ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTIUTE OF TECHNOLOGY

School of Mechanical and Industrial Engineering

Fabrication & Characterization of Hybrid Glass -Maize Stalk Fibers Reinforced Epoxy Composite for Bone Fracture Plate Application: An Experimental and Numerical Approach

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

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Declaration

This is to certify that the thesis prepared by Abeba Gachen, entitled " **Fabrication & Characterization of Hybrid Glass -Maize Stalk Fibers Reinforced Epoxy Composite for Bone Fracture Plate Application: An Experimental and Numerical Approach"** is hereby declared as my original work. It has not been submitted, either partially or in full, for a degree in any University or Institute. This thesis complies with the regulations regarding originality and quality.

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Dedicated to my mom & Kena

Abstract

Femur bone fractures are a common injury resulting from high-energy trauma caused by traffic accidents and falls from heights. The conventional use of bone fixation plates presents a challenge due to their stiffness mismatch compared to human cortical bone, leading to the stress shielding effect. To address this issue, a hybrid fiber-based polymer composite with mechanical properties closest to human bone can be used. This research aims to fabricate and characterize the mechanical and physical properties of a new glass-maize stalk fiber reinforced epoxy hybrid composite for femur bone fracture plates applications. The hand-layup technique, coupled with light compression molding, was employed to create a composite material using 3 mm fiber lengths and a fiber-to-matrix weight ratio of 30% and 70%, respectively. Various mechanical and physical tests were carried out on specimens prepared in accordance with ASTM standards to assess the performance of the composite. The composite with a composition of 25% glass fiber with 5% maize-stalk fiber reinforced epoxy showed the promising results for femur bone plate application, with a tensile strength of 166.64MPa, compressive strength of 265.08MPa, flexural strength of 275.64MPa, impact strength of 16.67J, and micro hardness of 42.57HV. The physical properties including water absorption and density are determined for the selected composite and found to be a water absorption of 1.93% and density of 1.4235g/cm^3 and these properties make the hybrid composite suitable for the intended application. Finite element analysis is carried out to validate the experimental findings using ANSYS 2021 R2 commercial software. The stress shielding effect has been reduced by using the hybrid composite, with a von Mises stress of 49.166MPa and total deformation of 4.4329mm. The results obtained from both experiments and FEA show that the glass fiber-maize stalk reinforced epoxy hybrid composite is a suitable alternative for bone plates, as it reduces the stress shielding effect associated with the use of metallic plates. Furthermore, the use of agricultural residue like maize stalk as a reinforcing material contributes to environmental sustainability.

Keywords: Mechanical characteristics, FEA, Maize-stalk fiber, Femur bone, Hybrid composite, and Bone plate

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Acronyms

ASTM	American Standard Test Methods
C1 – C7	Composite one – Composite seven
FRC	Fiber reinforced composite
FEM	Finite Element Method
FEA	Finite Element Analysis
GF	Glass fibers
MSF	Maize-stalk fiber
MPa	Mega Pascal
NaOH	Sodium Hydroxide
UTM	Universal Testing Machine
WHO	World Health Organization

Chapter One

1. Introduction

1.1 Background of the Study

The demand for advanced materials is growing quickly, both in terms of research and practical applications. It is widely understood that technological progress relies on advancements in the field of materials. It is evident to anyone that even the most cutting-edge turbine or aircraft design is useless without suitable materials capable of withstanding the required loads and conditions. Regardless of the specific field, the progress and improvement of materials ultimately determine the limits of advancement. Consequently, composite materials are a significant stride in the ongoing pursuit of optimizing materials (Chawla, 2012).

Composites are specially designed materials made up of multiple components. Presently, composite materials have found applications in various branches of engineering, including biomedical engineering, for the creation of novel devices and implants (Wang and Zhao, 2019). Composites' properties can be changed to suit a variety of requirements. Additionally, composites surpass the constraint of relying solely on single-phase materials by utilizing a combination of different materials (Nassar and Sider, 2021). Consequently, these materials exhibit enhanced compatibility with biological and mechanical properties of bodily tissues, resulting in improved strength, durability, and overall performance.

Fiber-reinforced composites, whether incorporating synthetic or natural fibers, are gaining importance as the market seeks lightweight materials with superior strength for specific applications. These composites offer a remarkable strength-to-weight ratio along with outstanding properties like durability, stiffness, damping, flexural strength, and corrosion resistance. Their diverse attributes have led to their widespread use across industries such as mechanical, construction, aerospace, automotive, biomedical, marine, and manufacturing.

Natural fibers have garnered significant interest as a possible substitute for synthetic fibers in improving the characteristics of different resins in advanced applications. This is because of their advantages such as a high strength-to-weight ratio, low density, and renewable nature (Kiruthika, 2017 ; Ahmad *et al.*, 2015 ; Saba *et al.*, 2016). Unlike synthetic fibers, natural fibers do not emit harmful gases during processing and are gentle on processing equipment. Natural fibers can be derived from plants, animals, or minerals, but plant-based or ligno-cellulosic fibers are the most commonly used due to their accessibility and ease of processing. These fibers are primarily made up of various chemical components, including cellulose, hemicellulose, lignin, pectin, and wax.

Bone is a remarkably active tissue that experiences ongoing changes in its structure and composition. When injured, bone possesses the ability to regenerate, restoring its biological and mechanical properties to their pre-damaged state (Giannoudis *et al.,* 2007 ; Wiesel *et al.,* 2007) . However, various diseases, disorders, and traumatic events affecting the skeletal system can cause damage. This damage can result in fractures and defects, which in turn may increase mortality rates. The impact on mortality varies depending on the specific bone affected (Melton *et al.,* 2013 ;Somersalo *et al.*, 2015 & 2016). While the exact reasons for this link are not fully understood, it is likely influenced by the additional health issues or comorbidities associated with these fractures or defects.

Defects and fractures may result in the requirement for an implant or they may be brought by the implant's existence. In addition, after blood, bone is the tissue that is transplanted into humans the most (Faour *et al.*, 2011 ; Turnbull *et al.*, 2018). As a result, it's critical to give considerable thought to treating skeletal system stress without endangering patients when designing orthopaedic devices. To promote primary bone healing, a bone plate is applied to shut the fracture gap and prevent further bone fracturing.

In 1980, the concept of employing composite materials for bone implants emerged (Liu and Wang, 2007). Composite materials with greater strength, stiffness, and resemblance to real bone have begun to be used in light of the challenges and failures with the earlier technologies. At least one of the components in medical composites ceramic, metal or polymer should be bioactive. Bioactivity is a key consideration when selecting a material for medical composite manufacture. Bones, which are classified as hard tissue, are characterized by their strength, rigidity, and high elasticity.

Human bones are structurally and naturally composite material made of collagen filaments and nano gems of hydroxyapatite which are residue in collagen strands (Ramakrishna *et al.*, 2001). The collagen fibers exhibit a low flexible modulus, while hydroxyapatite possesses a high flexible modulus and constitutes approximately 70% of the bone's dry weight, contributing significantly to the bone's strength and stability. With respect to reality, composite material could address incredible biocompatibility. These days it is demonstrated that composite materials are an excellent decision and substitute for bone embed in muscular medical procedures.

Since, natural fibers have some limitations such as hydrophilicity, significant moisture absorption, degradation at low temperatures, vulnerability to microorganisms, limited fire resistance, and notable fluctuations in mechanical properties (Flynn *et al.*, 2016 ; Valença *et al.*, 2015). Generally, the outer side of the bone plate interacts more with human cells, tissues, and other biological fluids, which enhances its wettability and influences the characteristics of the material. As a result, combining natural fibers with a modest amount of synthetic fibers can help to overcome the disadvantages of natural fibers while preserving their benefits (Priyanka *et al.*, 2017). Combining natural fibers with synthetic fibers provides advantages like reduced weight, cost-effectiveness, renewability, biodegradability, and eco-friendliness, while maintaining mechanical properties similar to conventional materials (Mahesh Kumar *et al.*, 2018). When utilizing composite materials as bone plates, it may be necessary to employ a hybrid composite that combines different types of fibers. This is done in order to achieve a desirable set of properties that can perform adequately in various directions. One type of fiber alone may not be able to fulfil all the necessary requirements.

Therefore, this study investigated the mechanical characteristics of a novel composite plate made from a combination of glass, maize stalk, and epoxy to determine its suitability for treating fractures in the femur bone, specifically in orthopaedic applications. To assess the mechanical characteristics of this hybrid composite material under the primary stresses encountered by orthopaedic femur fracture plates, experiments were performed to measure tensile and compressive properties. Evaluating the material's resistance to impact, particularly crucial for bone applications given the femur's susceptibility to bending forces due to its length, involved testing impact and flexural strength. Additionally, a micro-hardness examination was carried out to compare the surface hardness of this material with standard medical-grade metals used in similar applications. Furthermore, a water absorption test was conducted to explore the material's viability in environments where moisture exposure is a concern at fracture sites.

1.2 Statement of the Problem

Bone possesses a relatively fragile nature, yet it possesses adequate strength and resilience to endure significant pressure. The majority of fractures occur due to sudden and excessive force, which can be either direct or indirect in nature (Solomon *et al.*, 2010). Injuries are prevalent and on the rise in many developing countries, including Sub-Saharan Africa. According to a report from the World Health Organization (WHO), the mortality rate associated with injuries was highest in African nations, with Ethiopia ranking third after Nigeria and South Africa (WHO, 2004). Each year, over 16.2 million cases of fractures are treated (Idris *et al.,* 2010).. Research has indicated that road traffic accidents (RTAs) and armed conflict are the primary factors contributing to traumatic orthopaedic injuries (Huda *et al.*, 2014).

Traditionally, medical devices for bone fixation and repair have primarily been constructed from metals and utilized in medical treatments (Saravia *et al.*, 2015). Stainless steel, titanium, and their blends have been extensively employed in the treatment of fractures and the enhancement of bone regrowth (Paiva *et al.*, 2022). However, these metal devices and implants are not biodegradable, leading to the need for additional surgical interventions to remove the plates. Consequently, this often prolongs hospitalization periods, escalates healthcare costs, and heightens the chances of infections and complications.

A bone plate is employed to stabilize a fracture and minimize the gap, facilitating quicker initial bone recovery. Nevertheless, the utilization of a metal plate in conjunction with human cortical bone can hinder the efficacy of treating long bone fractures (Olmos *et al.*, 2022). The mismatch in stiffness between the plate and cortical bone causes stress shielding, causing increased stress to be borne by the plate rather than the cortical bone. This diversion of blood flow away from the bone beneath the plate leads to bone resorption and weakening over time (Al-Tamimi *et al.*, 2020).

Therefore, it was crucial to design a fracture plate that matched the mechanical properties of the cortical bone to reduce the negative effects of stress shielding. As a result, this study aimed to investigate the feasibility of employing a blend of hybrid glass fiber and maize stalk fiber composites in producing a bone fracture plate. This included conducting tests to analyze the mechanical and physical characteristics of the composite material and determining its appropriateness for the intended use through ANSYS simulations.

1.3 Objectives

1.3.1 General Objective

The main goal of this study was to fabricate and analyse the mechanical and physical properties of a composite material made from a combination of glass and maize stalk fibers, reinforced with epoxy. The research also aimed to assess the material's potential for use in orthopaedic bone plates through finite element analysis.

1.3.2 Specific Objectives

- To extract maize stalk fibers from maize plant using chemical extraction method.
- To fabricate hybrid glass-maize stalk fibers reinforced epoxy composite specimens with different fiber loading composition.
- To examine mechanical properties namely tensile, compression, flexural, impact and micro-hardness for different fiber loading compositions using ASTM test methods.
- To determine physical properties including density and water absorption capability for selected different fiber loading conditions.
- To investigate the effect of fiber loading on the mechanical and physical properties of hybrid composite specimen.
- To select proper hybrid composite composition and test its suitability for the orthopaedic bone plate application using FE analysis.

1.4 Research Question

1. How does fiber loading influence the mechanical and physical properties of hybrid composite specimens?
2. Can the selected hybrid composite composition be deemed suitable for orthopedic bone plate application based on finite element analysis (FEA) results?
3. What is the optimal hybrid composite composition that exhibits desired mechanical and physical properties for orthopedic bone plate application?
4. How do the mechanical and physical properties of the hybrid composite specimens compare to traditional orthopedic materials used for bone plates?

1.5 Scope of the Study

The goal of the study was to examine a novel composite material that might be applied to fracture plates, which are frequently used to treat lengthy bone fractures. Using a manual lay-up process, an epoxy hybrid composite reinforced with glass fibre and maize stalk was created.

Experimental methods were used to characterize the mechanical and physical properties, such as density, water absorption, micro-hardness, flexural, impact, and tensile. FE analysis was carried out for the bone fracture plate to check its suitability and applicability. The study was limited to modeling and FE analysis for the femur bone fracture plate only, and no manufacturing prototype was produced.

1.6 Significance of the research

The study aimed to address challenges associated with fracture healing in patients with osteoporosis and other metabolic disorders. The developed hybrid composite aims to improved complications that arose due to the use of metallic materials such as magnesium, titanium, or stainless steel. The study maximized the biological benefits while providing sufficient mechanical support for fractures at load-bearing sites. The study's findings have the potential to significantly improve the treatment of severe fractures, reduce complications, and enhance the healing process, leading to rapid healing. The hybrid composite material was biocompatible and low cost, making it a favorable option for fracture treatment. The study outcome was necessary for severe fractures that required realignment and fixation for proper healing.

1.7 Limitations of the study

During the course of conducting this thesis, numerous challenges were encountered. The foremost impediment involved the scarcity of experimental setups and the arduous task of sourcing specialized machinery for testing purposes, which incurred significant expenses per specimen. Furthermore, the existing body of literature pertaining to maize-stalk fiber, particularly concerning the extraction process and the integration of this fiber with other natural and synthetic fibers, was notably inadequate and scattered.

1.8 Organization of the thesis

This thesis is organized into five chapters as follows:

Chapter One: By delving into the topic's comprehensive context and research objectives, this chapter aims to provide an introductory backdrop.

Chapter Two: This section critically examines various literature sources to elucidate the intricate scientific principles governing hybrid composites (consisting of natural and synthetic fibers), femur bones, and fracture plates.

Chapter Three: With a focus on the materials employed, methodological procedures, and requisite conditions for specimen preparation, this chapter conveys the systematic framework for conducting tests.

Chapter Four: Through a thorough analysis of experimental tests and Finite Element Analysis, this chapter comprehensively presents and discusses the obtained results.

Chapter Five: Drawing upon the research conducted, this chapter succinctly summarizes the findings, offers valuable recommendations, and outlines potential future research directions.

Chapter Two

2. Literature Review

2.1 Introduction to Composite Materials

Haydaruzzaman *et al.*, (2010) described composite materials as a blend of two or more distinct materials with varying physical and chemical characteristics, resulting in a novel material with unique properties. These materials can replace traditional materials such as metals and wood due to their enhanced fracture toughness, superior temperature resistance, high specific strength, and ease of production. Composites comprise reinforcement materials that offer strength and rigidity, along with matrices that bind the reinforcement fibers, maintaining their position and orientation within the material.

2.2 Constituents of Composite Materials

The properties of composites are influenced in different ways by the selection of the reinforcing and matrix materials. As shown in Figure 2.1, the classification of composites might change depending on the particular kinds of materials used (Mallick, 2007).

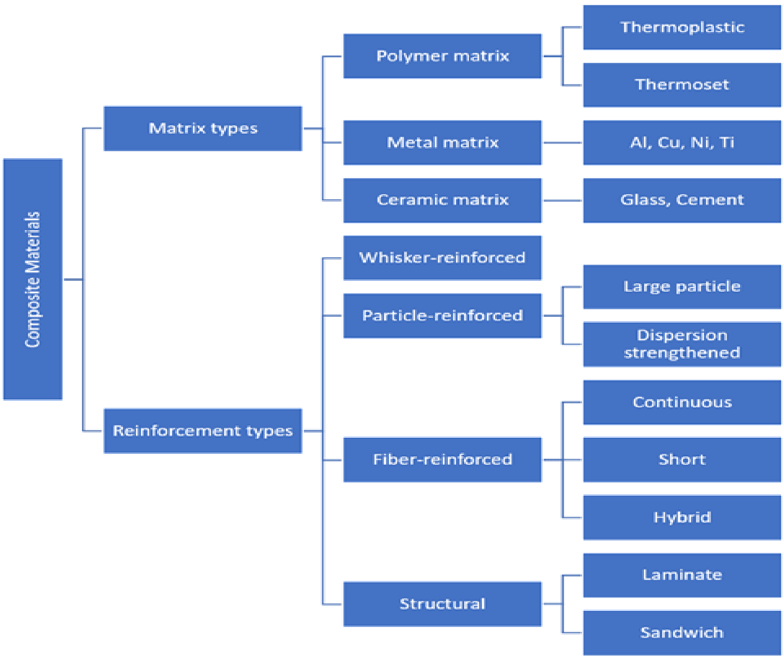


Figure 2.1 Classification of Composites based on the types of matrix and reinforcement materials (Mallick, 2007)

2.2.1 Matrix materials

The matrix materials act as a protective barrier around the reinforcement materials, maintaining their placement and enhancing the characteristics of the composite material as a whole. The most frequently utilized matrix materials to develop composite materials are discussed as follow:

i. **Ceramics**

Ceramics have excellent chemical and heat resistance, low density, and great hardness. Ceramic matrix materials are used in gas turbine engines, high-performance automotive disc brakes, and heat shields for space applications. Among the frequently utilized ceramic matrix materials are silicon carbide, silicon nitride, carbon, and aluminium oxide(Sharma *et al.*, 2020).

ii. **Metals**

Metals are frequently used as matrix materials in composites, particularly low-density metals or alloys. Their exceptional strength and heat conductivity render them appropriate for a multitude of engineering uses. Stainless steel, titanium, magnesium, and aluminum alloys are commonly utilized as metal matrices in composite materials (Sharma *et al.*, 2020).

iii. **Polymers**

Polymers are long-chain molecules with repeating units of atoms, commonly known as plastics. Polymers are commonly employed as materials for matrices in composites as a result of their versatility, lightweight nature, and ease of processing. They offer good corrosion resistance and can be tailored for specific applications (Sharma *et al.*, 2020). Polymer matrices are divided into two main groups: thermosets and thermoplastics.

a) **Thermoplastics:** The composition of thermoplastic matrix materials involves one- or two-dimensional molecules, so these polymers tend to make their properties weaker at an elevated temperature and roll back during cooling (Martin *et al.*, 2020). The common property is that all thermoplastics undergo large deformation before the final fracture. Commonly used thermoplastics are Nylon, polypropylene, acrylics, etc.

b) **Thermoset:** The commonly utilized matrix materials in composite manufacturing are thermosetting resins like epoxy, polyester, polyurethane, and various others. These resins offer suitable mechanical properties at a cost-effective price point (Wable *et al.*, 2021).

- **Epoxy** is the predominant resin utilized in polymer matrix composites, and it is widely recognized for its exceptional qualities. As an advanced thermosetting resin, epoxy does not release reaction byproducts during the curing process, resulting in minimal shrinkage. Additionally, it exhibits strong adhesion to various materials, excellent resistance to chemicals and environmental factors, and favorable chemical and insulating properties (Hu *et al.*, 2022). Given these superior advantages compared to alternative resin types, epoxy finds extensive use in diverse applications.

2.2.2 Reinforcement materials

Reinforcements play a crucial role in composites by imparting strength, stiffness, and supporting the structural load (Mathapati *et al.*, 2014). Consequently, the selection of the appropriate reinforcement is of great significance in achieving the desired properties in the final product. Various types of reinforcement materials exist, including particulates, whiskers, sandwiched materials and fibers (Rajak *et al.*, 2019).

i. Particulates

Particulates are tiny particles that are evenly distributed throughout the main material. By augmenting the composite, particulates have the ability to improve its mechanical characteristics, such as the Young's Modulus (a measure of stiffness) and tensile strength. Various types of particulate reinforcement exist, including ceramics, metals, and carbon black, which are incorporated into polymers (Rajak *et al.*, 2019).

ii. Whiskers

Whiskers are ultra-thin fibers with diameters that are typically less than 1 micron. They provide high strength and stiffness to the composite because of their large aspect ratio. Examples of whisker reinforcements include carbon whiskers, silicon carbide whiskers, and boron whiskers (Rajak *et al.*, 2019).

iii. Sandwiched materials

Sandwiched are composite materials that consist of two or more layers of different materials, with a thin layer of a high-strength material in the middle. The high-strength layer acts as a reinforcement, providing additional stiffness and strength to the composite (Rajak *et al.*, 2019).

iv. Fibers

Fibers are long, thin strands of material that are embedded within the matrix material. Fibers can significantly increase the tensile strength and stiffness of the composite. Common fiber reinforcements include carbon fibers, glass fibers, and aramid fibers (Rajak *et al.*, 2019). The fibers in a fiber reinforced composite influence the following aspects (Mallick, 2007).

- ✓ Density
- ✓ Tensile Strength and Modulus
- ✓ Compressive Strength and modulus
- ✓ Fatigue strength and Failure mechanisms

- ✓ Electrical and Thermal conductivities
- ✓ Cost of composite structure

The properties of fiber-reinforced composites are influenced by various factors related to the fibers used, with the most important ones being fiber length, fiber orientation, and fiber loading. Out of these factors, fiber orientation plays a crucial role in determining the characteristics of the composite material. Fibers possess remarkable tensile strength when aligned in the longitudinal direction, which enables the orientation to be utilized as a means of controlling the composite material's anisotropic properties (Kesarwani *et al.,* 2018).

The material has the potential to demonstrate increased flexibility when aligned along the direction of the fibers. Conversely, when the fibers are randomly oriented, the material is more likely to possess properties that are the same in all directions (isotropic). The proportion of fibers present in the composite, known as fiber loading, is another important factor. The strength and stiffness of the material are significantly influenced by the quantity of fibers, with higher volumes of fibers leading to greater strength and stiffness. However, it is important to be cautious about using an excessive amount of fiber, as it may not bond properly with the base matrix, necessitating careful consideration during the design process. Similarly, the length of the fibers is also a critical parameter that can impact various properties of the composite (Lubin, 2013 ; Kesarwani *et al.,* 2018).

2.3 Classification of Fibres

Fibers serve as the primary components responsible for bearing the load, while the matrix functions as an intermediary for transferring the load and safeguarding the fibers from external conditions. Typically, there are two main categories of fibers:

a) Synthetic Fibres and
b) Natural Fibres

a. Synthetic Fibres

Synthetic fibers refer to durable fibers that are artificially produced and obtained from chemical sources. They are primarily derived from petroleum by-products. The main types of synthetic fibers commonly utilized include glass fibers, carbon fibers, and kevlar fibers (Balasubramanian *et al.,* 2019).

Glass fiber is the oldest and well-known type of fiber. It is a material that is both extremely strong and lightweight. Although its strength properties are not as high as those of carbon fiber, it is less rigid (Sanjay and Yogesha, 2017). Its popularity stems from the combination of its good strength-to-weight ratio and its abundant and affordable availability. Glass fibers can be found in various forms, including continuous strands, chopped pieces, and woven fabrics. These fibers exhibit nearly isotropic behavior, meaning they possess similar conductivity properties in all directions. The microstructure of the fiber plays a crucial role in its ability to conduct heat effectively. Different types of glass fiber exist, such as A-glass, C-glass, E-glass, and AE-glass.

b. Natural Fibres

García *et al.* (2008) describe natural fibers as those that are not artificially produced, but rather originate from natural sources. These fibers can be obtained from a variety of plant sources, including sisal, hemp, bamboo, maize, coir, flax, kenaf, jute, ramie, oil palm, pineapple, banana, and cotton, as well as from animal sources, such as wool, silk, and chicken feathers (Mukhopadhyay and Fangueiro, 2009). Navarro *et al.* (2008) note that the characteristics of natural fibers can be affected by factors such as the type of fiber, moisture content, and form (e.g., yarn, woven, twine, chopped, felt). Furthermore, Ticoalu *et al.* (2010) point out that the properties of these fibers are also influenced by the location in which they are grown, the conditions under which they are cultivated, the specific part of the plant from which they are taken, the length of the growth period, and any retting or extraction processes used.

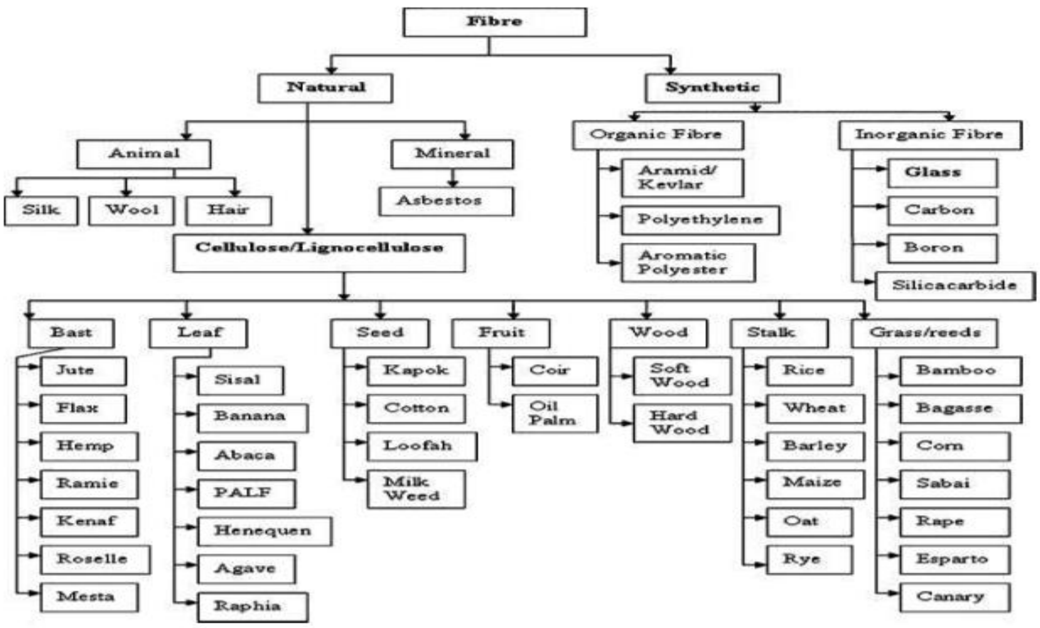


Figure 2.2 Classification of natural and synthetic fibres (Jawaid and Abdul Khalil, 2011)

Currently, plant fibers like stems, roots, leaves, seeds, timber, and grass have gained significance as essential components of strengthening materials. These plant fibers, particularly cellulose fibers, are predominantly derived from various types of crop straws such as corn, barley, bagasse, wheat, sorghum, and rice (Ramesh *et al.,* 2017).

Maize (Zea mays L.) is a widely grown cereal crop in Ethiopia, is recognized internationally for its importance compared to other cereals (Liverpool-Tasie *et al.*, 2017; Yami, Meyer and Hassan, 2020). In Ethiopia, maize covers around 2.526 million hectares of land and yields approximately 1055709.36 tons annually (Tekeste, 2021). This crop plays a significant role in the country as a source of food and income for farmers (Berhane *et al.*, 2013). Unfortunately, a large portion of maize stalks goes unused by local farmers, leading to wastage and environmental pollution through burning, which includes water and air pollution like haze (Ma *et al.*, 2018). The disposal of corn stalks has become a global issue that requires attention. Recent studies have explored the benefits of utilizing maize stalk waste in various applications such as fiber-reinforced bio-composite materials, affordable housing solutions, paper production, and packaging (Ma *et al.*, 2018 ; Li *et al.*, 2016). Research on the innovative utilization of corn stalk waste not only has the potential to address energy and environmental challenges but also to enhance the agricultural economy *(*Bi *et al.,* 2009).

2.4 Literature related to maize fiber

Reddy and Yang (2005) take out the fibres from maize stalks that resemble regular textile fibres in terms of their mechanical characteristics. Partial delignification is a step in the fibre extraction process that renders the fibres appropriate to be utilized in textile and various industrial settings. By employing scanning electron microscopy and X-ray diffraction techniques researchers discovered that maize stalk fibres have a microfibrillar angle that is comparable to ordinary bast fibres but a comparatively lower % crystallinity. According to this study, maize stem fibres can be used to make a variety of textile goods.

Kumar *et al.* (2011) produced composites utilizing the hand lay-up process using zea mays fibres with varying weight percentages. After applying an alkali treatment to the fibers and the composite's mechanical properties were analysed. The findings indicated that at a 40% fibre percentage, qualities increased, but at high fibre content weight, properties decreased. To evaluate the relationship between the fiber and matrix components, the researchers also described the properties of the composite materials.

Chigondo *et al.* (2013) investigated the utilization of maize stalk fibers to strengthen natural rubber composites in the production of shoe soles. Maize stalk fibres were developed for use as fillers in natural rubber composites. The FTIR method was used to alter and describe the fibres. The study's findings demonstrated that the treated fibres had excellent mechanical qualities and less moisture absorption. This implies that the modified fibres from maize stalks may be able to successfully strengthen natural rubber when it comes to making shoe soles.

Luo *et al.* (2017) investigated how different parts of the corn stalk, such as the stem, ear, husk, cob, and leaf, affected the production of corn fiber plastic composites (CFPC). It also examined the impact of the composition of cellulose, hemicellulose, and lignin fractions on the mechanical properties of CFPC. The results showed that hemicellulose and lignin had a significant influence on all properties of CFPC, and higher levels of cellulose and lignin improved the mechanical properties of CFPC. The corn plant's stem or cob was the optimal choice for creating CFPC (Corn Fiber Reinforced Polymer Composite). This material exhibited impressive characteristics, such as a remarkable flexural strength of 46.10 MPa and a tensile break strength of 26.58 MPa, when utilized as reinforcement. However, it was important for the hemicellulose content to be lower to ensure better water resistance of CFPC. On the other hand, CFPC reinforced with corn leaf performed poorly, with a flexural strength of 28.70 MPa and tensile break strength of 15.98 MPa, mainly due to the high hemicellulose content present in the corn leaf.

Chen *et al.* (2018) examined the potential of corn stalk flour (CSF) as a substitute for wood flour (WF) as a filler in PVC-based wood plastic composites (WPCs), with sisal fiber (SF) added to strengthen the composite's mechanical properties. The investigation assessed the composite's mechanical and water absorption characteristics, as well as the impact of incorporating both SF and CSF on these properties. The findings revealed that CSF's chemical makeup is comparable to WF's. Adding 5 mm-long SF enhanced the composite's mechanical properties without significantly affecting its water absorption behavior. Additionally, the research utilized scanning electron microscopy to investigate the fracture surface of the composite and assess how CSF and SF are distributed within PVC.

Workiye and Woldsenbet (2020) developed a composite material with geopolymer properties was created by utilizing cellulose fibers extracted from a single maize stalk and strengthening it with calcined kaolinite clay.The kaolinite clay was obtained from two different locations in

Ethiopia and underwent chemical composition analysis to serve as a precursor material. The cellulose fibers were extracted from a local maize variety using a retting process and then treated with 98% pure sodium hydroxide for a duration of 30 minutes. To determine their suitability as reinforcement, the tensile strength and young modulus of the fibers were assessed in accordance with ASTM D3822. An alkaline activator consisting of sodium hydroxide and sodium silicate was employed in a specific ratio. The geopolymer composites were strengthened with various weight percentages (0%, 0.1%, 0.2%, 0.6%, and 1%) of the single maize stalk cellulose fibers and subsequently subjected to compression strength testing following ASTM C1424 guidelines. The results of the compression strength measurements ranged from 16 MPa to 27 MPa, indicating that the addition of appropriate amounts of single maize stalk cellulose fibers can enhance the compression strength of a geopolymer material based on calcined kaolinite.

Łączny *et al.* (2021) examined how the size of fillers affected the mechanical and thermomechanical properties of composite materials made of polylactide (PLA) matrix and containing 15% by weight corn stalk (CS) fibers. Four variations of corn stalk fibers were employed, measuring 1 mm, 1.6 mm, 2 mm, and 4 mm in diameter. The results showed that when the size of the filler fibers increased, the characteristics related to the strength and resilience of the composite materials, such as tensile strength, bending strength, and impact energy absorption, decreased. Among the composites studied, the one with filler fibers measuring 1 mm in diameter displayed the most desirable mechanical and thermomechanical properties. To analyze the structures of the composites, X-ray microcomputed tomography and scanning electron microscopy were utilized. These examinations revealed that larger filler particles were not evenly distributed within the filler material, which led to a significant reduction in the mechanical and thermomechanical properties of the composite. The research concluded that environmentally friendly composites incorporating corn stalk fibers with diameters ranging from 1 to 2 mm could be a suitable alternative to traditional plastic-based materials in specific applications.

Devi *et al.* (2022) optimized extraction conditions were fine-tuned to enhance the quality and quantity of the fibers obtained. The best conditions included subjecting the maize stalk to a sodium hydroxide concentration of 5 g/L for 60 minutes at boiling point, with a material-to-liquor ratio of 1:50. The resulting maize stalk fibers displayed varied physical and chemical characteristics, suggesting their suitability for producing eco-friendly composite materials.

This research offered important knowledge on how to process and analyze maize stalk fibers for sustainable development.

2.5 Hybridization of natural fibre with synthetic fiber

Hybrid composites refer to materials that are created by combining multiple types of fibers in a shared matrix. These fibers can be a mix of natural and synthetic materials, allowing the resulting composites to benefit from the distinct advantages offered by each fiber type. When fibers, whether they are natural or synthetic, are added to a polymer matrix, it leads to considerable alterations in the mechanical characteristics of the composites (Khanam *et al.*, 2010). Notably, the mechanical properties experience greater enhancements when natural fibers are combined with glass or carbon fibers, as opposed to being combined exclusively with other natural fibers (Venkateshwaran *et al.*, 2011).

The utilization of hybrid composite materials, which blend synthetic and natural fibers, is gaining more attention. The attractiveness of natural fibers stems from their ability to biodegrade and their environmentally friendly nature, making them an appealing choice for reinforcing composites. Nonetheless, certain challenges, such as high moisture absorption and inadequate compatibility with other materials, have prompted researchers to explore the incorporation of synthetic or other natural fibers into natural fibers. This approach aims to overcome the limitations associated with natural fibers while retaining their environmental benefits. Table 2.1 provides a summary of different research efforts in this particular field, presenting an overview of the advantages and practical uses of hybrid composite materials.

Table.2.1. Work reported on mechanical characteristics of thermoset hybrid composites

Garadimani *et al.* (2015)	**Objectives**	To examine the mechanical characteristics of composites made from a combination of corn cob particles, E-Glass fibers, and a polymer matrix using hand layup.
	Method	Fabricated a composite panel with varying amounts of glass fibers and corn cob particles. These composites were subjected to mechanical testing in accordance with ASTM regulations to assess their performance. To create the hybrid

		composites for testing, different ratios of corn cob particles, E-glass fibers, and epoxy were utilized.
	Result	The incorporation of 25% corn cob particles and E-Glass fibers resulted in enhanced tensile strength and flexural strength in the composites when compared to the standard sample. It was observed that the mechanical characteristics of the composites improved as the weight percentage of E-Glass fiber increased.
Tewelde *et al.* (2022)	**Objectives**	Investigate the mechanical characteristics of a composite material created by blending glass and water hyacinth fibers through the hand layup technique.
	Method	The mixture of materials was created through a manual laying process, adhering to the guidelines outlined in ASTM D3410 and ASTM D3039 for compression and tensile testing. The characteristics of the material were studied to investigate how the amount of fibers present affected its mechanical properties.
	Result	The mechanical characteristics vary depending on the volume fraction. The introduction of glass fibers impacted both the tensile and compressive properties' outcomes.
Rana *et al.* (2017)	**Objectives**	The study focused on enhancing the durability properties of a composite material made from a mixture of glass fiber and acetylated sisal fiber, which were incorporated into an epoxy resin matrix.
	Method	The research reinforced an epoxy composite with acetylated sisal and glass fibers. It used two layers of glass fiber and different amounts of sisal fiber

		(0%, 2%, 4%, 6%) to test mechanical properties like tensile, flexural, and impact strength.
	Result	Tensile and flexural strength increased up to 4% weight percentage of sisal fiber and then decreased. Impact strength increased regularly. The study provides insights into the use of acetylated sisal fiber and glass fiber as reinforcements to enhance the mechanical properties of the composite.
Atiqah *et al.* (2014)	**Objectives**	To fabricate a composite material made of kenaf-glass fibers and unsaturated polyester using the sheet molding compound technique.
	Method	Kenaf fibers, treated and untreated, were mixed with unsaturated polyester resin in a 70:30 ratio by volume. Treated fibers underwent mercerization with 6% NaOH for 3 hours. Hybrid composites were tested for flexural, tensile, and impact strength following ASTM standards. Fracture modes were analysed using scanning electron microscopy.
	Result	The best flexural, tensile, and impact resistance were achieved using a composite material of treated kenaf reinforced with KG fibers in a 15/15 v/v ratio with UPE.
Raghavendra Rao *et al.* (2010)	**Objectives**	Investigated the bending and compression characteristics of composite materials that combine bamboo and glass fibers with epoxy resin.
	Method	The study involved comparing the properties of hybrid composites with and without alkali-treated bamboo fibers.

	Result	Both flexural and compressive properties of the hybrid composite increase with glass fiber content.
Prabhu *et al.* (2019)	**Objectives**	Sisal and waste tea fibers hybridized with Glass Fiber Reinforced Polymer using an epoxy matrix
	Method	Fibers were treated with 5% alkaline (NaOH) to enhance their properties. Mechanical properties (tensile strength, impact strength, flexural strength) and moisture absorption were evaluated. Chemical composition was analysed with FTIR, and sound absorption was tested using Impedance Test Tube method. Interfacial properties (internal cracks, blow holes, fiber pullouts) were assessed through SEM analysis.
	Result	By combining natural fibers with GFRP, the characteristics of the composites can be customized to fulfil specific needs and attain maximum efficiency.
Petrucci *et al.* (2015)	**Objectives**	Fabrication and assessing the characteristics of various hybrid composite laminates
	Method	The study includes creating hybrid laminates using vacuum infusion and testing them for tensile strength, three-point flexural strength, and interlaminar shear strength. The fracture surfaces of the laminates were later analysed using SEM.
	Result	The hybrid laminates show better mechanical performance compared to pure hemp and flax fiber laminates but are not as good as basalt fiber laminates. The combination of glass and flax with basalt fiber laminates offers the highest quality properties.

Arthanarieswaran *et al.* (2014)	**Objectives**	Evaluate the mechanical properties of composites made from banana and sisal fibers reinforced with epoxy, and how the addition of glass fibers affects their strength
	Method	Banana and sisal fibers, along with E-glass synthetic fibers, were intricately woven together and combined with an epoxy matrix. A total of nine laminates were created with varying arrangements of fibers. Mechanical properties like tensile, flexural, and impact strength were tested, along with the use of a SEM to analysed the interface and study microstructural properties.
	Result	The research offers a deeper understanding of how combining glass fibers affects the mechanical characteristics of the composites.

2.6 Fabrication Techniques of fiber reinforced Composite Materials

Numerous manufacturing techniques are employed to produce composite materials, encompassing manual application on exposed molds, hand layup with vacuum bag assistance, resin infusion, spray-up application, various forms of Resin Transfer Molding (RTM) such as VARTM and RTM light, hot press molding, cold/warm press molding, filament winding, pultrusion, and autoclave processing. The choice of technique is determined by factors such as the materials involved, the design requirements, and the intended application, as highlighted by Chand and Fahim (2020) and Salit *et al.* (2015).

i. Hand lay-up

The hand lay-up method is the most commonly used technique, which involves a higher labor force but has a lower cost, making it an economical choice (Salit *et al.*, 2015). This technique is carried out through a series of steps, starting with the application of a releasing agent on the mold, followed by the addition of a thin layer of resin and reinforcement material. The reinforcement is then thoroughly soaked with resin using rollers and brushes to ensure complete impregnation. The desired thickness is achieved by gradually adding layers, and after each layer is added, the product is given sufficient time to cure. Once the entire product has cured, it is removed from the mold (Chand and Fahim, 2020). It is important to note that this method only forms one side of the product, as the mold is open.

ii. Vacuum Bagging

Vacuum bag molding stands as a primary technique in composite fabrication for creating laminated composite structures, particularly favored within the aerospace sector. This method falls under prepreg molding and autoclave molding processes. The key difference lies in the curing stage: one occurs within a vacuum bag (oven), while the other takes place in an autoclave. By utilizing a bag to apply compaction pressure, this approach enhances the strength of the laminate. Vacuum bag molding represents an advanced iteration of the hand or wet lay-up process. Polymer options suitable for this technique encompass epoxy, phenolic, and Polyimide. Through vacuum bag molding, superior lightweight composite materials can be achieved, ensuring consistent and high mechanical properties in the resulting composite plates (Mujahid *et al.*, 2021).

iii. Compression molding

Compression molding is a type of composite manufacturing process that falls under the category of closed-mold techniques. It involves the use of paired metal molds and external pressure to produce high-volume composite parts, such as automotive components. There are two primary methods of compression molding: cold and hot. The cold press method only uses pressure and cures at room temperature, while the hot press method requires both temperature and pressure to transfer heat to the composite and initiate the curing process. This manufacturing technique is widely used and employs various raw materials, including fibers and matrices, prepregs, sheet molding compounds (SMC), and bulk molding compounds (BMC) (Kluge *et al.*, 2015).

iv. Resin transfer molding

Resin transfer molding (RTM) is a manufacturing process that takes place in a closed environment. It involves placing dry fiber reinforcements into a mold with the desired shape of the composite part. Another mold is then secured over the first, and resin is injected into the space between them. A release agent is applied to the mold surface to facilitate the removal of the finished composite. However, the use of matched molds can be expensive and is generally limited to smaller components that can withstand high pressures. RTM is commonly used for making hollow forms, intricate structures, automobile body parts, large containers, and bathtubs (Ageyeva *et al.*, 2019).

2.7 Human Bone

Bone is a sophisticated living material made up of an organic component that includes collagen, along with an inorganic part that features calcium-based crystals integrated within it (Uskoković *et al.,* 2019). Approximately 30% of bone's weight is matrix, 60% is mineral, and 10% is water (Ma *et al.*, 2022). The collagen in the bone matrix provides tensile strength, while the mineral component, primarily calcium phosphate, contributes to its compressive strength (Unal *et al.,* 2018). There are two categories of bone tissue: cortical (dense) and cancellous (spongy). Dense bone has a stiffness modulus ranging from 7–20 GPa and a compressive strength between 131–224 MPa, whereas spongy bones have a stiffness modulus and compressive strength of 50–100 MPa and 5–10 MPa, respectively(Mohamed, 2008).

Humans have about 206 bones in their body. Human bones are the structural support of the human body, they protect the internal organs, and they store minerals such as calcium and phosphorus. Bones are made up of living cells and a mineralized extracellular matrix that provide strength and flexibility. Based on their shape and functions they are five main types of bones in the human body (Al-Taki and Nahle, 2016): long bones, short bones, flat bones, irregular bones, and sesamoid bones.

1. Long bones: These bones are longer than they are wide and include bones of the arms and legs (femur, humerus, radius, ulna, tibia, fibula, etc.)

2. Short bones: These bones are roughly cube-shaped and provide stability and support, such as bones of wrist (carpals) and ankle (tarsals).

3. Flat bones: These bones are thin and flat providing protection and anchorage for muscles, such as the skull, sternum, scapula, pelvis, and ribs.

4. Irregular bones: These bones have an irregular shape and do not fit into any other bone category, such as the vertebrae, facial bones, and bones of the pelvis.

5. Sesamoid bones: These are small, round bones that are embedded in certain tendons. The most commonly known sesamoid bone is the patella (kneecap).

2.7.1 Femur Bone

The femur, the only bone in the thigh, is vital for supporting the body as it moves toward the knee, where it joins the upper portion of the tibiae. The femurs converge so tightly in knock-knee cases that the knees come into contact. With an average length of approximately 26.74% of a person's height, the femur is the longest and, by most accounts, the strongest bone in the body. This ratio is consistent across different genders and ethnicities with limited variation (Nareliya and Kumar, 2012). The femur is categorized as a long bone and is composed of two epiphyses, or the extremities that connect to neighbouring hip and knee bones, and a diaphysis, or the shaft, or body, as shown in figure 2.3.

Figure 2.3 Femur bone anatomy (Nareliya and Kumar, 2012)

The femur has two rounded ends and a long shaft in the middle. It’s the classic shape used for bones in cartoons: A cylinder with two round bumps at each end. Even though it’s one long bone, femur bone is made up of several parts (Chang and Hubbard, 2018). These include:

a) **Femur proximal aspect: -**the upper (proximal) end of femur connects to hip joint. The proximal end (aspect) contains the: head, neck., greater trochanter, lesser trochanter, intertrochanteric line and crest.

b) **Femur shaft: -**the shaft is the long portion of the femur that supports the weight and forms the structure of thigh. It angles slightly toward the centre of the body. The shaft of femur bone includes the: Linea aspera, gluteal tuberosity, Pectineal line and Popliteal fossa.

c) **Femur distal aspect:** -the lower (distal) end of the femur forms the top of knee joint. It meets the tibia (shin) and patella (kneecap). It includes the: medial and lateral condyles, medial and lateral epicondyles and intercondylar fossa.

2.8 Bone fracture and bone plate

A bone fracture is a medical condition in which a bone is broken or cracked. It can be caused by a variety of factors, including trauma, falls from a height, car accidents, sports injuries, and underlying medical conditions like osteoporosis or bone cancer. The bones that are frequently exposed to fractures are the long bones, such as the femur, tibia, and humerus. These bones are more prone to injury due to their length and the amount of stress and weight they bear (Katherine, 2013).

Bone plates are crucial for bone fracture healing, as they offer mechanical support for fractured bone and influence the biomechanical environment around the fracture site. Bone plates are the most popular implants for internal fixation, with numerous benefits, including stability, resistance to tension, compression, shear, torsion, and bending for plates and screws used in internal bone fracture fixation (Jain *et al.*, 1999). Stainless steel and titanium-based bone plates are the most common materials used in bone fracture internal fixation. Despite their rigidity, which ensures reliable fixation for fracture fragments, they have drawbacks, such as the undesirable stress shielding effect and the need for a second operation for implant removal. Moreover, these traditional bone plates are less effective in treating complex fractures (Nourisa and Rouhi, 2019).

Fractures of the bone can be repaired through various methods, namely external fixation and internal fixation. External fixation involves the use of devices and materials such as casts or splints to immobilize the fractured bone without the need to surgically open the surrounding tissue. Bone fracture devices maintain the bone in its proper position during healing. These are generally made up of a combination of woven cotton, a calcium sulphate base, and reinforcing materials such as fiberglass and polyesters, forming casts and splints. Internal fixation, however, involves surgical procedures and the use of implants to mend bone fractures. The choice of implants is determined by the specific fracture type and may include wires, pins, screws, bone plates, or intramedullary nails. Plates and screws are commonly utilized in internal fixation and can be made of Steel-Ti alloys or Co-Cr alloys. After a period of approximately 1-2 years following surgery, bone plates and screws are generally removed from the body (Kim *et al.*, 2020).However, after the removal of the plate, the bone may become weaker and more susceptible to fractures due to reduced stress-bearing capacity (Nareliya and Kumar, 2012).

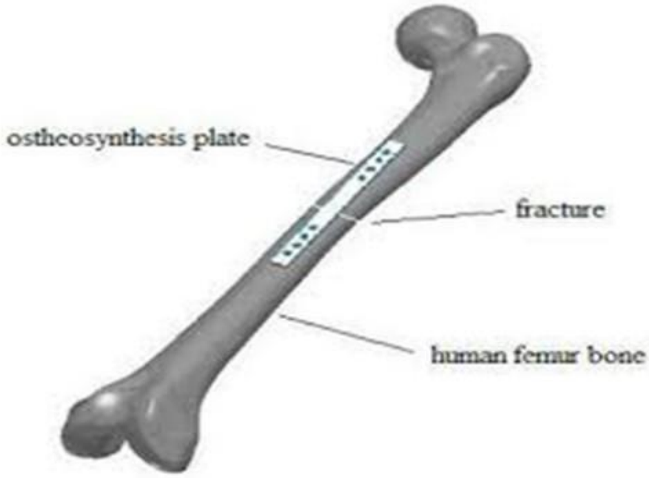


Figure 2.4 Fracture femur bone with metallic plate (Nareliya and Kumar, 2012)

Now days, polymeric composites are a better alternative material to metallic bone plates and ceramic composites since they are proven to have fewer failures than other groups. They exist in a variety of shapes and forms and are variable and distinct in their composition, performances, and qualities (Bagheri *et al.*, 2013).

2.9 Composite in Biomedical Application

Numerous research investigations have utilized natural fibers in the development of polymer composites intended for biomedical orthopedic implants. By manipulating the proportion and configuration of fibers, these materials, reinforced with fibers, can acquire a wide range of mechanical characteristics akin to those found in bone tissue (Ramakrishna *et al.*, 2001).

Namvar *et al.* (2014) investigated various natural fibers for use in the biomedical field, highlighting their distinct benefits compared to other materials. These advantages include superior strength compared to their weight, non-corrosive properties, high resistance to fractures, renewable sourcing, and sustainability.

According to research by Bharanichandar *et al.*(2014) and (Chandramohan and Marimuthu, 2016), positive mechanical characteristics were identified in polymeric composites reinforced with natural fibers like Sisal, Roselle, and Banana. These composite materials exhibit potential for utilization in bone grafting procedures, with the possibility of substituting traditional materials like metals, ceramics, and alloy plates. The mechanical characteristics of these hybrid composites were assessed through both experimental methods and simulation with ANSYS software.

2.10 Prior studies on bone fracture plate

Bagheri *et al.* (2014) conducted to assess the biomechanical characteristics of a novel composite bone fracture plate made from carbon fiber, flax, and epoxy (CF/flax/epoxy) for orthopedic trauma uses. The aim of the investigation was to contrast the rigidity and stress distribution of the new plate to a traditional clinical metal plate. The findings indicated that the axial stiffness of the CF/flax/epoxy-plated femur was comparable to that of the metal-plated femur. However, the bone underneath the CF/flax/epoxy plate exhibited notably higher surface stress on average compared to the bone under the metal plate. This suggests that the innovative CF/flax/epoxy material could potentially serve as a suitable choice for bone fracture plate applications, offering sufficient overall rigidity while minimizing stress shielding in comparison to a standard clinical metal plate.

Gouda *et al.* (2014) examined the mechanical properties of a hybrid natural fiber polymer composite material for prosthetic bone applications. This composite material contained 12%, 24%, and 36% fiber weight fractions, and was composed of continuous long fibers that were randomly oriented and had a low density, making it a cost-effective option. The researchers, employed Epoxy resin-LY556 as the base material and combined it with Sisal, Jute, and Hemp fibers to create a hybrid natural fiber polymer composite. The main objective of the study was to collect data on the femur bone's strength and properties and compare the experimental results of the composite material to those of the femur bone. The study's findings suggested that the 36% hybrid natural fiber polymer composite material was a suitable option for femur bone prosthetics due to its low weight, low density, high strength, and biocompatibility.

Manteghi *et al.* (2017) examined the viability of a glass, flax, and epoxy composite material for use in fracture plates or other methods of treating bone fractures. Glass and Epoxy make up the exterior layers of the sandwich-like composite plates, while Flax and Epoxy make up the centre. Numerous tests were performed on the specimens as part of the study, such as uniaxial tension, compression, three-point bending, Rockwell Hardness, and water absorption. As opposed to conventional metallic plates, the suggested hybrid composite plates offer substantially greater axial flexibility, according to the results. More ultimate strength under tension, compression, and bending was also demonstrated by them. The sandwich structure has better stiffness and strength in bending in relation to tension and compression because it has stiff and inflexible outer layers and a more flexible core. These characteristics elevate the proposed hybrid composite

Arumugam *et al.* (2020) studied the mechanical properties of a hybrid composite material for orthopaedic long bone plate applications made of glass fibre (GF), sisal fibre (SF), and chitosan (CTS). With GF/CTS/epoxy for the outside layers and SF/CTS/epoxy for the inside layers, the GF/SF/CTS hybrid composite features a unique sandwich structure. With a stiff external cortex and a spongy internal cancellous matrix, the composite plate mirrors the structure of human bones. The GF/SF/CTS hybrid composites have an elastic modulus of 18 GPa, an ultimate tensile strength of 146 MPa, and a bending strength of 343 MPa, according to the findings of the mechanical tests. Nevertheless, the biocompatibility of the composite material was not examined in this work. The GF/SF/CTS hybrid composite material appears to have promising mechanical capabilities for the fixing of bone fractures, according to the data.

Girimurugan *et al.* (2022) investigated the mechanical properties of a composite material made of jute fiber (JF) and sisal fiber (SF) with potential use in orthopaedic long bone plates. The outer layer of the composite included JF and epoxy, creating a hybrid composite that was tested for tensile, flexural, compression strength, and impact properties. Findings indicated that the JF-SF hybrid composite exhibited favourable qualities for orthopaedic bone fracture plates. This study underscores the potential of natural fiber composites in orthopaedic applications, presenting a substitute for conventional metallic bone plates.

Senthil *et al.* (2023) developed and evaluated a hybrid composite of carbon flax and bio epoxy for the treatment of femoral fractures. They designed the femur bone plate using SOLIDWORKS® 2020 3D modelling software, and they used compression moulding to produce hybrid composite laminates. Tensile, shear, flexural, and wear tests were among the material characterisation procedures performed on ASTM-shaped specimens to ascertain the produced hybrid composite's strength and wear properties. According to the test results, the hybrid composite reinforced with flax and carbon possesses qualities similar to those of human femur bone, which makes it a viable substitute for conventional metallic bone plates.

2.11 Need of finite element analysis for bone fracture plate

The technique of finite element analysis has been utilized in the field of orthopaedics to examine the actual mechanical behaviour and reaction of a bone when subjected to a fracture fixator. Finite element method has been employed in various orthopaedic research domains, including the analysis and design of orthopaedic devices, examination of tissue growth, remodelling, and degeneration, and skeletal analysis.(Zhang *et al.*, 2016 ; Ramlee *et al.*, 2014).

Das and Sarangi (2014) Performed finite element analysis on different biomaterials to evaluate the mechanical suitability of a simple bone plate. The plate was created using SolidWorks CAD tool, and a CT scan was carried out on a femur bone with horizontal and oblique fractures. The scan data was saved in DICOM format, and a 3D model of the femur bone was created by importing it into Mimics software.

Masood, Ahmad and Mufti (2013) Utilized finite element analysis to investigate the human femur bone by utilizing a 3D animated model of the femur bone created in Blender 2.63a software. The bone's polygonal mesh model was then transferred to ANSYS software for further evaluation after converting the CAD model through Pro/ENGINEER.

Kumar *et al.* (2015) utilized finite element analysis to examine the stress levels occurring at the hip contact area during everyday activities such as walking, running, jumping, and standing. The behaviour of the human femur bone was investigated by subjecting it to various loading conditions. A Solid Edge V19 CAD modelling software was utilized to build a representation of the femur bone, while ANSYS 14.0 software was employed to carry out the analysis. This analysis provides valuable insights into the stress distribution in fractured bones and aids in determining the appropriate artificial material required for mending the fractured bone.

Maharaj *et al.* (2013) stated that fractures of the femur bone are currently a common issue. The fractures can be treated by using bone plates for joining and repairing the bone. Choosing the right material for bone plates is crucial due to their implantation in the human body. This study involved examining bone plates crafted from different materials like stainless steel, Alumina, Titanium, Nylon, and PMMA to identify the most appropriate material for them.

A femur bone plate model was created using SolidWorks CAD modelling software and imported into ANSYS software for further analysis. The investigation focused on a male weighing 75 kg in a normal position, and it revealed the distribution of stress, fatigue failure, and overall deformation of the femur bone. The head side of the bone exhibited greater deformation, while the lower side experienced less deformation. The total equivalent stress obtained for Titanium was lower compared to the other materials, indicating that Titanium is the most suitable material for the bone plates.

Zakiuddin *et al.* (2016) examined the femur bone's structure, material properties, load capacity, and fracture risk. Elmer software was utilized to conduct vibrational analysis, while ANSYS software was employed for finite element analysis. The purpose of these analyses was to aid orthopaedic surgeons in tackling difficulties associated with hip implants.

2.12 Gaps identified

Based on the existing literature, it has been noted that natural fibres may eventually take the place of synthetic fibres in a variety of composite material applications. Additional understanding of the fibres' interaction with the matrix, the strength and modulus of the fiber's crystallinity, and the thermal degradation of the fibre composite has been made possible by the physical, chemical, mechanical, and thermal properties of both fibres and composites. Automotive and structural applications are where natural fibre uses are mostly focused. Challenges such as fiber swelling, moisture absorption, and surface degradation pose significant concerns in natural fiber composites; however, these limitations can be mitigated through hybridization with synthetic fibers. Several research gaps have been identified that require further investigation, including:

- The current metallic bone plates possess several drawbacks, including the stress shielding effect, non-biodegradability, and the need for a secondary surgery.
- There is a lack of research on using maize fiber as a material for reinforcement.
- The application of hybrid composites for bone fracture plates has been inadequately researched.
- In most studies, the evaluation of the stresses occurring between the human femur bone and bone plate was not conducted using finite element analysis.
- Despite the bone plate's direct exposure to biological fluids, its physical properties, like water absorption, are not considered.
- Several research studies have investigated the pollution caused by the burning of annual maize-stalk biomass.

Chapter Three

3. Materials and Methods

3.1 Research Methodology

To achieve the key research objectives, the following methods and materials were used including:

Reviewing Literature: which entails gathering and examining a range of articles, journals, and books that pertain to composites, natural fibers, synthetic fibers (with a focus on glass fiber), hybrid fibers, bone, and bone fracture plates. The primary goal of this was to gain a better understanding of the problem, examine potential solutions, and establish a course of action for achieving the research goals.

Natural fiber: The characteristics of natural fibers are influenced by the age and development stage of the plant. Hence, a maize-stalk plant was chosen considering these factors.

Selecting Fiber Matrix Composition: The matrix composition of fiber was selected by considering various fiber design parameters from different literature sources. Based on this information, fiber loading was applied to the matrix composition.

Selection of Extraction Method: The NaOH solution was employed as an extraction technique in order to improve the bonding between the fibers and the matrix, as well as to purify and whiten the surface of natural fibers.

Choice of Fabrication Technique: There are different methods available for producing composite materials, such as hand layup, compression molding, resin transfer, and vacuum bagging combined with hand layup. In this study, the method of hand layup was selected, followed by a light application of compression during the curing process, due to its simplicity and widespread accessibility.

Collection of Raw Materials: In this phase, the necessary materials such as epoxy, hardener, alkali agent, mold, and releasing agent were collected from different suppliers. The chosen reinforcing fibers, namely maize stalks and glass fibers, were fabricated in accordance with their compositions and layered (laminated) structures.

Composite Specimen's Preparation & Tests: The fabricated composite specimens underwent a series of tests in accordance with the standards set by ASTM. The tests include: tensile, flexural (3-point bending test), compression, impact, micro-hardness and water absorption tests.

Creating models, conducting simulations and analysing bone fracture plates: After obtaining the results, the best composition was selected for modeling, simulating, and analyzing using ANSYS software.

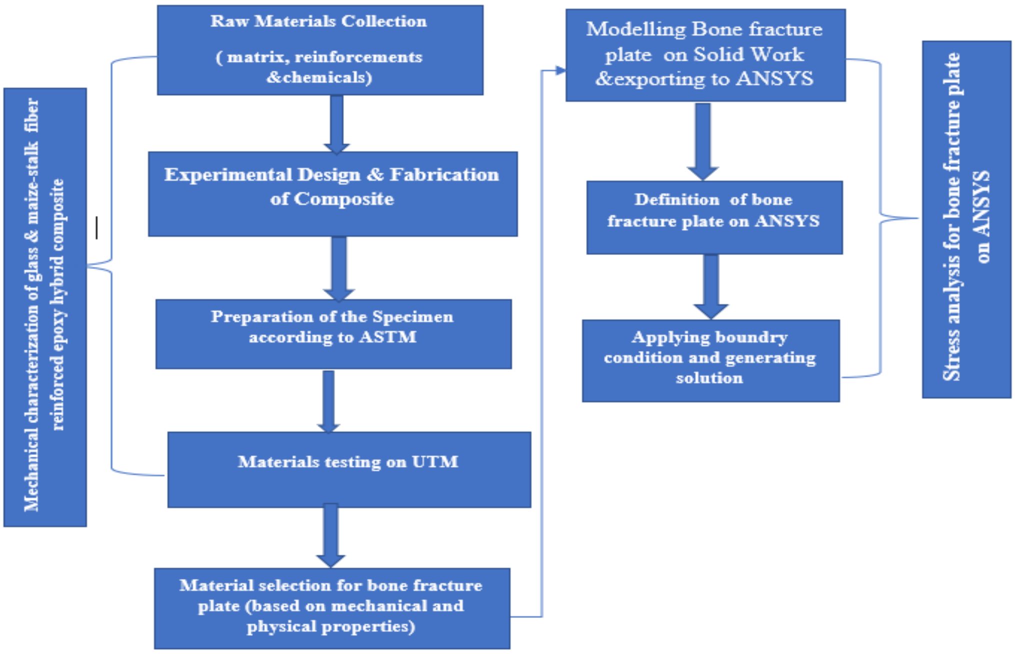


Figure 3.1 General methodology of the research

3.2 Materials Used

In case of materials selection for biomedical application the main consideration is bio-compatibility. Biocompatibility refers to a material's ability to elicit the necessary genetic response in a specific application. When a medical device or component interacts with a living system or tissue, it should not cause chemical reactions, irritation, or harm to the patient.

This study employed two distinct types of fibers to strengthen the structure, along with an epoxy resin as the binding material, in order to produce a composite material suitable for orthopaedic long bone plates. The reinforcing fibers included glass fiber and maize-stalk fiber. The polymer matrix, in this case epoxy resin, provided structure to the composite material and protected it from adverse conditions.

3.2.1 Epoxy resin and its hardener

Epoxy resin displayed superior adhesion characteristics compared to other types of resins. Additionally, it exhibited minimal shrinkage during the curing process, excellent resistance to chemicals, strong bonding with reinforcement materials, enhanced resistance to moisture, and exceptional mechanical properties. Epoxies were chosen for use in high-tech composites due to their ability to adhere well to various fibers, providing superior mechanical and electrical attributes as well as reliable performance at high temperatures. The hardener acted as a catalyst to kickstart a chemical reaction, converting the liquid resin into a solid form. Therefore, the process of curing Epoxy resin involved the introduction of a catalyst, which triggered a chemical reaction while keeping the composition of the resin unchanged. In this particular study, the hardener HY951 was employed as the curing agent. The resin and hardener were combined in a weight ratio of 10:1.After blending a specific quantity of hardener with the epoxy resin and stirring for 10-20 minutes, the mixture was poured into the mold as per (Gopalakrishnan *et al.*, 2018). This study employed both the epoxy resin LY556 and its corresponding hardener HY951, as demonstrated in figures 3.2 and 3.3, respectively. These materials were imported from India. Tables 3.1 and 3.2 detail the specifications for epoxy resin LY556 and hardener HY951.

Table 3.1 Property of Araldite Epoxy Resin LY 556

Specification	Epoxy Resin LY556
Model	Araldite
Colour	Clear liquid
Viscosity@25^0C	10000 - 12000 mPa s
Density@25^0C	1.15g/cm^3
Flash point	≥ 200^0C
Shelf life (at storage temperature between 2-40 ^{0}C)	Several years

Figure 3.2 Epoxy resin LY 556

Table 3.2 Property of Hardener HY 951

Specification	Hardner HY951
Model	Aradur
Colour	Colourless
Viscosity@25^{0}C	10- 20 mPa s
Density@20^{0}C	1 g/cm^3
Flash point	Closed cup:110^{0}C
Shelf life (at storage temperature between 2-40 ^{0}C)	Several years

Figure 3.3 Hardener HY 951

3.2.2 Reinforcement fibers

i. Maize stalk fiber

Composite structures rely on their reinforcement system for strength and stiffness. Fibers, particularly natural and synthetic fibers, are key players due to dominate in terms of t their volume, design flexibility, versatility, and properties. In this case, a mix of maize-stalk and glass fiber was used for reinforcement in a hybrid approach.

In this research, the utilization of maize stalk as a reinforcement is justified by several factors. Firstly, maize stalks are abundantly available in nature, making them a sustainable choice. Additionally, they possess desirable mechanical properties and have a high lignocellulose content, which enhances their strength and durability. Furthermore, maize stalks have a low density, making them lightweight and suitable for various applications. They are also easily accessible and cost-effective. Importantly, the use of maize stalks poses no health risks. Moreover, maize stalks are considered an underutilized agricultural waste, further emphasizing their potential as a valuable resource. Table 3.3 outlines the constituents of chemical composition of maize-stalk fiber.

Table 3.3 Chemical Composition of Maize-stalk Fiber (Reddy and Yang, 2005)

Constituents	% (percentage)
Cellulose	38-40
Hemi cellulose	28
Lignin	7-21
Ash	3.6-7
Wax	0.7

ii. Glass fiber

Glass fibers are synthetically produced materials frequently employed across diverse applications. This research employed glass fibers to improve the mechanical properties of a hybrid composite material. As a result, the moisture absorption of maize stalk fibers was also improved due to their advantageous properties and lower cost compared to many other synthetic fibers. The mechanical and physical properties of both maize stalk fiber and glass fibers are displayed in Table 3.4.

Table 3.4 Mechanical and physical properties of maize-stalk and glass fibers (Workiye and Woldsenbet, 2019 ; Kim *et al.*, 2011)

Maize-stalk fiber	Density (g/cm^3)	Tensile strength (MPa)	Elastic Modulus (GPa)	Elongation at break (%)
	1.5	1184.04	16.27	23.1
Glass fiber	2.5	2000~3500	70	2.5

In this work the randomly oriented glass fiber was collected from world glass fiber Addis Ababa, Ethiopia.

Figure 3.4 Randomly oriented glass fiber

3.3 Chemical Retting

Chemical retting, also known as surfactant retting, is an extraction process in which natural fibers are boiled with chemicals. One of the most popular methods for chemical retting is alkalization, where sodium hydroxide (NaOH) is used as an aqueous solution to remove lignin and hemicellulose. This chemical treatment is commonly employed to modify various natural fibers, resulting in a decrease in their ability to absorb water and enhancing the mechanical properties of composite materials This study utilized NaOH acquired from a local chemical supplier known as CARELABMED. The NaOH was in the form of pellets weighing 500g, as depicted in Figure 3.5.

Figure 3.5 Sodium hydroxide (NaOH) pellets

3.4 Fiber Collection and Extraction

To obtain natural cellulose fibers (Reddy and Yang, 2005) reported that lignocellulosic byproducts were treated with bacteria, fungi, mechanical means, and chemicals. The traditional method of retting, which involves the use of microorganisms in the environment to break down lignin, pectin, and other substances, is one way to extract fibers. Another common method of fiber extraction is the use of sodium hydroxide, as noted by (Workiye and Woldsenbet, 2019)

The local variety of dry maize-stalk after harvesting was collected from Goro which is located in Southwest Shewa Oromia Region in Ethiopia, 134 Km southwest of Addis Ababa. The next step was separating leaves and husks from the stalks using sickle, then cut into internodes and split into small piece enable to immerse in NaOH solution.

Various studies have employed different extraction techniques to obtain fiber from maize stalks. This particular research utilized a chemical extraction method to extract maize-stalk fiber. The extraction process involved multiple trials where key parameters such as chemical concentration, treatment time, temperature, and liquor-to-stalk ratio were varied to determine the optimal conditions for fiber quality and yield. After experimentation, the optimized conditions were established, which involved treating maize stalks with a 10 grams per liter sodium hydroxide solution for 2 hours at boiling temperature, using a liquor-to-stalk weight ratio of 30:1. The stalks and alkali solution were heated together in a beaker on a direct heater to separate cellulose fibers from lignin. Following extraction, the fibers were washed thoroughly with clean water to neutralize them. Subsequently, the neutralized fibers were dried under sunlight.

This extraction process was carried out at the Chemical Engineering laboratory of Addis Ababa Institute of Technology. The materials used and the detailed steps for extracting maize stalk fiber using the chemical extraction method can be found in the study by (Devi *et al.*, 2022), with a comprehensive illustration of the process provided in Figure 3.6.

Materials required:

- Maize stalks
- NaOH
- Water
- Beakers
- stirring rod
- Weighing scale
- Direct heater

Steps:

1. Collect the dry maize stalks from local farm cut using sickle close to the ground
2. Remove the leaves and husks from the stalks by using a knife
3. Cut in to internode and split in to small piece
4. Weigh the required amount of maize stalks and transfer them into a beaker.
5. Add 1% NaOH solution to the beaker containing maize stalks and stirring using glass rod until the NaOH is dissolved well.
6. Removing the lignin from cellulose manually.
7. Wash the fiber several times with clean water until PH is become neutral.
8. Dry the washed fiber in sun light

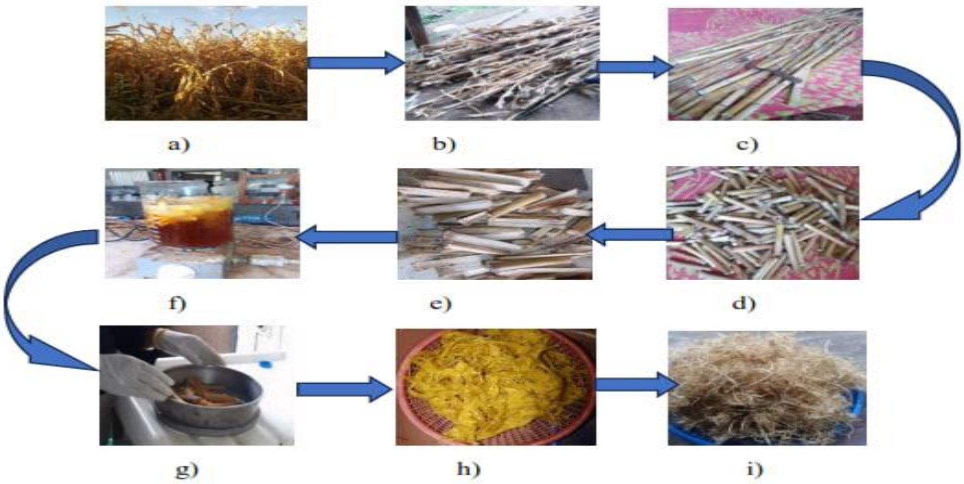


Figure 3.6 Extraction process of maize- stalk fiber a) Maize-stalk plant, b) Collected maize stalk, c) Maize-stalk after leaves and husk removed, d) Cutting internodes, e) Split into small pieces, f) Heating maize-stalk with NaOH, g) Manually separating lignin h) Washing fiber and i) Dry maize-stalk fiber

3.5 Rule of mixture: Volume and Mass Fraction Computation

The weight of the matrix was determined by multiplying the density of the matrix by the volume (volume in the mold). To match the weight of the matrix, a specified weight percentage of fibers was selected. In hybrid combinations, the weight of fiber obtained is divided between two types of fibers, maize-stalk, and glass fibers. The fiber loading percentage typically ranges from 30% to 50%, as suggested by Ismail *et al.* (2020) and Tewelde *et al*. (2022)for structural applications. Seven composite samples, labelled C1 to C7, were prepared with 30% glass and maize stalk fibers. The specific details of these composites can be found in Table 3.5 and Table 3.6. Throughout this process, the epoxy content was maintained at a constant percentage of 70 wt %. If V_c, V_m, and V_f represent the volumes of the composite, matrix, and fiber, respectively, the volume fractions of the matrix (v_m) and fiber (v_f) are defined as follows:

$$v_m = {}^{V_m}/_{V_c} \ , v_f = {}^{V_f}/_{V_c} \ where\ V_c = V_m + V_f \text{------------------------(1)}$$

- And if $m_c,\ m_f\ and\ m_c$ are masses of composite, matrix, and fiber, respectively, then mass fraction of matrix (M_m) and fiber (M_f) are defined below.

$$M_m = m_m/m_c\ and\ M_f = {}^{m_f}/_{m_c}\ where\ m_c = m_m + m_f \text{------------------------(2)}$$

- Using volume fractions, the overall density of the composite can be calculated as below. If ρ_m, ρ_f and ρ_c are densities of matrix, fiber and composite, respectively, then density of composite (ρ_c) can be calculated as shown below.

$$m_c = m_m + m_f$$

$$\rho_c v_c = \rho_m v_m + \rho_f v_f$$

- Dividing this relation by volume of composite, we can write:

$$\rho_c = {\rho_m v_m}/{v_c} + \frac{\rho_f v_f}{v_c}$$

$$\rho_c = \rho_m V_m + \rho_f V_f \text{------------------------(3)}$$

Table 3.5 Designation of Composites

Specimen	Composition (wt. %)		
	Glass fiber	Maize stalk	Epoxy
Specimen 1	30	0	70
Specimen 2	25	5	70
Specimen 3	20	10	70
Specimen 4	15	15	70
Specimen 5	10	20	70
Specimen 6	5	25	70
Specimen 7	0	30	70

Density from standard

Density of Glass fiber = 2.54 ${g}/{cm^3}$, Density of Maize Stalk Fiber = 1.5 ${g}/{cm^3}$ and Density of Epoxy LY556 = 1.15 ${g}/{cm^3}$

Volume of composite (V_c) $= 300 \times 300 \times 3mm^3 = 270{,}000mm^3\ or\ 270\ cm^3$

Composite -1

$v_g = 0.3$, $v_m = 0$, $v_e = 0.7$,

$V_G = V_c * v_g$

$V_G = 270 * 0.3 = 81cm^3$, $m_G = \rho_G * V_G = 2.54 * 81 = 205.74\ gram$

$V_m = V_c + v_m$ $m_m = \rho_m * V_m = 1.5 * 0 = 0gram$

$V_m = 270 * 0 = 0$

$V_E = V_c + v_e$

$V_E = 270 * 0.7 = 189cm^3$

$m_e = \rho_E * V_E = 1.15 * 189 = 217.35$

Mass of Composite -1

$m_{c1} = m_G + m_m + m_E$

$m_{c1} = 205.74 + 0 + 217.35 = 423.09\ gram$

Density of composite -1

$\rho_{c1} = \frac{m_{c1}}{V_{c1}} = \frac{423.09}{270} = 1.567\ {}^{g}/_{cm^3}$

Composite -2

$v_g = 0.25 \quad v_m = 0.05 \quad v_e = 0.7$

$V_G = V_c * v_g$

$V_G = 270 * 0.25 = 67.5cm^3$

$V_M = V_c + v_m$

$V_M = 270 * 0.05 = 13.5cm^3$

$V_E = V_c + v_e$

$V_E = 270 * 0.7 = 189cm^3$

$m_G = \rho_G * V_G = 2.54 * 81 = 171.45\ gram$

$m_M = \rho_m * V_m = 1.5 * 13.5 = 20.25gram$

$m_E = \rho_E * V_E = 1.15 * 189 = 217.35$

Mass of Composite -2

$m_{c2} = m_G + m_M + m_E$

$m_{c2} = 171.45 + 20.25 + 217.35 = 409.05\ gram$

Density of composite -2

$\rho_{c2} = \frac{m_{c2}}{V_{c2}} = \frac{409.05}{270} = 1.515\ {}^{g}/_{cm^3}$

Composite -3

$v_g = 0.2 \quad v_m = 0.1 \quad v_e = 0.7$

$V_G = V_c * v_g$

$V_G = 270 * 0.2 = 54cm^3$,

$V_M = V_c + v_m$

$V_M = 270 * 0.1 = 27cm^3$

$V_E = V_c + v_e$

$V_E = 270 * 0.7 = 189cm^3$

$m_G = \rho_G * V_G = 2.54 * 54 = 137.16\ gram$

$m_M = \rho_m * V_m = 1.5 * 27 = 40.5gram$

$m_E = \rho_E * V_E = 1.15 * 189 = 217.35gram$

Mass of Composite -3

$m_{c3} = m_G + m_M + m_E$

$m_{c3} = 137.16 + 40.5 + 217.35 = 395.01\ gram$

Density of composite -3

$\rho_{C3} = \frac{m_{c3}}{V_{c3}} = \frac{395.01}{270} = 1.463\ {}^{g}/_{cm^3}$

Composite -4

$v_g = 0.15,$ $v_m = 0.15,$ $v_e = 0.7$

$V_G = V_c * v_g$

$V_G = 270 * 0.15 = 40.5cm^3$, $m_G = \rho_G * V_G = 2.54 * 40.5 = 102.87\ gram$

$V_M = V_c + v_m$ $m_M = \rho_M * V_M = 1.5 * 40.5 = 60.75 gram$

$V_m = 270 * 0.15 = 40.5cm^3$ $m_E = \rho_E * V_E = 1.15 * 189 = 217.35$

$V_E = V_c + v_e$ **Mass of Composite -4**

$V_E = 270 * 0.7 = 189cm^3$ $m_{C4} = m_G + m_M + m_E$

Density of composite -4 $m_{C4} = 102.87 + 60.75 + 217.35 = 380.97 gram$

$\rho_{c4} = \frac{m_{c4}}{V_{c4}} = \frac{380.97}{270} = 1.411\ {}^{g}/_{cm^3}$

Composite -5

$v_g = 0.1$ $v_m = 0.2$ $v_e = 0.7$

$V_G = V_c * v_g$

$V_G = 270 * 0.1 = 27cm^3$, $m_G = \rho_G * V_G = 2.54 * 27 = 68.58\ gram$

$V_M = V_c + v_m$ $m_M = \rho_M * V_M = 1.5 * 54 = 81 gram$

$V_M = 270 * 0.2 = 54cm^3$ $m_E = \rho_E * V_E = 1.15 * 189 = 217.35$

$V_E = V_c + v_e$ **Mass of Composite -5**

$V_E = 270 * 0.7 = 189cm^3$ $m_{c5} = m_G + m_M + m_E$

Density of composite -5 $m_{c5} = 68.58 + 81 + 217.35 = 366.93 gram$

$\rho_{c1} = \frac{m_{c5}}{V_{c5}} = \frac{366.93}{270} = 1.359\ {}^{g}/_{cm^3}$

Composite -6

$v_g = 0.05$ $v_m = 0.25$ $v_e = 0.7$

$V_G = V_c * v_g$

$V_G = 270 * 0.05 = 13.5cm^3$, $m_G = \rho_G * V_G = 2.54 * 13.5 = 34.29\ gram$

$V_m = V_c + v_m$ $m_M = \rho_m * V_m = 1.5 * 67.5 = 101.25 gram$

$V_m = 270 * 0.25 = 67.5cm^3$ $m_E = \rho_E * V_E = 1.15 * 189 = 217.35$

$V_E = V_c + v_e$ **Mass of Composite -6**

$V_E = 270 * 0.7 = 189cm^3$ $m_{c6} = m_G + m_M + m_E$

Density of composite -6

$m_{c6} = 34.29 + 101.25 + 217.35 = 352.89\ gram$

$\rho_{c6} = \frac{m_{c6}}{V_{c6}} = \frac{352.89}{270} = 1.307\ {}^{g}/_{cm^3}$

Composite -7

$v_g = 0 \qquad v_m = 0.3 \qquad v_e = 0.7$

$V_G = V_c * v_g$

$V_G = 270 * 0 = 0cm^3$, $\qquad m_G = \rho_G * V_G = 2.54 * 0 = 0\ gram$

$V_M = V_c + v_m \qquad m_M = \rho_m * V_m = 1.5 * 81 = 121.5gram$

$V_M = 270 * 0.3 = 81cm^3 \qquad m_E = \rho_E * V_E = 1.15 * 189 = 217.35$

$V_E = V_c + v_e$

Mass of Composite -7

$V_E = 270 * 0.7 = 189cm^3 \qquad m_{c7} = m_G + m_M + m_E$

Density of composite -7

$m_{c7} = 0 + 121.5 + 217.35 = 338.85\ gram$

$\rho_{c7} = \frac{m_{c7}}{V_{c7}} = \frac{338.85}{270} = 1.255\ {}^{g}/_{cm^3}$

Where:

V_c −is volume of composite

V_G − is volume of glass fiber

V_m − is volume of maize stalk fiber

V_E − is volume of epoxy

m_e − mass of epoxy

V_g −is volume fraction of glass

V_m −is volume fraction of maize

V_e −is volume fraction of epoxy

m_G −mass of glass fiber

m_m −mass of maize stalk fiber

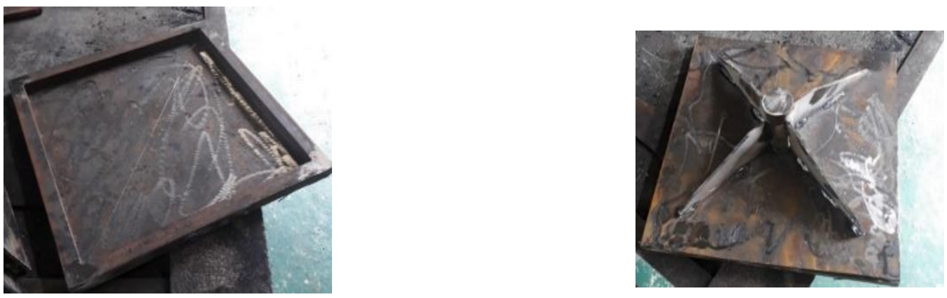
Table 3.6. Mass of epoxy matrix, glass fiber, maize-stalk fiber, and composite

Specimens	Glass fiber wt %	MSF wt %	Epoxy wt %	Glass fiber (g)	MSF (g)	Epoxy resin (g)	Total mass (g)
Neat GF	30	-	70	205.74	-	217.35	423.09
C2	25	5	70	171.45	20.25	217.35	409.05
C3	20	10	70	137.16	40.5	217.35	395.01
C4	15	15	70	102.87	60.75	217.35	380.97
C5	10	20	70	68.58	81	217.35	366.93
C6	5	25	70	34.29	101.25	217.35	352.89
Neat MSF	-	30	70	-	121.5	217.35	338.85

3.6 Mold preparation and making

A steel plate mold of dimensions 300X300X3 mm was prepared, and specimens were subsequently cut from the casting in line with ASTM Standards. The mold was designed using SolidWorks software, and the model was developed based on the required dimensions and the number of specimens and tests. The mold is comprised of two components, namely a base plate and an upper plate, as illustrated in Figure 3.7. The base plate is fabricated using a sheet plate that forms a frame with four RHS steel pieces welded together. Its internal dimensions correspond to the final size of the composite. On the other hand, the upper plate is composed of sheet metal and features a cylindrical block equipped with four wings. These wings serve to evenly distribute the pressure exerted by the press machine throughout the composite curing process. The upper plate has two parts: one that directly applies to the composite and another that covers the entire mold to ensure the correct thickness.

(a) Mold Base Design (b) Assembly design of Mold



(c) Fabricated Mold Base (d) Fabricated Mold Cover

Figure 3. 7 Mold modelling and making

3.7 Auxiliary Materials

During composite fabrication, some tools are essential for different stages of composite fabrication, ensuring proper lamination, mold release, and material handling, as shown in Figure 3.8.

1. Roller: The roller is used to apply pressure on the composite material during lamination. It helps remove air bubbles and ensures proper adhesion between layers.
2. Brush: A brush is used for applying resin or gelcoat onto the composite surface. It helps in spreading the material evenly and assists with impregnating reinforcement fibers.
3. Wax: The Miracle Gloss-Maximum Mold Release Wax 83.0, a type of wax, was utilized in this investigation. Its purpose is to serve as a mold release agent, which is commonly employed to prevent the composite material from adhering to the mold surface. This application facilitates the removal of the final product from the mold, simplifying the demolding process.
4. Plastic sheet: Plastic sheets are frequently employed as films for release or as barrier layers in the process of lamination. They serve the purpose of preventing the composite material from adhering to the mold or merging with adjacent layers, ensuring easy separation later.
5. Scissor: Scissor were used for cutting various materials like reinforcement fabrics, plastic sheet or excess composite material.

a). Roller

b). Brush

c). Wax

d). Scissor

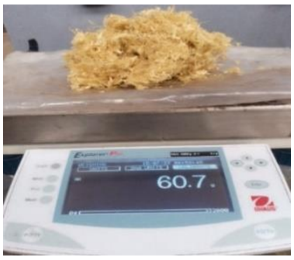
e). Plastic sheet

Figure 3.8 Auxiliary materials used for preparing composite

3.8 Fabrication procedures of the Hybrid Composite

In this study hand layup method was used because of its cheapest method of manufacturing, ideal for lower volumes, lower cost to tool and flexibility. Fabrication of hybrid composites specimens using glass fibers and maize stalk fibers reinforced with epoxy were achieved by the following steps (Sadashiva *et al.*, 2021):

1. **Fiber Preparation:** To ready the glass fibers and maize stalk fibers for use, they underwent a cleaning and drying process to eliminate impurities and moisture. The maize-stalk fibers were specifically cut into 3mm lengths due to their discontinuous nature and the challenge of obtaining long, fine fibers from their short single cells, as noted by (Reddy and Yang, 2005) This standardized fiber length was applied across all seven composite compositions. Following the principle of composite fabrication, the two types of fibers were measured, combined, and thoroughly mixed using a stirrer attached to a drilling machine. This stirring action ensured a uniform dispersion of the two fibers into each other, as illustrated in Figure 3.9.



a). Weighing maize-stalk fiber b). Weighing glass fiber

c). Stirring the two fibers on drilling machine d). Hybrid fiber

Figure 3.9 Fiber preparation

2. Cleaning mold and applying wax on plastic sheet: The mold was cleaned by using a soft brush to remove any loose debris, dust or particles from the mold surface. Two clean plastic sheets were placed on a smooth surface to cover the mold. One sheet was positioned at the bottom of the cavity, while the other was placed on top. Figure 3.10 shows the application of a plastic sheet release agent onto the sheets. The wax was evenly spread in a thin layer, covering the entire surface that would come into contact with the composite material. It may need to dry or cure for a specific period. Subsequently, the plastic sheet that was designated for the bottom was accurately positioned within the required space of the mold.

Figure 3.10 Applying Wax on Plastic Sheet

3. Epoxy Matrix Preparation: Prepare the epoxy resin by mixing the epoxy resin and curing agent (it's hardener) by 1:10 according to the manufacturer's instructions, as shown in Figure 3.11. This typically involves measuring and mixing resin and hardener in the recommended proportions. Ensure thorough mixing to achieve a homogeneous resin mixture. In this research all composite has a same weight for its epoxy (70%). As a result, the epoxy was measured on a scale to achieve the desired weight. The hardener was also measured according to a 1:10 ratio and mixed carefully and thoroughly using a stirrer. Throughout this process, efforts were made to minimize the presence of air bubbles.

a). Weighing Epoxy b) Weighing Hardener

Figure 3.11 Preparation of matrix and hardener

4. Hand lay-up

Afterwards, pouring a mixture of epoxy and hardener onto the prepared plastic sheet, followed by using a brush to evenly spread it throughout the mold. Figure 3.12 illustrates a consistent dispersion of both matrix and fibers. The fibers that had been prepared and mixed were subsequently added onto the mixture. Following this step, a roller was used to apply slight pressure, ensuring that the fibers were uniformly saturated.

a). Applying matrix on plastic sheet

b). Apply slight pressure using roller

Figure 3.12 Uniform distribution of matrix and fibers

After the completion of this procedure, the previously waxed second plastic sheet was placed on the composite's surface. The utilization of these plastic sheets also aids in achieving a refined surface finish for the final product.to ensure even distribution of moisture, a clean roller was used to apply pressure on the plastic sheet, aiding in the removal of any excess epoxy resin. As a final step, the composite was fully enclosed by covering the top of the mold with a lid, effectively sealing it.

5.Compress and Cure: The composite material underwent compression and curing in a hydraulic press machine, applying a consistent load of 50 tons (5 MPa) to achieve uniformity. This pressure helped eliminate excess epoxy and maintain a consistent thickness. The composite remained under this pressure for 24 hours at ambient temperature. Following this period, the mold was unlocked, and the composite material that formed was delicately taken out, as illustrated in Figure 3.13. This process was repeated for all samples, ensuring that each composite underwent the same production and curing steps at room temperature.

a). Compression & Curing

b). Final Product

Figure 3.13 Curing process and final product

3.9 Specimens Preparation for Testing

After the fabrication process was completed, the composites were cut using a vertical band saw machine in accordance with ASTM standards. The specific vertical band saw machine utilized was the 1610 model, equipped with a saw band width of 16 mm and a saw band length of 3140 mm. This machine features a cutting height of 255 mm and a working height of 1000 mm, with a saw blade speed that varies between 250 and 1000 m/min. The samples were then prepared for a range of mechanical properties tests, including tensile, compressive, flexural, impact, and micro hardness assessments. Furthermore, physical properties like water absorption and density were also prepared using the vertical band saw machine, as depicted in Figure 3.14 and Figure 3.15, respectively.

Figure 3.14 Vertical band saw machine

Figure 3.15 Specimens prepared for testing

3.10 Experimental Procedure

The hybrid composite plate was cut into the required specimen sizes for a series of mechanical tests. These tests were conducted at Bishoftu Defense Engineering College in Ethiopia and included tensile, compression, flexural, and impact experiments. The micro hardness test was performed at Adama Science and Technology University. A Gunt Hamburg WP 310 hydraulic material testing machine, which has a maximum capacity of 50kN, was used for the tensile, compression, and flexural tests. Meanwhile, the Vickers micro hardness tester and Charpy impact tester were used for the micro hardness and impact tests, respectively.

The assessment of the remaining physical properties, specifically density and water absorption, took place at the Addis Ababa Institute of Technology, School of Chemical Engineering. The results obtained from the different machines and experimental methods can be subjected to further evaluation and analysis.

A comprehensive analysis was conducted on precisely five specimens for each of the five mechanical properties, spanning across all seven composite compositions. This rigorous approach guaranteed the examination of no less than 175 specimen samples, thereby facilitating the acquisition of dependable outcomes while minimizing the potential for errors. Concerning the physical properties, three specimens were chosen from each composition. Furthermore, all procedures were meticulously executed under room temperature conditions.

3.10.1 Mechanical Characteristics

3.10.1.1 Tensile Test

In accordance with ASTM standards (ASTM D3039), tensile test experiments were conducted on composite specimens with dimensions of 250mm x 25mm x 3mm. For each composite composition (C1 to C7), five specimens were tested using a Gunt Hamburg WP 310 Hydraulic material testing machine equipped with a 50kN load cell and a testing speed of 6 mm/min. The specimens were positioned vertically and securely clamped at both ends, as shown in Figure 3.16. The specimens were subjected to quasi-static tensile loading until failure, and the ultimate strength and strain were recorded just before failure.

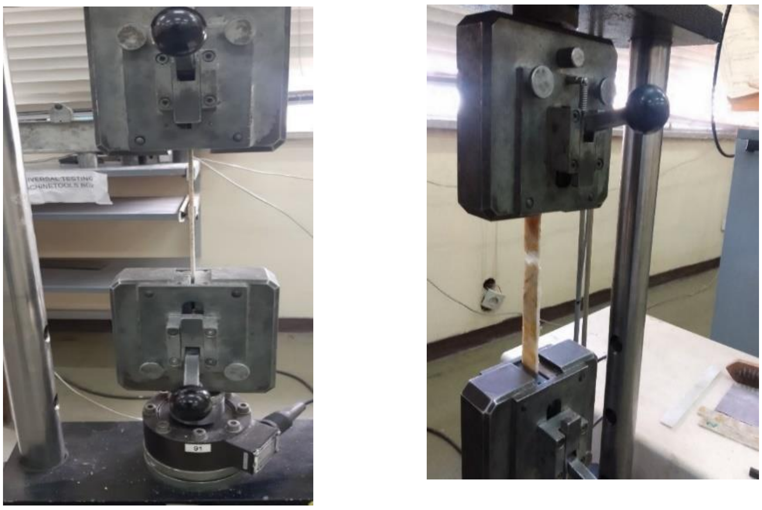


Figure 3.16 Tensile strength setup and specimen under tensile loading

3.10.1.2 Compression Test

In accordance with ASTM D3410, compression tests were executed on five samples from each composite material, designed for evaluating the compressive characteristics of rigid plastics. The experiments were conducted utilizing a universal testing machine equipped with a 50kN load cell and a testing speed of 3 mm/min. The samples utilized in the tests had specific measurements, including a length of 20 mm, a width of 10 mm, and a thickness of 3 mm. These specimens were securely clamped within hydraulic grips, ensuring that the applied force aligned with the long axis at both ends. This setup is depicted in Figure 3.17. The ultimate strength and strain were determined immediately prior to failure.

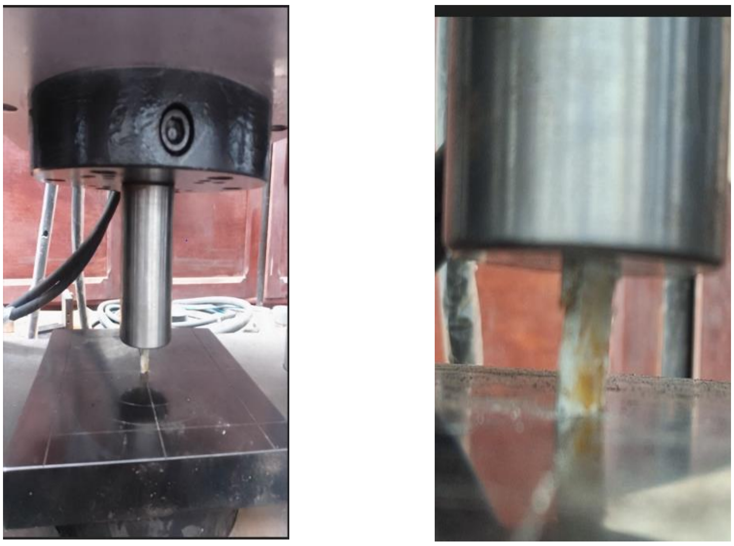


Figure 3.17 Compressive Strength Setup and Specimen under compressive stress

3.10.1.3 Flexural Test

The bending characteristics of polymer matrix composites were evaluated according to the ASTM D790 guidelines by selecting five samples from each composite material. These samples, measuring 125 mm in length, 13 mm in width, and 3 mm in thickness, were tested under quasi-static conditions until they failed. The testing machine used for previous tensile and compression tests was also employed for these experiments. The samples were positioned on a support bed with two points, spanning a distance of 125 mm, and a single upper jaw was applied at the centre of each sample, as illustrated in Figure 3.18.

Figure 3.18 Flexural test setup and specimen under bending stress

3.10.1.4 Impact Test

The toughness of a material's fracture is assessed through a Charpy impact test, where a sample is fixed in a testing device and fractured by a pendulum released at a 45-degree angle, as shown in Figure 3.19. The energy taken in by the sample during its breaking, indicating its toughness, is gauged with a dial indicator attached to the pendulum rod. This test is commonly employed to measure the ability of materials, including composites, to withstand impact forces. Specifically, the impact resistance of GF/MSF-reinforced epoxy composites was investigated by prepared five test samples for each composition. The toughness, which encompasses both the strength and ductility of the material, was determined through the Charpy impact test, following the ASTM standard D256. The resistance to impact was subsequently determined by dividing the measured energy absorbed during impact by the cross-sectional area of the sample (kJ/m^2).

Figure 3.19 Charpy impact test setup and specimen under impact load

3.10.1.5 Micro Hardness Tests

Micro-indentation hardness tests were conducted on seven samples of each composite composition, following the ASTM E384 standard, which is used for assessing the micro-hardness of materials. Samples measuring 30 mm × 30 mm were extracted from each of the seven composites, and a force of 10kgf was exerted using a diamond cone indenter with a radius of 0.2mm, as illustrated in Figure 3.20. The evaluations were executed at room temperature utilizing a micro-hardness testing apparatus. The entire procedure, encompassing the initial indentation, load holding period, and data collection, lasted 10 seconds in total, under the exclusive control of the hardness testing equipment. Five readings were directly taken from the testing device for every sample, and the mean of these measurements was recorded as the hardness of the material.

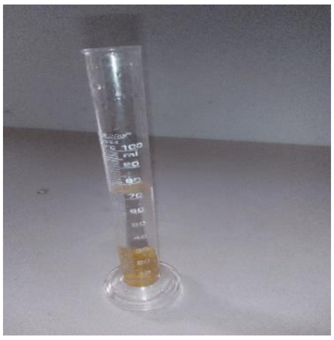
Figure 3.20 Micro hardness test setup

3.10.2 Physical Properties Test

3.10.2.1 Density Measurement

To test the density of a hybrid composite using a pycnometer, first, obtain a clean and dry pycnometer, which is a specialized glass container used to measure density. Next, accurately weigh the composite material and record its mass. Fill the pycnometer with a liquid, typically a liquid of known density such as water or ethanol, ensuring the volume of the water in the pycnometer. To determine the density of the composite material, first put it in a pycnometer filled with liquid, ensuring that the material is completely submerged. Then, measure the volume of water displaced after inserting the composite material and subtract it from the initial volume of water. Finally, calculate the density by dividing the mass of the composite by the difference in volume, following the ASTM D792 standard. This process is depicted in Figure 3.21(Bucci *et al.,* 2007).

a). Weighing specimen



b). Specimen in pycnometer

Figure 3.21 Procedure for density measurement

3.10.2.2 Water Absorption Measurement

During the water absorption experiment, all the samples were immersed in water at room temperature for a duration of 24 hours. Before submerging them, the weight of each sample was measured using an electronic balance and the measurements were noted. After the soaking period, depicted in Figure 3.22, the samples were removed from the water, cleaned to eliminate any excess surface moisture, and weighed once more. By following these procedures, the percentage increase in mass was determined using the provided formula.

$$\text{water absorption } \% = \frac{(\text{final weight} - \text{initial weight})}{\text{initial weight}}\ x100$$

Where; Initial weight is the weight measured before socking and

Final Weight is the weight measured after 24hrs socking

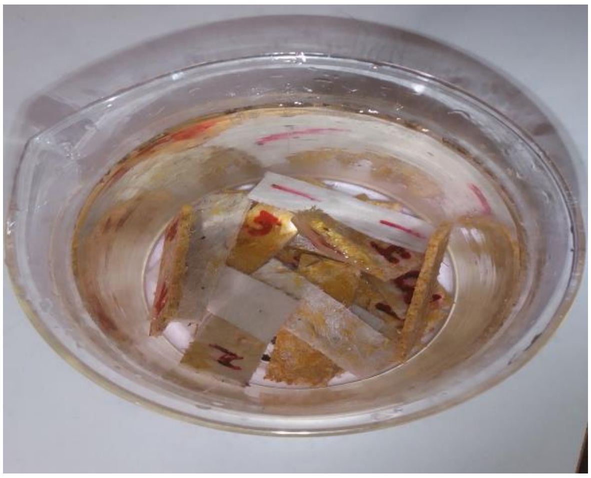


Figure 3.22 Specimens Socked in Water

3.10.3 Finite Element Analysis of Bone Fracture Plate

Finite Element Analysis (FEA) is a sophisticated computational method employed to anticipate the behavioral patterns of a component or assembly under specified circumstances. This numerical technique enables engineers to simulate physical phenomena, thereby diminishing the need for physical prototypes. FEA serves as an invaluable tool in the advancement of emerging technologies and contributes to enhancing the predictability of clinical rehabilitations in dentistry, implantology, prosthetics, and orthodontics.

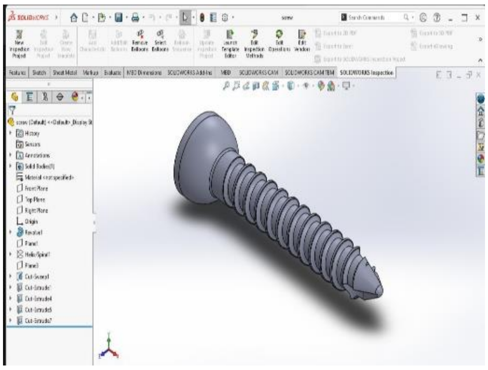
In the domain of ANSYS static structural analysis, the effects of constant loading on a structure are thoroughly examined, including the evaluation of stress, strain, and deformation under various loading conditions. As part of this investigation, the highly versatile finite element analysis (FEA) software, ANSYS 2021 R2, was utilized. The use of finite element analysis has gained significant popularity in the field of designing and evaluating internal fixation plates and screws. The objective is to overcome the main drawbacks of existing fixation devices, including their vulnerability to fatigue failure and the negative impact of stress shielding on the bone.

3.10.3.1 Finite Element Analysis procedures

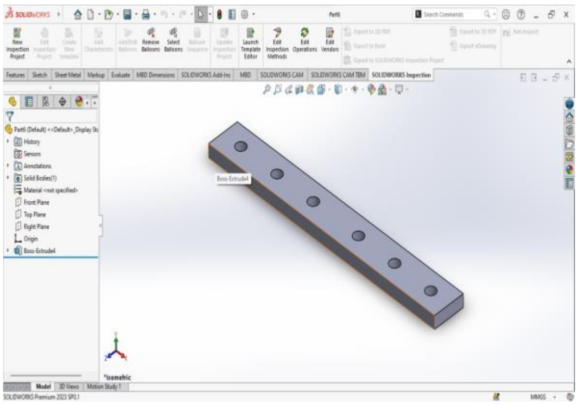
From experimental analysis the best result was obtained at composite composition of GF25/MSF5/E70 and take the material properties of this composite as bone plate and screw material, for further analyses using ANSYS software. The following steps that were followed in the analysis are explained below.

i. Geometry Generation

The intricate morphology of the femur bone, characterized by its asymmetry and curved structure in three dimensions, presents significant hurdles when attempting to create a comprehensive 3D model. To overcome these challenges, a downloaded version of the femur bone from GrabCAD and utilized cut function in SolidWorks for making transverse or horizontal fracture. This platform offers 3D printing software applications that greatly streamline the design and printing processes. Using SOLIDWORKS software, the accurate modeling of the screw and bone plate dimensions needed for the femur bone was achieved by referencing a reputable source (Kim *et al.,* 2011). This modeling is visually depicted in Figure 3.23 to Figure 3.25. The essential process entails securely joining the fractured femur bone and the bone plate, and this is successfully accomplished with the assistance of a screw.



3-D model of screw



b) Model of bone plate

Figure 3.23 3-D model of bone plate and screw

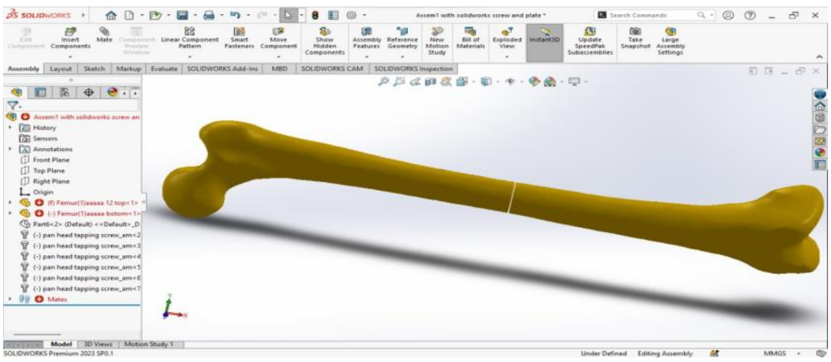


Figure 3.24 3-D model of transverse femur bone fracture

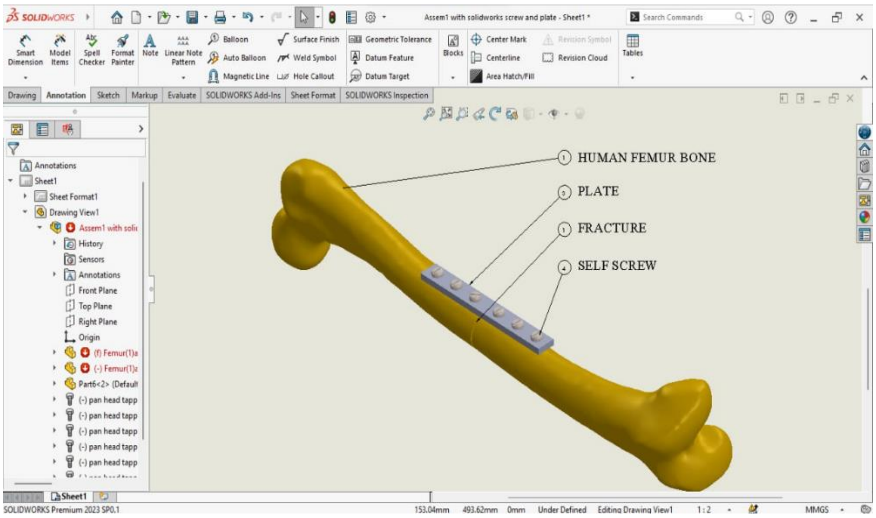


Figure 3.25 3-D assembly of bone, plate and screw

ii. Assigning the Materials

The structural characteristics of human bone display notable variations and complexity, making it difficult to accurately determine the material properties in different directions of the bone model. There are two methods available for assigning materials: using the Mimics software or the Finite Element module. ANSYS allows direct assignment of material properties. A summary of the mechanical properties assigned to the femur bone, plate, and screw within the software can be found in Table 3.7. The analysis primarily focuses on density, Young's modulus, and Poisson's ratio. Engineering data for the glass/maize-stalk/epoxy composite material is presented in Figure 3.26.

Table 3.7 Mechanical properties of femur bone, plate and screw

Femur bone & fracture plate materials	Density (kg m^{-3})	Young's Modulus (GPa)	Poisson Ratio (γ)	Ultimate Tensile Strength (MPa)	Ultimate Compressive Strength (MPa)
Femur bone	1750	16.7	0.3	50-150	205
GF/MSF/EPOXY	1423.5	11.1	0.34	166.64	265.08

To define the material properties of the human femur with a fracture plate, certain assumptions are usually made due to the complexity and variability of human bones:

Assumptions:

a. Homogeneity: Consistent material composition throughout the femur, disregarding regional variations.

b. Isotropy: Femur exhibits consistent mechanical properties regardless of loading direction.

c. Linear Elasticity: Material properties of the femur follow linear elastic behavior within the elastic limit.

d. Uniform and Perfect Contact: Fracture plate is perfectly fitted with uniform contact on the femur.

e. No Biological Factors: Assumed material properties focus solely on mechanical characteristics, excluding biological factors and natural healing processes.

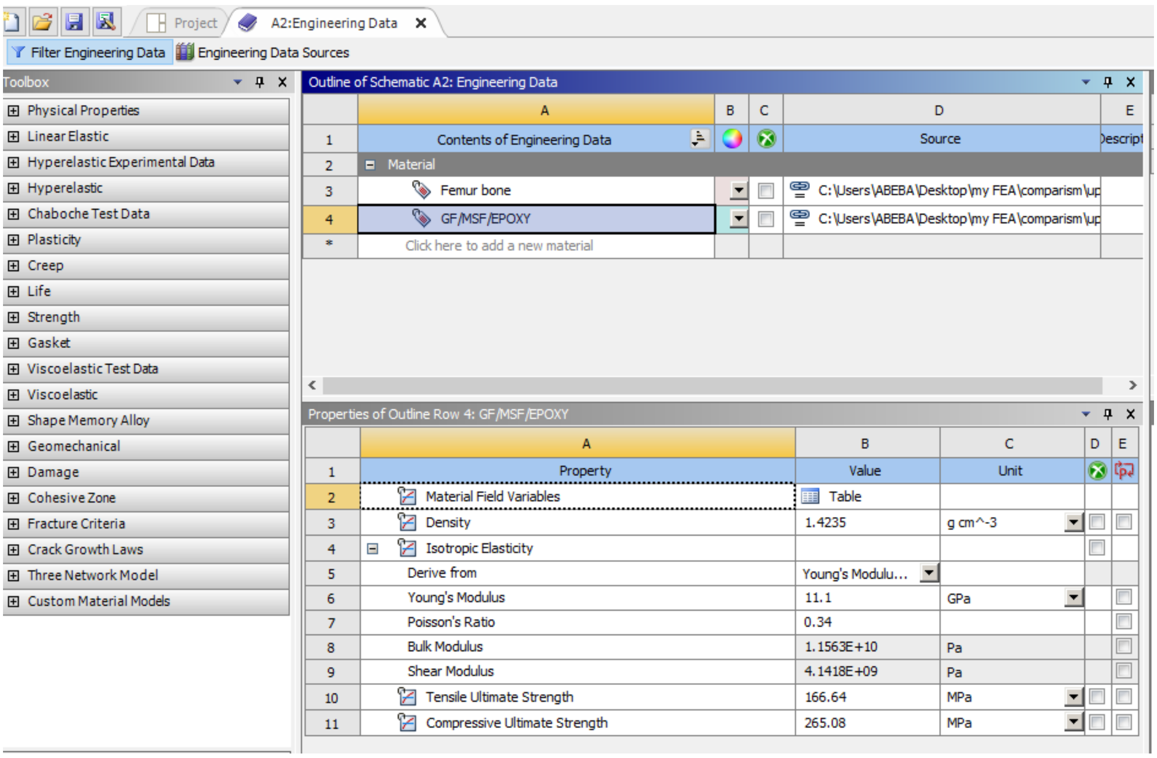


Figure 3.26 Engineering Data of Glass/Maize -stalk/Epoxy composite material

iii. Import of Geometry

The 3D model generated with SOLIDWORKS software and saved in IGS format was brought into the ANSYS software to conduct an analysis. This study utilizes two different materials, namely the femur bone and the bone plate, as well as the screw. To accurately represent the components, material properties are assigned. In this particular research, a recently developed composite material known as glass-maize stalk fiber reinforced epoxy hybrid composite is assigned to both the bone plate and the screw. The imported geometry is depicted in Figure 3.27.

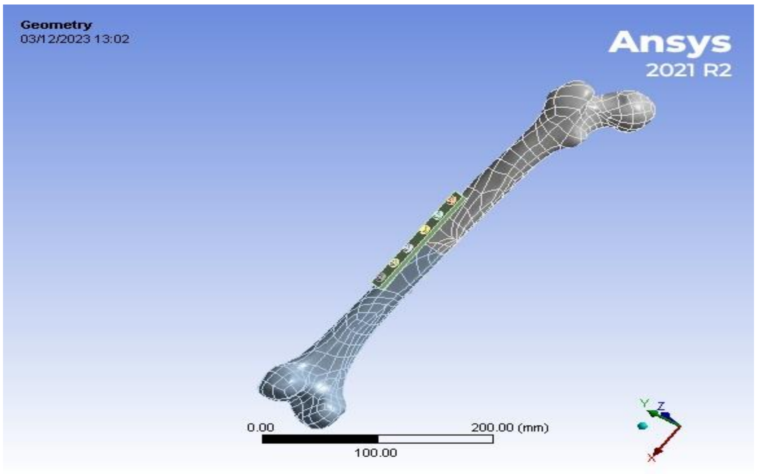


Figure 3.27 Imported Geometry

iv. Mesh generation

Meshing is a critical aspect of Finite Element (FE) analysis, involving the spatial discretization of geometry into nodes and elements. In this study, the patch conforming method to utilize tetrahedral elements for both the bone and implant individually. Figure 3.28 illustrates the mesh that was generated. To ensure accuracy, focused on refining the mesh primarily on the upper section of the femur bone, as this area directly bears the applied load. Additionally, a body sizing mesh type with an element size of 2mm for the entire assembly, enhancing the overall quality of the mesh and subsequently yielding improved results. As a result, ANSYS generated a total of 1,099,533 nodes and 776,000 elements.

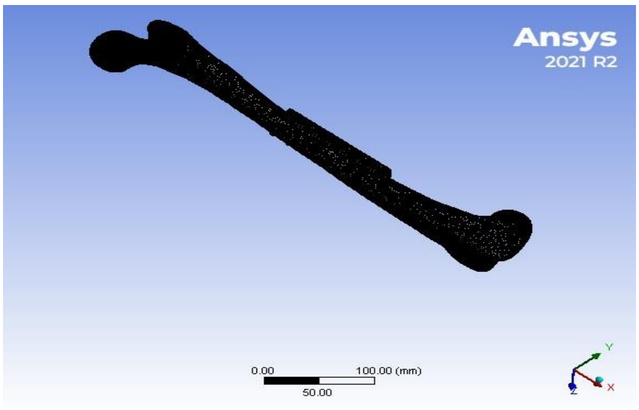
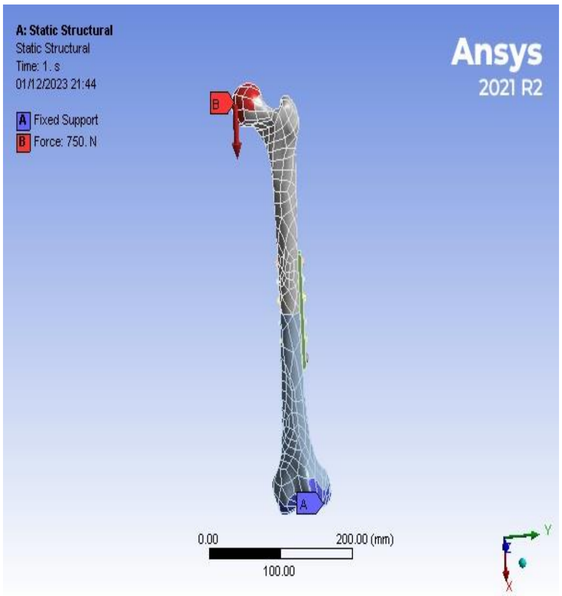


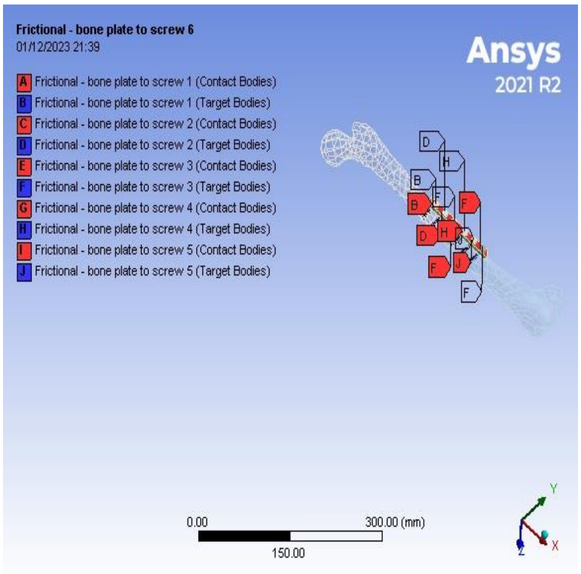
Figure 3.28 Mesh generation of the bone-bone plate assembly

v. Boundary conditions

The loading scenario was determined by assuming a person's weight of 75 kg, with a downward force of 750N applied in the X direction at the femur head, as depicted in Figure 3.29 (a) by the red colour. The lower surface of the femur bone, including the lateral condyle, medial condyle, and patellar surface, was fixed using a boundary condition, as shown in Figure 3.29 (a) by the blue colour. Within the ANSYS simulation module, contact between the assembled surfaces was automatically generated, with bonded contact settings applied by default. However, for the contact between the fractured femur bone segments, a fully bonded contact was selected. Additionally, to account for contact stress and joint friction, a frictional coefficient of 0.2 (Lewis *et al.*, 2021) was used to connect the screws with the plate.



a) Force applied and fixed support on femur bone



b) Contacts between bone plate and screw

Figure 3.29 Boundary condition force applied, fixed support and contacts

vi. Solution

This study investigates the stress distribution and total deformation in a human weighing 75 kg during a normal position. The paper's results and discussion section goes into further detail on the outcomes, which were produced based on the input parameters.

Chapter Four

4. Results and Discussions

4.1 Result and Discussions of Mechanical Characteristics

Seven composite samples were subjected to testing in accordance with ASTM standards to evaluate the characteristics of Glass-Maize stalk fiber reinforced Epoxy hybrid composites that were fabricated. Out of the seven samples, two were not hybrid in nature. Specifically, the first sample consisted entirely of pure glass, while the seventh sample utilized pure maize stalk fiber. The remaining five samples were hybrid and incorporated reinforcement that had been cut into 3mm lengths. At least five specimens were prepared and tested for each composition, and from those, three specimens were chosen for additional analysis. Every composite underwent testing, and the subsequent findings are presented and discussed below.

4.1.1 Tensile Characteristics

According to ASTM D3039, the tensile behaviors of five tested specimens for each configuration was examined, as shown in figures 4.1 through 4.7 of this study. Upon reaching their maximal value, all specimens exhibited catastrophic collapse followed by a sudden decline in load. Up until failure, the specimens showed linear behaviors in brittle fracture. These results were up as a result of the test data analysis.

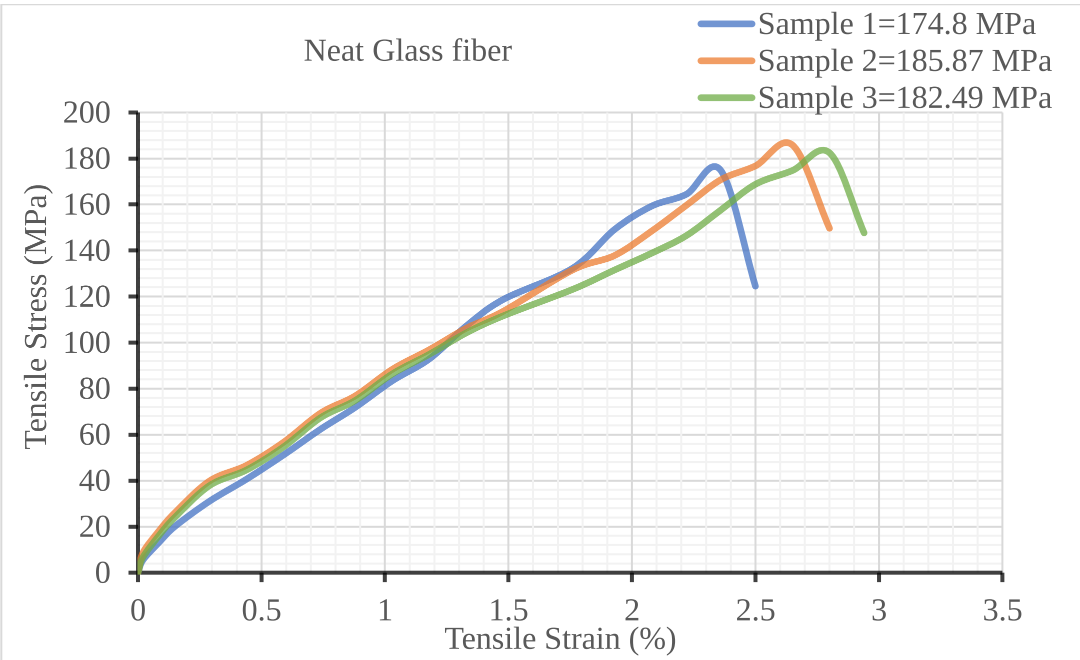


Figure 4. 1 Tensile Stress – Strain Curve for Composite-1 (30% GF, 0%MSF and E70%)

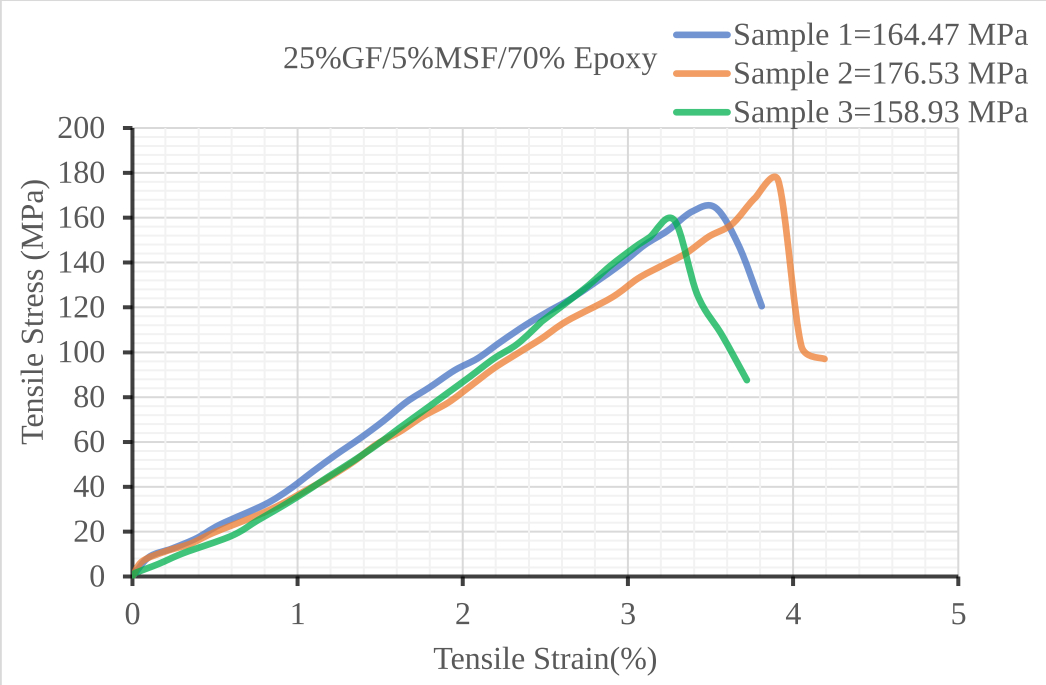


Figure4.2 Tensile Stress-Strain Curve for Composite-2(25%GF,5%MSF and 70%Epoxy)

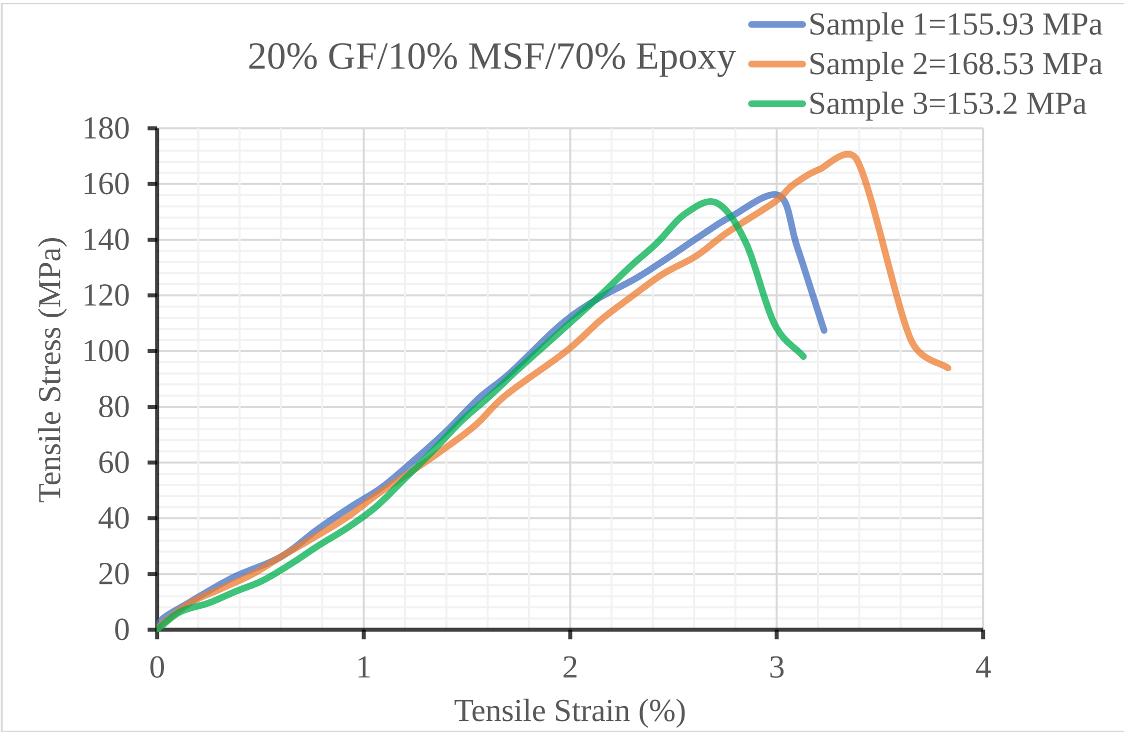


Figure 4.3Tensile Stress-Strain Curve for Composite-3(20%GF,10%MSF and 70%Epoxy)

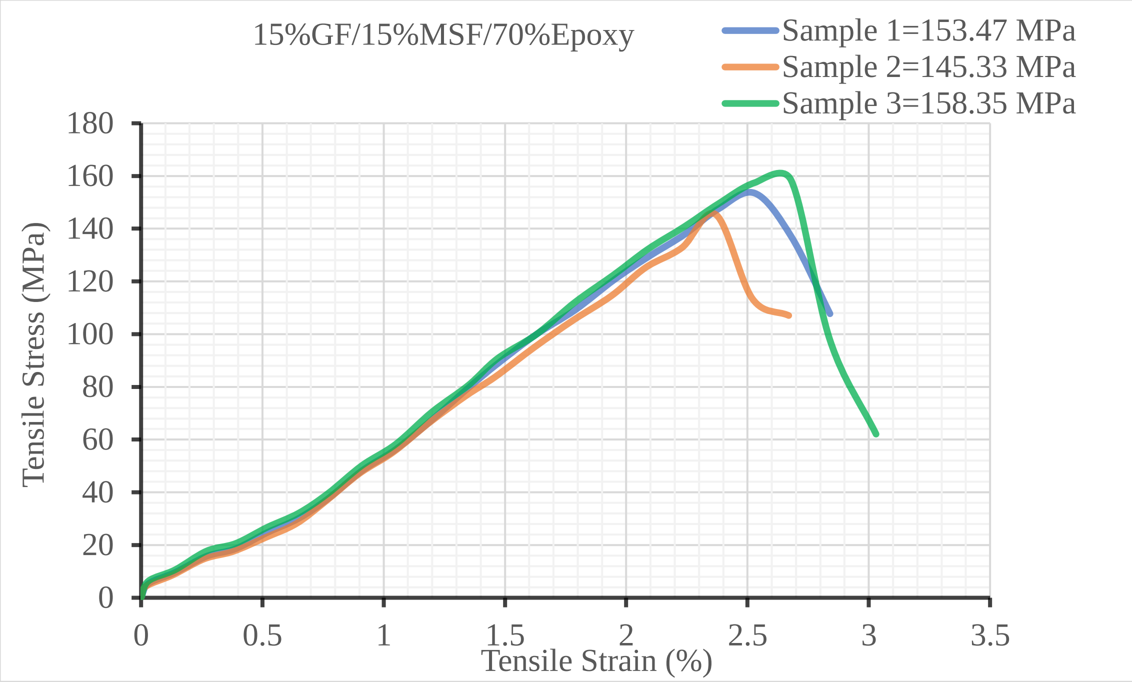


Figure 4.4Tensile Stress-Strain Curve for Composite-4(15%GF,15%MSF and 70%Epoxy)

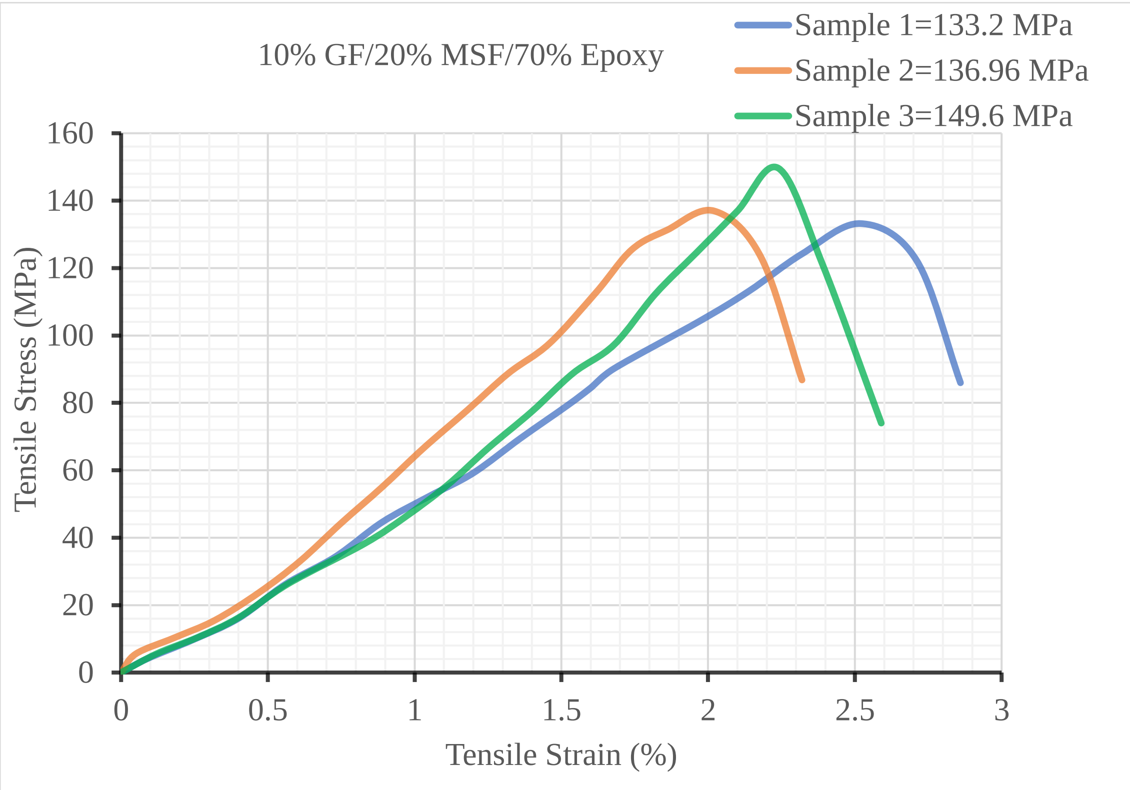


Figure 4.5Tensile Stress-Strain Curve for Composite-5(10%GF,20%MSF and 70%Epoxy)

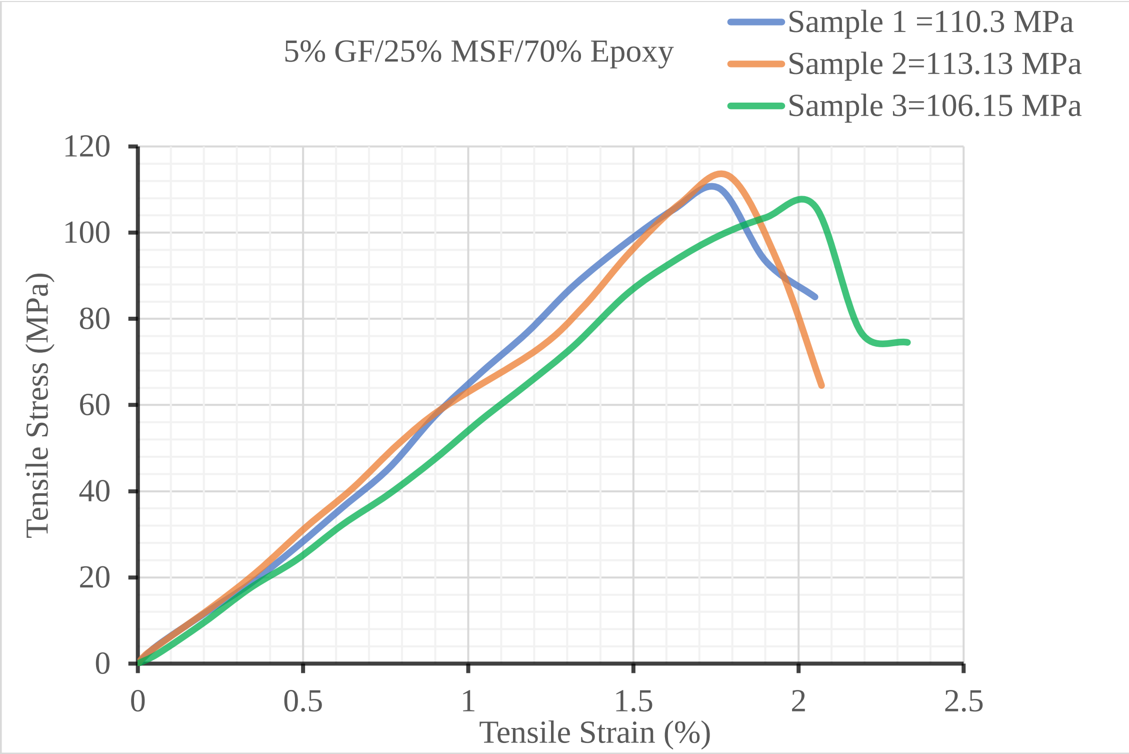


Figure 4.6 Tensile Stress-Strain Curve for Composite-6(5%GF,25%MSF and 70%Epoxy)

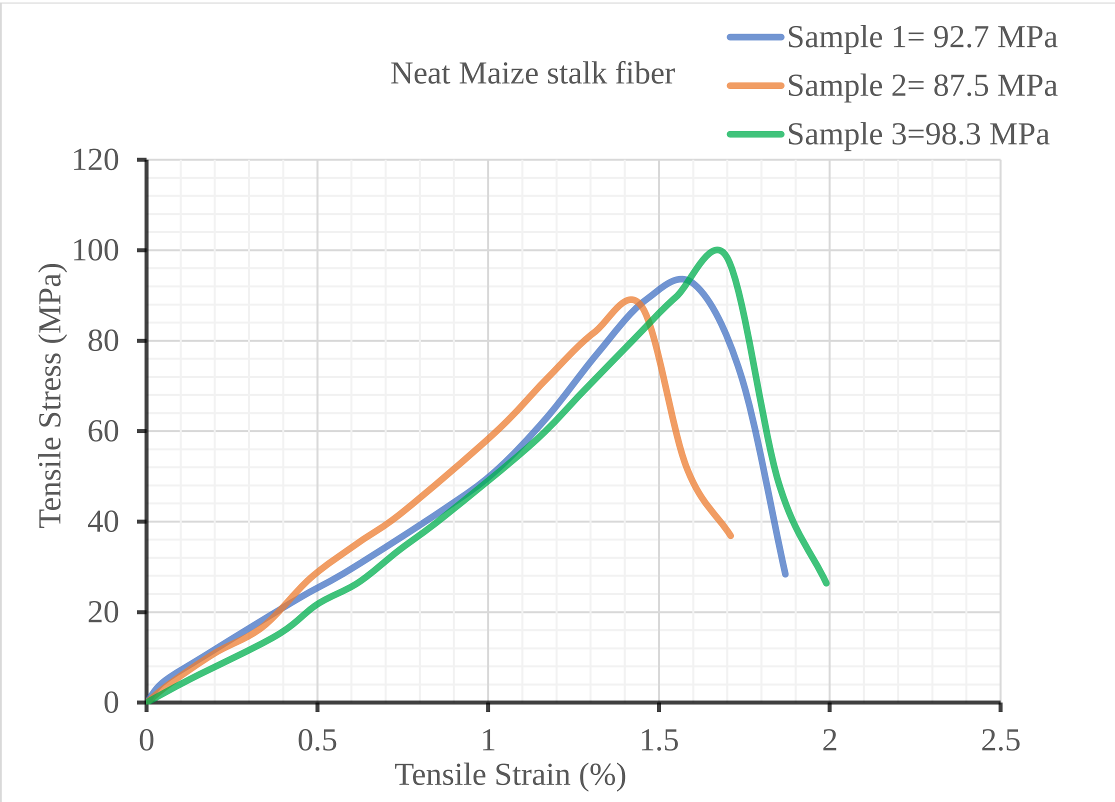


Figure 4.7TensileStress-StrainCurvefor Composite-7(0%GF,30%MSF and 70%Epoxy)

4.1.1.1 Tensile characteristics discussion in terms of fiber loading and application

To effectively reduce movement between the plate and bone interface and ensure a consistent stress distribution along the plate, it is crucial to carefully evaluate the elasticity modulus and tensile strength of the material chosen for the fixation plate. The stress-strain curves for each composite sample are displayed in Figure 4.8. On the other hand, Figure 4.9, displays a comparison graph of the axial Young's modulus in the longitudinal direction of the fiber. The tensile strength and modulus of the composites at room temperature, were found to be between 92.83 and 181.05 MPa and 4.8 and 12.5 GPa, respectively. These values fall within the typical range for cortical bone, which has a modulus of 7 to 30 GPa and a strength of 50 to 150 MPa (Brydone *et al.,* 2010).

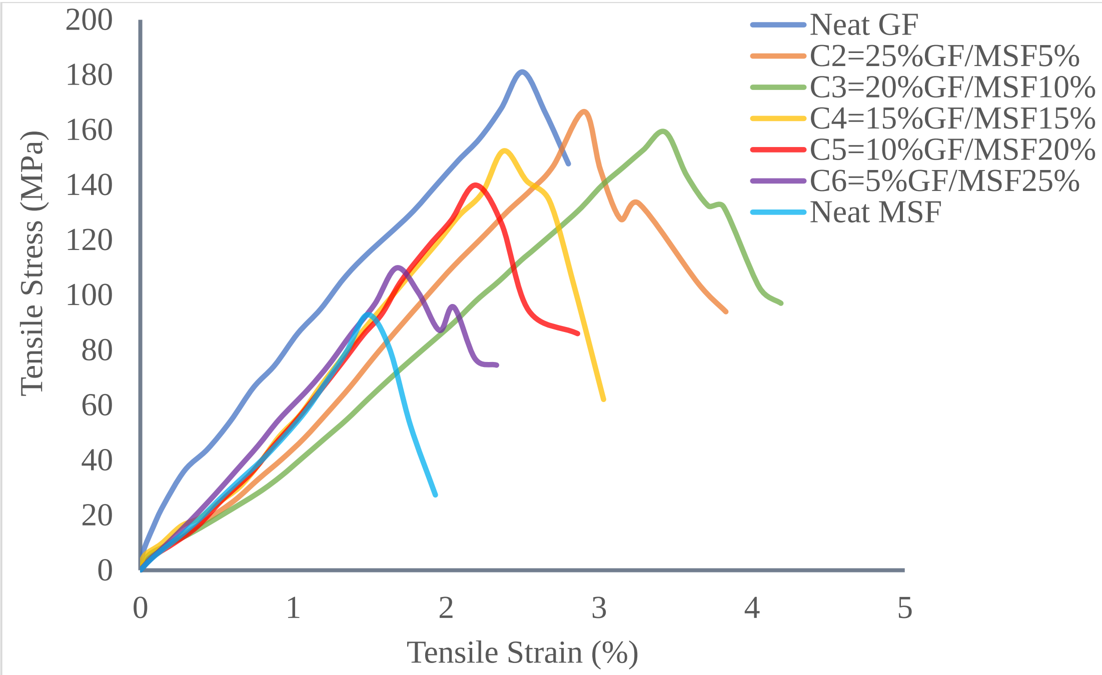


Figure 4.8 Stress–strain behaviour of GF/MSF reinforced epoxy composites under tensile loading

As shown in Figure 4.8, the findings reveal the tensile behavior of the stress-strain curve in relation to the composite materials. It displays the tensile strength results for seven different fiber loadings in composites. Among these, the composite made with a fiber weight percentage of 25GF/5MSF exhibited the maximum tensile strength of 166.64 MPa, at C2. On the other hand, the composite with 20% weight fraction of glass fibre and 10% weight fraction of maize-stalk fibre (C3) had the second-highest tensile strength, indicating a mere 7% decline from the maximum strength.

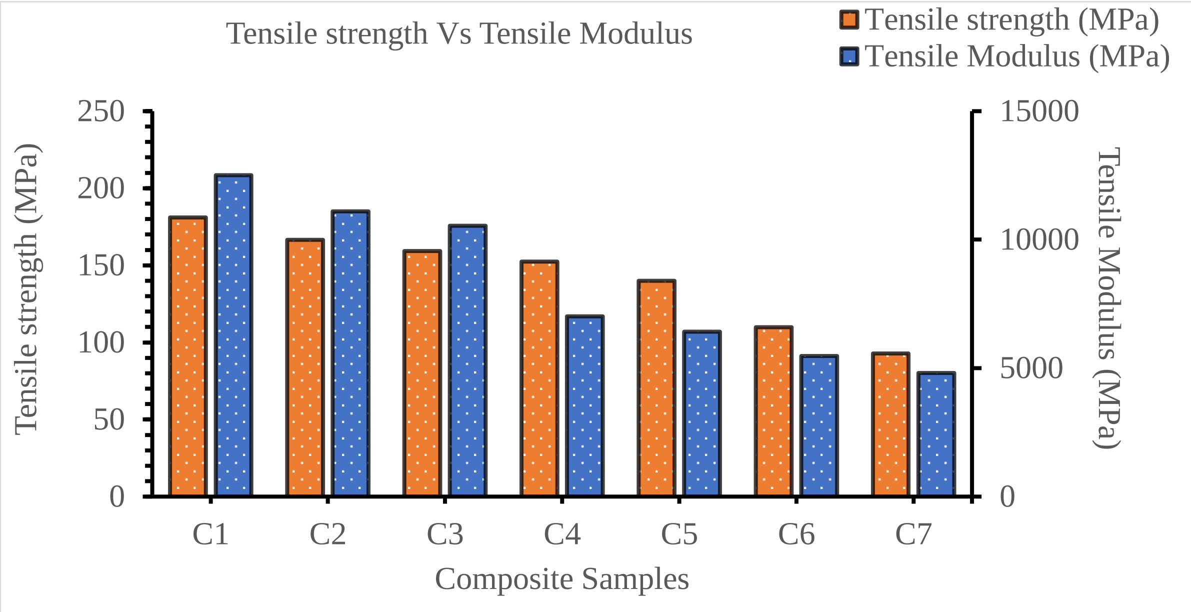


Figure 4.9 Tensile modulus Vs Tensile strength of GF/MSF reinforced Epoxy hybrid composite

In contrast, the tensile strength of the neat maize-stalk fiber (MSF) exhibited the lowest value, declining by 44% from the second composite (C2). The tensile modulus exhibited a comparable pattern, with the composite containing 25% glass fiber and 5% maize stalk fiber achieving the peak value of 11.1GPa. As a reference, the 30%GF composite showed a relatively high tensile strength, differing by 8% from the hybrid composites. This decline in tensile strength and modulus was attributed to the increased proportion of maize-stalk fibers and the subsequent decrease in glass fibers. The experimental data for tensile strength and modulus are presented in Table 4.1.

Table 4.1Experinmental result for tensile test

Standard	Sample	Tensile Strength (MPa)	Tensile Modulus (GPa)
ASTM D3039	C1	181.05	12.506
	C2	166.64	11.101
	C3	159.22	10.535
	C4	152.38	7.014
	C5	139.92	6.419
	C6	109.86	5.472
	C7	92.83	4.808

The study found that reducing the amount of glass fiber used led to a decline in tensile strength. This finding aligns with prior research, such as (Ismail *et al.*, 2020) investigation on combining glass fibers with rice husk fibers in an epoxy composite, which demonstrated that increasing glass fiber content enhanced tensile strength. The researchers proposed that this trend can be attributed to the enhanced adhesion between the fibers and the matrix. The ratio of the fiber length to its diameter, known as the fiber aspect ratio, plays a crucial role in determining the mechanical properties of the composite material. A higher aspect ratio generally leads to improved load transfer from the matrix to the fibers, enhancing the overall strength and stiffness of the composite. The high aspect ratio of the maize-stalk fibers in this study facilitated efficient transfer of stress between the matrix and the fibers (Ashori *et al.,* 2014).

4.1.2 Flexural Characteristics

To reduce the influence of calculations involving shear forces in directions perpendicular to the plane, a bending test was performed on the composite material. The test used a span of 125 mm and a span-to-thickness ratio of about 42:1. This high ratio was chosen to prevent local stress failures caused by contact. The composite specimens all failed under quasi-static conditions. The graph in figure 4.12 illustrates the relationship between flexural strength and applied force for hybrid composites Epoxy reinforced with GF/MSF. These composites were subjected to a three-point bending test to determine their flexural properties. The bending strength was recorded from the machine using equations that take into account the width (B), thickness (H), maximum applied force (Fmax), and span length of the specimen (L).

Section modulus (W_b) $$W_b = \frac{B*H^2}{6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.1$$

Maximum bending Moment (M_{bmax}) $$M_{bmax} = \frac{F_{\max*L}}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

Thus, the flexural strength become;

Flexural Strength(δ_{bmax}) $$\delta_{bmax} = \frac{M_{bmax}}{W_b} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

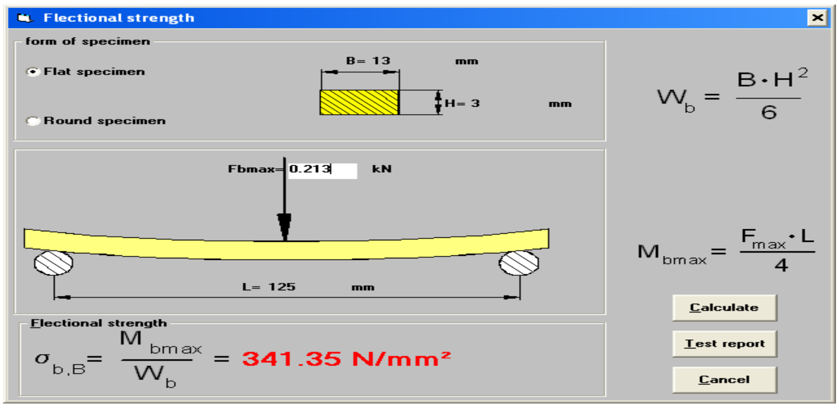


Figure 4.10 Computer output of three-point bending sample

Table 4.2 Experimental result for flexural test

Standard	Sample	Flexural Strength (MPa)	Applied Force (N)
ASTM D790	C1	347.8	217
	C2	275.64	172
	C3	222.21	132.6
	C4	218.5	136.3
	C5	176.3	110
	C6	161.3	100.6
	C7	145.3	90.6

4.1.2.1 Flexural characteristics discussion in terms of fiber loading and application

The fracture plate needs to have sufficient flexural strength to withstand the forces exerted on it during normal physiological activities, such as walking or bearing weight. If the flexural strength of the plate is insufficient, it may deform or fail, compromising the stability of the fracture fixation. Figure 4.11 presented the damaged specimens after bending test. The flexural characteristics of hybrid composites improve with higher glass fiber content, as indicated by the graphs in Figure 4.12. Among these composite materials, with the greatest flexural strength was found to contain 5% maize stalk fiber and 25% glass fiber loading, followed by the specimen with 20% glass fiber and 10% maize stalk fiber, which exhibited a flexural strength of 222.21 MPa. The difference between these two specimens is 19.4% lower than the second one. In contrast, the lowest flexural strength of 145.3 MPa was observed when pure maize stalk fiber was used. These flexural strength results are consistent with previous studies involving hybrid composites of glass fiber with bagasse and corn-stalk reinforced polymer (Ashori *et al.,* 2014).

Figure 4.11 Specimens after bending test

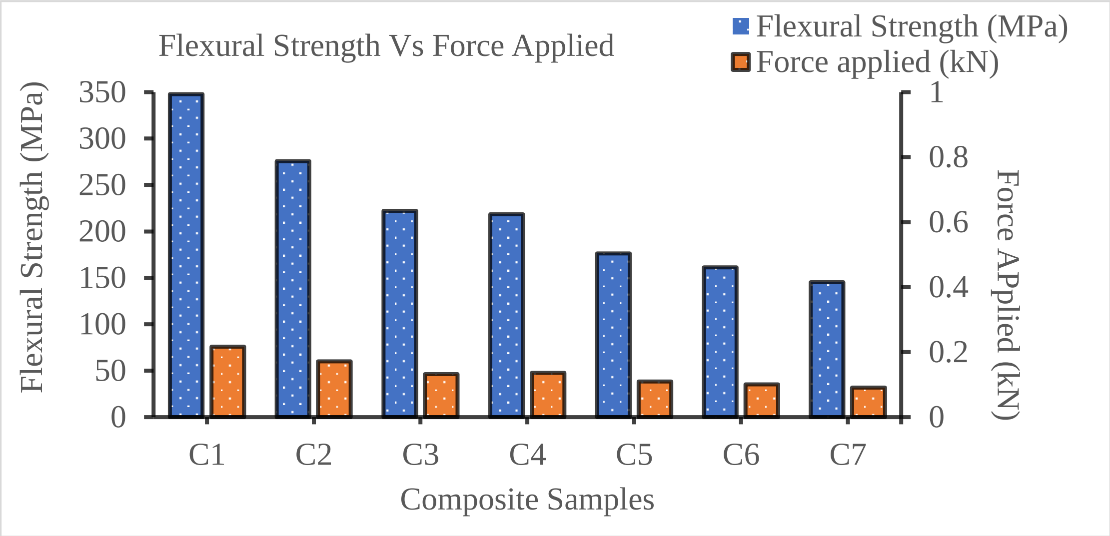


Figure 4.12 Flexural Strength Vs Force Applied

In the three-point flexure test, composite samples undergo compression, tension, and shear stresses, with failure primarily occurring from bending and shearing forces. The incorporation of rigid glass fibers into hybrid composites improves their resistance to shearing, consequently enhancing their flexural strength. Moreover, the robust glass fiber layers effectively manage compressive and tensile stresses in the hybrid composites, leading to an overall enhancement in flexural strength. It is crucial to recognize that higher levels of fiber loading can decline flexural properties. This decrease is linked to heightened fiber-to-fiber interactions and dispersion, which ultimately reduce the mechanical properties of the composites.

4.1.3 Compressive Characteristics

The compressive test was conducted following ASTM D3410 guidelines, utilizing a total of thirty-five samples containing various fiber loadings and reinforcement with chopped fibers, similar procedure for the tensile test. Three specimens showing similar results from each composite composition were selected for repeatability. The results obtained from testing all seven specimen samples are displayed in figures 4.13 to 4.19.

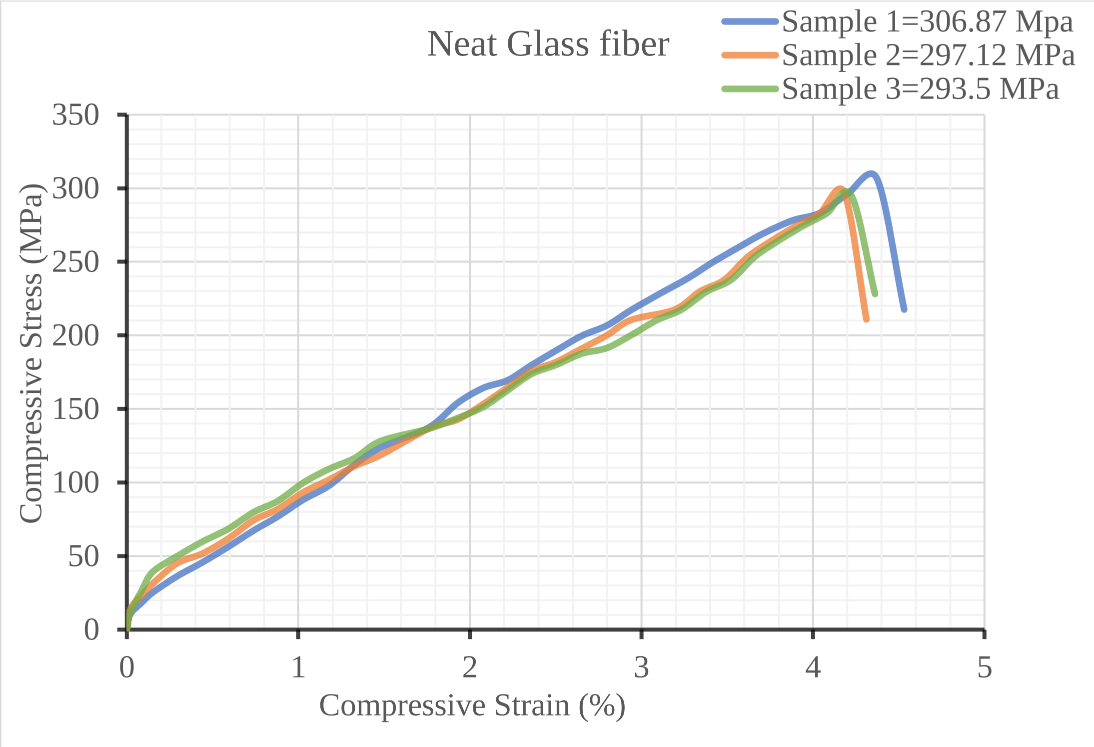


Figure 4.13 Compressive Stress-Strain Curve for Composite-1 (30% GF, 0%MSF and E70%)

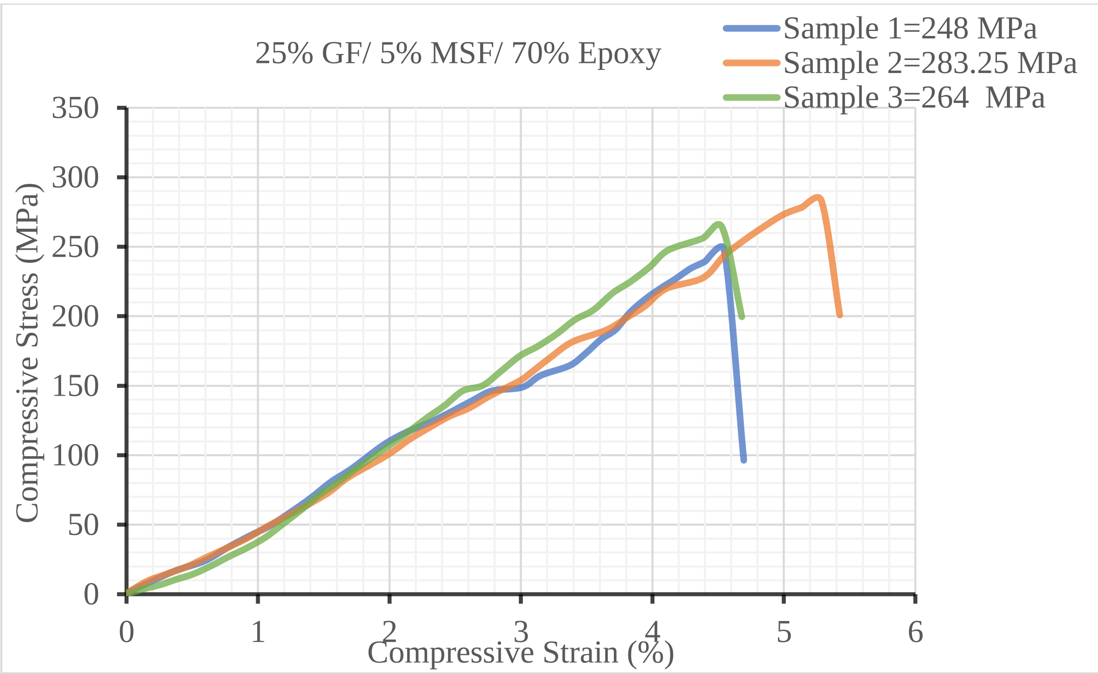


Figure 4.14 Compressive Stress-Strain Curve for Composite-2 (GF25%, MSF 5% and E70%)

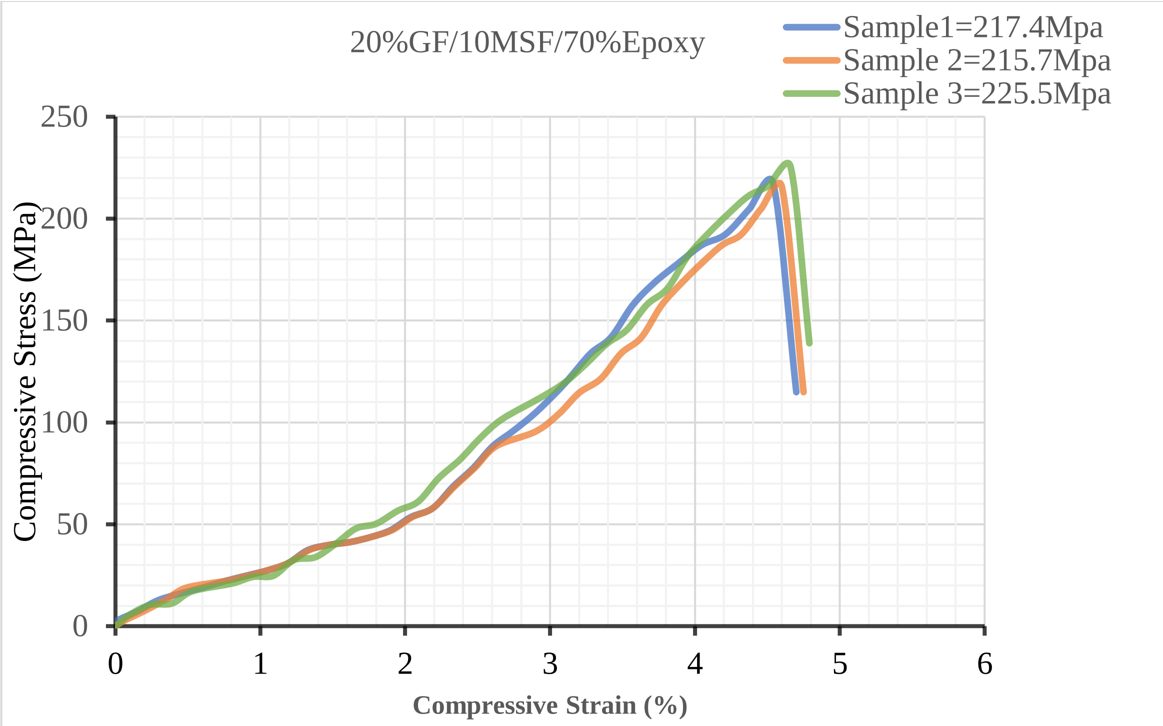


Figure 4.15 Compressive Stress-Strain Curve for Composite-3 (GF20%, MSF 10% and E70%)

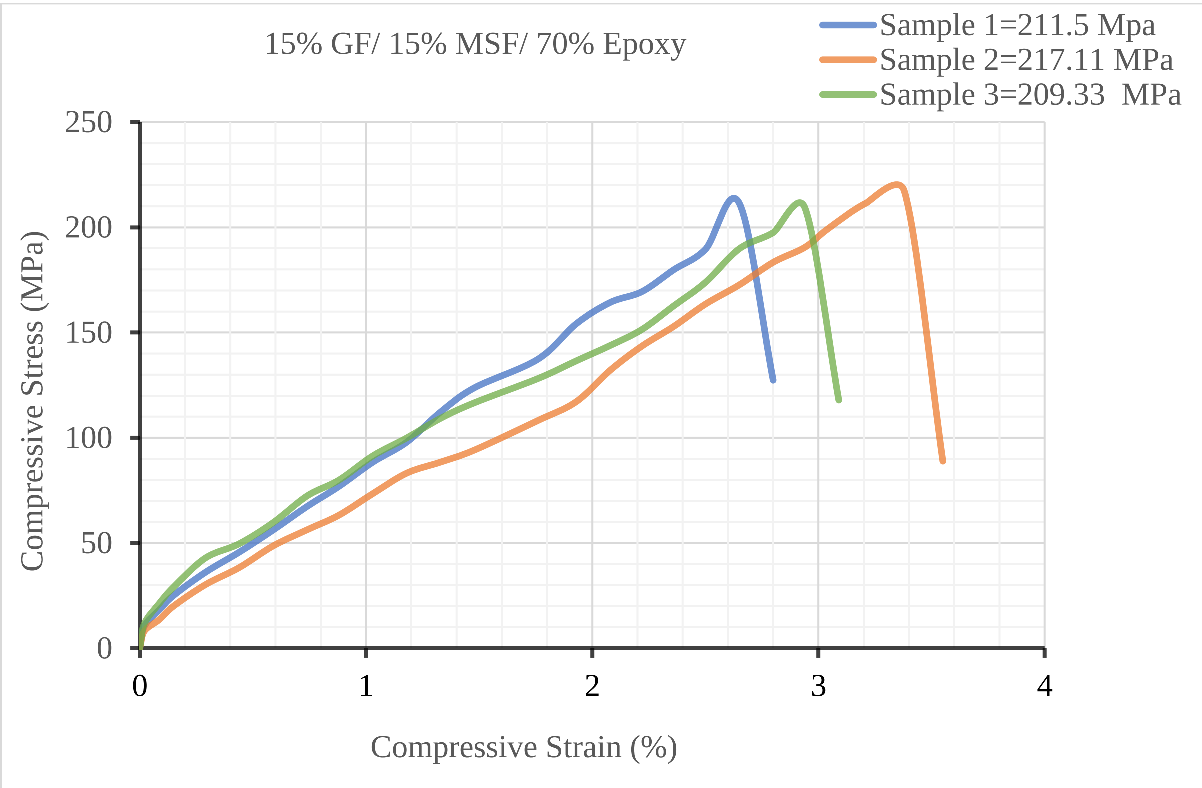


Figure 4.16 Compressive Stress-Strain Curve for Composite-4 (GF 15%, MSF 15% and E70%)

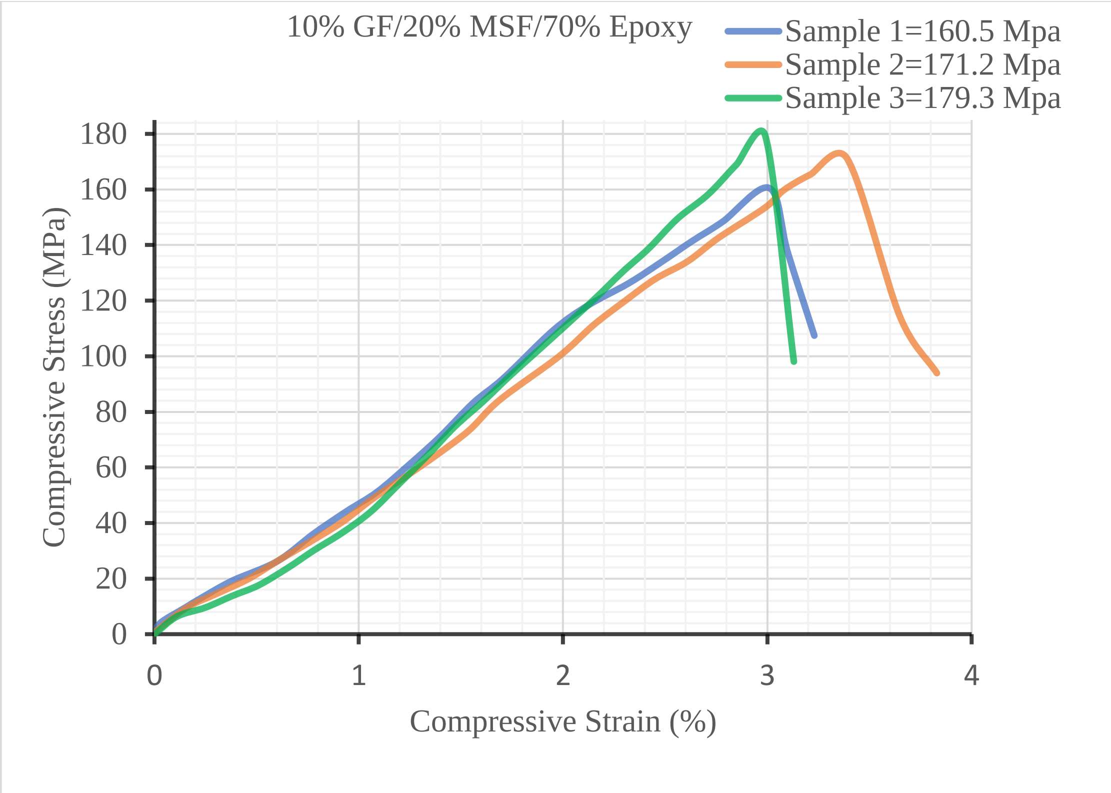


Figure 4.17 Compressive Stress-Strain Curve for Composite-5 (GF 10%, MSF 20% and E70%)

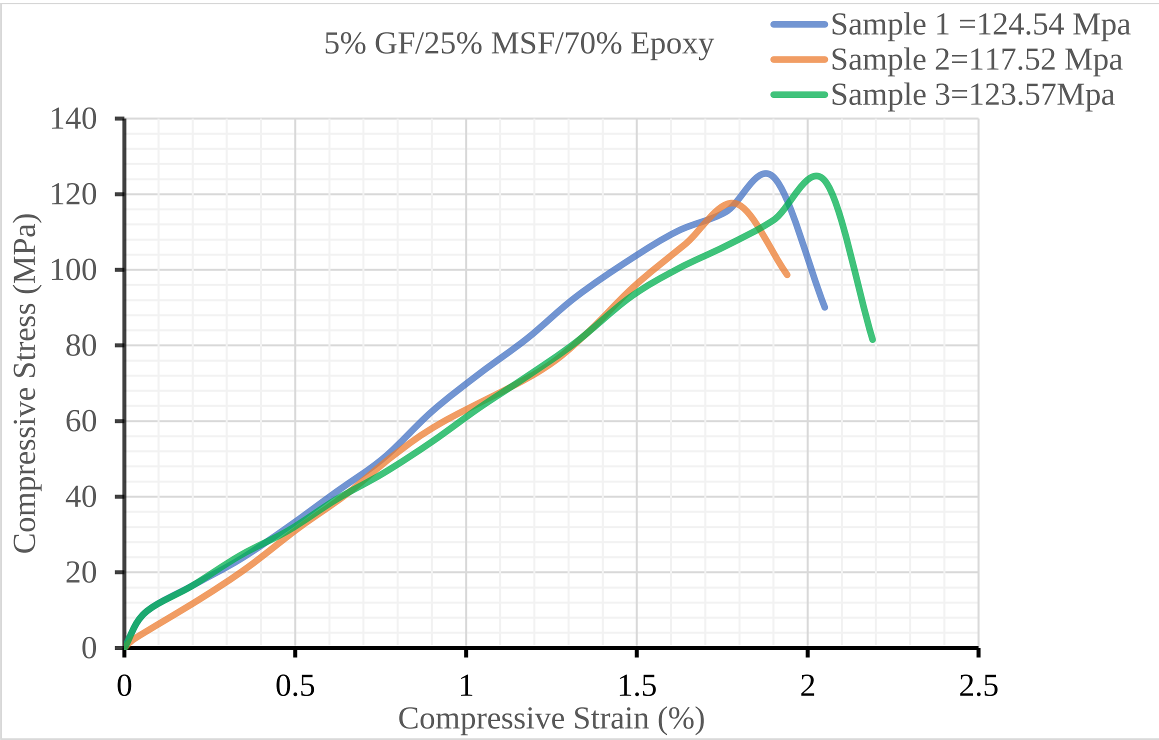


Figure 4.18 Compressive Stress-Strain Curve for Composite-6(GF 5%, MSF 25% and E70%)

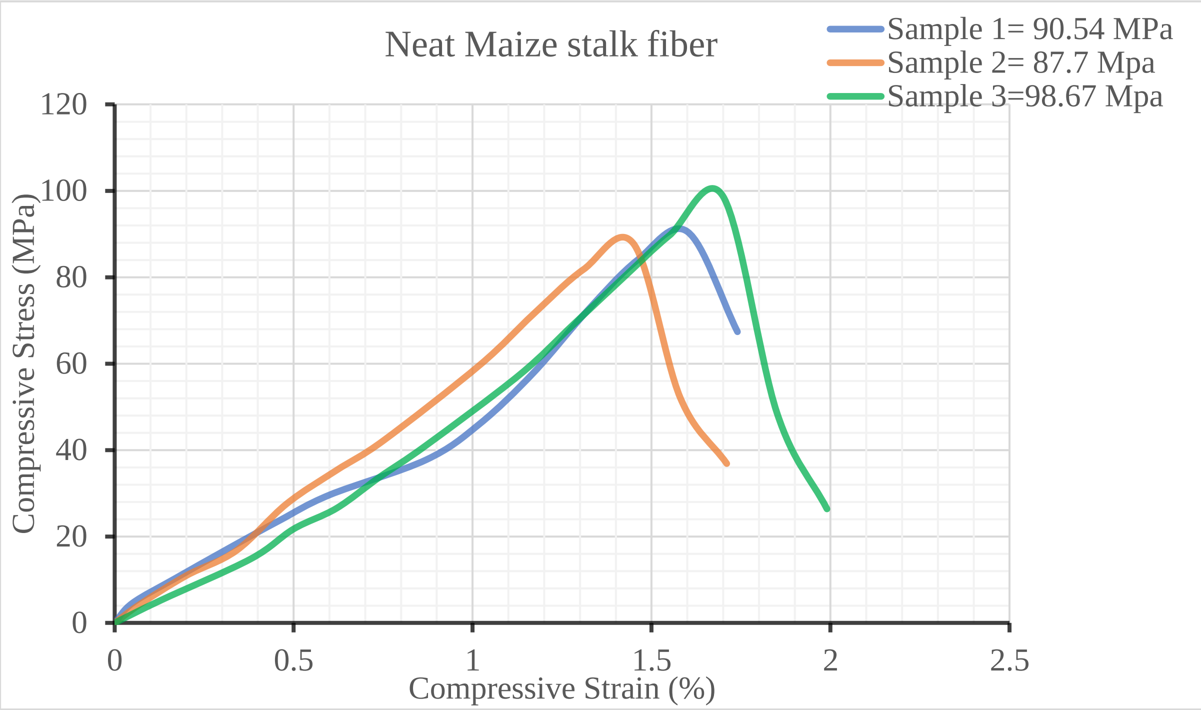


Figure 4.19 Compressive Stress-Strain Curve for Composite-7(GF 0%, MSF 30% and E70%)

4.1.3.1 Compressive characteristics discussion in terms of fiber loading and application

The resistance of a material to breaking under compression stress is crucial for bone plate applications. The results pertaining to the evaluation of the compressive strength of the seven distinct composite types are depicted in Figure 4.20. The non-hybrid composite made purely of glass fibers (GF) exhibited remarkably high compressive strength and modulus compared to the hybrid composite with 13.1% difference value from C2 (25GF/5MSF). The composite with the composition of 25% glass fibers and 5% maize-stalk fiber (MSF) displayed the highest compressive strength, reaching an impressive 265.08 MPa.

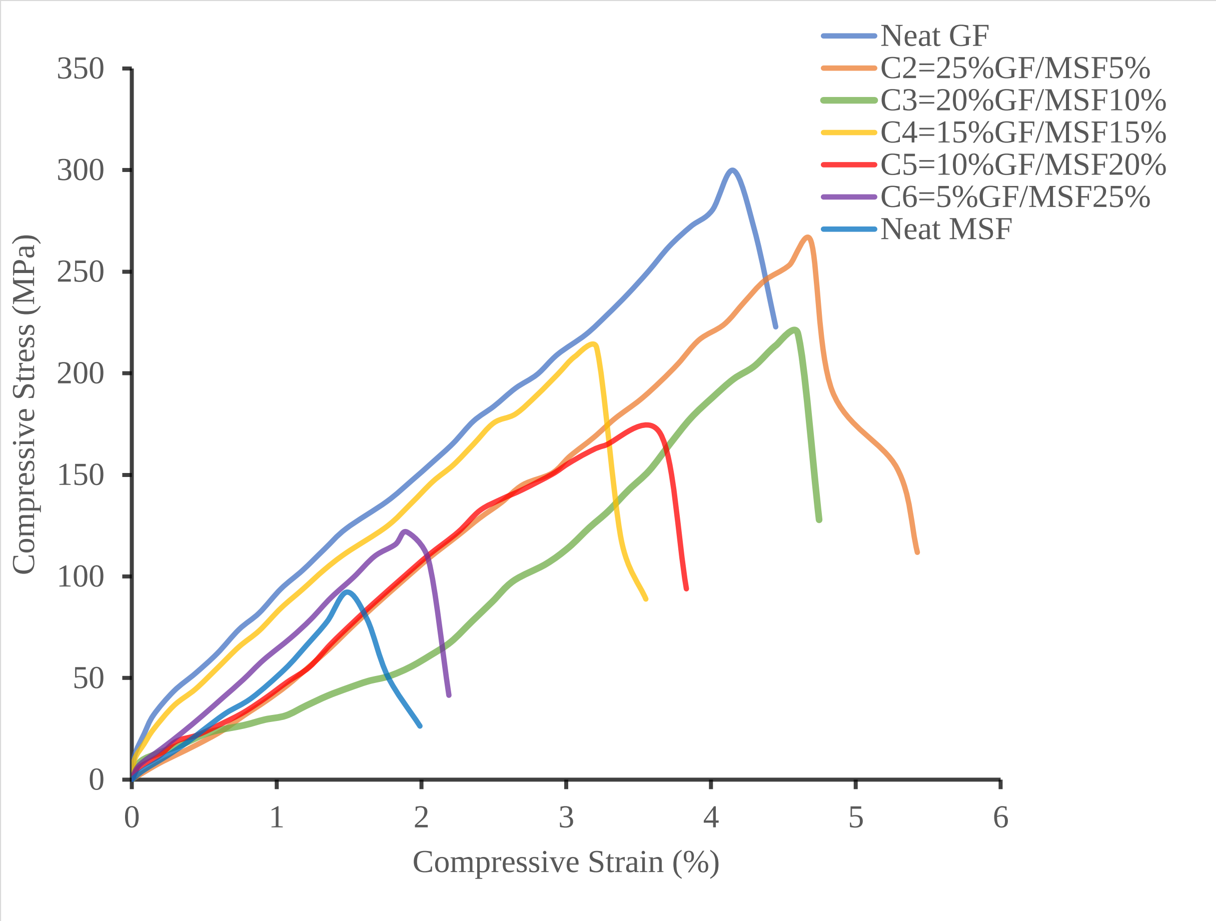


Figure 4.20 Stress–strain behaviour of GF/MSF reinforced epoxy composites under compressive loading

In addition, this research reveals that the compressive strength of the GF/MSF composite is influenced by alterations in the fiber weight percentage. The composite with the highest proportion of maize stalk fiber exhibits the lowest compressive strength, as shown in Table 4.3.

Table 4.3 Experimental result for compressive test

Standard	Sample	Compressive Strength (MPa)	Compressive Modulus (GPa)
ASTM D3410	C1	299.83	7.183
	C2	265.08	5.652
	C3	219.53	4.700
	C4	212.65	3.494
	C5	170.33	2.852
	C6	121.87	1.896
	C7	92.3	1.325

The visual representation in Figure 4.20 demonstrates that the compressive strength of the material significantly improves with the inclusion of glass fibers, which aligns with the findings of a recent study by (Tewelde *et al.,* 2022). This research explored the mechanical properties of hybrid composites combining with water hyacinth and glass fibers, concluding that the combination of these two materials enhances compressive strength compared to non-hybrid alternatives. The compressive strength and modulus values of the composites at room temperature were measured to be between 92.3 to 299.83 MPa and 1.325 to 7.183 GPa, respectively, as depicted in Figure 4.21.

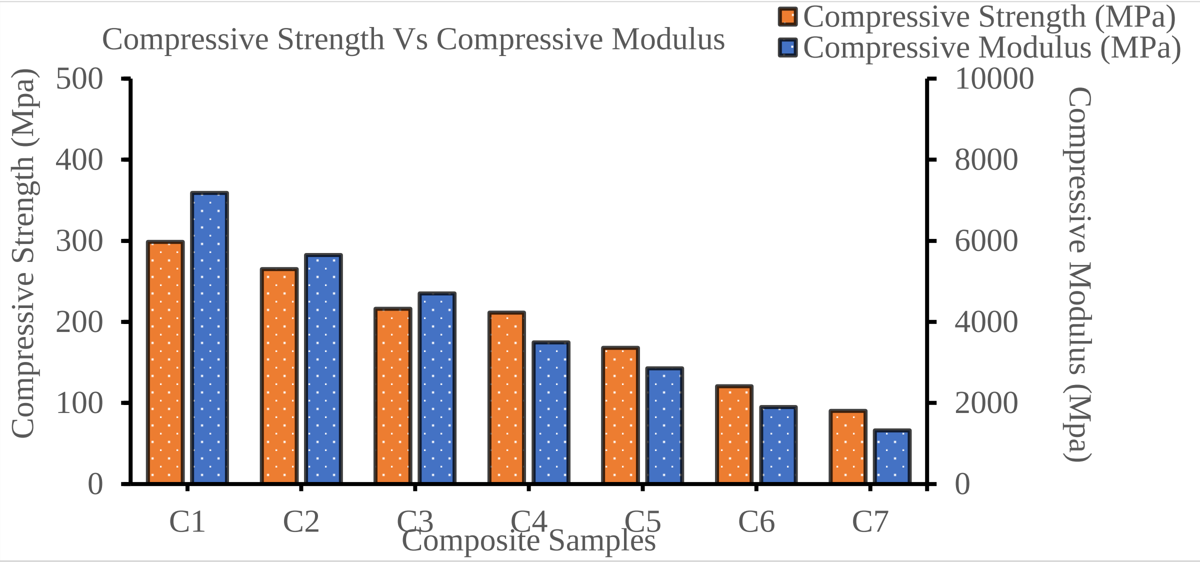


Figure 4.21 Compressive modulus Vs Compressive strength of GF/MSF reinforced Epoxy hybrid composite

4.1.4 Impact Properties

Figure 4.22 depicts the effect of different fiber loadings on the impact strength of composite materials made from epoxy and a combination of glass fiber and maize stalk fiber. The results show that the composite composition of 25% GF and 5% MSF by weight demonstrates the highest impact resistance. This superior performance is attributed to the optimal fiber content that enhances the stress distribution between the fibers and the matrix, as well as ensures excellent dispersion of the fibers within the composite. However, it is important to note that composites with MSF weight fractions exceeding 10% experience a notable decrease in impact strength compared to other compositions. This decline is associated with greater fiber-to-fiber interaction under higher loadings, which reduces the effectiveness of stress transfer from fibers to the matrix, the matrix, thereby compromising the impact resistance of the composite materials.

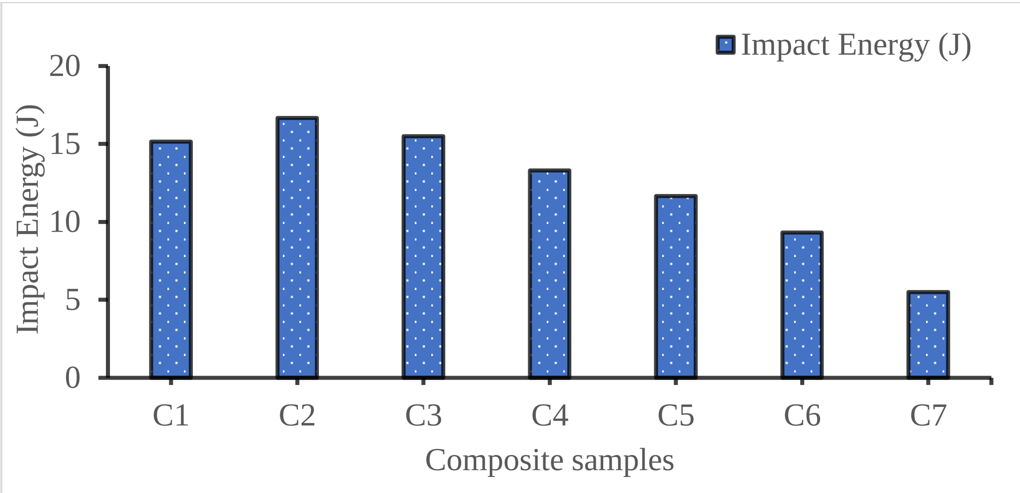


Figure 4.22 Impact energy Vs Composite

4.1.4.1 Impact Properties discussion in terms of fiber loading and application

The capacity of a material to endure sudden force without breaking is a crucial characteristic when considering its suitability for bone plate applications. Notably, exceptional impact strength is observed in the C2 configuration (GF25/MSF5), exhibiting 16.67J and 30.3kJ/m^2 of impact resistance. Conversely, the lowest impact strength is recorded in C7 (pure maize stalk), with values of 5.5J and an impact resistance of 10kJ/m^2. The trend of increasing impact strength is attributed to the presence of fibers in sufficient quantities, which facilitates efficient stress transfer from the fiber to the matrix.

Table 4.4 Experimental result for impact energy test

Standard	Sample	Impact Energy (J)	Impact Resistance (KJ/m^2)
ASTM D256	C1	15.16	27.5
	C2	16.67	30.3
	C3	15.5	28.18
	C4	13.3	24.18
	C5	11.67	21.2
	C6	9.33	16.96
	C7	5.5	10

The results of the experiment indicate that the impact resistance of C2 is sufficient to protect human bones from damage caused by external impacts. Figure 4.22 displays the outcomes of the impact tests, revealing impact strengths ranging from 5.5J to 16.67J.

4.1.5 Micro Hardness Behaviour of GF/MSF Hybrid Composite

The average Vickers micro hardness values for the hybrid composite samples reinforced with Glass Fiber (GF) and Maize-Stalk Fiber (MSF) are summarized in Table 4.5. All specimens exhibited diamond-shaped indentations on their tested surfaces.

Table 4.5 Average values of Micro hardness properties of GF/MSF/Epoxy hybrid composite

Standard	Sample	Applied weight (kg.f)	Vickers Micro Hardness (HV)
ASTM E384	C1		46.87
	C2	10kg.f	42.57
	C3		42.43
	C4		34.97
	C5		39.27
	C6		38.27
	C7		32.67

The highest average Vickers micro hardness attained at neat glass fiber reinforced composite(30%GF) with value of 46.87 HV, as shown in Figure 4.23. This result is due to unique properties and structure of glass fiber such as: chemical composition, strong intermolecular forces, amorphous structure and high surface area. The second highest micro hardness was observed in the composite comprising of glass fiber at a weight fraction of 25% and maize-stalk fiber at a weight fraction of 5% (C2), showing a decrease of only 9.2% compared to the C1.

Conversely, the lowest micro hardness value of 32.67 HV was observed in composite C7, which was 23.3% lower than that of composite C2.

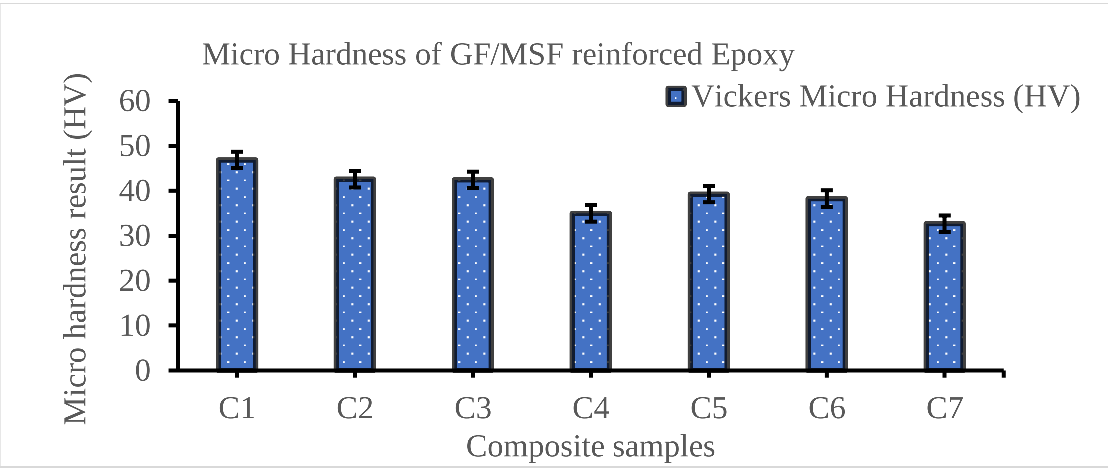


Figure 4.23 Micro hardness of GF/MSF composite

The lower hardness of composites C4, C5, C6, and C7 can be explained by the uneven distribution of materials during fabrication and the inherent flexibility of maize stalk fibers within the composite.

Similar to other properties studied in this research, the micro hardness of the material is influenced by fiber loading, manufacturing process, and temperature. Based on the experimental findings, composite C2 holds promise in providing insights into the long-term performance and stability of fracture fixation.

4.2 Physical characteristic of hybrid composite

4.2.1 Density of hybrid composite

The density of composites has a directly influence the bone plates performance in various ways, including flexibility, weight, and biocompatibility. For each composite, a minimum of three tests were conducted, and the average measured densities values of the are summarized and reported in Table 4.6. The density properties of the GF/MSF/Epoxy composite are displayed in the figure 4.24. As observed from the figure, the maximum density was recorded at C1 with 30% GF and 0% MSF. As the glass fiber weight percentage decreases, the density decreases as well. This is because of the properties of a high density of glass fibers. On the other hand, the minimum density was observed at C7 where pure maize stalk fiber was used, measuring 1.0844 g/cm^3, which is 32% lower than that of C1. This is because natural fibers, such as maize stalk fiber, have inherently low density.

Table 4.6 Density behaviors of GF/MSF/Epoxy

Standard	Sample	Mass of the sample (g)	Volume of the sample(cm^3)	Density of the sample (g/cm^3)
ASTM D792	C1	8.7765	5.5	1.5957
	C2	8.5412	6	1.4235
	C3	7.9655	5.7667	1.3812
	C4	8.4492	7.333	1.1521
	C5	7.7706	6.7	1.1597
	C6	6.9536	6	1.1589
	C7	6.8318	6.3	1.0844

For other hybrid composite samples (C2, C3, C4, C5 and C6) the density was decreasing in continuous manner as the glass fiber wt.% is decreasing as shown in figure 4.24.

Composites with lower density tend to exhibit higher flexibility, enabling better adaptation to the natural movement of bones. Composite materials with densities closer to that of bone, which is approximately 1.75 g/cm³, (Dhanopia and Bhargava, 2017) can enhance biocompatibility. When the density of the composite material is comparable to that of bone, it facilitates better integration and lowers the possibility of unfavorable reactions by minimizing material property mismatch. The weight of the bone plate is also influenced by the density of the composite. Reducing the total weight of the implant through the use of lighter materials can improve patient comfort and speed up the healing process after surgery.

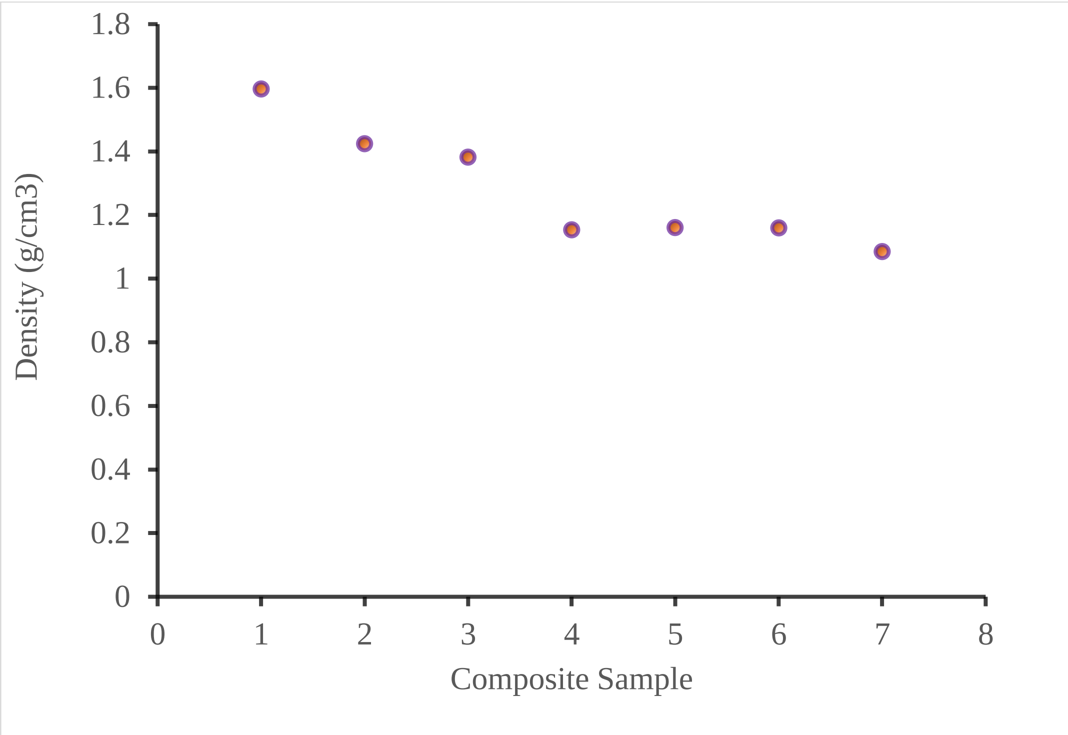


Figure 4.24 Density Vs Composite samples

4.22 Water Absorption Behaviour

The average rate of water absorption of the GF/MSF/Epoxy composite after a 24-hour period is shown in Table 4.7. As the percentage of maize stalk fibre in the composite increases, Figure 4.25 shows that the rate of water absorption increases. This is mostly because maize stalk fiber's high cellulose content makes it possible for it to retain water molecules by forming hydrogen bonds inside the fibre cell wall.

Table 4.7 Water absorption behaviour of GF/MSF/Epoxy hybrid composite

Standard	Sample	Initial weight (g)	Final weight (g)	Water absorption (%)
ASTM D570	C1	8.7765	8.8603	0.9457
	C2	7.9655	8.1226	1.93
	C3	8.5412	8.7693	2.6
	C4	7.770	8.4146	7.65
	C5	6.9536	7.624	8.79
	C6	8.4492	9.6574	12.51
	C7	6.8318	8.500	19.63

The lowest water absorption rate is seen at C1, which is only 0.9457%, due to the hydrophobic quality of the glass fiber. When the maize stalk-epoxy composite is used without glass fiber, the water absorption rate is measured at 19.63%. However, when glass fiber is added along with maize-stalk fiber, there is a substantial decrease in water uptake. Specifically, adding a small amount of glass fiber C2 (5 wt.%GF) leads to a decrease in water absorption rate by 1.93%.

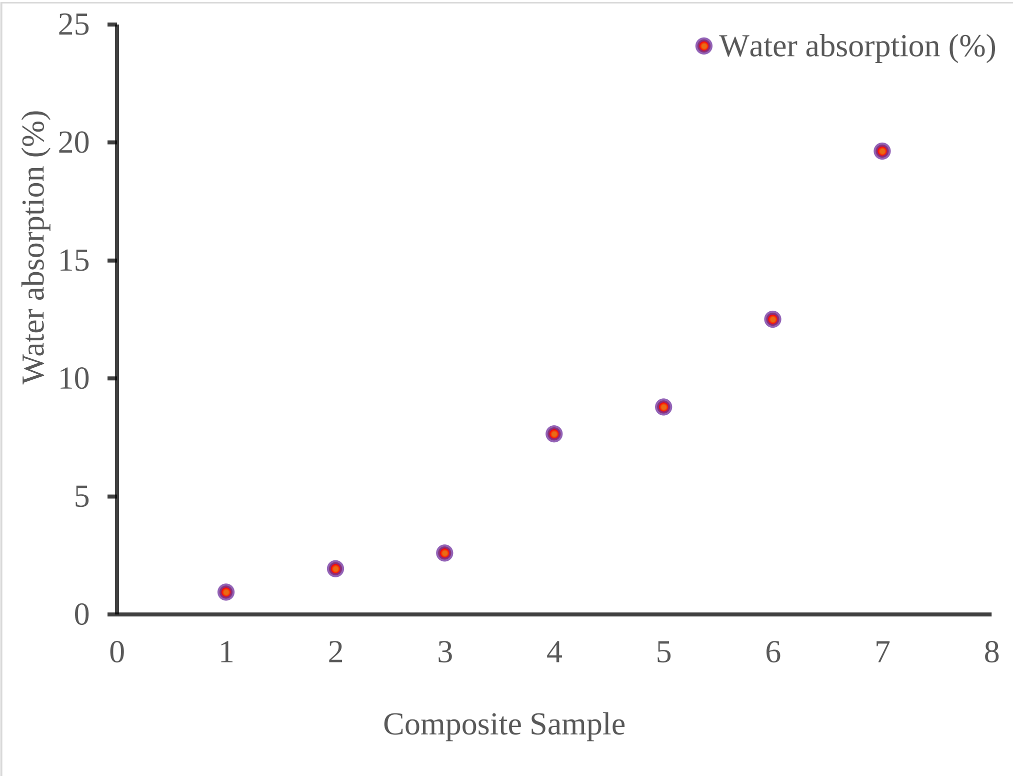


Figure 4.25 Water absorption percentage Vs Composite

The capacity of a material to resist water is a crucial characteristic for its application as a bone plate. Excessive water absorption can adversely affect biocompatibility by initiating chemical reactions or degradation processes within the material, leading to the release of potentially harmful byproducts or the formation of microorganisms. This could elevate the risk of infection or adverse reactions in the surrounding tissues (Park *et al.*, 2012). Furthermore, a material with a hydrophilic nature can potentially affect the shape and fit of the bone fracture plate, possibly resulting in misalignment or loosening of the plate.

4.3 Comparison to prior studies and existing materials

The existing literature presents scattered findings regarding the mechanical characteristics of hybrid composites utilized in applications for bone fracture plates. Some of previous studies on hybrid composites and the metals used for bone fracture plate are summarized in Table 4.8 revealing disparities in the reported results compared to the current study. These differences can be ascribed to various variables, including the use of distinct natural and synthetic fibres, variations in the matrix's contents, varying percentages of fibre or matrix weight, and different manufacturing techniques.

However, the suggested GF/MSF/Epoxy hybrid composite's mechanical characteristics are within the range documented in earlier research. Consequently, it is conceivable to improve fracture healing and permit the underlying bone to carry a significant amount of the applied stress by developing a fracture fixing mechanism with decreased axial stiffness. In addition, the mechanism needs to be sufficiently rigid to bend in order to avoid too much movement at the fracture site.

Table 4.8 Comparison of mechanical and physical properties of GF/MSF/Epoxy hybrid composites to previous studies

Properties	Tensile Strength (MPa)	Compressive Strength (MPa)	Flexural Strength (MPa)	Impact Strength (J)	Micro Hardness	Water Absorption (%)	Density(g/cm^3)	References
Material								
Femur Cortical bone	50-150	205	-	-	-	-	1.75	Brydone *et al.,* (2010)
SS316L	485	570	-	-	-	-	7.75	Dhanopia *et al.,* (2017)
Ti-6Al-4V	993	1086					4.5	Dhanopia *et al.,* (2017
Glass/Flax /Epoxy	408.25	261.21	>500	-	-	6.035	-	Manteghi *et al.,* (2017)
Glass/Sisal/Chiston/ Epoxy	146	380	343	-	59.6	3.436	-	Arumugam *et al.,* (2020)
Carbon/Fax/bio epoxy	339.63	-	234.96	-	-	-	-	Senthil *et al.,* (2023)
GF/MSF/ Epoxy	166.64	265.08	275.64	16.67	42.57	1.93	1.4235	Current Study

The current investigation yielded experimental results for the GF/MSF/Epoxy hybrid composite, revealing a tensile strength of 166.64 MPa. This value is relatively close to the tensile strength observed in the human femur bone, which falls within the range of 50-150 MPa. However, the hybrid composite's tensile strength is considerably lower than that of stainless steel (485 MPa) and titanium (993 MPa). Likewise, in terms of Young's modulus of elasticity, the human femur bone exhibits a range of 7-20 GPa, along with a compressive strength ranging from 131-224 MPa (Mohamed, 2008). These values are substantially lower than those of stainless steel (200 GPa; 570 MPa) and titanium (105 GPa; 1086 MPa). However, the current hybrid composite falls within the range of the human femur bone for tensile strength modulus (166.64MPa, 11.1GPa) and compressive strength and modulus (265.08,5.652GPa).

Consequently, the present hybrid composite specimens exhibit mechanical characteristics that are adequately strong to reduce the stress shielding phenomenon, maintain stability at the site of fracture, immobilize nearby bone fragments, and withstand loads commonly encountered in clinical settings.

4.4 Finite Element modelling of bone fracture plate

i. Equivalent (Von-Mises) Stress

The hybrid composite material consisting of 25% glass, 5% maize stalk, and 70% epoxy used for a bone fracture plate yields a maximum von Mises stress of 49.166 MPa and a minimum of 2.283 x 10^-10 MPa, which is lower than the yield stress of 85.1 MPa. The impact of the bone plate's material on the resulting von Mises stresses when employing glass-maize stalk fiber-reinforced epoxy is depicted in Figure 4.26, which shows that stresses at the bone plate decrease significantly when using the GF/MSF/Epoxy material instead of titanium and stainless steel. This is due to the flexible properties of the glass-maize stalk fibers-reinforced epoxy hybrid composite, which are closer to the cortical bone compared to other metallic plates.

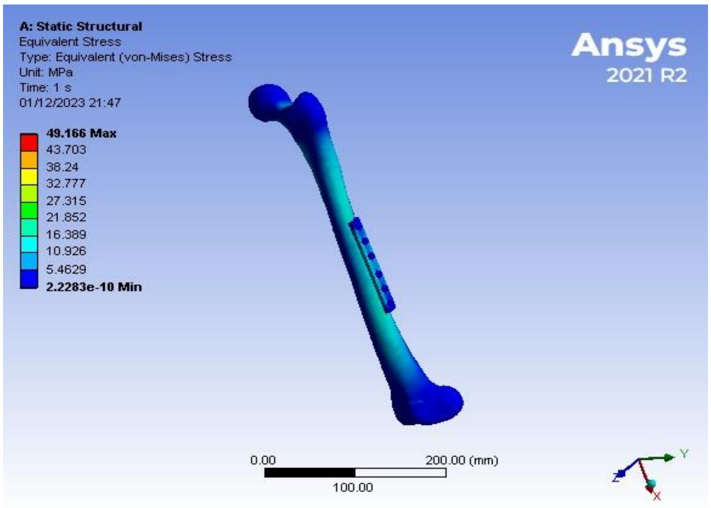


Figure 4. 26 Equivalent Von Mises Stress Result

The findings also reveal that the greatest stress occurs in the plate and bone at the location where the fracture has occurred. By utilizing a hybrid composite material with a lower Young's modulus than metals, it can be effectively addressing concerns associated with bone softening, weakening, and the requirement for additional surgeries caused by excessive loads on the bone instead of the plate. These composite bone plates play a vital role in restoring the bone's load carrying capacity by offering mechanical support. Through external fixation to the bone using screws, the plate helps distribute the load evenly across the fracture site. As a result, the bone becomes capable of bearing weight and transmitting forces more efficiently, thereby facilitating the healing process.

ii. Total Deformation

The Glass/Maize-stalk/Epoxy hybrid composite achieved a maximum total deformation of 4.4329mm and a minimum deformation of 0 mm when used as a bone fracture plate. Figure 4.27 clearly demonstrates that the femur's head experiences the highest level of deformation, while the lower end experiences the lowest.

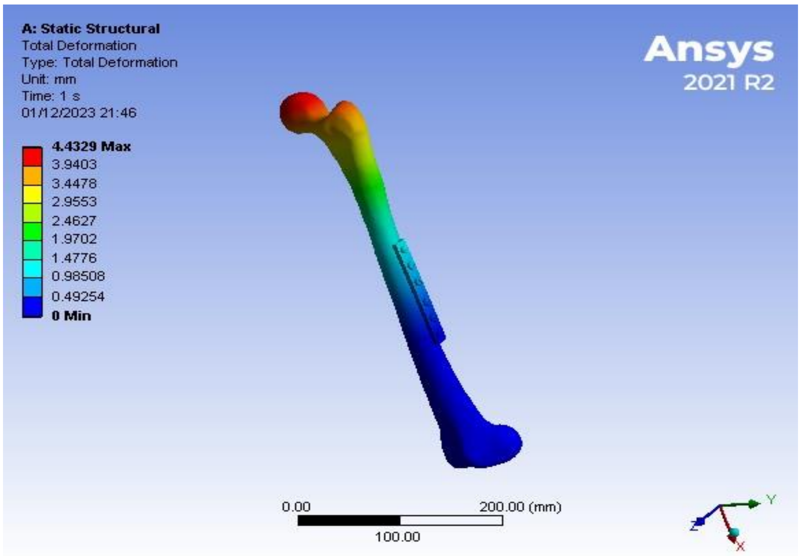


Figure 4.27 Total Deformation Result

The results indicate that most of the weight during daily tasks is borne by the top part of the thigh bone. The study's findings indicate that the hybrid composite provides enhanced stability, enabling it to withstand heavier loads. Furthermore, it offers the advantages of being lighter in weight and potentially providing better distribution of stress, which can be highly advantageous for patients.

4.5 Comparing FEA Results to Prior Studies

The comparative analysis conducted between the existing materials utilized in bone fracture plates and the outcomes of the present study, relying on finite element analysis results, rendered meaningful and intelligent insights. The Table 4.8 provided to indicate that the Glass/Maize-stalk/Epoxy hybrid composite material, with a composition of 25/5/70, exhibits promising characteristics that make it a potential alternative to metals.

Table 4.9 Comparison of FEA of GF/MSF/Epoxy hybrid composites to previous studies

Materials	Equivalent Stress (MPa)		Total Deformation (mm)		Reference(s)
	Max	Min	Max	Min	
SS316L (alloy metals)	405.71	0.001253	2.5722	0	Dhanopia and Bhargava (2017)
Ti-6Al-4V (alloy metals)	332.27	0.001259	2.6959	0	
Nylon6/6 (polymer)	601.3	0.001247	2.4758	0	
PMMA (Thermoplastic)	59.488	0.001316	3.9512	0	
Alumina Al_2O_3 (ceramic)	467.12	0.001253	2.523	0	
Glass/Maize-stalk/Epoxy	49.166	2.283 e^{-10}	4.4329	0	Current study

This material possesses a significantly lower equivalent stress and deformation, suggesting its suitability for replacing metals in bone fracture plate applications. Looking ahead, the utilization of composite materials, which are combinations of different elements, in the orthopaedic field is expected to undergo revolutionary transformations. These materials offer exceptional corrosion resistance, making them highly durable and long-lasting. Moreover, they are cost-effective compared to traditional metal alternatives. The easy manufacturability of hybrid composites enables their mass production, further supporting their practicality in orthopedic applications. Finally, the enhanced patient comfort provided by these materials enhances the overall treatment experience, making them even more appealing for the future of orthopedics.

Chapter Five

5. Conclusion, Recommendation and Future Work

5.1 Conclusion

In conclusion, femur bone fractures are a commonly occurring injury resulting from high-energy trauma caused by accidents such as motor vehicle collisions and falling from heights. The conventional use of bone fixation plates for treatment presents a challenge due to their stiffness compared to human cortical bone, leading to the stress shielding effect. To address this issue, an alternative solution can be found in utilizing a hybrid polymer composite material.

This study focused on producing GF/MSF reinforced Epoxy hybrid composite scaffolds using the hand layup method. Notably, the incorporation of agricultural residue like maize-stalk fibers as reinforcement materials contributes to environmental sustainability. The research examined various mechanical and physical properties of the glass/maize-stalk/epoxy hybrid composite, including tensile, flexural, compression, impact, micro-hardness, density, and water absorption properties.

By analyzing these properties, the study suggests practical implications of this combination of materials in the development of bone fixation plates. Finite element analysis results further support the material's suitability for this purpose. Therefore, this research contributes to the advancements in both mechanical engineering and sustainable materials, opening new avenues for improving the treatment of femur bone fractures and promoting eco-friendly practices in the field.

The following results are obtained from the current experiment's evaluation and numerical investigation.

- ❖ The integration of NaOH in the chemical extraction method successfully extracts maize-stalk fiber.
- ❖ Through the hand layup technique, a hybrid composite of glass-maize-stalk reinforced epoxy has been developed.
- ❖ Significant enhancement in mechanical properties is observed in composites reinforced with maize-stalk fiber through hybridization.
- ❖ From experimental results 25GF/5MSF hybrid composite composition has the potential to withstand clinical-type forces similar to those experienced by the femur bone during

normal daily activities. It exhibits exceptional ultimate strengths in tension (166.64 MPa), compression (265.08 MPa), flexural (275.64 MPa), and impact (16.67J).

- Among the various combinations, composite sample C2 (25GF/5MSF/Epoxy) demonstrates the highest Vickers hardness of 42.57 HV.
- Water absorption properties reveal that the 25GF/5MSF hybrid composite exhibit a lower water absorption percentage of 1.93% compared to the 30% MSF composites (19.63%).
- The lowest density was obtained from composite C2 with 25GF/5MSF composition having 1.4235g/cm^3.
- Finite Element Analysis (FEA) demonstrates that the glass-maize stalk reinforced epoxy hybrid composite mitigates stress shielding effects when compared to metallic implants, with a von Mises stress of 49.166 MPa and total deformation of 4.4329 mm.
- The fabricated hybrid composite closely emulates the properties of the femur bone, displaying excellent strength, stiffness, and promising potential for replacing metallic plates.

5.2 Recommendation

The glass/maize-stalk/epoxy hybrid composite offers exceptional properties ideal for various applications, particularly in the medical field for bone fixation plates. Prior to integrating this advanced composite, thorough assessment of factors such as compatibility, structural integrity, and performance expectations is essential to ensure effective utilization.

- Exploring different compositions and orientations for the glass/maize-stalk/epoxy material is highly recommended.
- The glass/maize-stalk/epoxy hybrid composite is recommended for various applications.
- It is highly recommended to perform comprehensive testing to assess biocompatibility and reduce potential risks associated with fabricated hybrid composite plates.
- It is recommended to make enhancements and optimizations to create a strong base for the clinical application of this hybrid composite.
- Consider replacing existing metallic bone fixation plates with the glass-maize stalk reinforced epoxy hybrid composite material.

5.3 Future Work

As the future work for this thesis paper, the following activities will be undertaken:

- To ensure safety and compatibility with the human body, will be conduct advanced biocompatibility tests like hemocompatibility, "in vitro" stability, and cytotoxicity on hybrid composite scaffolds.
- Using advanced fabrication methods, like Vacuum bag molding, to strengthen the connection between the fiber and matrix material, leading to enhanced structural durability.
- Conducting corrosion tests on the hybrid composite materials to evaluate their resistance to degradation over time.
- Using finely ground maize-stalk fiber in manufacturing to improve the strength and effectiveness of the hybrid composite material.
- Performing scanning electron microscopy (SEM) and fatigue failure analysis on Glass-maize stalk fiber reinforced epoxy composite to assess its microstructure and resistance to fatigue failure.
- Investigating the potential of utilizing surface coatings on hybrid composite plates to improve their characteristics related to friction and wear, known as tribological properties.

References

Ageyeva, T., Sibikin, I. and Kovács, J.G. (2019) 'Review of thermoplastic resin transfer molding: Process modeling and simulation', *Polymers*, 11(10), p. 1555. Available at: https://doi.org/10.3390/polym11101555.

Ahmad, F., Choi, H.S. and Park, M.K. (2015) 'A review: Natural fiber composites selection in view of mechanical, light weight, and economic properties', *Macromolecular Materials and Engineering*, 300(1), pp. 10–24. Available at: https://doi.org/10.1002/mame.201400089.

Al-Taki, M. and Nahle, I.S. (2016) 'Bones and Fractures', in *Hamilton Bailey's: Demonstrations of Physical Signs in Clinical Surgery, 19th Edition*. CRC Press, pp. 147–165. Available at: https://doi.org/10.1201/b20728-9.

Al-Tamimi, A.A., Quental, C., Folgado, J., Peach, C. and Bartolo, P.(2020) 'Stress analysis in a bone fracture fixed with topology-optimised plates', *Biomechanics and Modeling in Mechanobiology*, 19(2), pp. 693–699. Available at: https://doi.org/10.1007/s10237-019-01240-3.

Arthanarieswaran, V.P., Kumaravel, A. and Kathirselvam, M. (2014) 'Evaluation of mechanical properties of banana and sisal fiber reinforced epoxy composites: Influence of glass fiber hybridization', *Materials and Design*, 64, pp. 194–202. Available at: https://doi.org/10.1016/j.matdes.2014.07.058.

Arumugam, S., Kandasamy, J., Md Shah, A.U., Hameed Sultan, M.T., Safri, S.N.A., Abdul Majid, M.S., Basri, A.A. and Mustapha, F. (2020) 'Investigations on the Mechanical properties of glass fiber/sisal fiber/chitosan reinforced hybrid polymer sandwich composite scaffolds for bone fracture fixation applications', *Polymers*, 12(7), pp. 1–19. Available at: https://doi.org/10.3390/polym12071501.

Ashori, A., Nourbakhsh, A. and Tabrizi, A.K. (2014) 'Thermoplastic Hybrid Composites using Bagasse, Corn Stalk and E-glass Fibers: Fabrication and Characterization', *Polymer - Plastics Technology and Engineering*, 53(1), pp. 1–8. Available at: https://doi.org/10.1080/03602559.2013.832854.

Atiqah, A., Maleque, M.A., Jawaid, M. and Iqbal, M. (2014) 'Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications', *Composites Part B:Engineering*,56,pp. 68–73. Available at: https://doi.org/10.1016/j.compositesb.2013.08.019.

Bagheri, Z.S., El Sawi, I., Schemitsch, E.H., Zdero, R. and Bougherara, H. (2013) ‘Biomechanical properties of an advanced new carbon/flax/epoxy composite material for bone plateapplications’,*JournaloftheMechanicalBehaviorofBiomedicalMaterials*,20,pp.398406.Availableat:https://doi.org/10.1016/j.jmbbm.2012.12.013.

Bagheri, Z.S., Tavakkoli Avval, P., Bougherara, H., Aziz, M.S., Schemitsch, E.H. and Zdero, R. (2014) ‘Biomechanical analysis of a new carbon fiber/flax/epoxy bone fracture plate shows less stress shielding compared to a standard clinical metal plate’, *Journal ofBiomechanicalEngineering*,136(9),p.91002.Available at: https://doi.org/10.1115/1.4027669.

Berhane, G., Paulos, Z., Tafere, K. and Tamru, S., (2013) ‘Patterns in foodgrain consumption and calorie intake’, *Food and Agriculture in Ethiopia: Progress and Policy Challenges*, 9780812208, pp. 190–216. Available at: https://doi.org/10.9783/9780812208610.190.

Bharanichandar, J., Chandramohan, D. and Murali, B. (2014) ‘Natural Fiber Reinforced Polymer Composite in Synthetic Bone Grafting – A New Approach’, *Issue*, 16(16), pp. 588–596.

Bi, Y.Y., Wang, Y.J. and Gao, C.Y. (2009) ‘Problems of burning straw and its management countermeasures in China’, *J Anhui Agric Sci*, 37(27), pp. 13181–13184.

Brydone, A.S., Meek, D. and MacLaine, S. (2010) ‘Bone grafting, orthopaedic biomaterials, and the clinical need for bone engineering’, *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*, 224(12), pp. 1329–1343. Available at: https://doi.org/10.1243/09544119JEIM770.

Bucci, D.Z., Tavares, L.B.B. and Sell, I. (2007) ‘Biodegradation and physical evaluation of PHB packaging’, *Polymer Testing*, 26(7), pp. 908–915. Available at: https://doi.org/10.1016/j.polymertesting.2007.06.013.

Chand, N. and Fahim, M. (2020) *Tribology of Natural Fiber Polymer Composites, Second Edition*, *Tribology of Natural Fiber Polymer Composites, Second Edition*. Woodhead publishing. Available at: https://doi.org/10.1016/C2018-0-04814-8.

Chandramohan, D. and Marimuthu, K. (2016) ‘Bio Composite Materials Based on Bio Polymers And Natural Fibers -Contribution As Bone Implant’, *International Journal of Advanced Medical Sciences and Applied Research*, 1(January 2011), pp. 9–12.

Chang, A. and Hubbard, J.B. (2018) ‘Anatomy, Bony Pelvis and Lower Limb, Femur’, in

StatPearls.StatPearlsPublishing.Availableat:http://www.ncbi.nlm.nih.gov/pubmed/30422577.

Chawla, K.K. (2012) ‘Metal Matrix Composites, Composite Materials’, *i springers, New York, NY* [Preprint].

Chen, J., Zou, Y., Ge, H., Cui, Z. and Liu, S.(2018) ‘Mechanical and water absorption behaviors of corn stalk/sisal fiber-reinforced hybrid composites’, *Journal of Applied Polymer Science*, 135(26), p. 46405. Available at: https://doi.org/10.1002/app.46405.

Chigondo, F., Shoko, P., Nyamunda, B.C. and Moyo, M. (2013) ‘Maize stalk as reinforcement in natural rubber composites’, *International Journal of Scientific & technology Research*, 2(6), pp. 263–271.

Das, S. and Sarangi, S.K. (2014) ‘Finite element analysis of femur fracture fixation plates’, *International Journal of Basic and Applied Biology,* 1(1), pp. 1–5.

Devi, S., Poonia, P.K., Kumar, V., Tiwari, A., Meena, R.K., Kumar, U., Gulnaz, A. and Al-Sadoon, M.K. (2022) ‘Characterization of Natural Fiber Extracted from Corn (Zea mays L.) Stalk Waste for Sustainable Development’, *Sustainability (Switzerland)*, 14(24), p. 16605. Available at: https://doi.org/10.3390/su142416605.

Dhanopia, A. and Bhargava, M. (2017) ‘Finite Element Analysis of Human Fractured Femur Bone Implantation with PMMA Thermoplastic Prosthetic Plate’, *Procedia Engineering*, 173, pp. 1658–1665. Available at: https://doi.org/10.1016/j.proeng.2016.12.190.

Faour, O., Dimitriou, R., Cousins, C.A. and Giannoudis, P.V., (2011) ‘The use of bone graft substitutes in large cancellous voids: Any specific needs?’, *Injury*, 42(SUPPL. 2), pp. S87–S90. Available at: https://doi.org/10.1016/j.injury.2011.06.020.

Flynn, J., Amiri, A. and Ulven, C. (2016) ‘Hybridized carbon and flax fiber composites for tailored performance’, *Materials and Design*, 102, pp. 21–29. Available at: https://doi.org/10.1016/j.matdes.2016.03.164.

Garadimani, K.R., Raju, G.U. and Kodancha, K.G. (2015) ‘Study on Mechanical Properties of Corn Cob Particle and E-Glass Fiber Reinforced Hybrid Polymer Composites’, *American Journal of Materials Science*, 5(3C), pp. 86–91. Available at: http://journal.sapub.org/materials.

García, M., Garmendia, I. and García, J. (2008) ‘Influence of natural fiber type in ecocomposites’, *Journal of Applied Polymer Science*, 107(5), pp. 2994–3004. Available at: https://doi.org/10.1002/app.27519.

Ghani, A., Ahmad, M.N., Hakak, A., Nabi, F., Ashraf, U. and Majeed, M. (2018) ‘An analytical study of pattern of orthopedic injuries among patients presenting to the emergency department in a tertiary care hospital at GMC Jammu’, *J Med Sci Clin Res,* 11, pp. 529–535.

Giannoudis, P. V., Einhorn, T.A. and Marsh, D. (2007) ‘Fracture healing: The diamond concept’, *Injury*, 38(4 SUPPL.), pp. S3–S6. Available at: https://doi.org/10.1016/S0020-1383(08)70003-2.

Gopalakrishnan, T., Jayakanth, J.J., Gnanavel, C.S.R. and Sridhar, R. (2018) ‘Analysis of Hybrid Natural Fiber Composite for Bio-Medical Application’, *International Journal of Emerging Technologies in Engineering Research (IJETER)*, 6(4), pp. 274–277. Available at: www.ijeter.everscience.org.

Gouda, T.A., Jagadish, S.P., Dinesh, K.R., Gouda, H. and Prashanth, N. (2014) ‘Characterization and Investigation of Mechanical Properties of Hybrid Natural Fiber Polymer Composite Materials Used As Orthopaedic Implants for Femur Bone Prosthesis’, *IOSR Journal of Mechanical and Civil Engineering*, 11(4), pp. 40–52. Available at: https://doi.org/10.9790/1684-11424052.

Haydaruzzaman, Khan, A.H., Hossain, M.A., Khan, M.A. and Khan, R.A., (2010) ‘Mechanical properties of the coir fiber-reinforced polypropylene composites: Effect of the incorporation of jute fiber’, *Journal of Composite Materials*, 44(4), pp. 401–416. Available at: https://doi.org/10.1177/0021998309344647.

Hu, H., Liu, J., Liu, Z., Li, C., Wang, C., Chen, X. and Shen, Y., (2022) ‘Improving mechanical, thermal, and erosive wear performance of natural bamboo fibers modified epoxy resin matrix composites’, *Composites and Advanced Materials*, 31, p. 263498332211433. Available at: https://doi.org/10.1177/26349833221143395.

Huda, N., Gupta, P., Pant, A., Iqbal, A., Julfiqar, M., Khan, M.Z. and Agrawal, N.K. (2014)‘Pattern of Orthopaedic injuries among patients attending the emergency department in a tertiary care hospital - An analytical study’, *Acta Medica International*, 1(1), pp. 10–14. Available at: https://doi.org/10.5530/ami.2014.1.4.

Idris, S.A., Mohammed, O.B. and Basheer, E.S., 2010. ‘Why do people prefer traditional bonesetters in Sudan?', *Sudan Journal of Medical Sciences*, 5(3). Available at: https://doi.org/10.4314/sjms.v5i3.62008.

Ismail, M., Rejab, M.R.M., Siregar, J.P., Mohamad, Z., Quanjin, M. and Mohammed, A.A. (2020) 'Mechanical properties of hybrid glass fiber/rice husk reinforced polymer composite', *MaterialsToday:Proceedings*,27(xxxx),pp.17491755.Availableat:https://doi.org/10.1016/j.matpr.2020.03.660.

Jain, R., Podworny, N., Hupel, T.M., Weinberg, J. and Schemitsch, E.H. (1999) 'Influence of plate design on cortical bone perfusion and fracture healing in canine segmental tibial fractures',*Journal of Orthopaedic Trauma*, 13(3), pp. 178–186. Available at: https://doi.org/10.1097/00005131-199903000-00005.

Jawaid, M. and Abdul Khalil, H.P.S. (2011) 'Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review', *Carbohydrate Polymers*, 86(1), pp. 1–18. Available at: https://doi.org/10.1016/j.carbpol.2011.04.043.

Katherine, A. (2013) 'Official CPC Certification Study Guide', *American Medical Association*, p. 108.

Kesarwani, P., Jahan, S.J. and Kesarwani, K. (2018) 'Composite : Classification and its manufacturing process', *International Journal of Applied Research*, 1(9), pp. 352–358. Available at: www.allresearchjournal.com.

Kim, H.J., Kim, S.H. and Chang, S.H. (2011) 'Finite element analysis using interfragmentary strain theory for the fracture healing process to which composite bone plates are applied', *CompositeStructures*,93(11),pp.29532962.Availableat:https://doi.org/10.1016/j.compstruct.2011.05.008.

Kim, T., See, C.W., Li, X. and Zhu, D. (2020) 'Orthopedic implants and devices for bone fractures and defects: Past, present and perspective', *Engineered Regeneration*, 1(April), pp. 6–18. Available at: https://doi.org/10.1016/j.engreg.2020.05.003.

Kiruthika, A. V. (2017) 'A review on physico-mechanical properties of bast fibre reinforced polymer composites', *Journal of Building Engineering*, 9(June 2016), pp. 91–99. Available at: https://doi.org/10.1016/j.jobe.2016.12.003.

Kluge, N.J., Lundström, T.S., Westerberg, L.G. and Olofsson, K.(2015) 'Compression moulding of sheet moulding compound: Modelling with computational fluid dynamics and validation', *Journal of Reinforced Plastics and Composites*, 34(6), pp. 479–492. Available at: https://doi.org/10.1177/0731684415573981.

Kumar, K.N., Tandon, T., Silori, P. and Shaikh, A.(2015) 'Biomechanical Stress Analysis of a Human Femur Bone Using ANSYS', *Materials Today: Proceedings*, 2(4–5), pp. 2115–2120. Available at: https://doi.org/10.1016/j.matpr.2015.07.211.

Kumar, M.A., Reddy, G.R., Mahesh, K.V., Chakradhar, K.V.P. and Reddy, Y.M. (2011) 'Performance of Zea mays fiber reinforced epoxy composites', *International Journal of Fiber and Textile Research*, 1(1), pp. 22–27. Available at: http://www.urpjournals.com.

Łączny, D., Macko, M., Moraczewski, K., Szczepański, Z. and Trafarski, A. (2021) 'Influence of the size of the fiber filler of corn stalks in the polylactide matrix composite on the mechanical andthermomechanicalproperties',*Materials*,14(23).Availableat:https://doi.org/10.3390/ma14 237281.

Lewis, G.S., Mischler, D., Wee, H., Reid, J.S. and Varga, P., (2021) 'Finite element analysis of fracture fixation. *Current osteoporosis reports*, *19*(4), pp.403-416.

Li, P., Cai, D., Luo, Z., Qin, P., Chen, C., Wang, Y., Zhang, C., Wang, Z. and Tan, T., (2016)'Effect of acid pretreatment on different parts of corn stalk for second generation ethanol production',*BioresourceTechnology*,206,pp.8692.Availableat:https://doi.org/10.1016/j.biortec h.2016.01.077.

Liu, Y. and Wang, M. (2007) 'Developing a composite material for bone tissue repair', *Current Applied Physics*, 7(5), pp. 547–554. Available at: https://doi.org/10.1016/j.cap.2006.11.002.

Liverpool-Tasie, L.S.O., Omonona, B.T., Sanou, A. and Ogunleye, W.O. (2017) 'Is increasing inorganic fertilizer use for maize production in SSA a profitable proposition? Evidence from Nigeria',*FoodPolicy*,67,pp.41–51.Available at: https://doi.org/10.1016/j.foodpol.2016.09.011.

Lubin, G. (2013) *Handbook of Composites*, *Handbook of Composites*. Springer Science & Business Media. Available at: https://doi.org/10.1007/978-1-4615-7139-1.

Luo, Z., Li, P., Cai, D., Chen, Q., Qin, P., Tan, T. and Cao, H., (2017) 'Comparison of performances of corn fiber plastic composites made from different parts of corn stalk', *IndustrialCropsandProducts*,95,pp.521527.Availableat:https://doi.org/10.1016/j.indcrop.201 6.11.005.

Ma, C., Zhang, S., Dong, R., Wang, M., Jia, W. and Lu, Z., (2018) 'Corn Stalk Fiber-Based

Biomass Brick Reinforced by Compact Organic/Inorganic Calcification Composites', *ACS SustainableChemistryandEngineering*,6(2),pp.20862093.Availableat:https://doi.org/10.1021/acssuschemeng.7b03509.

Ma, C., Du, T., Niu, X. and Fan, Y., (2022) 'Biomechanics and mechanobiology of the bone matrix', *Bone Research*, 10(1), p. 59. Available at: https://doi.org/10.1038/s41413-022-00223-y.

Maharaj, P.S.R.S., Maheswaran, R. and Vasanthanathan, A. (2013) 'Numerical analysis of fractured femur bone with prosthetic bone plates', *Procedia Engineering*, 64, pp. 1242–1251. Available at: https://doi.org/10.1016/j.proeng.2013.09.204.

Mahesh Kumar T, Ravi Kumar P, Duru Anitha, Praveen B. (2018) 'Experimental investigation and analysis of a mechanical and thermal properties of hybrid polymer composite plates', *International Journal of Mechanical and Production Engineering Research and Development*, 8(2), pp. 53–64. Available at: https://doi.org/10.24247/ijmperdapr20186.

Mallick, P.K. (2007) *Fiber-reinforced composites: materials, manufacturing, and design*. CRC press.

Manteghi, S., Mahboob, Z., Fawaz, Z. and Bougherara, H. (2017) 'Investigation of the mechanical properties and failure modes of hybrid natural fiber composites for potential bone fracture fixation plates', *Journal of the Mechanical Behavior of Biomedical Materials*, 65, pp. 306–316. Available at: https://doi.org/10.1016/j.jmbbm.2016.08.035.

Martin, I., Saenz del Castillo, D., Fernandez, A. and Güemes, A. (2020) 'Advanced thermoplastic composite manufacturing by in-situ consolidation: A review', *Journal of Composites Science*, 4(4), p. 149. Available at: https://doi.org/10.3390/jcs4040149.

Masood, M.S. (2015) 'Unconventional Modeling and Stress Analysis of Femur Bone under Different Boundary Condition', *Australian Journal of Basic and Applied Sciences*, 4(12), pp. 331–335.

Mathapati, S.S., Tech, M. and Kakamari, P. (2014) 'Analysis and characterization of Tensile and Compressive Properties of the Chopped Strand Mat E-Glass Fiber Reinforced Epoxy Composites', *Advanced Engineering and Applied Sciences*, 4(3), pp. 29–33. Available at: http://www.urpjournals.com.

Melton, L.J., Achenbach, S.J., Atkinson, E.J., Therneau, T.M. and Amin, S. (2013) 'Long-term mortality following fractures at different skeletal sites: A population-based cohort study’, *OsteoporosisInternational*,24(5),pp. 1689–1696. Available at: https://doi.org/10.1007/s00198-012-2225-1.

Mohamed, A.M.F.S. (2008) ‘An overview of bone cells and their regulating factors of differentiation’, *Malaysian Journal of Medical Sciences*, 15(1), pp. 4–12.

Moukbil, Y., Isindag, B., Gayir, V., Ozbek, B., Haskoylu, M.E., Oner, E.T., Oktar, F.N., Ikram, F., Sengor, M. and Gunduz, O.(2020) ‘3D printed bioactive composite scaffolds for bone tissue engineering’,*Bioprinting*,17(3),pp.278314.Availableat:https://doi.org/10.1016/j.bprint.2019.e00064.

Mujahid, Y., Sallih, N., Mustapha, M., Abdullah, M.Z. and Mustapha, F.(2021) ‘Effects of processing parameters for vacuum-bag-only method on void content and mechanical properties of laminated composites’, *Polymer Composites*, 42(2), pp. 567–582. Available at: https://doi.org/10.1002/pc.25848.

Mukhopadhyay, S. and Fangueiro, R. (2009) ‘Physical modification of natural fibers and thermoplastic films for composites - A review’, *Journal of Thermoplastic Composite Materials*, 22(2), pp. 135–162. Available at: https://doi.org/10.1177/0892705708091860.

Namvar, F., Jawaid, M., Tanir, P.M., Mohamad, R., Azizi, S., Khodavandi, A., Rahman, H.S. and Nayeri, M.D., (2014) ‘Potential use of plant fibres and their composites for biomedical applications’,*BioResources*,9(3),pp.5688–5706.Availableat: https://doi.org/10.15376/biores.9.3.

Nareliya, R. and Kumar, V. (2012) ‘Finite Element Application to Femur Bone’, *Journal of BiomedicalandBioengineering*,3(1),pp.57–62.Availableat: http://www.bioinfo.in/contents.php?id=87.

Nassar, M.M.A. and Sider, I. (2021) ‘Evaluation of novel compatibility strategies for improving the performance of recycled low-density polyethylene based biocomposites’, *Polymers*, 13(20), p. 3486. Available at: https://doi.org/10.3390/polym13203486.

Navarro, M., Michiardi a, Castaño O, Planell JA. (2008) ‘Biomaterials in orthopaedics’, *Journal of the Royal Society Interface*, 5(27), pp. 1137–1158. Available at: https://doi.org/10.1098/rsif.2008.0151.

Noorunnisa Khanam, P., Abdul Khalil, H.P.S., Jawaid, M., Ramachandra Reddy, G., Surya

Narayana, C. and Venkata Naidu, S., 2010. 'Sisal/carbon fibre reinforced hybrid composites: tensile, flexural and chemical resistance properties', *Journal of Polymers and the Environment*,18, pp. 727–733.

Nourisa, J. and Rouhi, G. (2019) 'Prediction of the trend of bone fracture healing based on the results of the early stages simulations: a finite element study', *Journal of Mechanics in MedicineandBiology*,19(5),p.1950021.Availableat:https://doi.org/10.1142/S0219519419500210.

Olmos, A.A., Fertuzinhos, A., Campos, T.D., Dias, I.R., Viegas, C.A., Pereira, F.A., Quyền, N.T., de Moura, M.F., Zille, A. and Dourado, N., (2022) 'Osteosynthesis Metal Plate System for Bone Fixation Using Bicortical Screws: Numerical–Experimental Characterization', *Biology*, 11(6), p. 940. Available at: https://doi.org/10.3390/biology11060940.

Paiva, J.C., Oliveira, L., Vaz, M.F. and Costa-de-Oliveira, S. (2022) 'Biodegradable Bone Implants as a New Hope to Reduce Device-Associated Infections—A Systematic Review', *Bioengineering*, 9(8), p. 409. Available at: https://doi.org/10.3390/bioengineering9080409.

Park, S.W., Yoo, S.H., An, S.T. and Chang, S.H. (2012) 'Material characterization of glass/polypropylene composite bone plates according to the forming condition and performance evaluation under a simulated human body environment', *Composites Part B: Engineering*,43(3),pp.1101–1108.Availableat: https://doi.org/10.1016/j.compositesb.2011.09.008.

Petrucci, R., Santulli, C., Puglia, D., Nisini, E., Sarasini, F., Tirillo, J., Torre, L., Minak, G. and Kenny, J.M. (2015) 'Impact and post-impact damage characterisation of hybrid composite laminates based on basalt fibres in combination with flax, hemp and glass fibres manufactured byvacuuminfusion',*CompositesPartB:Engineering*,69,pp.507515.Availableat:https://doi.org/10.1016/j.compositesb.2014.10.031.

Petrucci, R., Santulli, C., Puglia, D., Sarasini, F., Torre, L. and Kenny, J.M., 2013. Mechanical characterisation of hybrid composite laminates based on basalt fibres in combination with flax, hemp and glass fibres manufactured by vacuum infusion. *Materials & Design*, *49*, pp.728-735.

Prabhu, L., Krishnaraj, V., Gokulkumar, S., Sathish, S. and Ramesh, M., (2019) 'Mechanical, chemical and acoustical behavior of sisal - Tea waste - Glass fiber reinforced epoxy based hybrid polymer composites', *Materials Today: Proceedings*, 16, pp. 653–660. Available at:

https://doi.org/10.1016/j.matpr.2019.05.142.

Priyanka, P., Dixit, A. and Mali, H.S. (2017) ‘High-Strength Hybrid Textile Composites with Carbon, Kevlar, and E-Glass Fibers for Impact-Resistant Structures. A Review.’, *Mechanics of Composite Materials*, 53(5), pp. 685–704. Available at: https://doi.org/10.1007/s11029-017-9696-2.

Raghavendra Rao, H., Varada Rajulu, A., Ramachandra Reddy, G. and Hemachandra Reddy, K., (2010) ‘Flexural and compressive properties of bamboo and glass fiber-reinforced epoxy hybrid composites’, *Journal of Reinforced Plastics and Composites*, 29(10), pp. 1446–1450. Available at: https://doi.org/10.1177/0731684409105077.

Rajak, D.K., Pagar, D.D., Kumar, R. and Pruncu, C.I. (2019) ‘Recent progress of reinforcement materials: A comprehensive overview of composite materials’, *Journal of Materials Research andTechnology*, 8(6), pp. 6354–6374. Available at: https://doi.org/10.1016/j.jmrt.2019.09.068.

Ramakrishna, S., Mayer, J., Wintermantel, E. and Leong, K.W.(2001)‘Biomedical applications of polymer-composite materials: a review’, *Composites science and technology*, 61(9), pp. 1189–1224.

Ramesh, M., Palanikumar, K. and Reddy, K.H. (2017) ‘Plant fibre based bio-composites: Sustainable and renewable green materials’, *Renewable and Sustainable Energy Reviews*, 79, pp. 558–584. Available at: https://doi.org/10.1016/j.rser.2017.05.094.

Ramlee, M.H., Kadir, M.R.A., Murali, M.R. and Kamarul, T. (2014)‘Biomechanical evaluation of two commonly used external fixators in the treatment of open subtalar dislocation-A finite element analysis’, *Medical Engineering and Physics*, 36(10), pp. 1358–1366. Available at: https://doi.org/10.1016/j.medengphy.2014.07.001.

Rana, R.S., Rana, S. and Purohit, R. (2017) ‘Characterization of Properties of epoxy sisal / Glass Fiber Reinforced hybrid composite’, *Materials Today: Proceedings*, 4(4), pp. 5445–5451. Available at: https://doi.org/10.1016/j.matpr.2017.05.056.

Reddy, N. and Yang, Y. (2005) ‘Biofibers from agricultural byproducts for industrial applications’,*Trends in Biotechnology*, 23(1), pp. 22–27. Available at: https://doi.org/10.1016/j.tibtech.2004.11.002.

Saba, N., Paridah, M.T., Abdan, K. and Ibrahim, N.A. (2016) ‘Thermal properties of oil palm nano filler/kenaf reinforced epoxy hybrid nanocomposites’, *AIP Conference Proceedings*, 1787, pp. 133–138. Available at: https://doi.org/10.1063/1.4968118.

Sadashiva, M., Kumar, S.P., Yathish, M.K., Satish, V.T., Srinivasa, M.R. and Sharanraj, V. (2021) ‘Experimental investigation of bending characteristics of hybrid composites fabricated by hand layup method’, in *Journal of Physics: Conference Series*. IOP Publishing, p. 12033. Available at: https://doi.org/10.1088/1742-6596/2089/1/012033.

Salit M. S., Jawaid M., Bin Yusoff N., and Hoque M. E. (2015) '*Manufacturing of natural fibre reinforced polymer composites*, *Manufacturing of Natural Fibre Reinforced Polymer Composites*. Springer. Available at: https://doi.org/10.1007/978-3-319-07944-8.

Sanjay, M. and Yogesha, B. (2017) ‘Studies on Natural/Glass Fiber Reinforced Polymer Hybrid Composites: An Evolution’, *Materials Today: Proceedings*, 4(2), pp. 2739–2747. Available at: https://doi.org/10.1016/j.matpr.2017.02.151.

Saravia, H., McDaniel, S.R., Pham, T.H., Nelson, C.L. and Gunther, S. (2015) ‘Bone fixation device, tools and methods’. Google Patents.

Senthil Maharaj, P.S.R. and Vasanthanathan, A. (2023) ‘An insight into the mechanical and tribological behavior of carbon-flax reinforced bioepoxy hybrid composite bone plates for orthopedic applications’, *Polymers and Polymer Composites*, 31, p. 09673911231178444. Available at: https://doi.org/10.1177/09673911231178444.

Sharma, A.K., Bhandari, R., Aherwar, A. and Rimašauskienė, R. (2020) ‘Matrix materials used in composites: A comprehensive study’, *Materials Today: Proceedings*, 21, pp. 1559–1562. Available at: https://doi.org/10.1016/j.matpr.2019.11.086.

Solomon, L., Warwick, D. and Nayagam, S., (2010) *Apley’s system of orthopaedics and fractures*. CRC press.

Somersalo, A., Paloneva, J., Kautiainen, H., Lönnroos, E., Heinänen, M. and Kiviranta, I. (2015) ‘Increased mortality after upper extremity fracture requiring inpatient care’, ActaOrthopaedica,86(5),pp.553557.Availableat:https://doi.org/10.3109/17453674.2015.10 43833.

Somersalo, A., Paloneva, J., Kautiainen, H., LÖNnroos, E., HEinÄNen, M. and Kiviranta, I. (2016) ‘Increased mortality after lower extremity fractures in patients< 65 years of age. *Acta orthopaedica*, *87*(6), pp.622-625.

Tekeste, K. (2021) 'Climate-Smart Agricultural (CSA) practices and its implications to food security in Siyadebrina Wayu District, Ethiopia', *African Journal of Agricultural Research*, 17(1), pp. 92–103. Available at: https://doi.org/10.5897/ajar2020.15100.

Tewelde, S.A., Lemu, H.G. and Dawit, J.B. (2022) 'Mechanical property characterization of water hyacinth and glass fiber reinforced hybrid composite', *Materials Today: Proceedings*, 62(P12), pp. 6445–6449. Available at: https://doi.org/10.1016/j.matpr.2022.04.115.

Ticoalu, A., Aravinthan, T. and Cardona, F. (2010) 'A review of current development in natural fiber composites for structural and infrastructure applications. In *Proceedings of the southern region engineering conference (SREC 2010)* (pp. 113-117). Engineers Australia.

Turnbull, G., Clarke, J., Picard, F., Riches, P., Jia, L., Han, F., Li, B. and Shu, W.(2018) '3D bioactive composite scaffolds for bone tissue engineering', *Bioactive materials*, 3(3), pp. 278–314.

Unal, M., Creecy, A. and Nyman, J.S. (2018) 'The Role of Matrix Composition in the Mechanical Behavior of Bone', *Current Osteoporosis Reports*, 16(3), pp. 205–215. Available at: https://doi.org/10.1007/s11914-018-0433-0.

Uskoković, V., Janković-Častvan, I. and Wu, V.M. (2019) 'Bone Mineral Crystallinity Governs the Orchestration of Ossification and Resorption during Bone Remodeling', *ACS Biomaterials Science and Engineering*, 5(7), pp. 3483–3498. Available at: https://doi.org/10.1021/acsbiomaterials.9b00255.

Valença, S.L., Griza, S., de Oliveira, V.G., Sussuchi, E.M. and de Cunha, F.G.C., (2015) 'Evaluation of the mechanical behavior of epoxy composite reinforced with Kevlar plain fabric and glass/Kevlar hybrid fabric', *Composites Part B: Engineering*, 70, pp. 1–8. Available at: https://doi.org/10.1016/j.compositesb.2014.09.040.

Venkateshwaran, N., ElayaPerumal, A., Alavudeen, A. and Thiruchitrambalam, M. (2011) 'Mechanical and water absorption behaviour of banana/sisal reinforced hybrid composites', *MaterialsandDesign*,32(7),pp.40174021.Availableat:https://doi.org/10.1016/j.matdes.2011.03.002.

Wable, V., Biswas, P.K., Moheimani, R., Aliahmad, N., Omole, P., Siegel, A.P., Agarwal, M. and Dalir, H. (2021) Engineering the electrospinning of MWCNTs/epoxy nanofiber scaffolds to enhance physical and mechanical properties of CFRPs. *Composites Science and Technology*,*213*,pp.02663538.Availableat:https://doi.org/10.1016/j.compscitech.2021.10894

1.

Wang, M. and Zhao, Q. (2019) 'Biomedical composites', *Encyclopedia of Biomedical Engineering*, 1–3, pp. 34–52. Available at: https://doi.org/10.1016/B978-0-12-801238-3.99868-4.

Wang, G., Chen, C., Li, J., Zhou, B., Xie, M., Hu, S., Kawamura, K. and Chen, Y., (2011) 'Molecular composition and size distribution of sugars, sugar-alcohols and carboxylic acids in airborne particles during a severe urban haze event caused by wheat straw burning. *Atmospheric Environment*, *45*(15), pp.2473-2479.

World Health Organization and Global Buruli Ulcer Initiative, (2004) '*Report of the 7th WHO Advisory Group Meeting on Buruli Ulcer: 8-11 March 2004, WHO headquarters, Geneva, Switzerland* (No. WHO/CDS/CPE/GBUI/2004.9). World Health Organization.

Wiesel, S.W. and Delahay, J.N. (2007) *Essentials of orthopedic surgery: Third edition*, *EssentialsofOrthopedicSurgery:ThirdEdition*.Springer.Availableat:https://doi.org/10.1007/978-0-387-38328-6.

Workiye, A. and Woldsenbet, E. (2019) 'Tensile Strength of Maize Stalk and Husk single Cellulose Fiber', *International Journal of Engineering and Technology*, 11(4), pp. 1057–1065. Available at: https://doi.org/10.21817/ijet/2019/v11i4/191104013.

Workiye, A. and Woldsenbet, E. (2020) 'Development of Maize Stalk Cellulose Fiber Reinforced Calcined Kaolinite Clay Geopolymer Composite', *Proceedings of Engineering and Technology Innovation*, 16, pp. 30–38. Available at: https://doi.org/10.46604/peti.2020.4599.

Yami, M., Meyer, F. and Hassan, R. (2020) 'The impact of production shocks on maize markets in Ethiopia: implications for regional trade and food security',*Agricultural and Food Economics*, 8(1), p. 8. Available at: https://doi.org/10.1186/s40100-020-0153-5.

Zakiuddin, K.S., Khan, I.A. and Hinge, R.A. (2016) 'a Review Paper on Biomechanical Analysis of Human Femur', *International Journal of Innovative Research in Science and Engineering*, 2(03), pp. 356–363.

Zhang, Y.K., Wei, H.W., Lin, K.P., Chen, W.C., Tsai, C.L. and Lin, K.J. (2016) 'Biomechanical effect of the configuration of screw hole style on locking plate fixation in proximal humerus fracture with a simulated gap: A finite element analysis. *Injury*, *47*(6), pp.1191-1195. Available at: https://doi.org/10.1016/j.injury.2016.02.028.

Appendices

Appendix A

Sample test report

Test report

Kind of test:	Tensile test DIN 50106
Material of specimen:	composite
Dimensions of specimen:	Tension specimen B25 x 250 DIN 50125
Temperature:	20°C
Upper/lower tensile yield strength ReU/ ReL:	______________
Yield stress Rp:	______________
Tensile Strength Rm:	176.53N/mm²
Elongation at fracture A:	______________
Contraction at fracture Z:	______________
Date:	26.08.2023
Name of tester:	______________
Signature:	______________

Figure A.1 Tensile test report

Test report

Kind of test:	Compression test DIN 50106
Material of specimen:	composite
Dimensions of specimen:	press specimen123 x 250 DIN 50106
Kind of differential length-measurement:	between the compression plates
Lubrication of compression plates:	yes
Temperature:	20°C
Compression strength:	264 N/mm^2
Values for changing of shape:	______________________
Date:	26.08.2023
Name of tester:	______________________
Signature:	______________________

Figure A.2 Compression test report

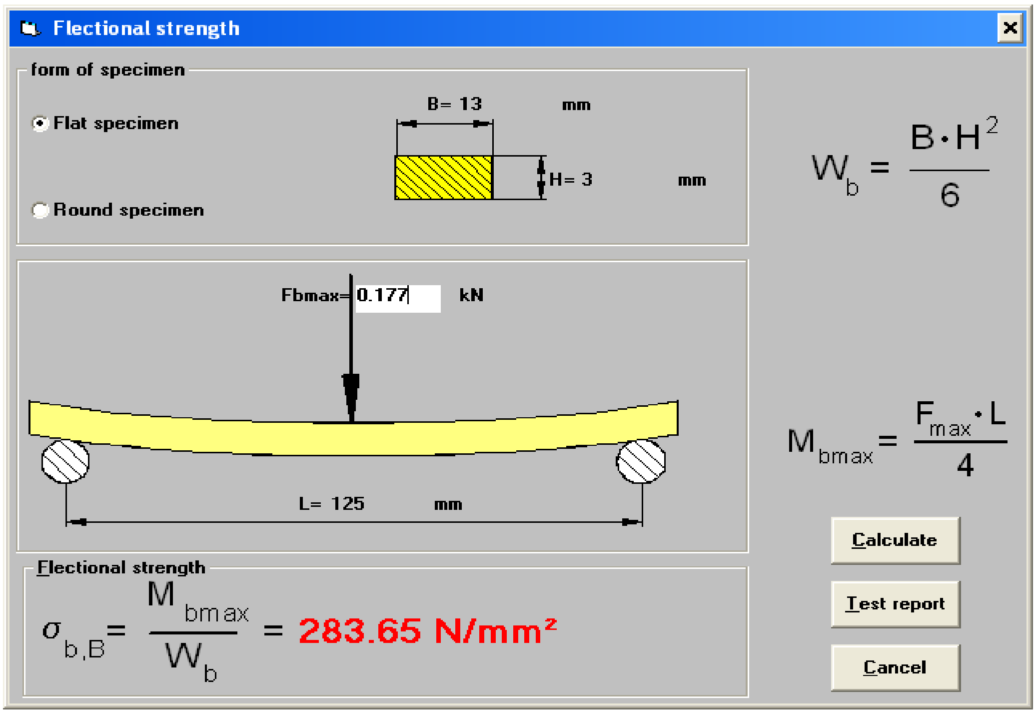


Figure A.3 Flexural test output

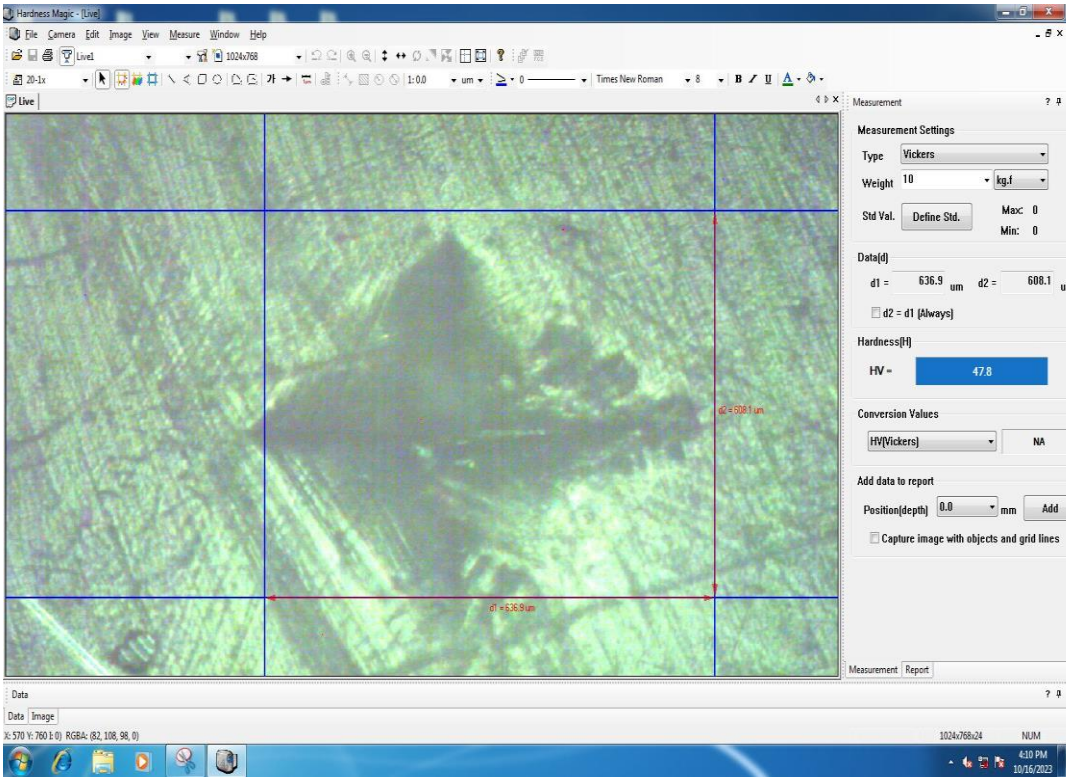


Figure A.4 Micro-hardness test result

Appendix B

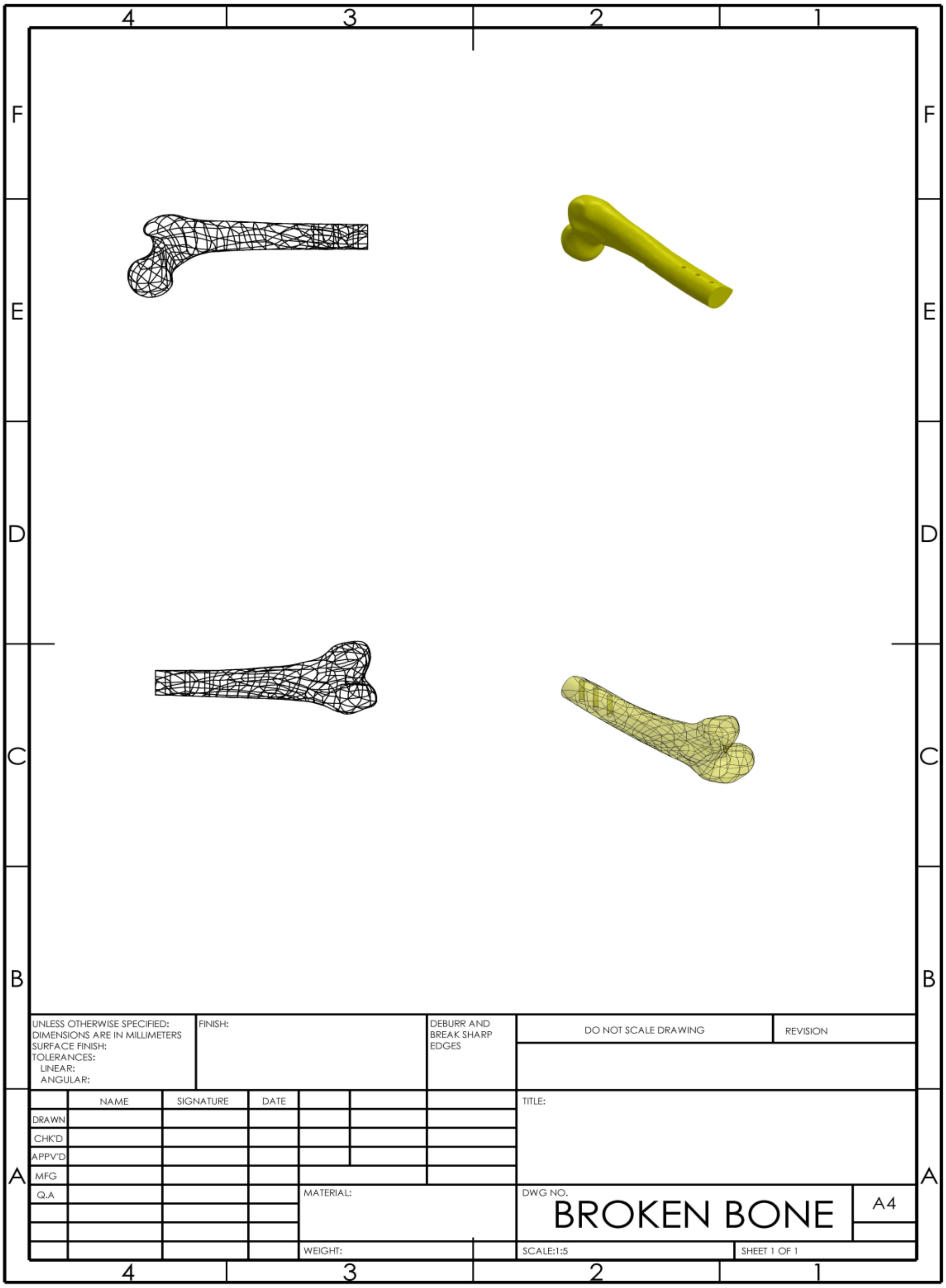


Figure B.1 Femur bone fracture

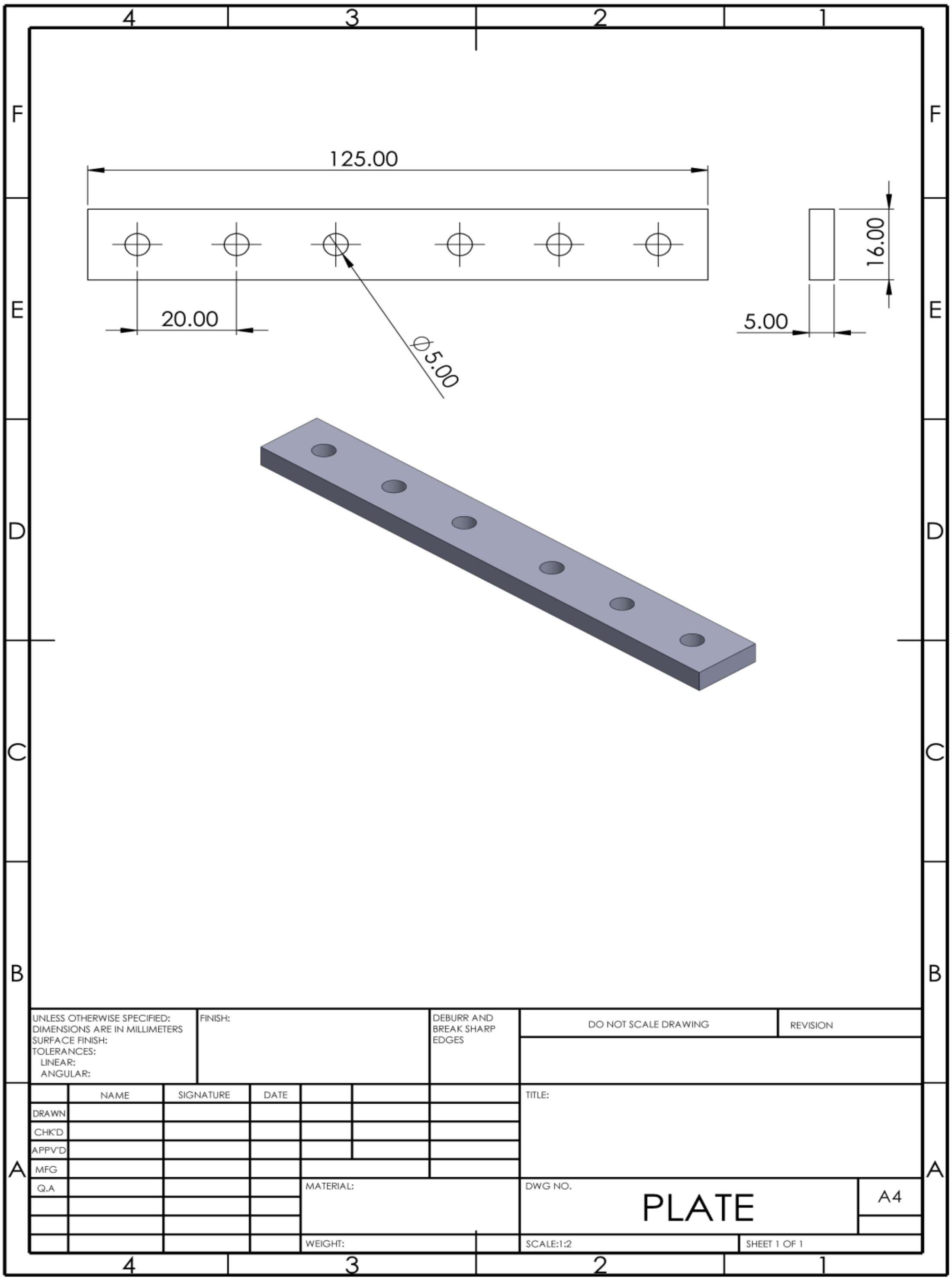


Figure B.2 Bone fracture plate

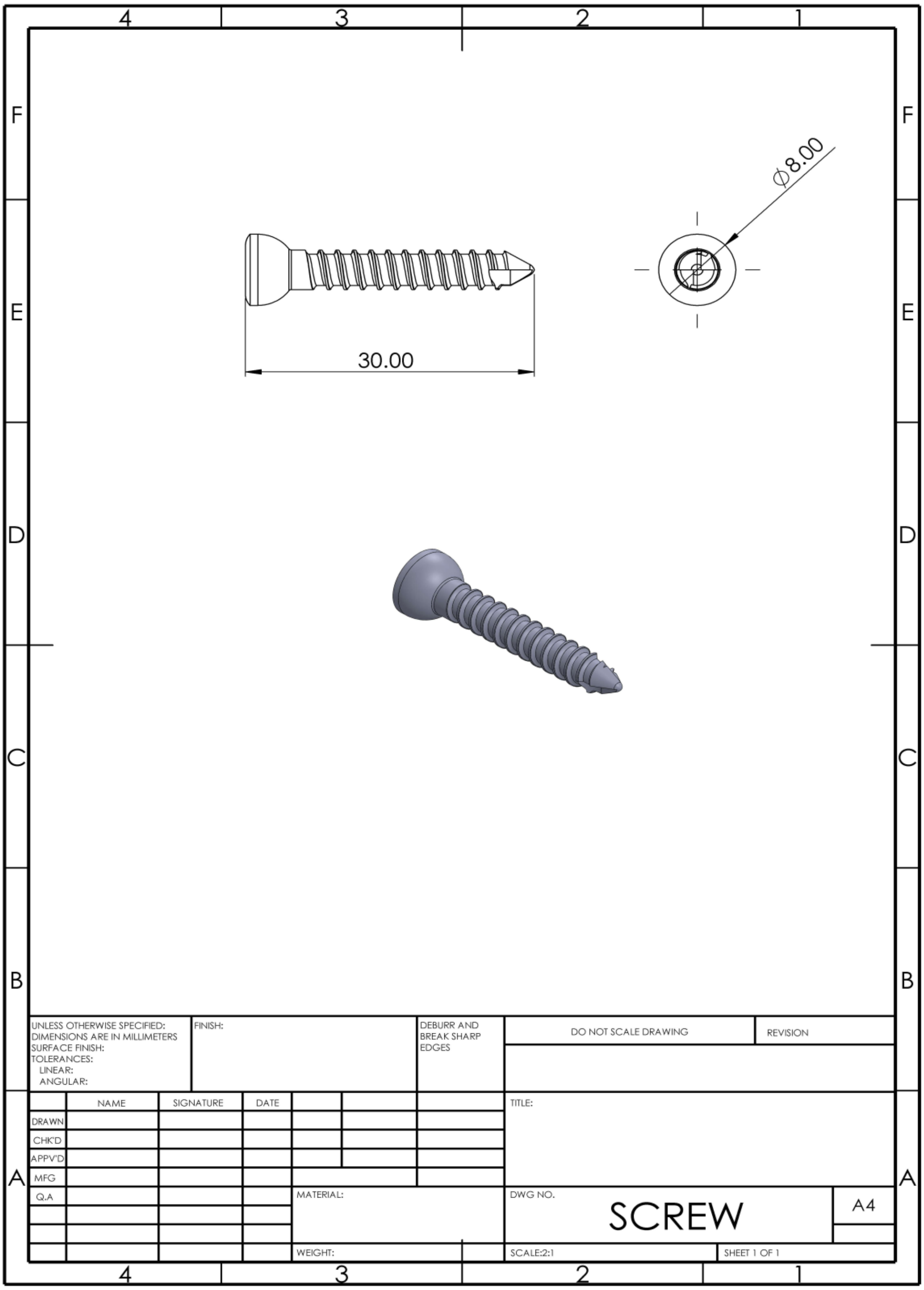


Figure B.3 Screw

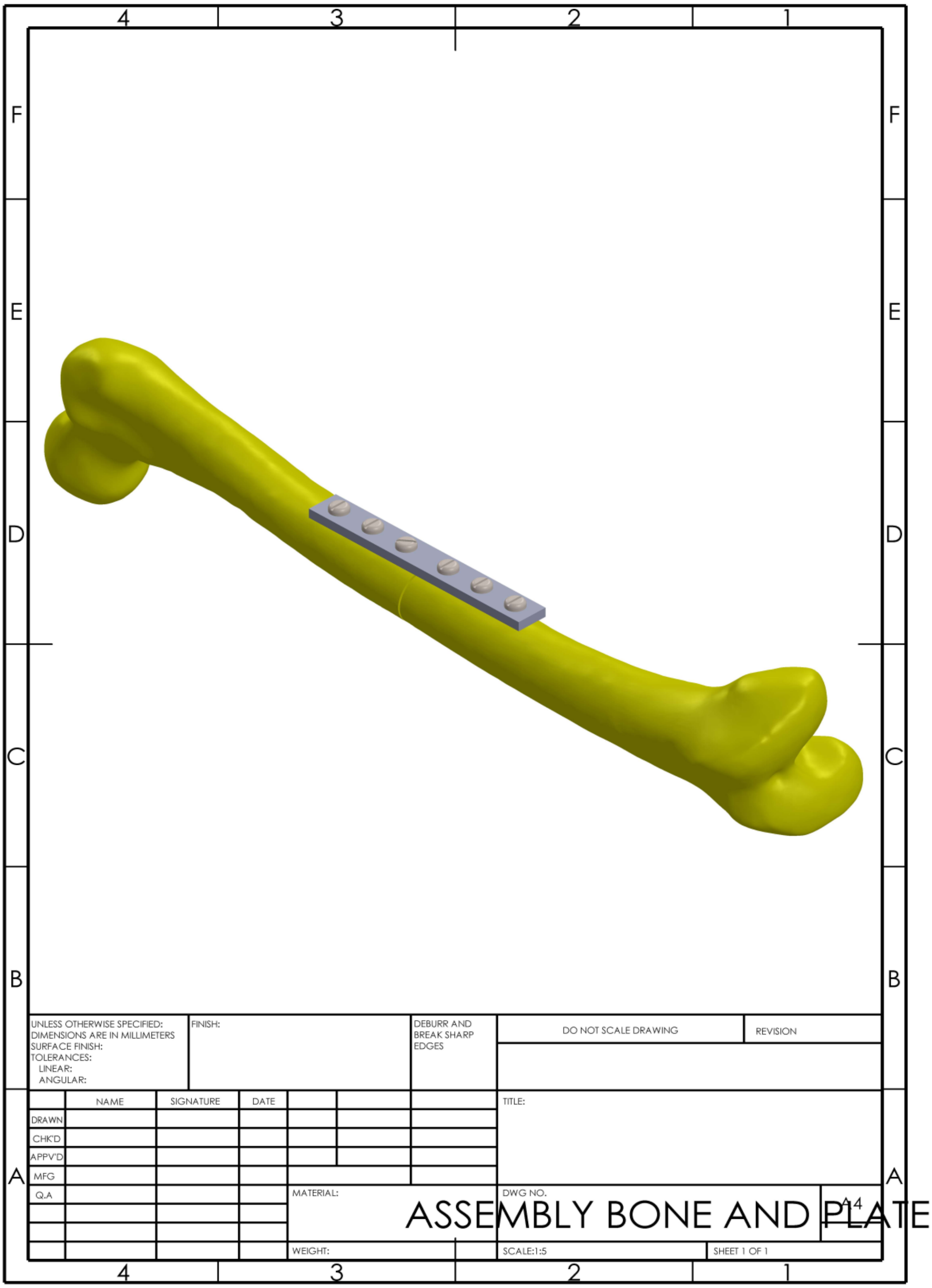


Figure B.4 Assembly of femur bone with plate

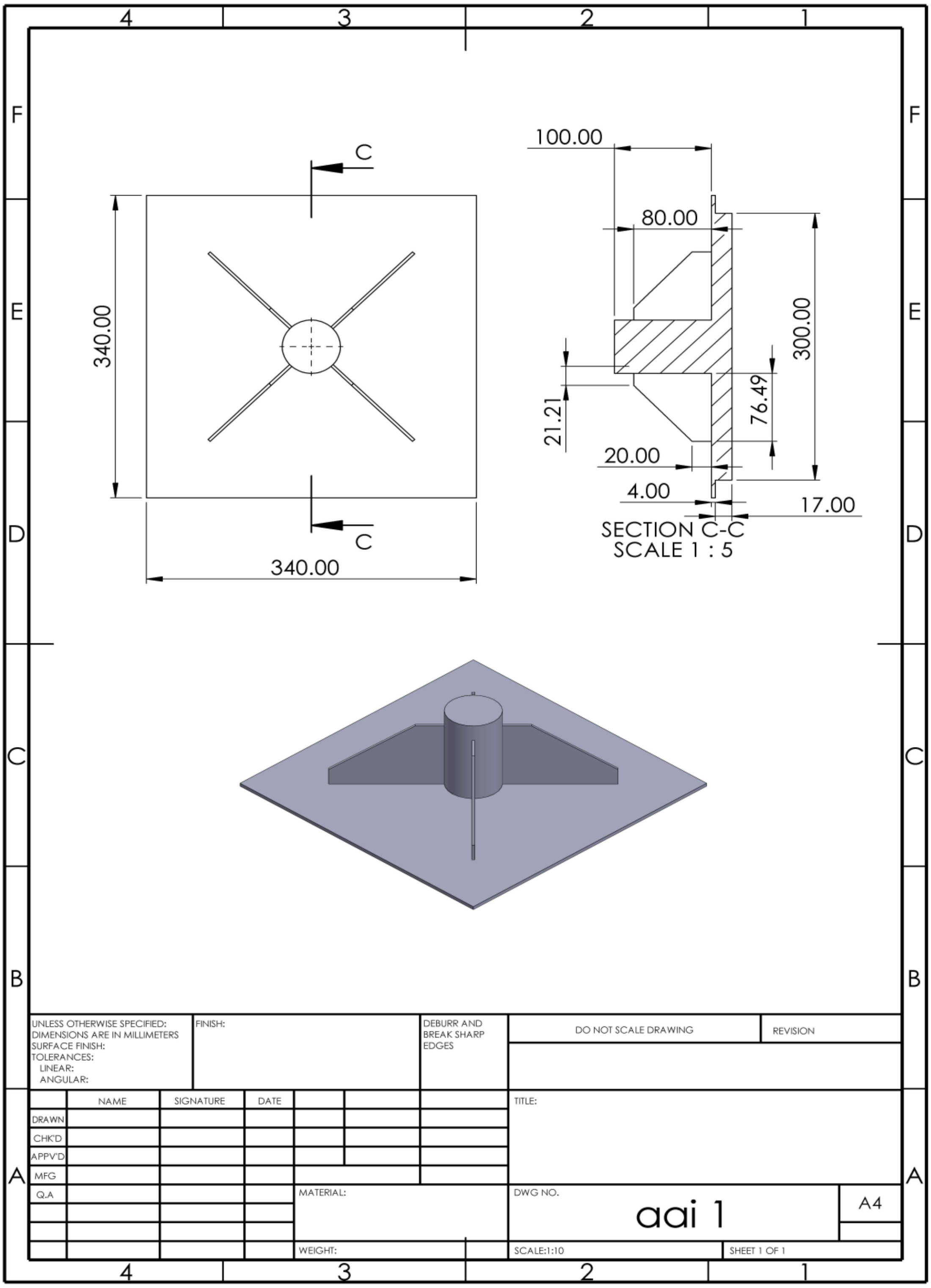


Figure B.5 The upper part of mold

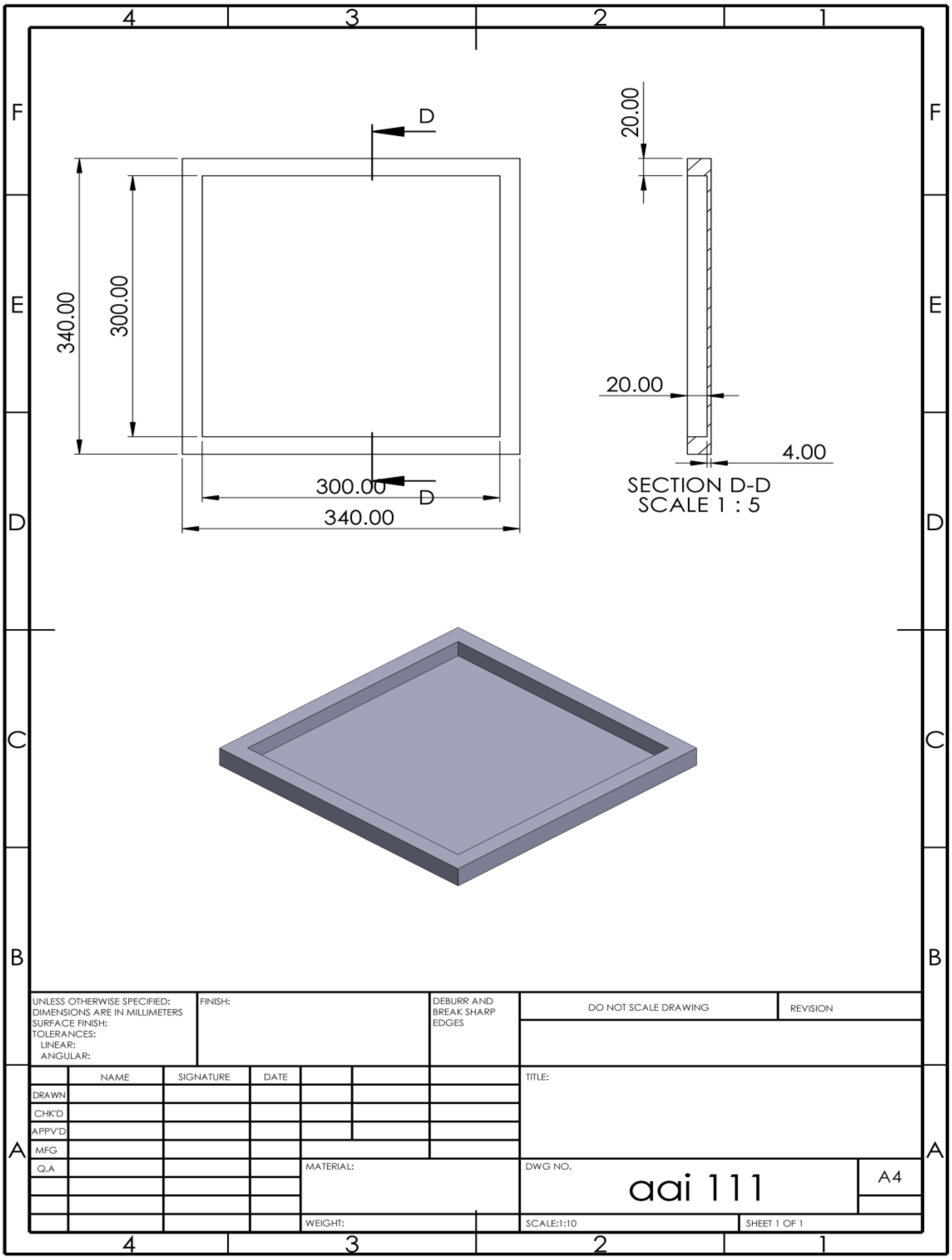


Figure B.6 The base part of mold

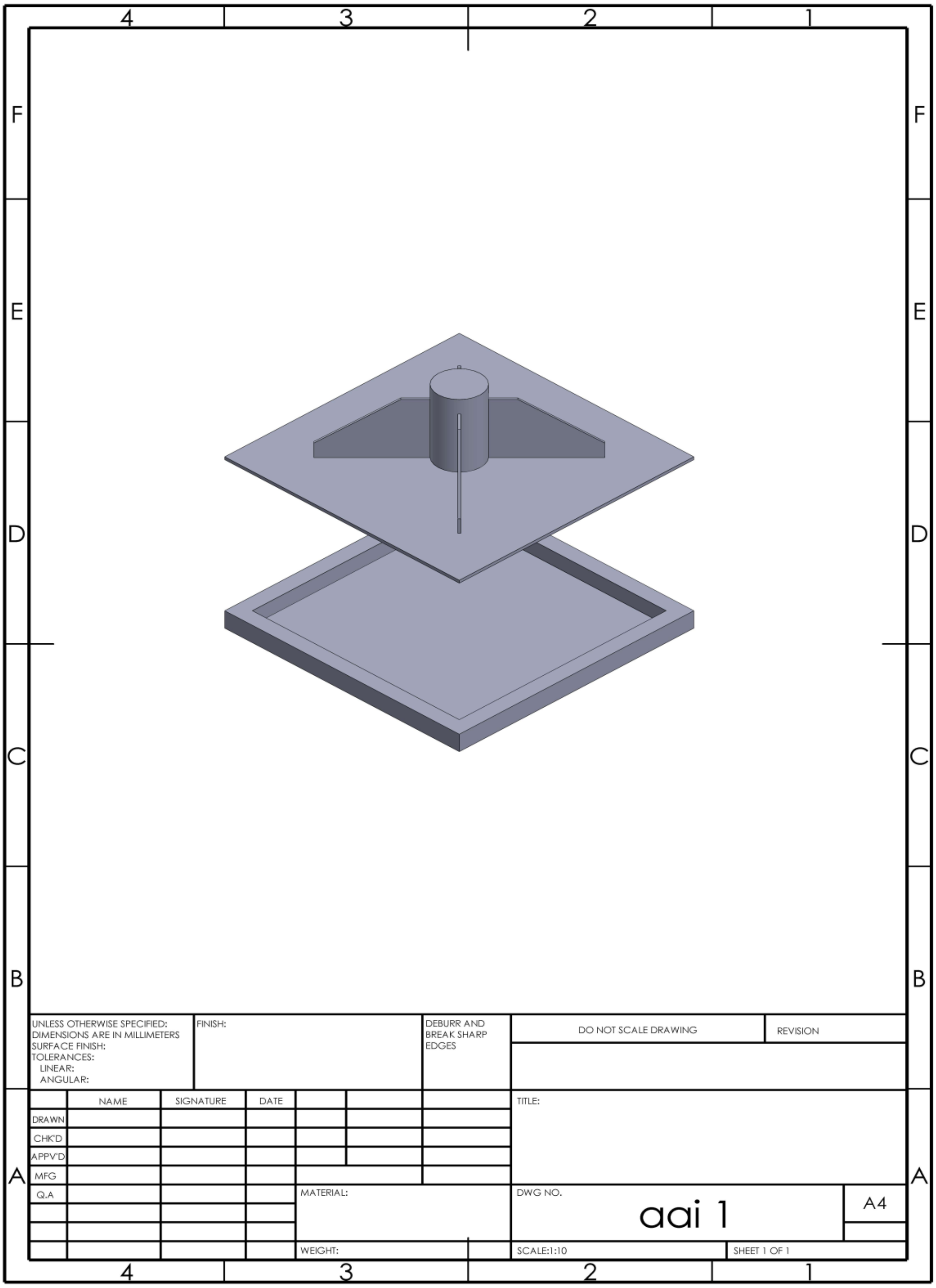


Figure B.7 Assembly of mold