water absorption of each sample was then measured using a water immersion test.

The results showed that the water absorption of the composite decreased with the addition of Al_2O_3 filler. The sample with 10% Al_2O_3 filler had the lowest water absorption, which was 3.06%.

This trend can be explained by the following factors:

- Al_2O_3 filler is a hydrophobic material, which means that it repels water. Therefore, adding Al_2O_3 filler to the composite can reduce the number of hydrophilic sites on the surface of the composite and reduce its water absorption.
- Al_2O_3 filler can also improve the connection between the fibers and the resin matrix. This can reduce the number of micro pores in the composite, which can also help to reduce water absorption.

The results of this study suggest that Al_2O_3 filler can be used to reduce the water absorption of glass-sisal fiber reinforced polyester composite. This can be beneficial for applications where the composite will be exposed to water or humid environments.

3.8.5. Density Measurement

3.8.5.1 Density test procedure

Using the Archimedes principle, the density was determined. A digital balance was used to weigh the composite specimen, and the weight of each specimen was noted. Following the completion of the weight recording, the specimens were submerged in a water-filled measuring container. The specimen's rise in water level was measured to determine its volume after it had been completely submerged in the liquid. Equation 3.6 was used to calculate the density based on the mass and volume of the specimens

$$p = m/ v_f - v_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where ρ is the density of the composite,

m is the mass of a single specimen

V_f is the volume of the water when a specimen is immersed.

V_i is the volume of the water before a specimen is immersed.

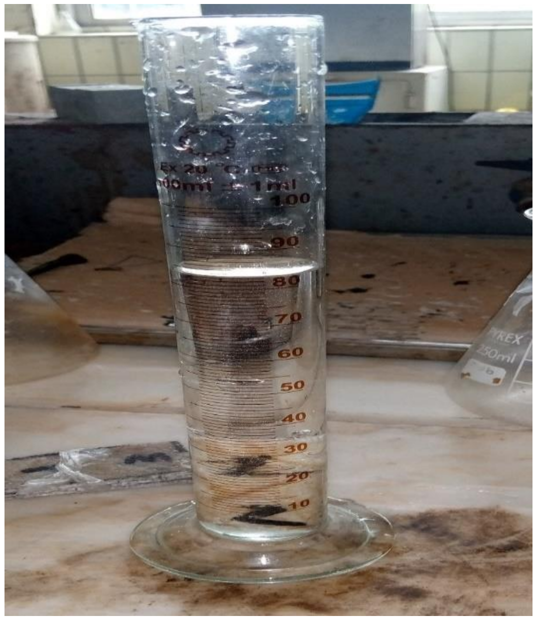


Figure 54 Specimen immersed in water filled measuring container

3.8.5.2 Density Test Result

The density of composite was calculated using Archimedes principle. The results of the different composite samples found are depicted in Table 17.

Table 13 Density test result of six samples and their average

NO.	Composite Composition	Sample NO	Density g/cm3
Sample 1	Glass fiber 25 %Sisal fiber 15%Polyester resin 60%Al2O3 filler 0%	1	1.15
		2	1.2
		3	1.86
		Average	1.41
Sample 2	Glass fiber 24 %, Sisal fiber 14%, Polyester	1	1.4
		2	1.2

	resin 60%, Al2O3 filler 2%	3	1.5
		Average	1.37
Sample 3	Glass fiber 23%, Sisal fiber 13%, Polyester resin 60%, Al2O3 filler 4%	1	1.5
		2	1.47
		3	1.6
		Average	1.52
Sample 4	Glass fiber 22%, Sisal fiber 12%, Polyester resin 60%, Al2O3 filler 6%	1	1.48
		2	1.5
		3	1.35
		Average	1.44
Sample 5	Glass fiber 21%, Sisal fiber 11%, Polyester resin 60%, Al2O3 filler 8%	1	1.3
		2	1.33
		3	1.05
		Average	1.22
Sample 6	Glass fiber 20%, Sisal fiber 10%, Polyester resin 60%, Al2O3 filler 10%	1	1.1
		2	1.3
		3	1.36
		Average	1.25

3.8.5.3 Density test result discussion

The density of the composites ranges from 1.52 g/cm³ to 1.22 g/cm³. The density of the hybrid composite decreases as the volume of Al2O3 increases. Figure 4.1 shows the variation of density in the six composite samples. Sample 3 has the highest density, with a value of around 1.5.2 g/cm³.

In general, the density test results conclude that increasing the content of glass Al2O3 decreases the weight of the developed composite.

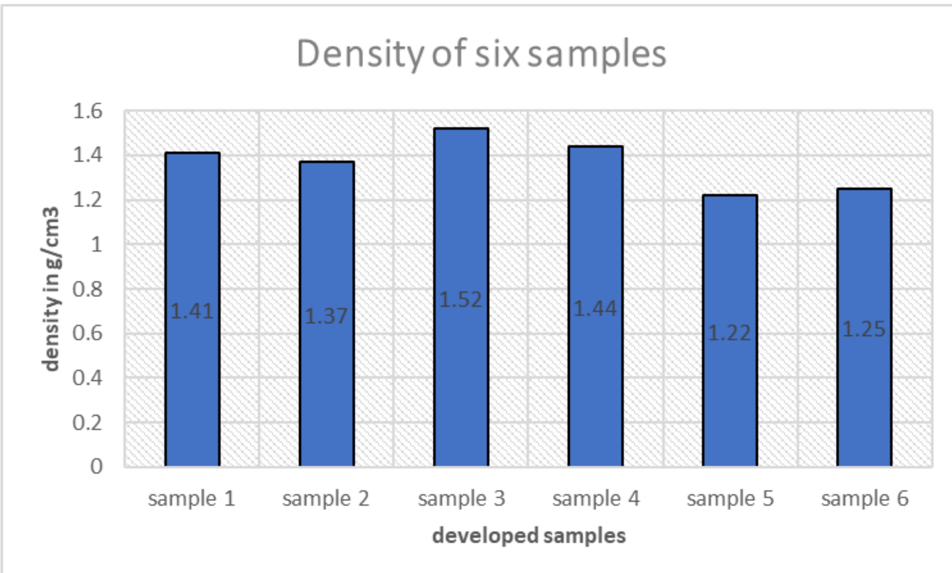


Figure 55 Density tests of the six composites

CHAPTER FOUR

SIMULATION OF WIND TURBINE BLADE

4.1 Finite Element Modeling

Throughout their service life, wind turbine blades are exposed to a range of static and dynamic loads. It's critical to confirm that the blades are built to sustain these stresses without breaking. A strong technique for forecasting the structural and dynamic behavior of wind turbine blades under varied stress scenarios is finite element analysis (FEA).

ANSYS 2023 is a commercial FEM software package that offers a comprehensive set of tools for pre-processing, solving, and post-processing FEA models. In the context of wind turbine blade analysis, ANSYS can be used to:

Create a 3D geometric model of the blade

Mesh the model with finite elements

- Apply boundary conditions and loads
- Solve the FEA equations
- Post-process the results to visualize and analyze the stress, strain, and deformation of the blade

A static and dynamic analysis of a wind turbine blade is typically performed to predict the blade's response to static loads, such as wind pressure and self-weight. The following steps are typically involved in analysis of a wind turbine blade using ANSYS:

1. Modeling: A 3D geometric model of the blade is created using the ANSYS geometry modeler.
2. Meshing: The geometric model is meshed with finite elements using the ANSYS mesher.
3. Applying boundary conditions and loads: The boundary conditions and loads are applied to the model using the ANSYS load applicator.
4. Solving: The FEA equations are solved using the ANSYS solver.

5. Post-processing: The results are post-processed to visualize and analyze the stress, strain, and deformation of the blade using the ANSYS post-processor

4.2 Determining the Material's Engineering Data

To begin the defining process in ANSYS, click the engineering tab at the top of the workspace. Following the selection of this tab. The name of the material should be described in a new Material that is inserted. The innovative material in this instance was named Glass – Sisal fiber reinforced polyester composite with Al_2O_3 filler (Al_2O_3 6%Glass22%/Sisal12%/Polyester 60%). Because of its improved mechanical and physical characteristics during experimental investigation, this ratio was chosen.

The following presumptions are made prior to entering the necessary data:

Assumptions

• By assuming all of the above, it was assumed that the material is linearly elastic isotropic material.

• There is homogeneous mixing of the fiber and matrix.

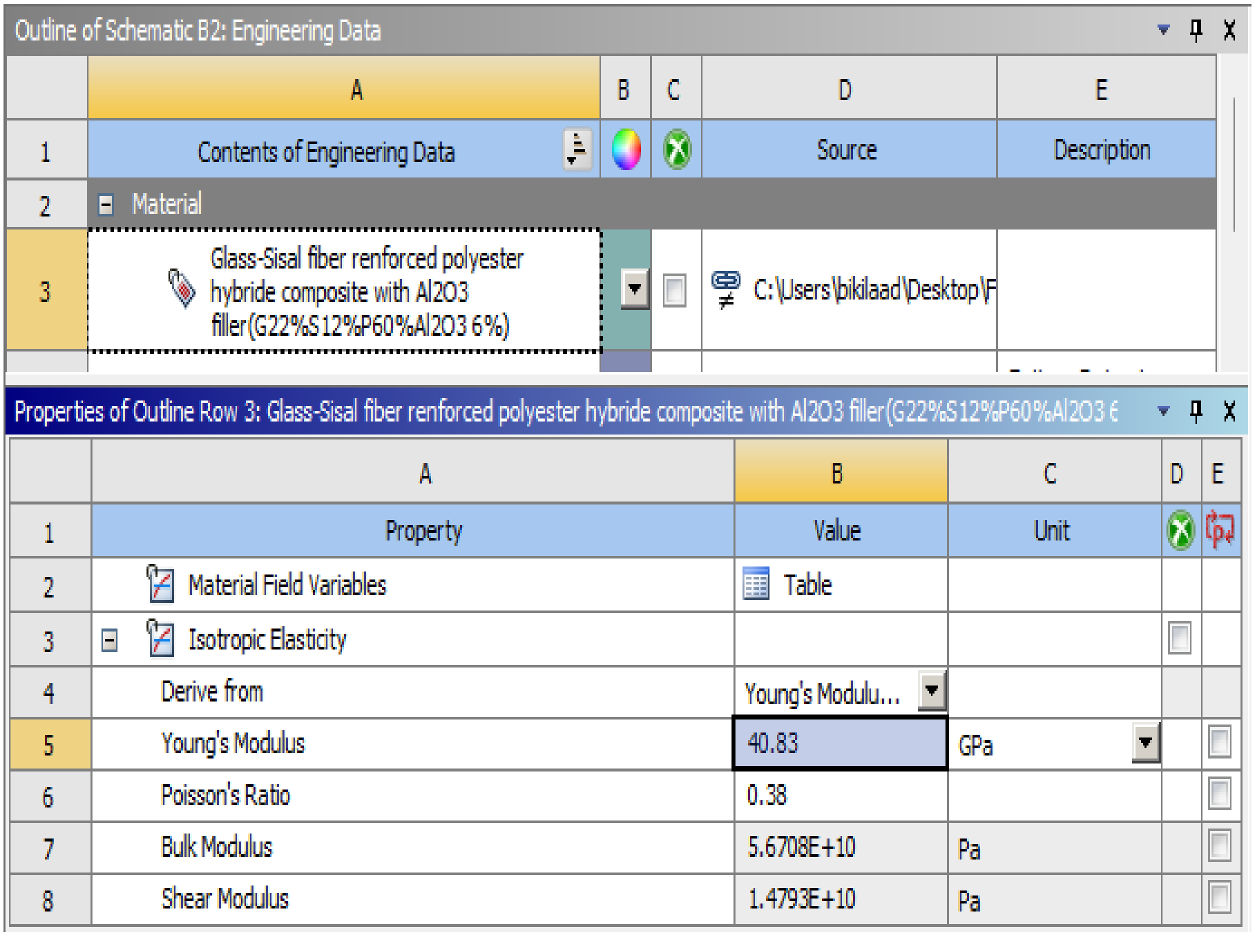
• Completely bound together between the fiber and matrix;

• Homogenous

The chosen composite attributes were added to the data for this study. Properties from experimental tests, such as density and tensile strength and from rule of mixture young's modulus and Poisson's ratio, are used as input for the analysis.

Density = 1.44 grams per cubic centimeter Young's modulus = 40.83 Gpa

Strength in tensile = 96.66 Mpa Ratio of Poisson = 0.38


Outline of Schematic B2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Glass-Sisal fiber renforced polyester hybride composite with Al2O3 filler(G22%S12%P60%Al2O3 6%)			C:\Users\bikilaad\Desktop\F	

Properties of Outline Row 3: Glass-Sisal fiber renforced polyester hybride composite with Al2O3 filler(G22%S12%P60%Al2O3 6

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Isotropic Elasticity				
4	Derive from	Young's Modulu...			
5	Young's Modulus	40.83	GPa		
6	Poisson's Ratio	0.38			
7	Bulk Modulus	5.6708E+10	Pa		
8	Shear Modulus	1.4793E+10	Pa		

Figure 56 Material assignment

4.3 Modeling of Wind Turbine Blade in ANSYS.

ANSYS 2023 Design Modeler was used to simulate the wind turbine after taking into account literature [96]. An application for 3D modeling called Design Modeler is built within the ANSYS workbench software. This is the general geometry of a wind turbine blade.

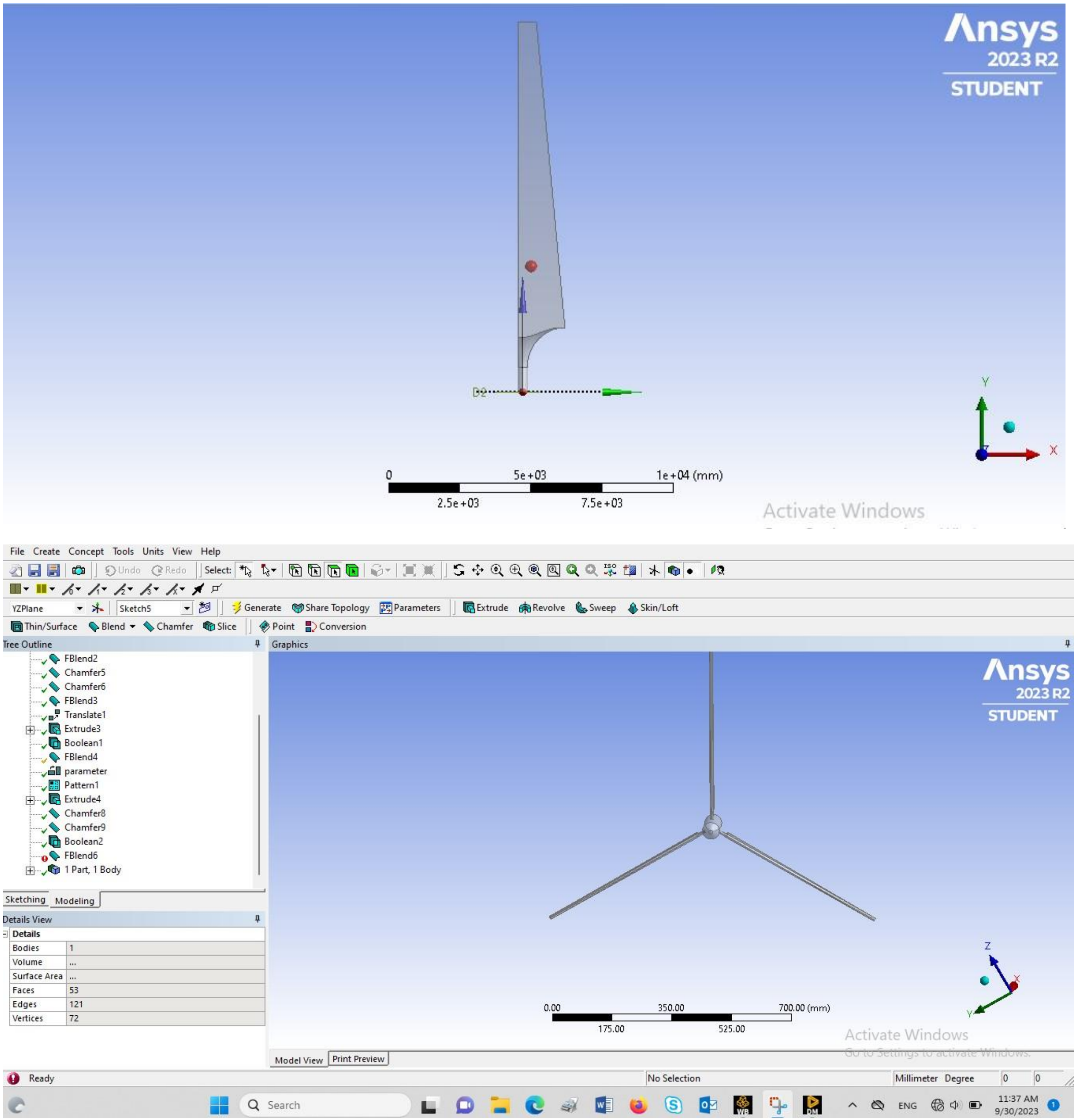


Figure 57 Wind turbine blade model

4.4 Mesh creation

It is the division of a continuous geometric space into topological and discrete cells. Here, default mesh controls are established for the model and fine meshing was utilized to size the mesh.

.

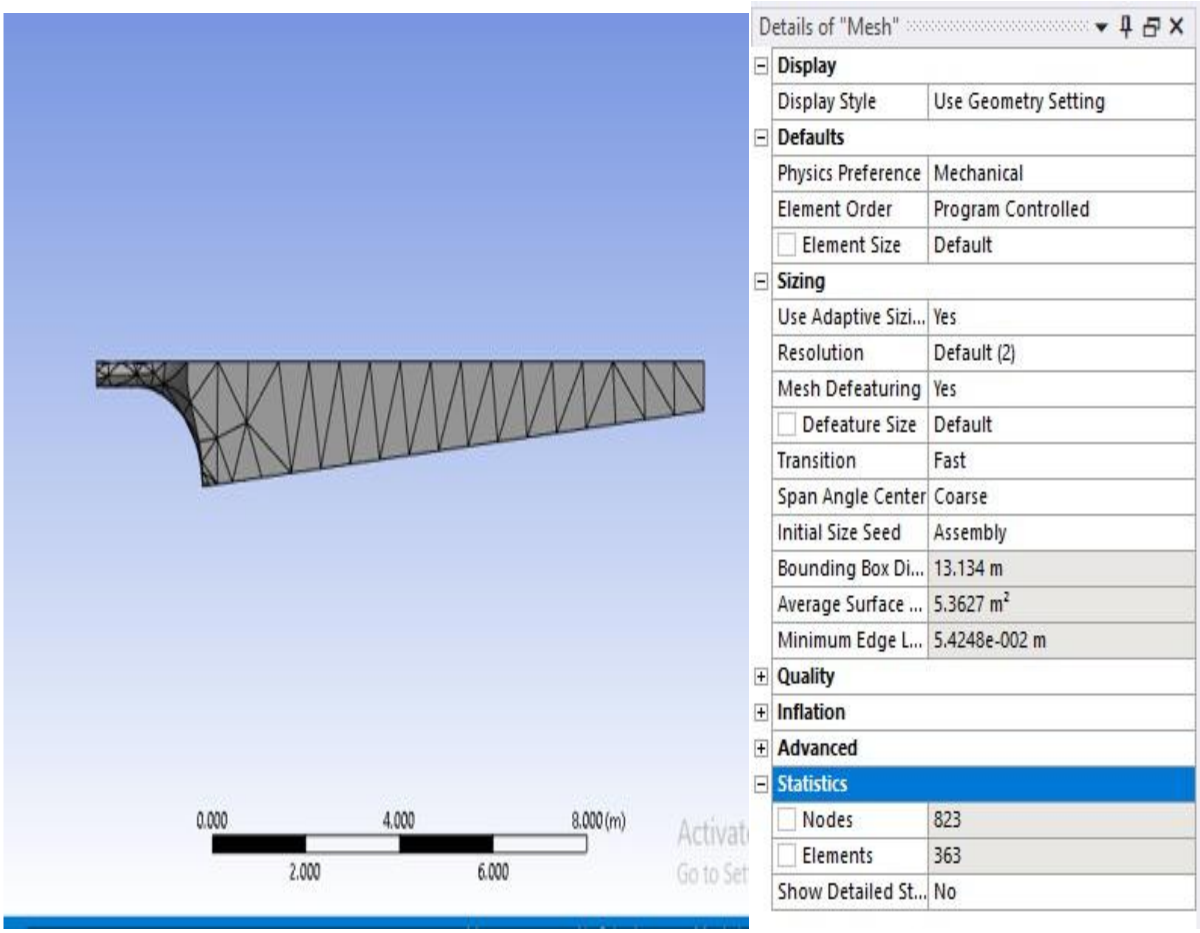


Figure 58 Mesh generation

4.5 Implementing Load and Boundary Conditions

Applying proper loading and boundary conditions is the next phase in ANSYS. One fixed support at the turbine blades root was utilized for the wind turbine blade analysis. Furthermore, two pressures were applied at the bottom, one on the normal to Flap Area surface and one on the Edge Area Force.

The pressure and force are derived from a review of the literature by [96].

F= (Π*P* V2*D2*)/9=364554N P=1.29Kg/m3

PEDGE=0.032842mpa V=10m/S

PFLAP=0.019288mpa D=30m

Total surface area= 3*107 mm2

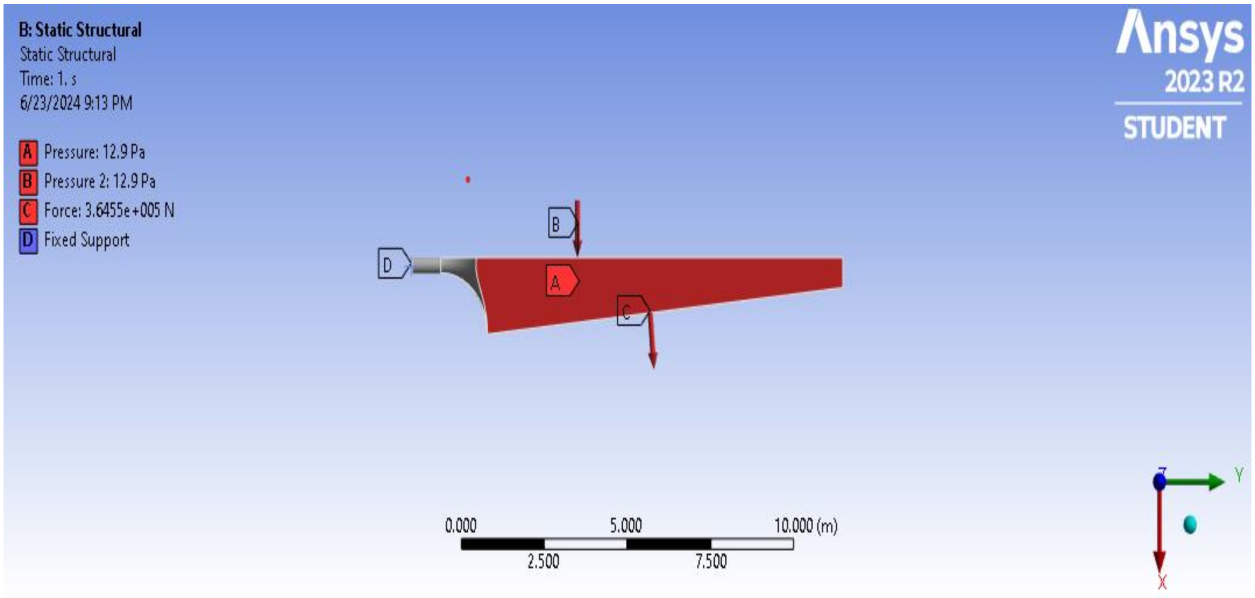


Figure 59 Applied boundary condition on model

4.6 Generating solutions

Total deformation and equivalent Elastic von Mises Stress were generated in static structural analysis based on input parameters, and total deformation was generated in modal analysis based on input parameters.

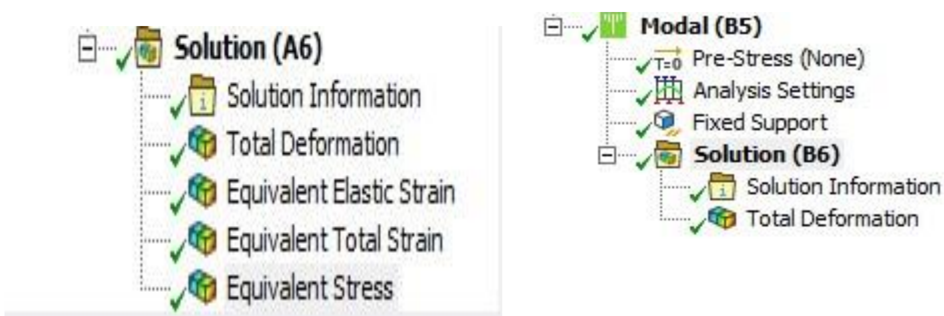


Figure 60 Generated static and modal results

4.5 FE Simulation Result and Discussion

The equivalent von mises stress obtained for the Al2O3 filled Glass/Sisal/Polyester hybrid composite used in wind turbine blades has a maximum value of 0.73726Gpa, a minimum value of 6008.5Pa and average 87.592 Mpa.

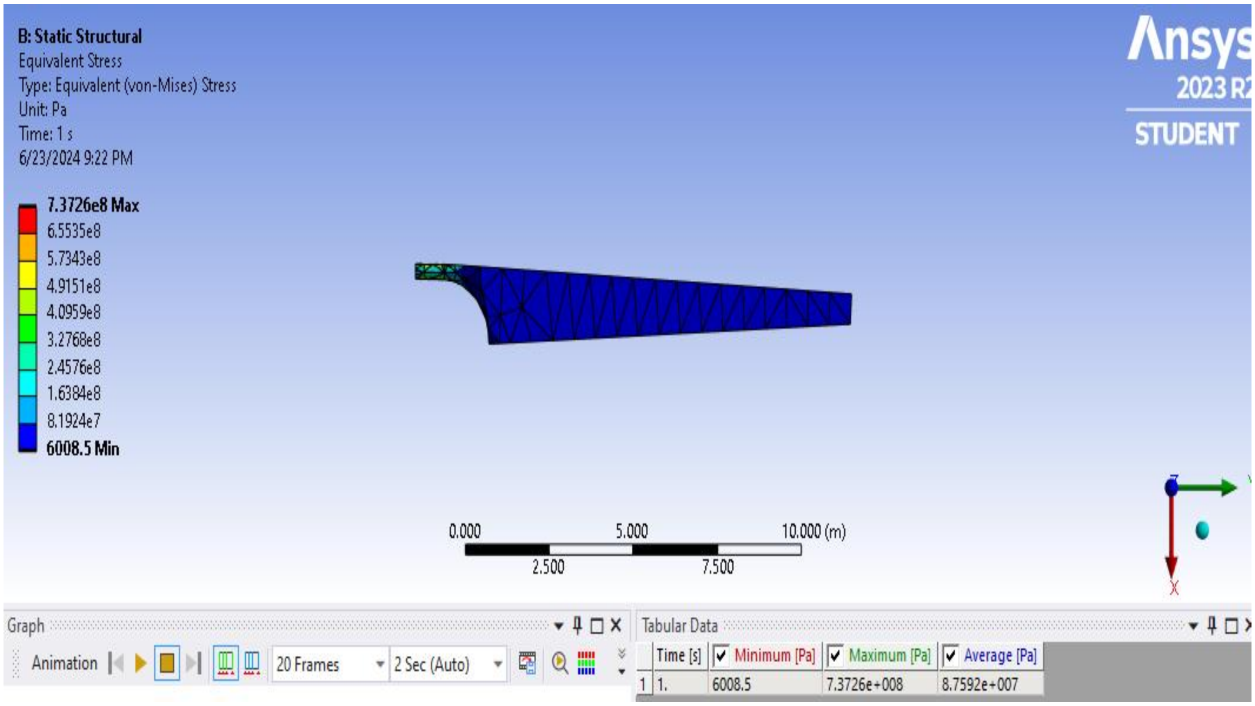


Figure 61 Result of total stress

Static deformation: The deformation measured on the Al2O3-filled Glass/Sisal/Polyester hybrid composite wind turbine blade material has a maximum value of 0.29631 and a minimum value of 0.

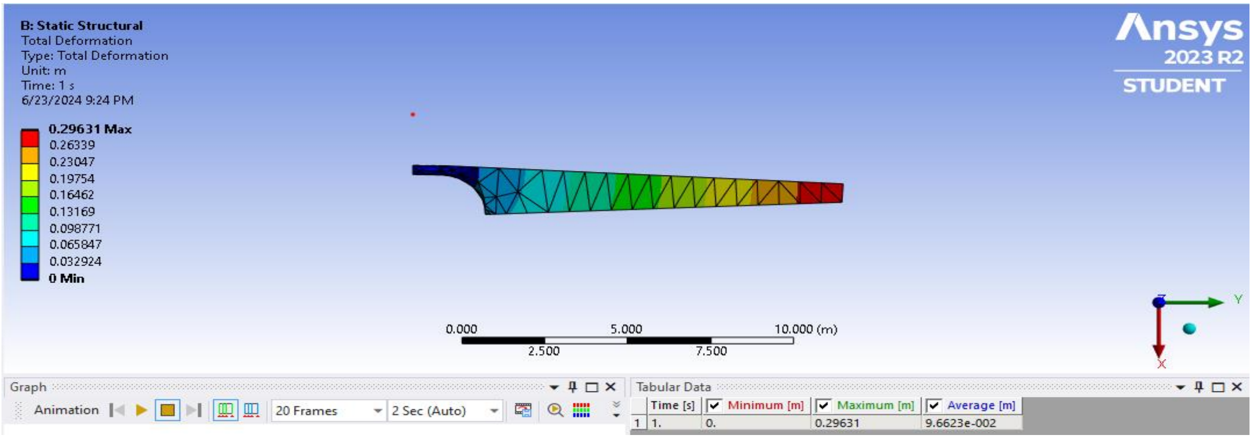


Figure 62 Result of static deformation

Modal deformation: The deformation measured on the Al2O3-filled Glass/Sisal/Polyester hybrid composite wind turbine blade material has a maximum value of 0.0036937 and a minimum value of 0.0016887

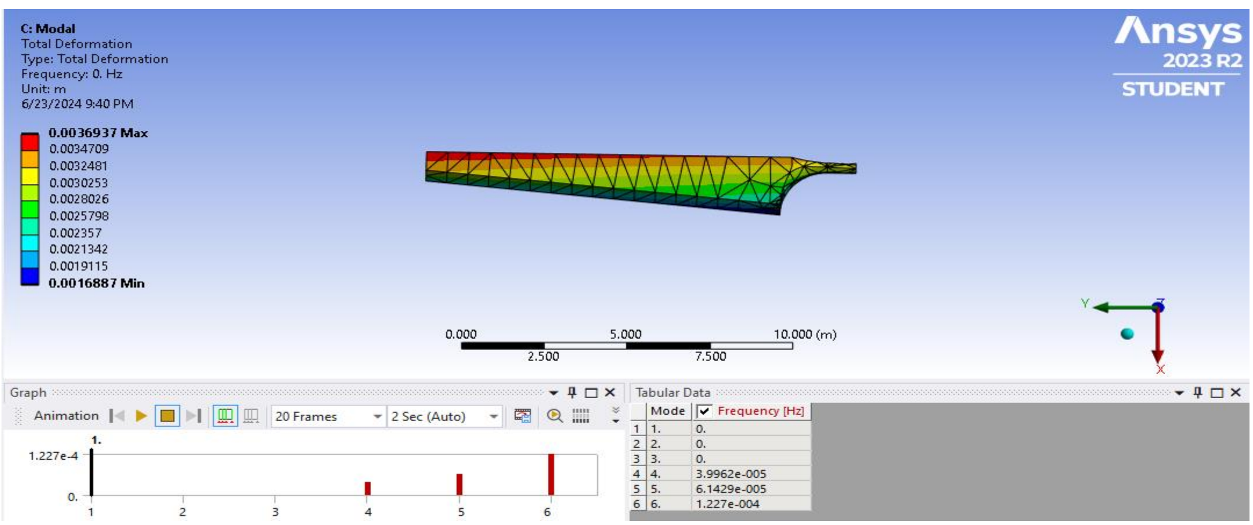


Figure 63 Result of modal deformation

Equivalent von mises stress: The finite element analysis (FEA) results showed that the maximum stress in the blade occurs at the tip. However, the averege stress value obtained for the Al2O3 filled Glass/Sisal/polyester composite with composition of 6/22/12/60 is still significantly lower than the material Average yield strength. This suggests that the composite material has a high potential to replace the traditional material used in the production of wind turbine blades.

The addition of Al_2O_3 particles to the composite material was found to improve the strength of the material. The sisal fibers also helped to improve the toughness of the material. The overall performance of the composite material was found to be very good, making it a suitable candidate for use in wind turbine blade manufacturing.

The FEA results also showed that the socket design is very efficient in distributing the load evenly. This helps to reduce the stress concentration at the bottom of the blade which is a major cause of failure in conventional wind turbine blades.

Overall, the research results indicate that the Al_2O_3 filled Glass/Sisal/polyester composite with composition of 6/22/12/60 has the potential to be a viable replacement for the conventional material used for manufacturing of wind turbine blades. This composite material offers several advantages over conventional materials, including higher strength and stiffness, better toughness, and lower weight.

Deformation: The static and modal deformation values obtained for the Al_2O_3 filled Glass/Sisal/polyester composite with composition of 6/22/12/60 are very low. This indicates that the material is very stiff and capable of withstanding the loads applied by the user of the wind turbine blade. This is a significant advantage over conventional materials, which are more prone to deformation under load.

The low modal deformation values also indicate that the composite material has good damping properties. This means that it can effectively absorb vibrations.

Overall, the research results indicate that the Al_2O_3 filled Glass/Sisal/polyester composite with composition of 6/22/12/60 is a very promising candidate for use in wind turbine blade manufacturing. It offers several advantages over conventional materials, including high stiffness, good damping properties, and low weight.

4.4 Comparison of Al_2O_3 Hybrid Composites for Potential Wind Turbine Blade Applications

Table describe the Comparison of Al_2O_3-filled glass/sisal fiber reinforced polyester composite with other composite materials used for wind turbine blade

Table 14 Comparison of new material with other composite materials

Study	Matrix Material	Fiber Reinforcement	Al2O3 Content (wt%)	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (kJ/m²)	Density (g/cm³)	Water Absorption (%)
Current Research	Polyester	22% Glass, 12% Sisal	6	93.66	176.29	22.17	1.44	3.26
Ahamed et al. [97]	Epoxy	40% Kenaf	15	28.3	53.8	N/A	1.18	3.98
Wang et al. [98]	Epoxy	30% Glass	9	52	88	18.5	1.32	2.8
Zhang et al. [99]	Polypropylene	30% Jute	5	31.2	45.8	N/A	0.98	3.1

Discussion

- The current research demonstrates superior mechanical properties (tensile and flexural strength) compared to Ahamed et al. [100] and Zhang et al. [101] at similar Al2O3 content. This could be attributed to the synergistic effect of combining glass and sisal fibers in the current study.
- Wang et al. [102] showcase higher tensile and flexural strength than the current research at a higher Al2O3 content (9 wt%). However, their composite exhibits a higher density which might not be ideal for wind turbine blade applications aiming for weight reduction.
- The current research offers a good balance between mechanical properties, density, and water absorption, making it a promising candidate for wind turbine blade material based on the presented data.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The best composition was found to be 6% Al_2O_3, 22% glass fiber, 12% sisal fiber, and 60% polyester. The results demonstrated that the inclusion of Al_2O_3 enhanced the mechanical capabilities of the HFRC. For possible use in wind turbine blades, the study examined the compositional characteristics of hybrid fiber reinforced composites (HFRC), including tensile, flexural, impact, water absorption, and density properties. The HFRC exhibited the maximum tensile strength (93.66 MPa), flexural strength (176.29 MPa), and impact strength (22.17kJ/m^2) among glass, sisal, and polyester fibers in different proportions. It also had the lowest density (1.22 g/cm^3) and water absorption (3.26%).

These findings suggest that the HFRC, which is composed of 60% polyester, 22% glass fiber, 12% sisal fiber, and 6% Al_2O_3, could be a viable substitute material for wind turbine blades. Compared to conventional materials like glass fiber reinforced composites, it has a variety of benefits, including as:

- The tensile strength of the optimal HFRC composition is significantly higher than that of traditional glass fiber reinforced composites (GFRC), which is typically around 50-70 MPa. This suggests that the HFRC could be used to design wind turbine blades that are lighter and/or stronger than GFRC blades.
- The flexural strength and impact strength of the optimal HFRC composition are also higher than those of GFRC. This suggests that the HFRC could be more resistant to damage from wind loading and other external forces.
- The water absorption of the optimal HFRC composition is comparable to that of GFRC. This suggests that the HFRC should be able to withstand the harsh environmental conditions that wind turbine blades are exposed to.
- The density of the optimal HFRC composition is lower than that of GFRC. This suggests that wind turbine blades made from the HFRC could be lighter than GFRC blades, which could reduce the overall cost of wind turbines.

- Overall, the results of this study are very promising and suggest that the HFRC with 6% Al_2O_3, 22% glass fiber, 12% sisal fiber, and 60% polyester has the potential to be a viable alternative material for wind turbine blades.

Further research is needed to validate the performance of this HFRC in real-world wind turbine applications. However, the results of this study suggest that it has the potential to be a viable alternative to traditional materials

5.2 Recommendation

The research's conclusions led to the following recommendations being made for future research on Al_2O_3-filled glass/sisal/polyester hybrid composites and practical applications:

1. The potential applications of the newly developed composite shall be investigated. The composite developed in this study has promising physical and mechanical properties, making it a potential candidate for a wind turbine blade material of applications. Future research should focus on investigating the suitability of the composite for applications, such as automotive components, and aerospace structures.
2. Improve the composite's mechanical and physical qualities by changing the fiber form and Al_2O_3 filler content. The physical and mechanical properties of the composite can be further enhanced by changing the fiber form (e.g., unidirectional, yarn, mat) and Al_2O_3 filler content. Future research should systematically investigate the effect of these variables on the composite properties and optimize them for specific applications.
3. Investigate the effect of using different binding matrix types. The binding matrix type contributes significantly to the mechanical and physical characteristics of the composite. Future research should investigate the effect of using different binding matrix types, such as thermosetting and thermoplastic polymers, on the composite properties and examine the effect of Al_2O_3 filler on these properties.
4. Investigate the effect of using different manufacturing techniques. The manufacturing technique used to fabricate the composite can also affect its physical and mechanical properties. Future research should investigate the effect of using different manufacturing techniques, such as vacuum-assisted resin infusion, thermoforming, extrusion, and injection molding, on the composite properties and examine the effect of Al_2O_3 filler on these properties.

By carrying out the above research recommendations, researchers can further improve the physical and mechanical properties of Al_2O_3-filled glass/sisal/polyester hybrid composites and expand their potential applications.

5.3 Future research areas

This research work mainly addresses the effect Al_2O_3 filler on
Glass/sisal fibers reinforced polyester composite on density, water observation capacity impact, tensile and flexural strengths properties. But there might be some other related research
Areas that will be studied in the future such as

- ✓ Investigate Surface morphology
- ✓ Investigate the fatigue failure
- ✓ Investigate the thermal analysis of suggested material

REFERENCE

1) M. Ramesh, “Flax (Linumusitatissimum L.) fiber reinforced polymer composite materials: A review on preparation, properties and prospects,” Prog. Mater. Sci., vol. 102, no. December 2017, pp. 109–166, 2019.
2) Natural and Synthetic Fiber Reinforced Composites: Synthesis, Properties and Applications" by Wiley [Wiley, 9783527349302]
3) Kumar M, “Mechanical behavior of sisal fiber and epoxy resin matrix composite," International journal of pure and applied research in engineering and technology, vol. 3, no. 4, pp. 325-332, 2014.
4) Hybrid Composites for Next-Generation Applications" by Mohammed Khait and Mohsen Abdelmoumen in Materials (MDPI, Open Access Journal) [DOI: 10.3390/ma12101624]
5) Life Cycle Assessment of Natural Fibre-Reinforced Composites" by A.K. Mohanty et al. in Journal of Polymers and the Environment [DOI: 10.1007/s10924-005-0002-0]
6) Natural and Synthetic Fibers for Hybrid Composites" by Mohammed M. Reddy et al. in IntechOpen [DOI: 10.5772/intechopen.8907]
7) G., & Jacobs, J. (2014). Engineering Materials for High Temperature Applications. Butterworth-Heinemann. https://shop.elsevier.com/books/high-temperature-coatings/bose/978-0-7506-8252-7
8) Smith, B. T., Welch, T., Witt, A. M., Stewart, K. M., Lee, K., DeNeale, S. T., Bevelhimer, M. S., Burress, T. A., Pracheil, B. M., Pries, J. L., O’Connor, P. W., Curd, S. L., Ekici, K., Papanicolaou, T., Tsakiris, A.,

Kutz, B., Bishop, N., McKeown, A., Rabon, D., . . . McManamay, R. A. (2017). A Multi-Year Plan for Research, Development, and Prototype Testing of Standard Modular Hydropower Technology. https://doi.org/10.2172/1343501

9) K. Kaw, Mechanics of Composite Materials, Taylor & Francis Group, 2006.

10) P. Sinha, "composite materials and structures," 1995.

11) V, Corey, "Composite Materials" Condensed Book Series.

12) School of Materials Science and Engineering - UNSW Sydney. (n.d.). Matrix materials. Retrieved from https://www.unsw.edu.au/science/our-schools/materials/engage-with-us/high-school-students-and-teachers/online-tutorials/composites

13) M. Mohan Kumar, M. Manikandan, & P. Jeyakumar (2016). Composites Communications, 1, 18–28

14) Bhadeshia, H. K. D. H. (2001). Specialty metal matrix composites. Materials Science and Engineering: A, 317(1-2), 15–27

15) W. J. Clegg, K. K. Chawla (2007). Ceramic Matrix Composites.

16) Mallick, P. K. 2008. Fiber-reinforcement composites, materials, manufacturing anddesign. (3rd ed.). USA: CRC Press, Taylor and Francis Group, 2008.

17) M. M. Schwartz (2014). Composite Materials Handbook, 2nd Edition. Chapman and Hal

18) P. Kesarwani, S.Jahan, and K.Kesarwani, "Composites:Classification and its manufacturing process," Int. J. Appl. Res., vol. 1, no. 9, pp. 352–358, 2015.

19) Mallick, P. K. (2007). Fiber-Reinforced Composites: Materials, Processing, and Applications. Elsevier

20) Torres F.G. and Cubillas, "Study of the Interfacial Properties of Natural Fibers Reinforced Polyethylene," Polymer Testing, vol. 24, pp. 694–698, 2005

21) Kumar M, “Mechanical behavior of sisal fiber and epoxy resin matrix composite,"International journal of pure and applied research in engineering and technology, vol. 3,no. 4, pp. 325-332, 2014.

22) E. Eskezia, “Finite Element Analysis of Internal Door Panel of a Car by using Bamboo Fiber Reinforced Epoxy Composite,” 2016.

23) L. WEINDLING, "Long vegetable fibers", New York: Columbia University Press, 1947.

24) M. Bisanda, "Properties of sisal-CNSL composites," Journal of Materials Science, vol. 27,pp. 1690-700, 1992.

25) WILSON, "Sisal. Vol. II," Hard Fibers Research Series, Rome, 1971.

26) C. Jane Bare, “Life cycle impact assessment research developments and needs,” Clean Technologies and Environmental Policy, pp. 341–351, 2009.

27) K. KALLAPUR, "Fiber reinforced natural rubber composites - physical and mechanical properties", In: Bark and leaf fibers of India. Bombay: KVIC, 1962.

28) M. Naveen, "Mechanical and physical properties of sisal and hybrid sisal fiber-reinforced polymer composites", Malaysia: Woodhead publishing, 2019, pp.427–440.

29) G. Asfaw, "Investigation of the reasons for the Unique Growth and Development of Agave Species (Agave Sisalana and Agave Americana) crop plants at the Southern, Central, North Western and Eastern Parts of

Tigray, Ethiopia," Current Research Journal of Biological Sciences, July 15, 2011.

30) Kuruvilla Joseph, "A review on sisal fiber reinforced polymer composites,"evistaBrasileira de EngenhariaAgrícola e Ambiental, vol. 3, no. 3, pp. 367-379, 999.

31) A. Lightness, “the inevitable renaissance of minimum energy structures”, 2nd ed.,Rotterdam, 1999.

32) M. Bisanda, "Properties of sisal-CNSL composites," Journal of Materials Science, vol.27, pp. 1690-700, 1992.

33) F. Campbell, Structural Composite Materials. 2010.

34) J. Saheb, "Natural fiber polymer composites: a review", vol. 18, 1999, pp. 351-63

35) K. Mallick, Fiber reinforced composites materials, manufacturing, and design, Third edition, Michigan, 2007.

36) Mazumdar, "Composites Manufacturing: Materials, Produc./t, and Process Engineering",CRS press, 2002.

37) Professor GüneriAkovali, “Hand book of Composite Fabrication", Edition Ankara,2001.

38) K. Chawla, “Composite materials: science and engineering", Verlag, New York: Springer Science and Business Media, 2012

39) Jawaid, M., & Abdul Khalil, H. P. S. (2011). Cellulosic/synthetic fiber reinforced polymer hybrid composites: A review. Carbohydrate Polymers, 86(1), 1-18.

40) D. K. K. Cavalcanti, M. D. Banea, J. S. S. Neto, R. A. A. Lima, L. F. M. da Silva, and R. J. C. Carbas, “Mechanical characterization of intralaminar natural fibre-reinforced hybrid composites,” Compos. Part B

Eng., vol. 175, no. July, p. 107149, 2019, doi: 10.1016/j.compositesb.2019.107149

41) L. Mohammed, M. N. M. Ansari, G. Pua, M. Jawaid, and M. S. Islam, “A Review on Natural Fiber Reinforced Polymer Composite and Its Applications,” Int. J. Polym. Sci.,vol. 2015, 2015, doi: 10.1155/2015/243947.

42) B. Koohestani, A. K. Darban, P. Mokhtari, E. Yilmaz, and E. Darezereshki,“Comparison of different natural fiber treatments: a literature review,” Int. J. Environ.Sci. Technol., vol. 16, no. 1, pp. 629–642, 2019, doi: 10.1007/s13762-018-1890-9

43) M. Boopalan, Composites: Part B 51, 2013, pp.54–57.

44) Olddogsnewtruck,“Homemade Flax Break,” 2017.https://olddogsnewtruck.wordpress.com/tag/homemade-flax-break/ (accessed Jun. 30,

45) Akram Khan, Mohd, Guru, Sapana, Padmakaran, Prabha, Mishra, Deepti, Mudgal, Manish, &Dhakad, Savita. (2011). Characterization Studies and Impact of ChemicalTreatment on Mechanical Properties of Sisal Fiber. Composite Interfaces, 18(6), 527-541.doi: 10.1163/156855411X610250R.

46) Velmurugan, "Composites: Part A," vol. 38, pp. 1077–1087, 200.

47) Maiti, S., Bhowmick, A. K., & De, D. K. (2001). Rubber-carbon black composites: Chemical bonding and its impact on performance. Rubber Chemistry and Technology,74(3), 404-436.

48) Alexandre, M., Dubois, P., & Jerome, C. (2002). Polymer-layered silicate nanocomposites: Preparation, properties and applications. Materials Science and Engineering: R: Reports,39(4), 1-25.

49) Mishra, S., Tripathy, S. K., Mohanty, S., & Nayak, S. K. (2014). Fabrication and performance evaluation of hybrid composites based on natural fiber and synthetic fiber.Composites Part A: Applied Science and Manufacturing, 56, 20-28.

50) Wang, J., & Shaw, L. L. (2006). Metal matrix composites. Springer.

51) Soad Z. Al Sheheri, Zahra M. Al-Amshany, Qana A. Al Sulami, Nada Y. Tashkandi,Mahmoud A. Hussein & Reda M. El-Shishtawy, 2019 The preparation of carbon nanofillers and their role on the performance of variable polymer nano composites, Designed Monomers and Polymers, 22(1),8-53.

52) Zhang, H., Zhang, Y., & Wang, J. (2023). Effect of silica nanoparticles on the mechanical and thermal properties of high-density polyethylene composites. Journal of Applied Polymer Science, 140(15), e52877.

53) Kontou, E., Chondros, T. G., & Tzatzalos, E. (2022). Nano-fibrillated cellulose as sustainable reinforcement for low-density polyethylene composites: Mechanical, thermal,and barrier properties. Polymer Composites, 43(10), 4753-4768.

54) Dorigato, A., Pegoretti, A., & Sgroi, M. (2021). Mechanical and wear properties of polypropylene composites reinforced with short glass fibers: A comparison between injection molding and fused deposition modeling. Polymers, 13(12), 1996

55) Reshmi Olayil et al 2021 IOP Conf. Ser.: Mater. Sci. Eng. 1059 012006

56) Dress, Genetu A, Woldemariam, MH, &Redda, DT. (2021). Influence of Fiber Orientation on Impact Resistance Behavior of Woven Sisal Fiber Reinforced Polyester Composite.

57) Advances in Materials Science and Engineering, 2021.Scarponi, C., Sarasini, F., Tirillo, J., Lampani, L., Valente, T., & Gaud Enzi, P. (2015). Low velocity impact response of hemp fiber reinforced bio-based epoxy laminates, Proceedings of 5thConference on Natural Fiber Composites for Industrial Applications, (pp. 1-4). Sapienza University de Roma, Rome: Italy.

58) Faris, M. A., &Sapuan, S. M. (2014). Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers in sustainable automotive industry.Journal of Cleaner Production, 66, 347 – 354.

59) Swoffs, Y., Gorbatikh, L., &Verpoest, I. (2014). Fiber hybridization in polymer composites: A review. Composites Part A: Applied Science and Manufacturing, 67, 181–200.

60) Ashby, M. F., &Cebon, D. (1992). Materials Selection in Mechanical Design. (4th ed.).Oxford: Pergamon Press.

61) Matthews, F. L., & Rawlings, R. D. (1994). Composite materials: Engineering and science. (1st ed.). Oxford: Chapman & Hall.

62) Yosif G.: 'Hybrid Anisotropic Materials for Wind Power Turbine Blades.' Taylor & Francis Group, CRC Press, 2012.

63) R.T. DuraiPrabhakaran: 'Future materials for wind turbine blades –a critical review'

64) Carbon Fiber vs. Fiberglass: A Comparison between the Two Materials Which Materia Is Superior?Available online https://infogr.am/carbon-fiber-vs-fiberglass (accessed on 8 November 2017).

65) Wind Power Monthly Webpage. Available online:https://www.windpowermonthly.com/article/1419306/turbines-year-rotor-blades (accessed on 8 November 2017).

66) Kalagi, G.; Patil, R.; Nayak, N. Natural Fiber Reinforced Polymer Composite Materials for Wind TurbineBlade Applications. Int. J. Sci. Dev. Res. 2016, 1, 28–37.

67) F. Campbell, Structural Composite Materials. 2010

68) Ong, C.-H.; Tsai, S.W. The Use of Carbon Fibers in Wind Turbine Blade Design: A SERI-8 Blade ExampleSAND2000-0478; Sandia National Laboratories Contractor Report; Sandia NL: Albuquerque, NM, USA, 2000.

69) Nijssen, R.P.L. Fatigue Life Prediction and Strength Degradation of Wind Turbine Rotor Blade Composites. Ph.D. Thesis, Knowledge Centre Wind Turbine Materials and Constructions (KC-WMC), Wieringerwerf, The Netherlands, 2007.

70) Joncas, S. Thermoplastic Composite Wind Turbine Blades: An Integrated Design Approach. Ph.D. Thesis, TU Delft, Delft, The Netherlands, 2010.

71) Holmes, J.W.; Sørensen, B.F.; Brøndsted, P. Reliability of Wind Turbine Blades: An Overview of MaterialsTesting. In Proceedings of the Wind Power Shanghai 2007,Shanghai, China, 1–3 November 2007.

72) Holmes, J.W.; Brøndsted, P.; Sørensen, B.F.; Jiang, Z.H.; Sun, Z.H.; Chen, X.H.Development of a Bamboo-Based Composite as a Sustainable

Green Material for Wind Turbine Blades. J. Wind Eng. 2009,33, 197–210. [CrossRef]

73) Fahamsyah H. Latief, AchmadChafidz, HarriJunaid, Adel Alfozan, and Rawaiz Khan Effect of Alumina Contents on the Physic mechanical Properties of Alumina (Al2O3) Reinforced Polyester Composites Received 19 October 2018; Accepted 26 January 2019; Published 24 February 2019

74) WasimAkram, Sachin Kumar Chaturvedi, Syed Mazhar Ali Comparative Study Of Mechanical Properties Of E-Glass/Epoxy Composite Materials With Al2O3, CaCo, SiOAND PBO fillers International Journal of Engineering Research & Technology (IJERT)Vol. 2 Issue July2013https://4spepublications.onlinelibrary.wiley.com/doi/epdf/10.1002/pc.25927

75) A. Nabhan, Mohamed Taha, Nouby M. Ghazaly, Available online 26 October 20220142-9418/© 2022 Published by Elsevier Ltd. This is an open access article under the CC BY NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/)

76) Asutosh panda, A study on thermal conductivity of epoxy/al2o3 composites a thesis submitted in partial fulfillment of the requirement for the award of the degree of master of technology in mechanical ngineering(thermal engineering) By (roll no. 211me3357).

77) Journal of Modern Mechanical Engineering and Technology, 2021, 8, 48-56E-ISSN: 2409-9848/21 © 2021 Zeal PressInvestigation of Hybrid Composite Properties Fabricated from Bagasse Fibers Reinforced with Al2O3and SiC for Light Weight Applications YobsanAlemu , Gutata Kabeta Woyessa, Moera GutuJiru, Genet BekeleAlemu ,LamrotKebedeand

MeseretTedesa ,Department of Mechanical Design and Manufacturing Engineering Adama Science and Technology

78) F. H. Latief, A. Chafidz, H. Junaedi, A. Alfozan, and R. Khan, “Effect of alumina contents on the physic mechanical properties of alumina (Al2O3) reinforced polyester composites,” Adv. Polym. Technol., vol. 2019, pp. 1–10, 2019.

79) Balachander, J.; Chandramohan, D.; Murali, B. Natural Fiber Reinforced Polymer Composite in Synthetic Bone Grafting—A New Approach. J. Middle East Appl. Sci. Technol. 2014, 16, 588–596.

80) Cheour, K.; Assarar, M.; Scida, D.; Gong, X.L. Long-term Immersion in Water of Flax glass Fiber HybridComposites: Effect of Stacking Sequence on the Mechanical and Damping Properties. Fiber Polym. 2020, 21,162–169. [CrossRef]

81) Devaraj E., Hanumantharaju H. G., Avinash M The study of mechanical behaviour of Al2O3 filler: epoxy composites: Polymer composites Paperback – 3 July 2014

82) S. V., G. Chidambaram and S. Ashokraj Published 4 November 2019 , Enhanced mechanical properties of glass fiber-reinforced polymer composites with addition of AL2O3

83) Sridharan, S. (2008). Delamination behavior of composites (1st ed.). Cambridge England: Woodhead Publishing Limited.

84) R. Rana, A. Kumre, S. Rana, and R. Purohit, “Characterization of Properties of epoxy sisal / Glass Fiber Reinforced hybrid composite,” Mater. Today Proc., vol. 4, no. 4, pp.5445–5451, 2017, doi: 10.1016/j.matpr.2017.05.056.

85) C. M. Meenakshi and A. Krishnamoorthy, "Study on the effect of surface modification on the mechanical and thermal behaviour of flax, sisal and glass fiber-reinforced epoxy hybrid composites," J. Renew. Mater., vol. 7, no. 2, pp. 153–169, 2019, doi:10.32604/jrm.2019.00046.

86) K. Shaker et al., "Bioactive woven flax-based composites: Development and characterization," J. Ind. Text., vol. 46, no. 2, pp. 549–561, 2016

87) Nilagiri Balasubramanian KB, RameshT. 2018 Role, effect, and influences of micro and nanofillers on various properties of polymer matrix composites for microelectronics: A review, PolymAdv Technol. 29(6)1568–1585.

88) Rothon.R,2016 Nanofillers, Polymers, and Polymeric Composites: A Reference Series, ISBN: 978-3-642-37179-0, 1-21.

89) Pharr, G., & Oliver, W. C. (2011). Applied Nanoindentation in Advanced Materials. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA.

90) Smith, L. E., & Fanconi, B. M. (1985). Institute for Materials Science and Engineering polymers : https://doi.org/10.6028/nbs.ir.85-3190

91) MatWeb, Overview of materials for Polyester (Thermoset) – Rigid

92) L. Yan, N. Chouw, and X. Yuan, "Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment," J. Reinf. Plast. Compos., vol. 31, no. 6, pp. 425–437, 2012, doi: 10.1177/0731684412439494.

93) Mirabedini, A., Ang, A., Nikzad, M., Fox, B., & Lau, K. T. (2020). Evolving Strategies for Producing Multiscale Graphene-Enhanced Fiber-

Reinforced Polymer Composites for Smart Structural Applications. Advanced Science, 7(11). https://doi.org/10.1002/advs.201903501

94) Camargo, P. H. C., Satyanarayana, K. G., & Wypych, F. (2009). Nanocomposites: synthesis, structure, properties and new application opportunities. Materials Research, 12(1), 1–39. https://doi.org/10.1590/s1516-14392009000100002

95) P. T. R. Swain and S. Biswas, "Physical and mechanical behavior of Al2O3 filled jute fiber reinforced epoxy composites,"Composites Science and Technology, vol. 2, no. 2, pp. 67–71,2014.

96) International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056 Volume: 05 Issue: 06 | June-2018 www.irjet.net p-ISSN: 2395-0072 Structural analysis of composite wind turbine blade

97) Ahamed, S., Sapuan, S., Sultan, M. T. H., & Rahman, M. M. (2019). Mechanical and morphological properties of kenaf/glass fiber-reinforced polyester composites with the addition of Al2O3 nanoparticles. Journal of Materials Science: Materials in Electronics, 30(1), 748-763.

98) Wang, S., Hu, X., Liu, J., Li, Y., & Feng, H. (2021). Effects of Al2O3 content on the mechanical properties, tribological behavior, and water absorption of kenaf fiber-reinforced epoxy composites. Materials Research Express, 8(11), 115002.

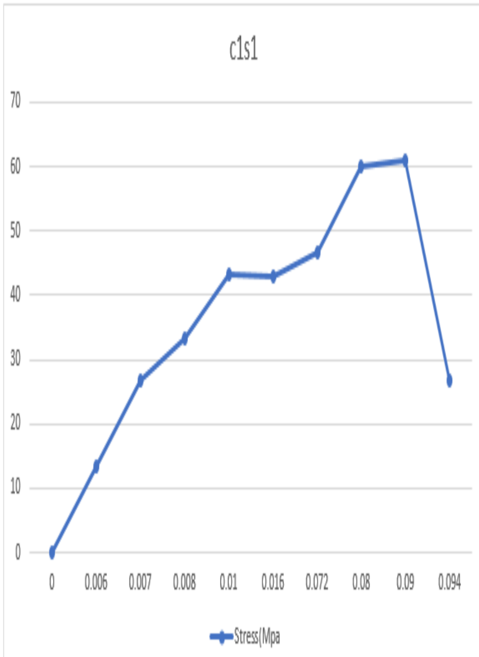
99) Zhang, J., Fan, W., Yan, C., & Li, H. (2020). Preparation and characterization of glass fiber/epoxy composites filled with Al2O3 nanoparticles. Polymer Composites, 41(11), 3391-3400.

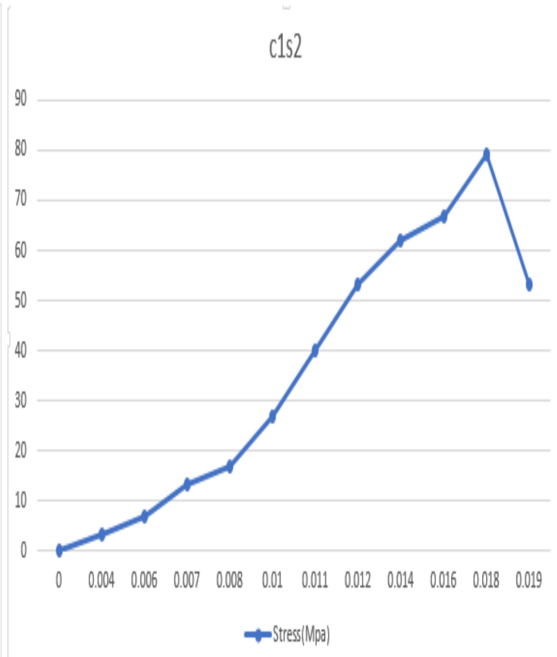
100)

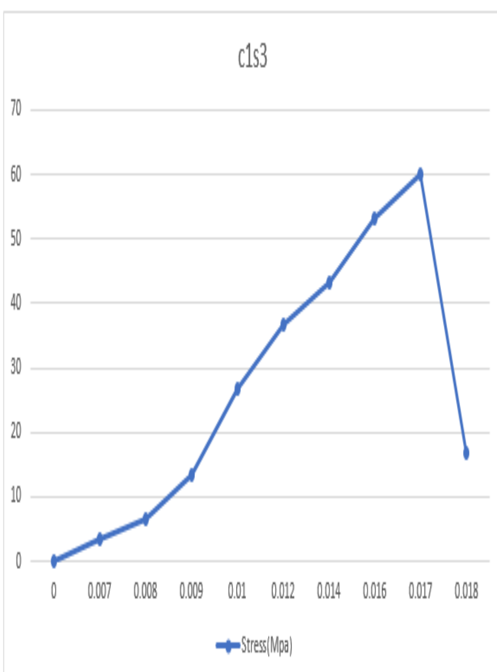
101)

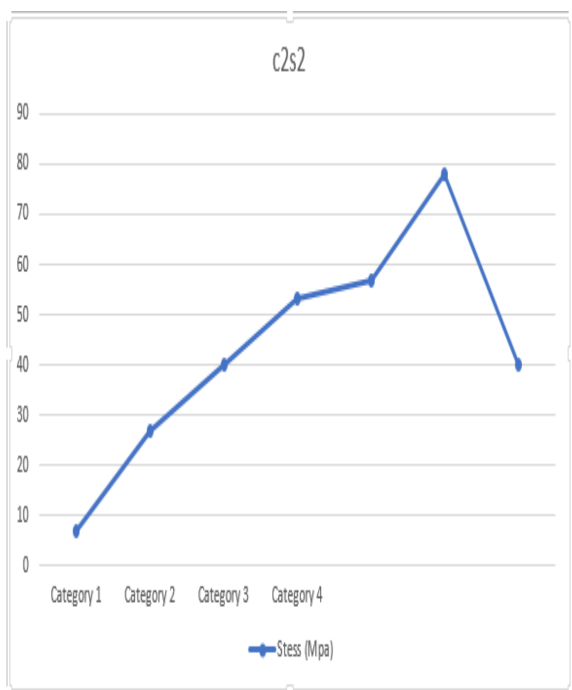
APPENDICES

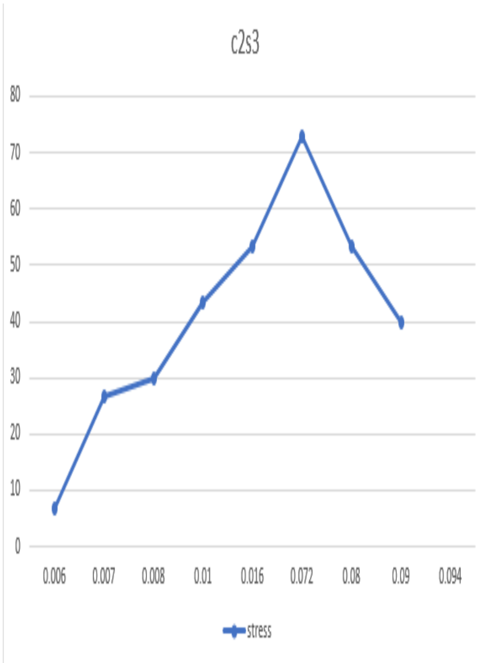
A.TENSILE TEST RESULTS FOR EACH SAMPLES

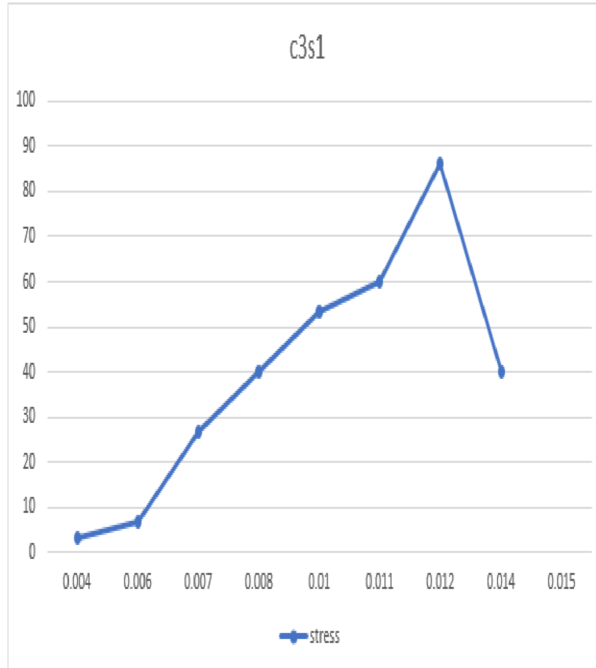


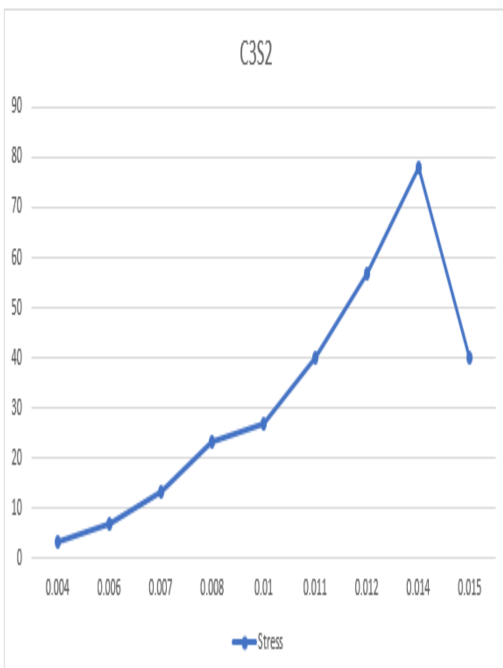


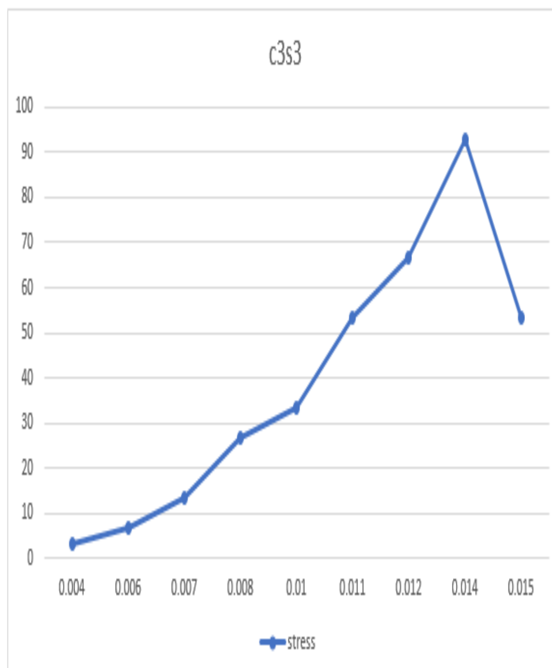


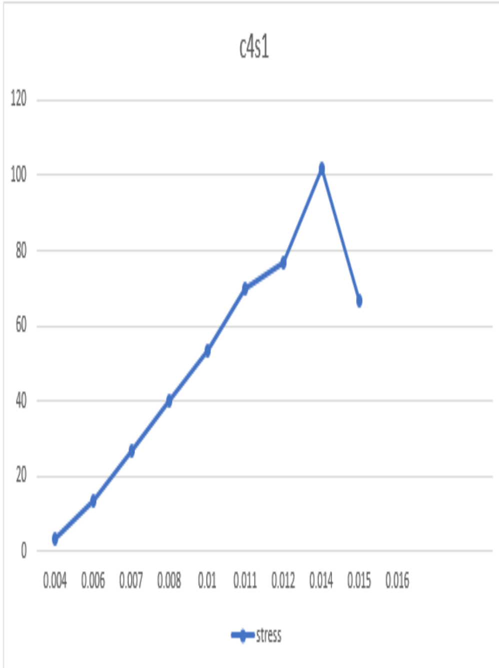



c2s3
80
70
60
50
40
30
20
10
0
0.006
0.007
0.008
0.01
0.016
0.072
0.08
0.09
0.094
stress

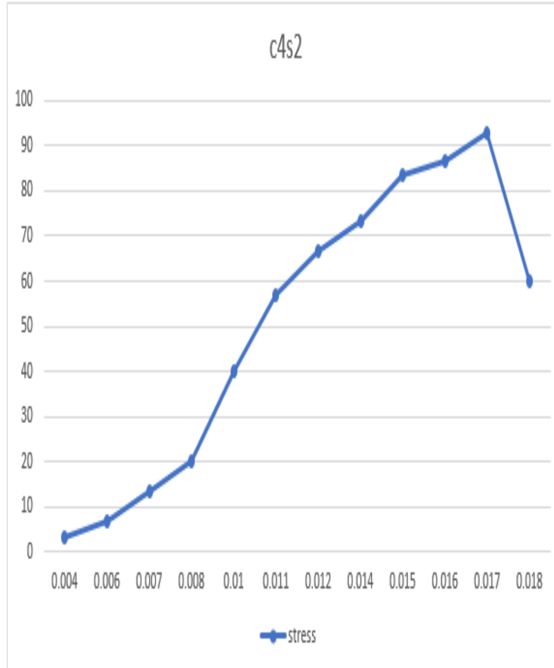

c3s1
100
90
80
70
60
50
40
30
20
10
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
stress


C3S2
90
80
70
60
50
40
30
20
10
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
Stress

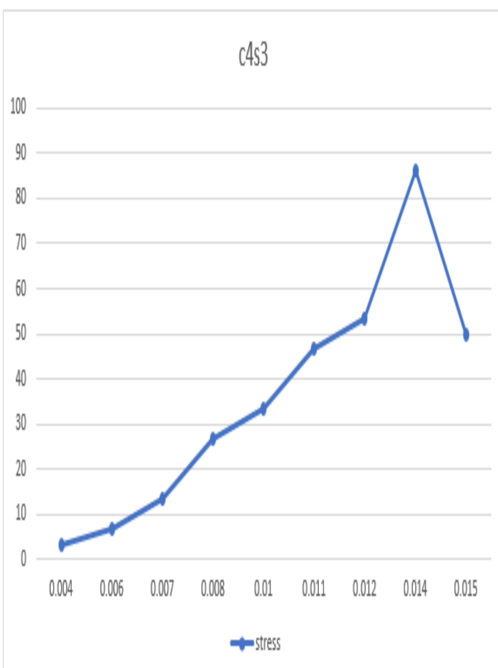

c3s3
100
90
80
70
60
50
40
30
20
10
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
stress



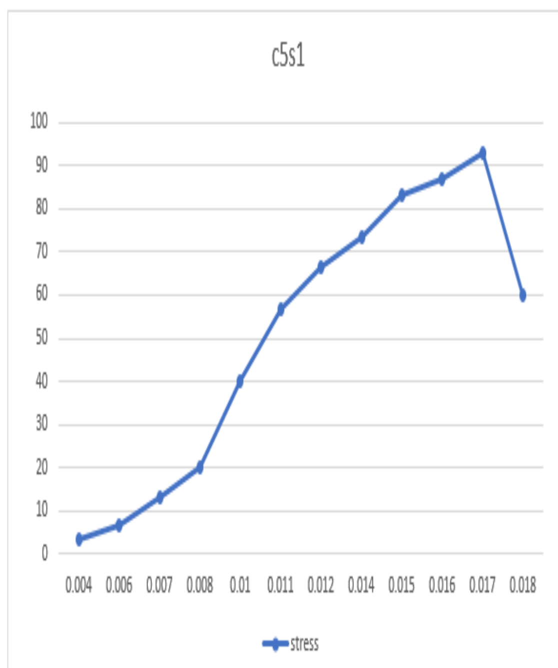
c4s1
120
100
80
60
40
20
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
0.016
stress



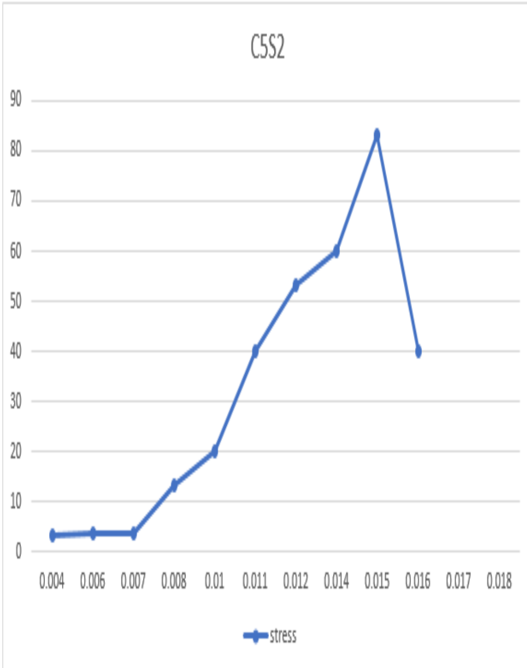
c4s2
100
90
80
70
60
50
40
30
20
10
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
0.016
0.017
0.018
stress

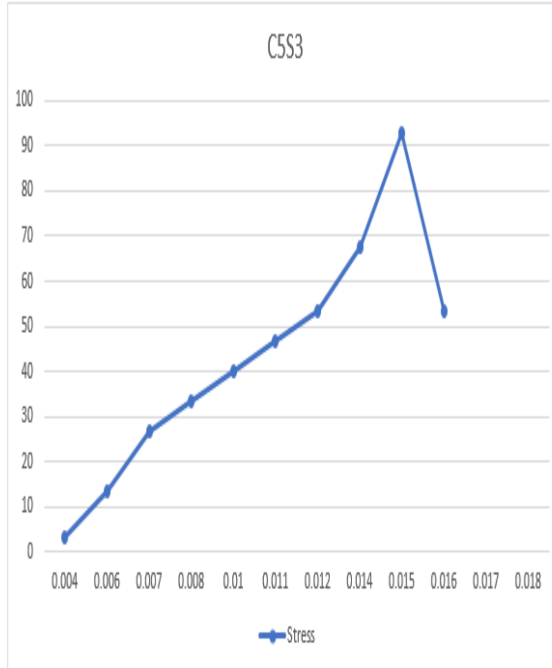


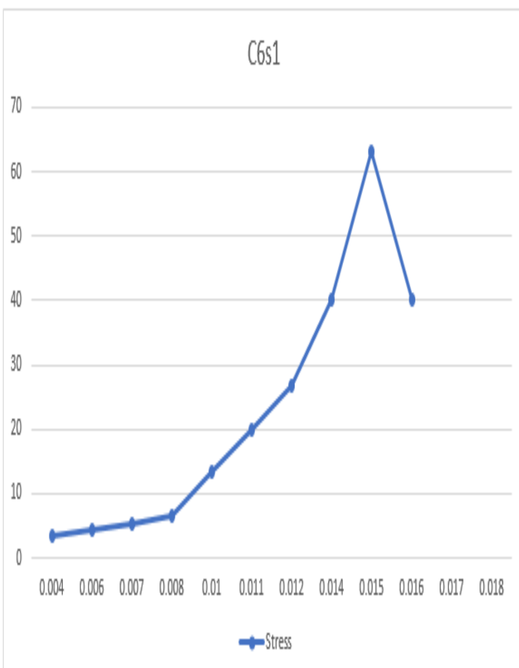
c4s3
100
90
80
70
60
50
40
30
20
10
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
stress

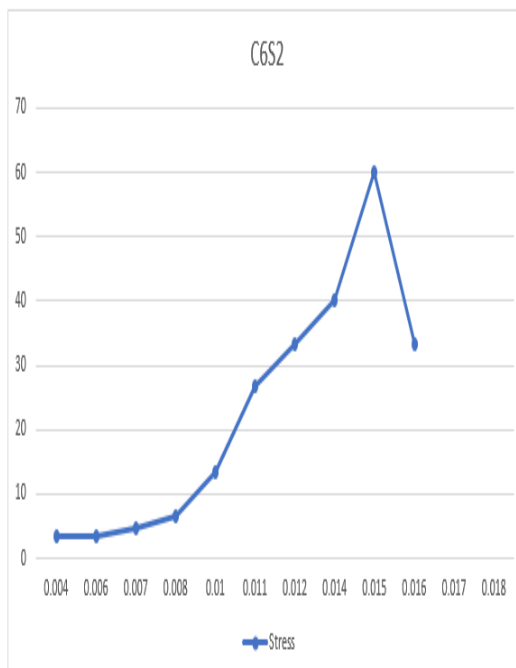


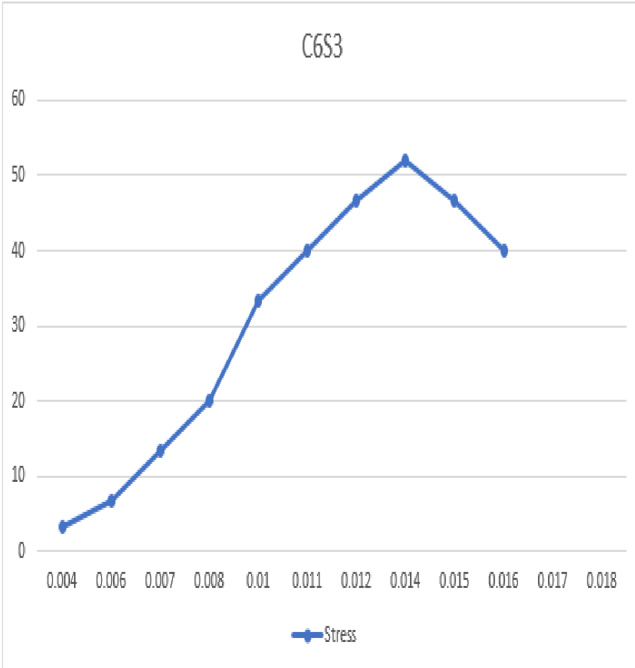
c5s1
100
90
80
70
60
50
40
30
20
10
0
0.004
0.006
0.007
0.008
0.01
0.011
0.012
0.014
0.015
0.016
0.017
0.018
stress


C5S2
90
80
70
60
50
40
30
20
10
0
0.004 0.006 0.007 0.008 0.01 0.011 0.012 0.014 0.015 0.016 0.017 0.018
stress


C5S3
100
90
80
70
60
50
40
30
20
10
0
0.004 0.006 0.007 0.008 0.01 0.011 0.012 0.014 0.015 0.016 0.017 0.018
Stress

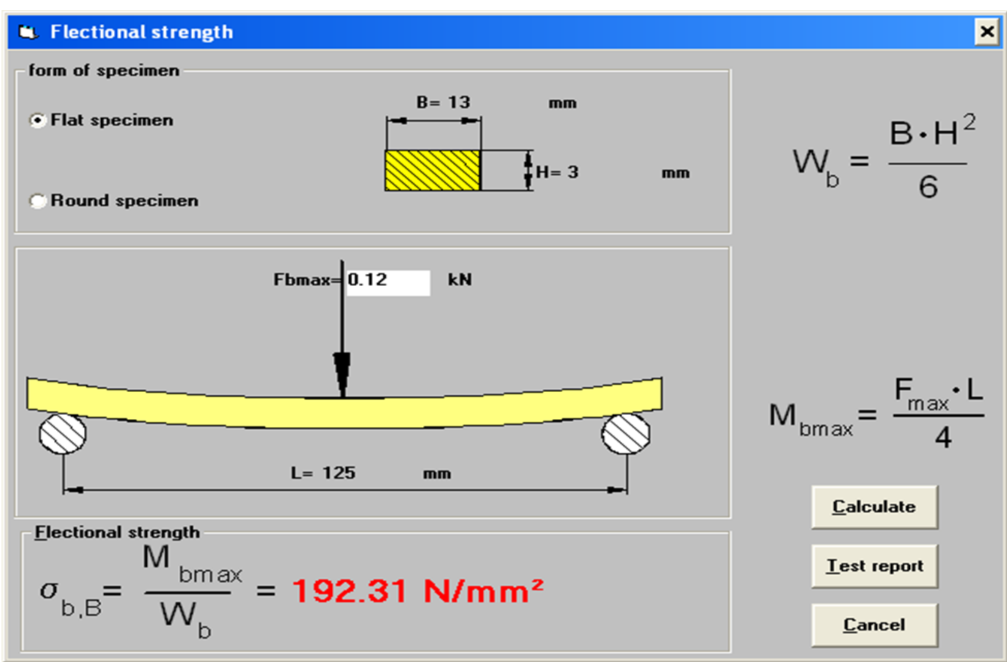

C6s1
70
60
50
40
30
20
10
0
0.004 0.006 0.007 0.008 0.01 0.011 0.012 0.014 0.015 0.016 0.017 0.018
Stress


C6S2
70
60
50
40
30
20
10
0
0.004 0.006 0.007 0.008 0.01 0.011 0.012 0.014 0.015 0.016 0.017 0.018
Stress

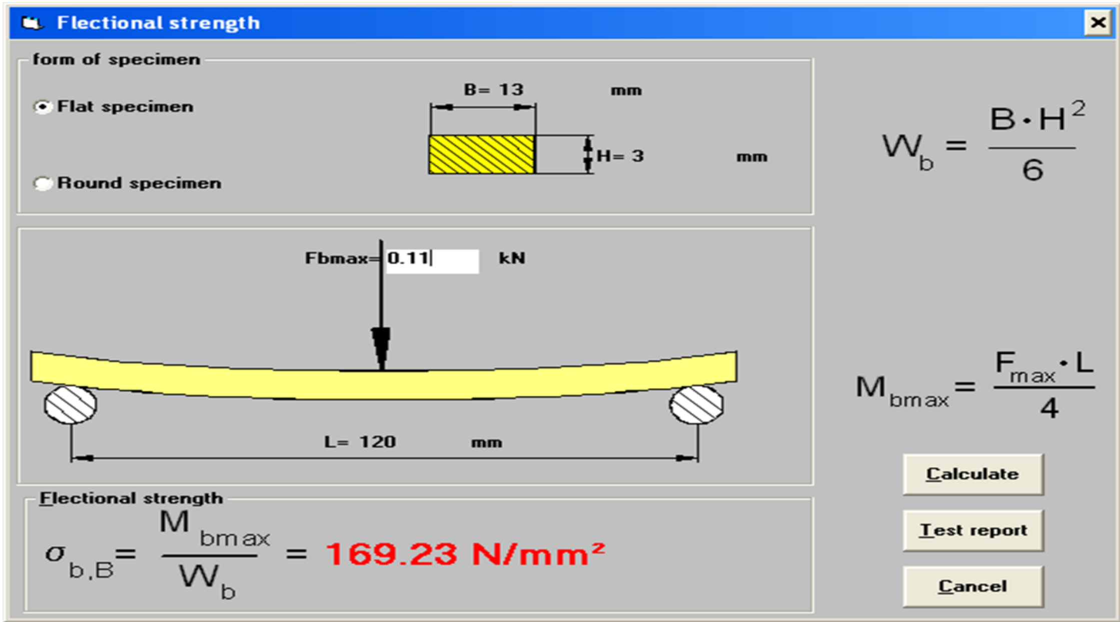


B.FLEXURAL STRENGTH RESULT OF EACH SAMPLE

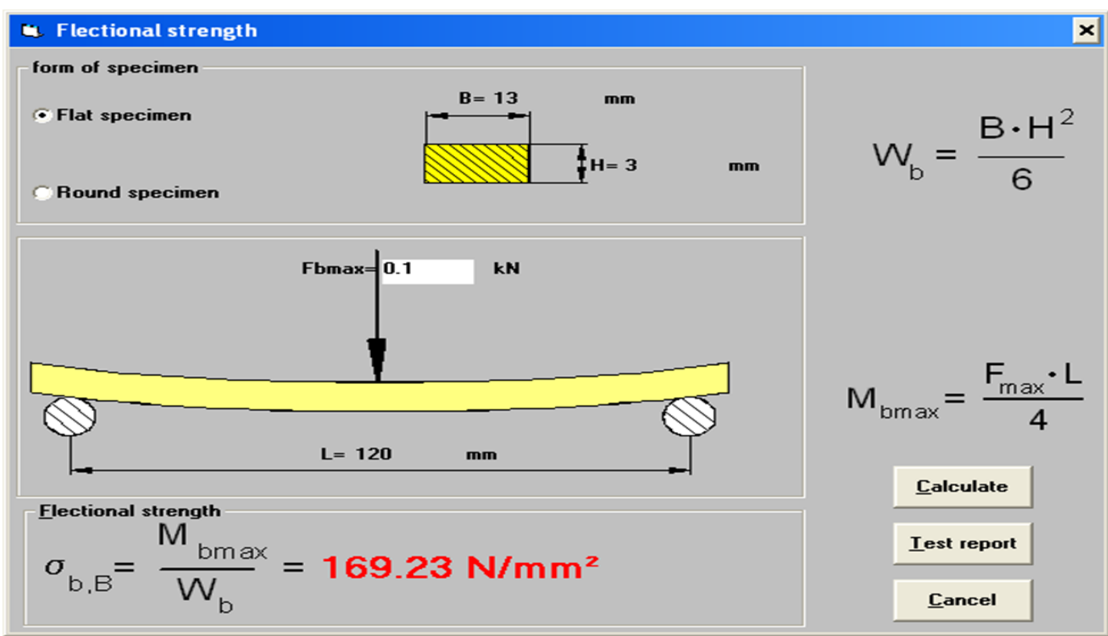
C1S1



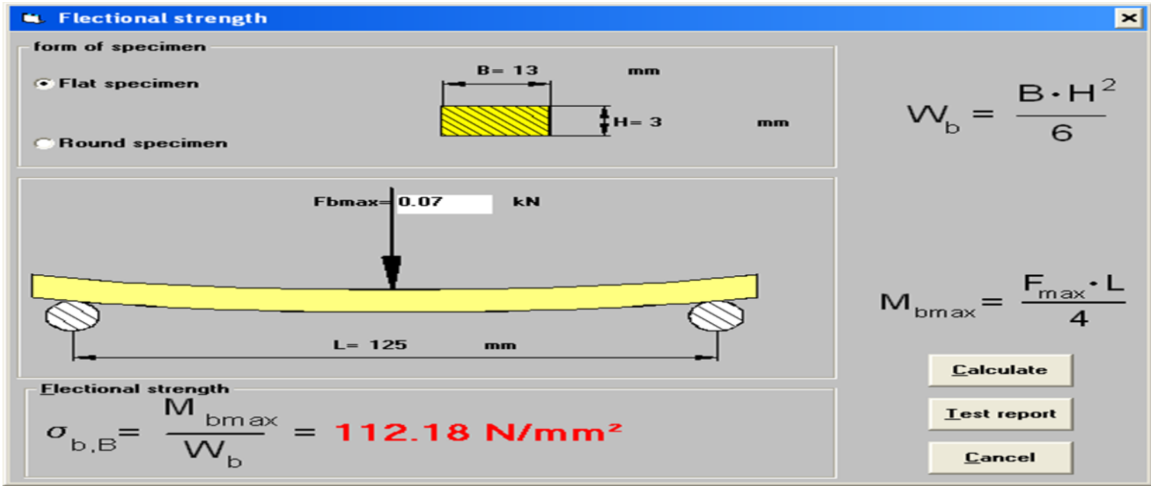
C1S2


Flectional strength
form of specimen
Flat specimen
Round specimen
B= 13 mm
H= 3 mm
Fbmax= 0.11 kN
L= 120 mm
Flectional strength
= 169.23 N/mm²
Calculate
Test report
Cancel

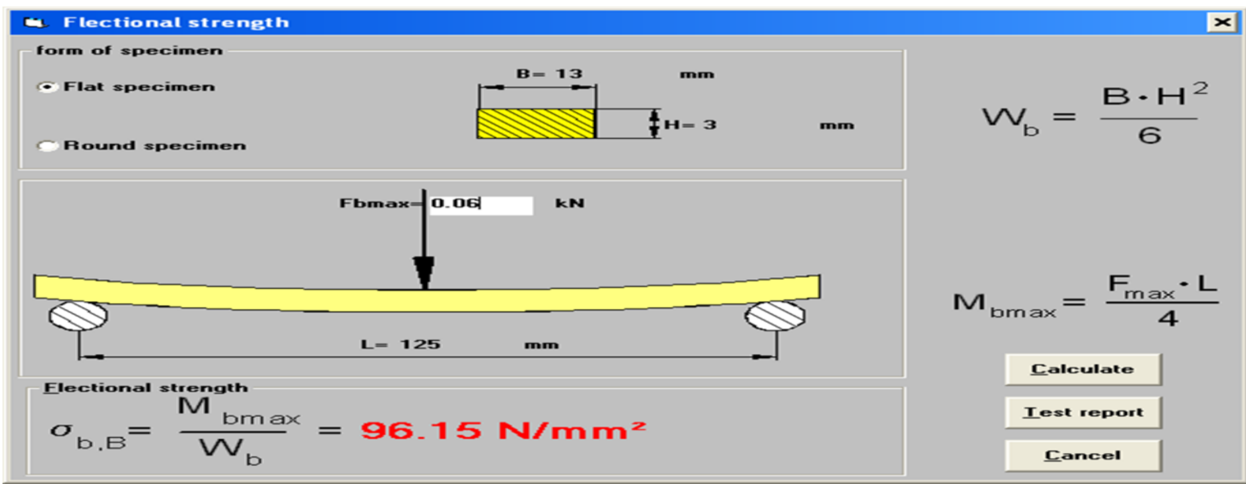
C1S3


Flectional strength
form of specimen
Flat specimen
Round specimen
B= 13 mm
H= 3 mm
Fbmax= 0.1 kN
L= 120 mm
Flectional strength
= 169.23 N/mm²
Calculate
Test report
Cancel

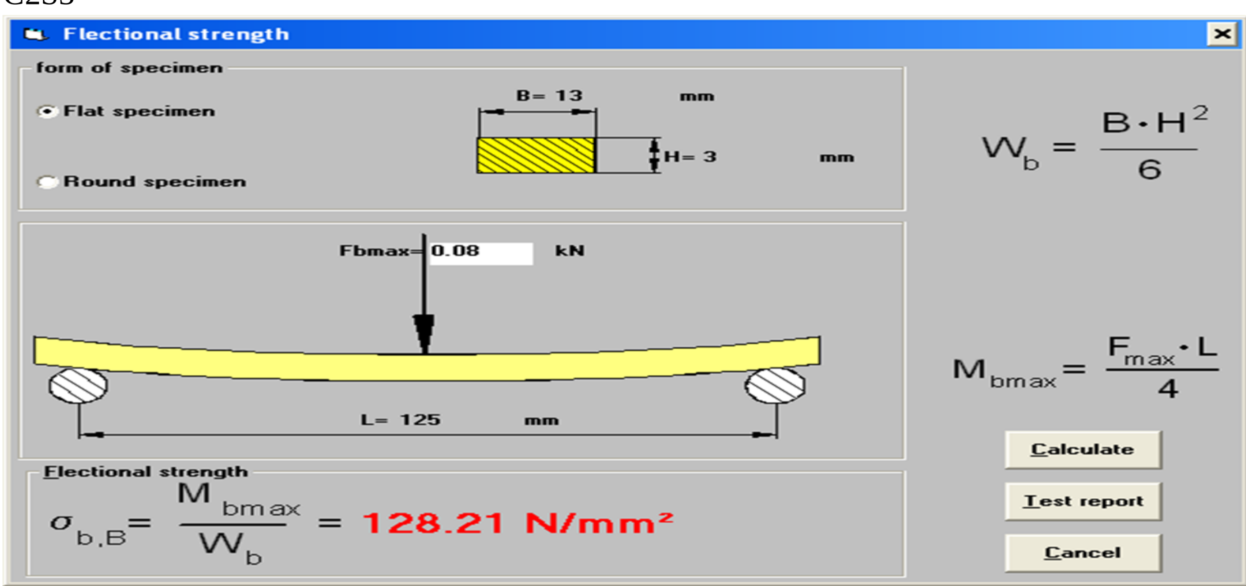
C2S1



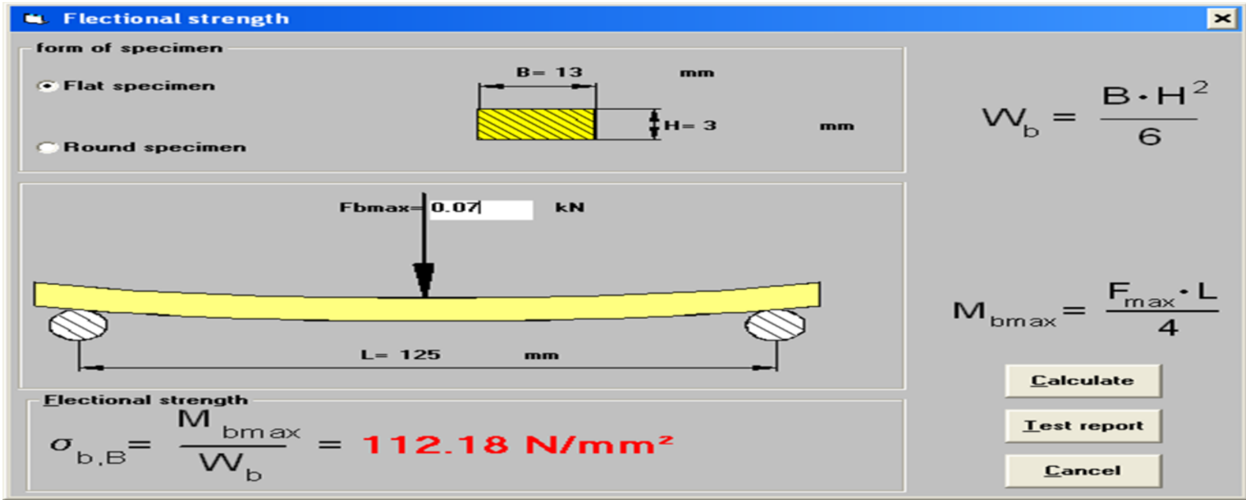
C2S2



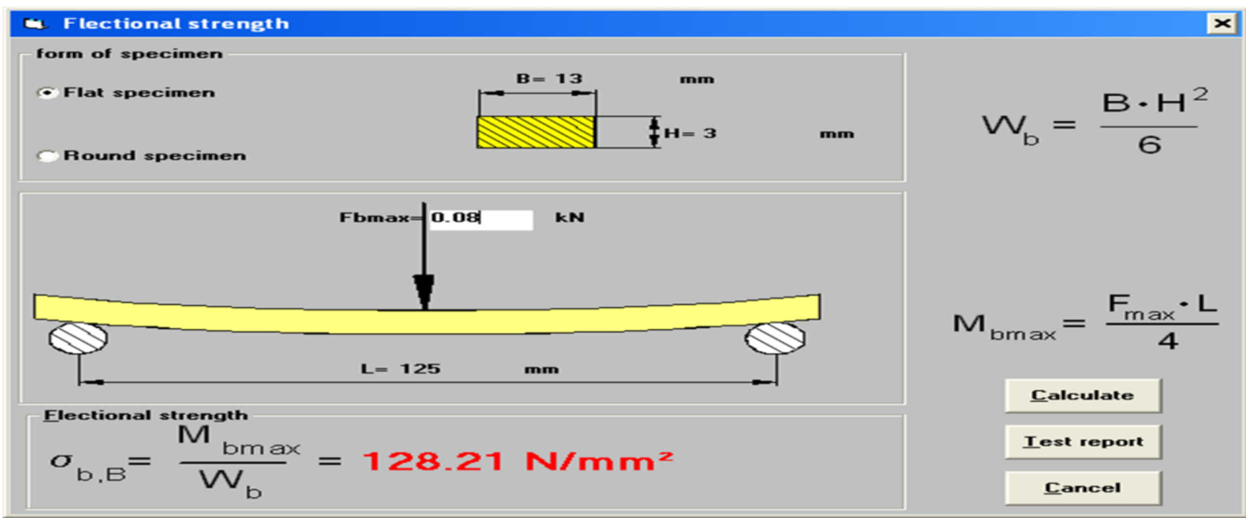
C2S3



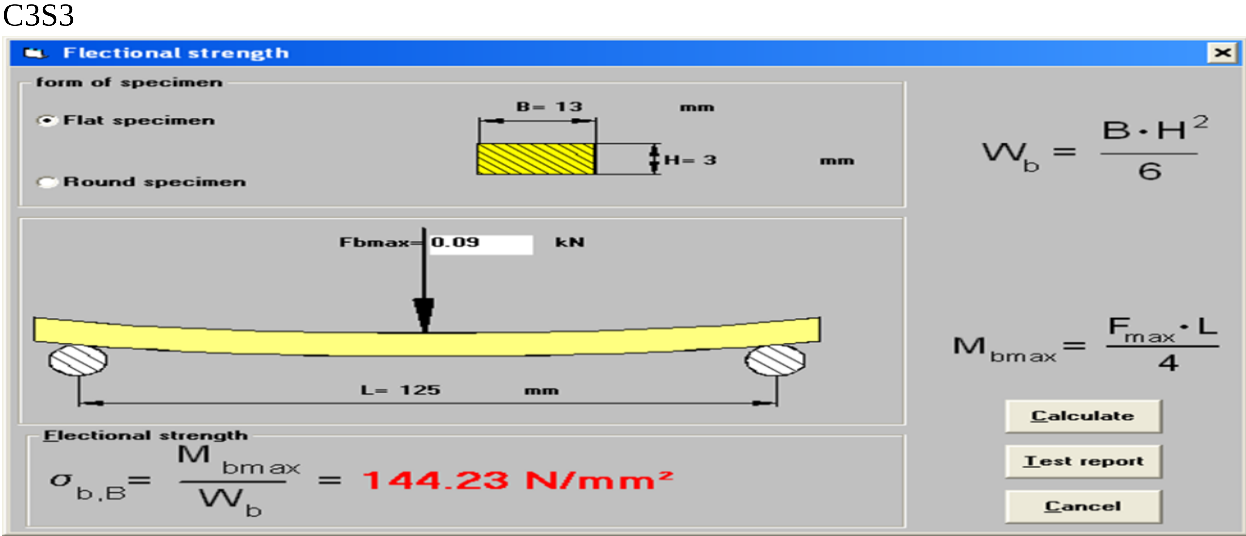
C3S1



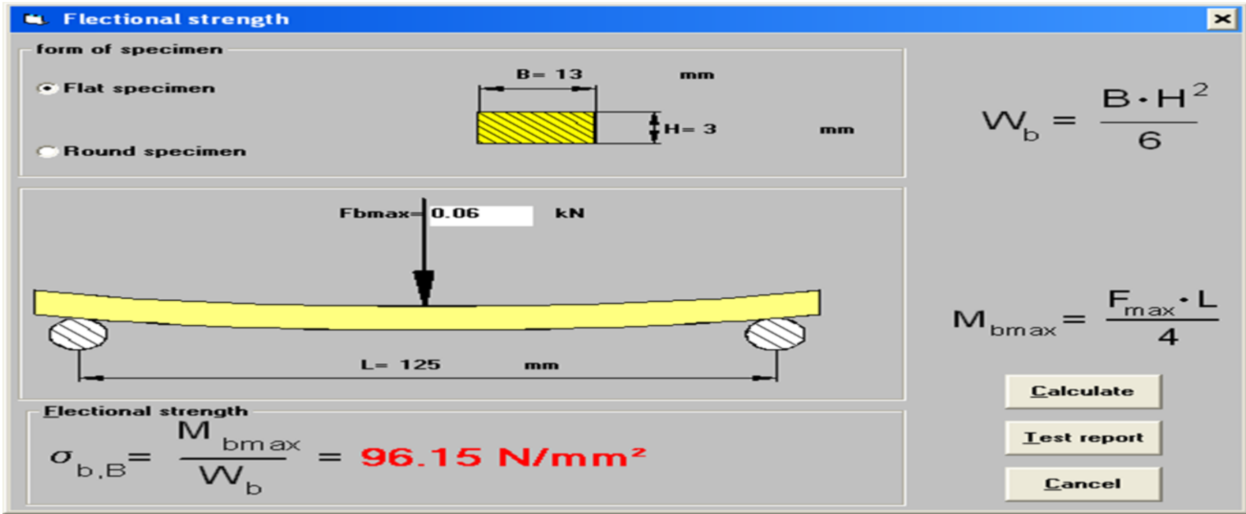
C3S2



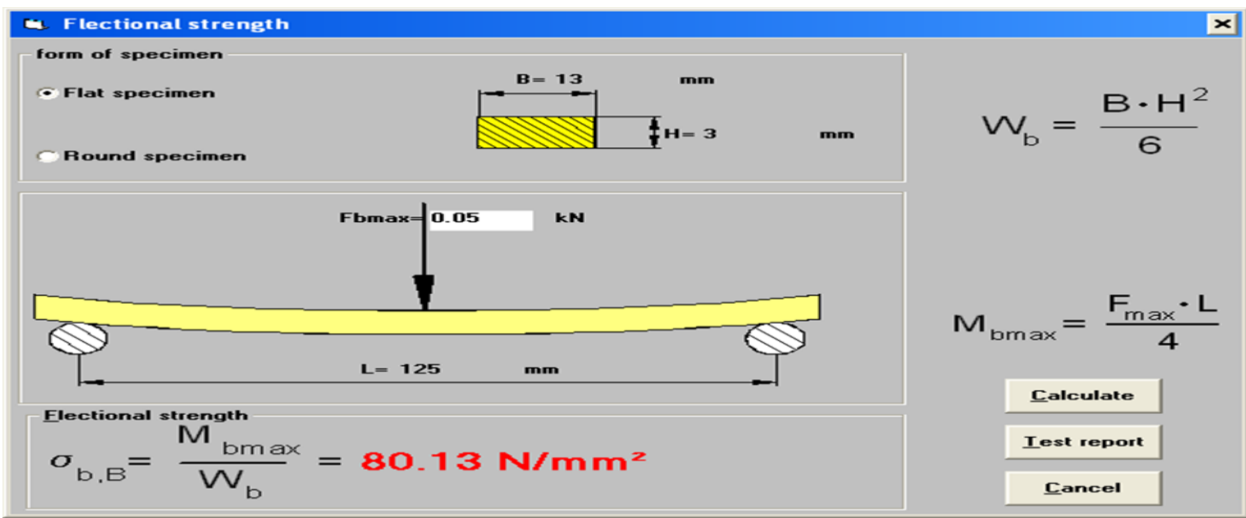
C3S3



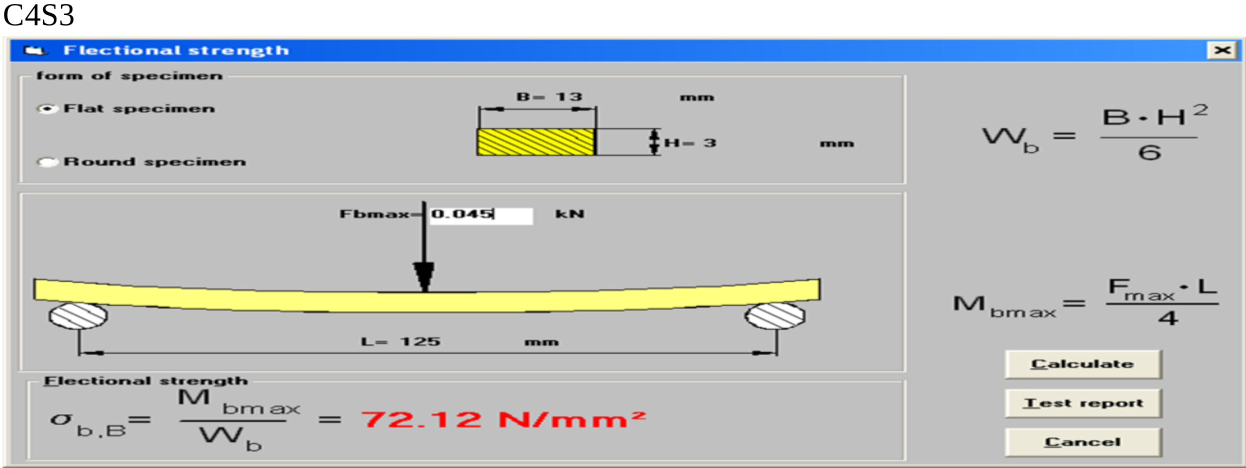
C4S1



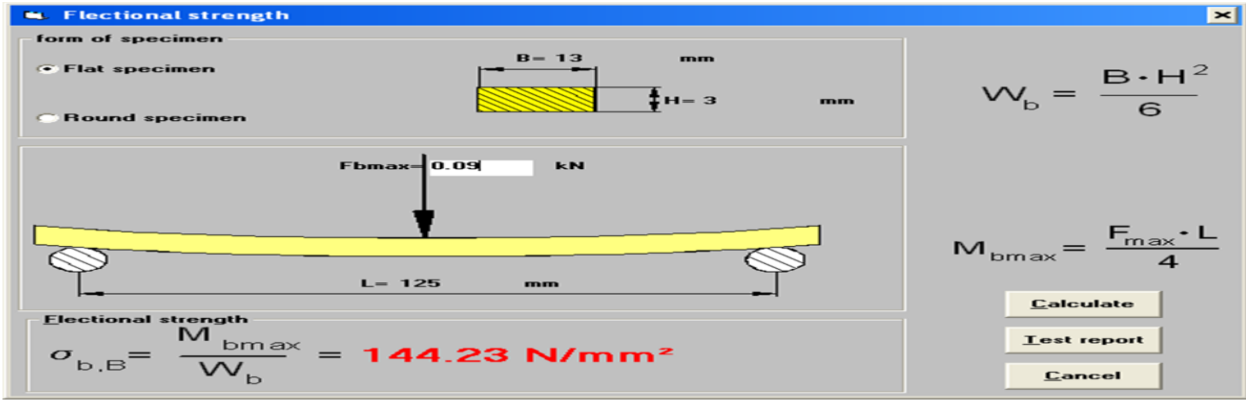
C4S2



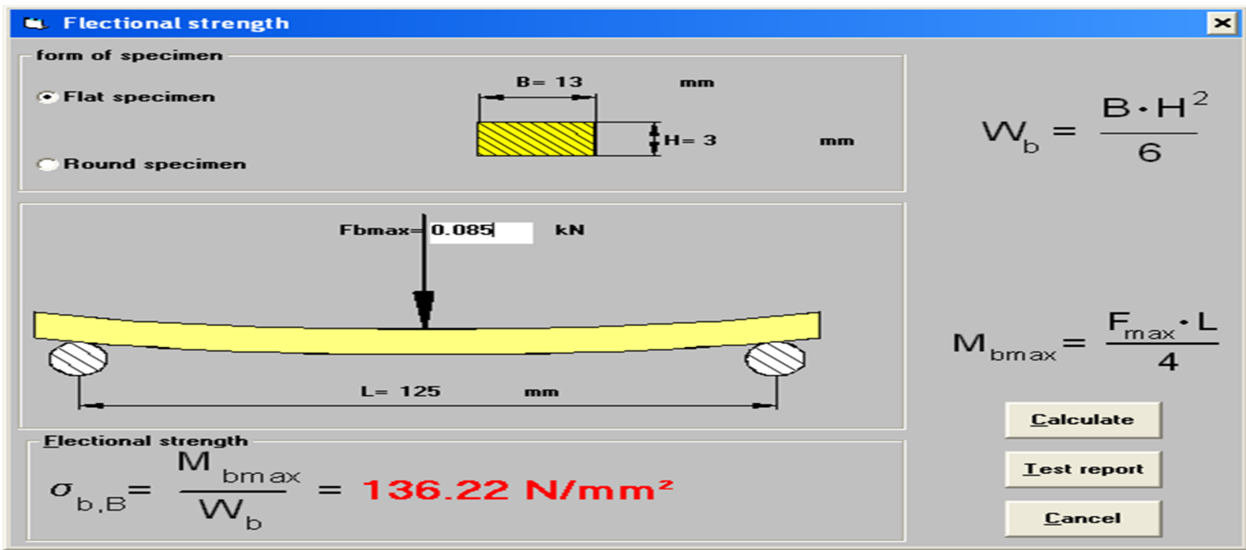
C4S3



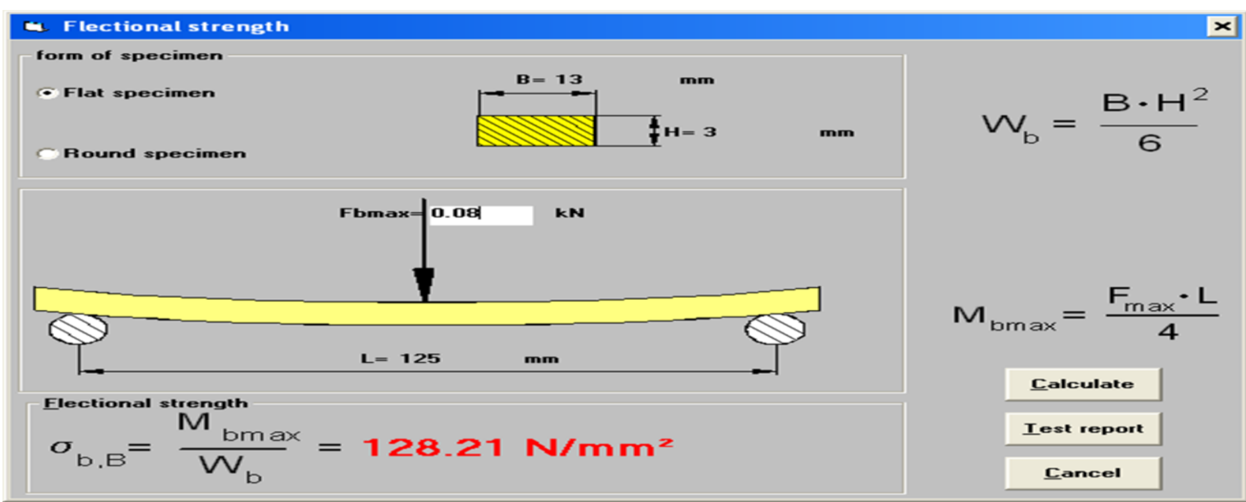
C5S1



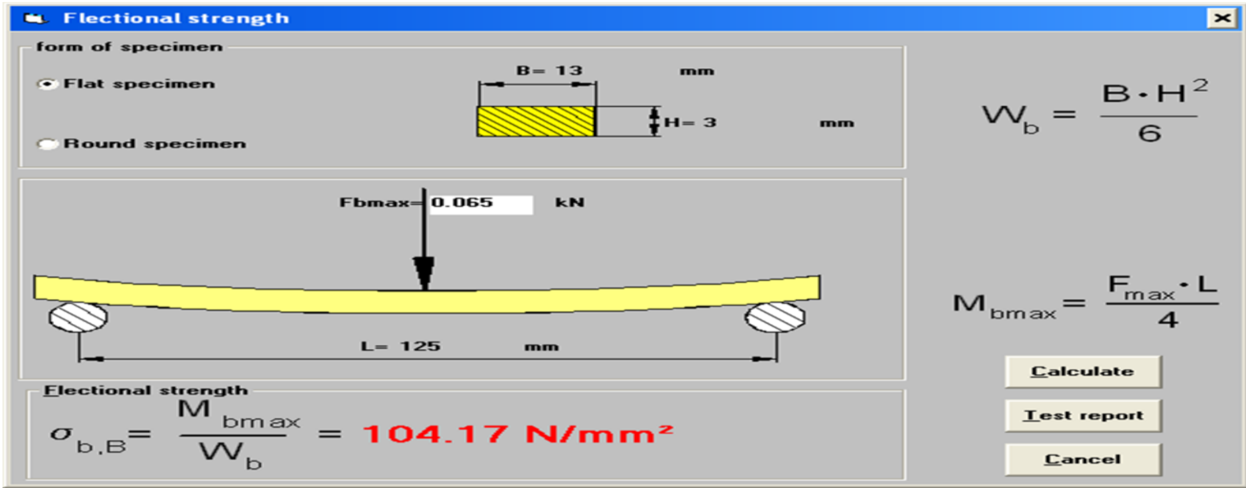
C5S2



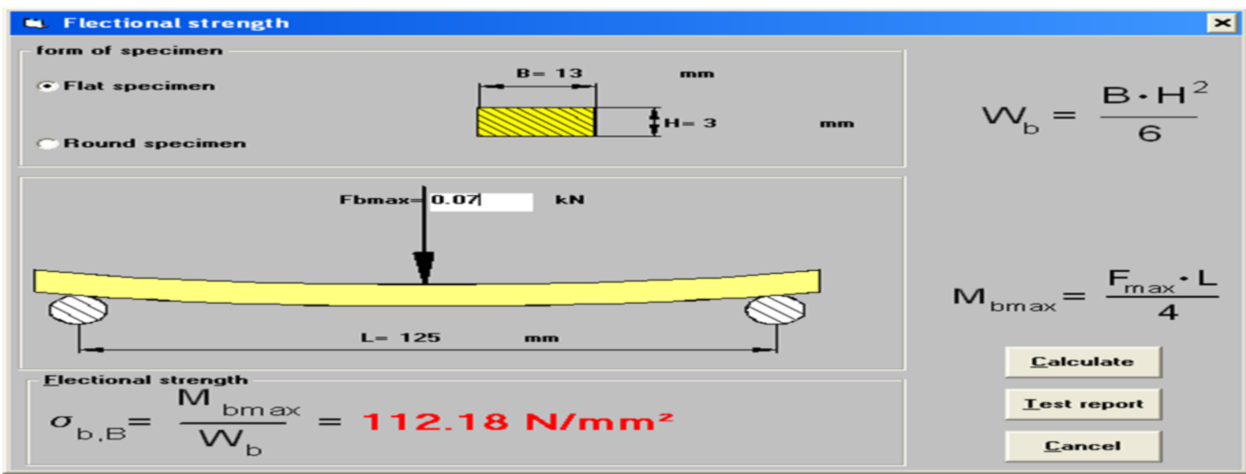
C5S3



C6S1



C6S2



C6S3