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Original Article

Sisal Reinforced Unsaturated Polyester Cast for Treatment of Bone Fractures

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***Abstract** - Bones make up the human skeleton. Human skeletons have various functions, some of which include protecting the body's important organs such as the heart, kidneys and liver, offering structural support to the body, storing mineral ions such as calcium and magnesium and producing blood cells, among many other functions. Bone fractures occur when the force exerted on the bone is stronger than the bone itself. The most common method of treating bone fractures is casting. Casts are molded around the fractured area to offer stiffness and proper alignment of the broken bone during the healing period. Two types of casts commonly used today are Plaster of Paris (POP) cast and fiberglass cast. POP casts used have been characterized by heaviness, non-biodegradability and hygroscopic nature, which results in easy cracking when they are exposed to water. Fiberglass casts, on the other hand, have been associated with a relatively higher cost and non-biodegradability. The objective of the research was to design and manufacture an alternative cast that minimizes or eliminates the drawbacks of the two types of casts commonly used. The aim is to manufacture a lighter, less costly and eco-friendly cast using materials that are readily available. Sisal fibres together with unsaturated polyester resin were selected as the best materials for the design. Sisal reinforced UP samples were manufactured using a simple lay-up technique followed by press molding during the curing stage. An experimental design varying the sisal and resin mass fractions in the samples was created. Three mechanical properties, namely, tensile, flexural, and compressive strength, were tested using a universal testing machine. A sisal reinforced unsaturated polyester cast made with an optimum mass fraction of 10% sisal and 90% UP resin gave the best strength properties. This cast had better tensile, flexural and compressive strength than a plaster cast. It also proved to be lighter than a plaster cast from the analysis of their densities. In comparison to fiberglass cast, sisal reinforced UP cast showed lower tensile strength and flexural strength than fiberglass cast. It also proved to be denser than fiberglass cast. These results show that fiberglass cast remains superior among the three casts in terms of the physical and mechanical properties under consideration in this study. However, this new cast proved to have the best compressive strength, a key property in this application, as compared to the two casts.*

***Keywords** - Bone fractures, Sisal reinforced fibers, Tensile strength, Compression strength, Flexural strength.*

1. Introduction

Bone is a hard, specialized tissue that forms part of the skeletal framework in vertebrates. In humans, the skeleton initially consists of about 270 bones at birth, but this number reduces to roughly 206 in adulthood due to the fusion of certain bones. Through its bones, the human skeleton performs six primary functions. These include providing structural support for the body, enabling movement, safeguarding vital organs, producing blood cells within the bone marrow, and serving as a reservoir for mineral ions like calcium [1].

There are four main types of bones in the human body that make up the human skeleton. This classification is mainly based on the shape and size of the bone [2]. These are classified as long bones, short bones, flat bones, and irregular bones.

A bone fracture is essentially a disruption in the continuity of a bone, occurring when the force applied to it exceeds its structural strength. Bone fractures are mostly caused by trauma, which is a result of a direct hit or kick to the body. This may be in the form of a fall, a car accident, etc. Some medical conditions also tend to weaken the bones, making them more prone to cracking. Repetitive motions that strain and tire the muscles, hence putting excess pressure on the bones, may also easily lead to fractures. Figure 1 shows a fractured bone.

Therefore, for a fracture to heal, the bones must be held in the correct position and protected for a given period. Bone healing is a natural process that involves restoring the fractured bone to its natural state. The healing process takes about 4-8 weeks, after which the patient can recover fully in strength, movement and sensitivity. The period it takes for a bone to heal depends on factors such as the severity of the fracture, age of the patient and the method used to manage the fracture, among others.

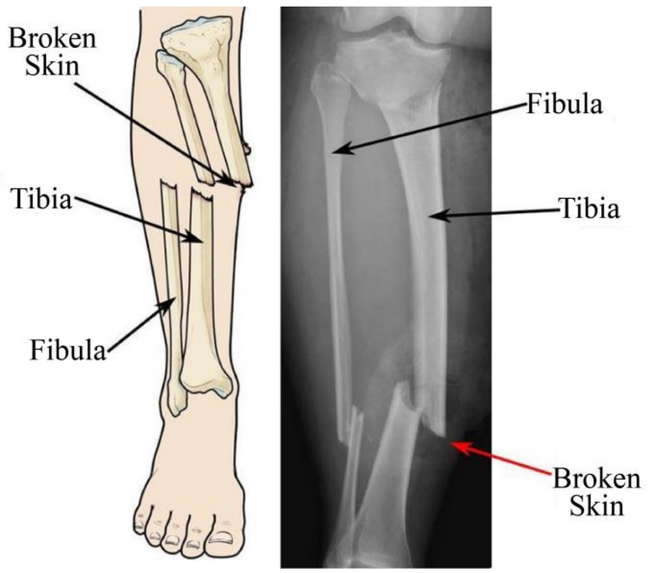

Fig. 1 Example for a small figure: Illustration of a fractured bone [1]

Methods of treatment of fractures can be broadly classified into two. These are surgical and conservative methods. The surgical method involves performing a surgical operation that directly holds the fractured bone together. This is done by surgically inserting metal rods or plates with locking and stabilizing screws to hold the bone pieces together, thus limiting movement of the bone during the healing process. However, this method is only applied if conservative treatment has failed [2].

Conservative methods involve non-surgical procedures performed to immobilize the bone, preserve alignment of the bone fractures and aid in the union of the two bone pieces. Common methods include the use of splints and casting methods [3]. Splints, also known as half casts, are orthopedic tools designed to immobilize an injured limb, helping maintain bone alignment until complete healing occurs. Splints provide less support compared to casts but can be tightened or loosened easily depending on the swelling in the affected limb. The most common conservative method of managing fractures is the use of casts. Casts are molded around the fractured area to immobilize the bone, thus aiding in healing. The cast offers support and stiffness to the affected area. The two types of casts commonly used today are gypsum plaster casts, such as Plaster of Paris (POP) and fiberglass (synthetic) casts.

Despite its frequent use, Plaster of Paris (POP) casts have some limitations. Due to their heaviness, POP casts are uncomfortable and tend to cause pressure sores on the affected area during the healing period (Parmar et al., 2014). This type of cast absorbs moisture easily; this means that exposure to water results in easy cracking. These casts also cause numbness in the affected area, which is because of their heaviness and tight fit [4]. Lastly, POP is not an eco-friendly material. It takes a long time to decompose and is therefore harmful to the environment if disposed of inappropriately.

Moreover, fiberglass cast have their own limitations. This type of cast, made of glass fibers and a polymer-based resin, is non-biodegradable and therefore not an eco-friendly material. Their manufacturing process is quite expensive since glass fibers are difficult to machine. Lastly, they do not allow easy molding during applications, as in the case with plaster casts [3].

Limitations of the two types of casts explained in the preceding section validate the need for the development of casting material to be used for managing bone fractures, such as a bio-composite consisting of a cellulose-based fiber and a suitable polymeric resin. The aim is to make a cast that is lighter, more comfortable, less costly and eco-friendly, using materials that are readily available. According to Alternate Materials for Glass Fibers [5], cellulosic fibers have certain advantages over glass fibers. These include good strength properties at minimum density, low cost, readily available, biodegradable, and recyclable. Therefore, the purpose of this research was to develop an alternative casting material that can be used to manage bone fractures from sisal reinforced fibers.

Fibres have been used in medical applications, and some studies have been presented. [6] investigated the development of an orthopedic cast using sisal fibres reinforced with unsaturated polyester resin, targeting a lightweight, cost-effective, and eco-friendly alternative to conventional casts. The composite's strength, moldability, and biodegradability demonstrated strong potential for fracture treatment. Similarly, [7] explored natural fibres, particularly sisal, for medical composites, emphasizing improved mechanical performance, reduced weight, and enhanced biodegradability as sustainable alternatives to non-biodegradable casts. [8] examined the versatility of unsaturated polyester resin in medical applications, highlighting its integration with natural fibres to create lightweight, durable, and chemically resistant orthopedic casts. [9] also evaluated unsaturated polyester resin for medical composite development, focusing on its favorable mechanical properties, moldability, and environmental resistance. When combined with natural fibres, it proved suitable for orthopedic applications, offering a biodegradable and high-performance option for bone fracture management. Collectively, these studies underscore the potential of sisal fibre-reinforced unsaturated polyester composites as sustainable, high-strength, and patient-friendly alternatives in orthopedic cast fabrication.

2. State of the Art

2.1. Gypsum Plaster Casts

Plaster of Paris (POP) casts are widely used in the management of bone fractures in hospitals, among other medical applications. The casting material consists of a cotton bandage with a hard coating or covering on its top and bottom surfaces. This hard coating or covering is the POP material. This type of plaster is prepared by heating gypsum (Calcium sulphate di-hydrate) in a kiln at high temperatures, where it is partially dehydrated (75% of water removed) [10].

Gypsum is first dried and ground into a fine powder. The fine powder is charged into large steel kettles heated by gas burners. The kettle's contents are heated, and as the water of crystallization is released, the escaping steam causes the gypsum to boil, resulting in calcination. [4]. The calcination reaction is shown in Equation (1).

Calcium Sulphate di-hydrate → Calcium Sulphate hemihydrate + water

$$CaSO_4.2H_2O \rightarrow CaSO_4.\tfrac{1}{2}H_2O + 1\tfrac{1}{2}H_2O \qquad (1)$$

The POP powder is sold to manufacturers of medical plaster bandages. Different methods of manufacturing plaster bandages have been employed in their production. In one technique, the process begins with the preparation of the plaster weight to be applied to the textile material (gauze sheet) and drying the powder to a dry mass. The next step involves preparing a suspension for the gypsum binder. Here, the dry powder is mixed with chemical solvents that are unreactive with the powder. A mixture of methanol and methylene chloride is used as a solvent in this case. The resulting suspension is known as gypsum slurry. Methyl cellulose, a special chemical, is introduced into this suspension to help stick the plaster on the textile material. The gauze sheet is then pulled through a bath of the gypsum suspension; it picks up the suspension and is then passed to the drying unit. The solvents in the suspension are vaporized at a temperature of 60-90 ^{0}C in the drying unit. The drying phase takes about 5-15 minutes. After drying, the finished bandages are cut into the required size, wound into rolls and packaged in polyethylene storage papers. This technique is considered environmentally unsafe due to the emission of hazardous chemical fumes during drying in the production process. It is also costly since several chemicals are used in the successful preparation of the gypsum suspension [11]

Another technique used in the manufacture of these bandages involves the use of water heated to a temperature of 90-100 ^{0}C, used as the liquid component in the preparation of the gypsum suspension. The suspension is then maintained at a level of at least 80 ^{0}C. It is scientifically proven that in the temperature range of 80-100 ^{0}C the gypsum binder does not hydrate; it remains in the form of calcium sulphate hemihydrate. The gauze is then impregnated with the suspension, and heat treatment is carried out at a temperature of 100-300 0C until the gauze and layer of gypsum suspension applied to it are completely dried. Adhesives used in this technique include starch and casein, among others. This technique eliminates the use of hazardous chemicals as compared to the technique discussed previously. It is therefore considered environmentally safer than its alternative.

Plaster bandages have quite a few desirable properties that have seen them remain dominant in most hospitals to date. These include lower cost, easy availability, excellent mold and very few instances of allergic reactions. The average density of plaster casts ranges from 1.0 g/cm^3 to 1.15 g/cm^3. Their stiffness ranges from 13.61 x 10^3 N/m to 22.44 x 10^3 N/m. POP bandages tested before have an average compressive strength of 2.407 MPa, tensile strength of 4 MPa and flexural strength of about 15 MPa [12].

Plaster bandages, however, have certain limitations during use. They have a low strength-to-weight ratio and, as a result, they are heavy and uncomfortable on the body part. Due to their heaviness, this type of cast causes pressure sores on the affected area. The heaviness and tight fit of these casts also cause numbness in the affected area. During setting, water that evaporates from the plaster cast leaves pores in the molded structure. These pores can even take up to 50% density of the cast. The pores make the cast highly susceptible to cracking when exposed to water; this means that patients using POP casts must be extra cautious to prevent damage to the cast by water. Once the healing process is done, this material must be removed. POP takes a long time to decompose and is therefore not an eco-friendly material if not disposed of appropriately.

2.2. Fiberglass

Fiberglass casts, also known as synthetic casts, were mainly developed to minimize some of the limitations associated with POP casts. The use of composite materials technology in cast manufacturing provides significant benefits, including an improved strength-to-weight ratio and greater design flexibility. [13]. There has been a notable increase in the use of resin-impregnated fabric bandages, with knitted fiberglass fabric coated in polyurethane resin being the most common. The production of a strong yet flexible casting fabric from continuous filament fiberglass largely depends on choosing the right glass fiber diameter and the specific knitting pattern used. [14]. In manufacturing, knitted fiberglass rolls are coated with a urethane pre-polymer resin to create tape rolls. These rolls are activated by immersing them in water at room temperature, then removed and gently squeezed to drain excess water. They are subsequently wrapped, layer by layer, around the injured area to form the mold. [15]. This forms layers of circular cast around the part.

Fiberglass is composed of countless ultra-fine glass fibers, each with a diameter typically between 3.8 and 20 mm

[15]. Fibers come in various shapes and forms, including continuous fibers, roving, staple fibers, and chopped strands. Among these, continuous fibers and chopped strands are most frequently used with resin. Silica-based glass fibers are the predominant type in manufacturing, though different applications require specific glass fiber types. Table 1 presents typical properties and descriptions of various glass fiber types. [16].

Glass fibers serve as reinforcement in plastics to enhance tensile strength, flexural modulus, creep resistance, impact resistance, dimensional stability, and resistance to heat and chemicals. However, they also present drawbacks, such as increased wear on machines and tools from abrasion during machining, warpage, reduced weld and knit line strength, and lower surface quality, among other issues..

Table 1. Classes of glass fibers and their properties [16]

Glass Fibre Type	Description	Density (g/cm^3)	Tensile Strength (GPa)	Young's Modulus (GPa)
E-glass	E for good electrical insulation	2.54	1.7 to 3.5	69 to 72
S-glass	S for high silica; able to with stand high temperatures	2.48	2.0 to 4.5	85
C-glass	C for corrosion resistance	2.48	1.7 to 2.8	70
Cemfil	Alkali resistant glass fibre	2.70	_	80

2.3. Comparison between Gypsum Plaster and Fiberglass Casts

Fiberglass casts have several properties that make them a better choice than POP casts. These include a higher strength-to-weight ratio (this means they are lighter), more radiolucent, shorter curing time, stronger construct, and improved breathability. However, this type of cast has its disadvantages. Their manufacturing process is quite expensive since glass fibers are difficult to machine. This drawback explains why they are quite uncommon in hospitals today, despite having better strength properties than plaster casts. They do not allow easy molding during applications, as in the case of plaster casts. Lastly, fiberglass casts are made from glass fibers and polymeric resin, which are non-biodegradable and therefore not eco-friendly upon disposal. Table 2 gives a summarized comparison of the major properties of POP casts and fiberglass casts [3].

Table 2. Comparison of plaster versus fiberglass cast [3]

	Plaster casts	Fiberglass casts
Strength	Average	Excellent
Weight	Heavier	Lighter
Cost	Lower	Higher
Water resistance	Poor	Excellent
Curing period	48 to 72 hrs	Less than 30 mins
Radiolucency	Poor	Good

2.4. Polyurethane Resin

Polyurethane (PU) is a type of polymer consisting of urethane linkages. It is widely utilized in various industrial applications, such as adhesives, insulation materials, coatings, and elastomers. [17]. PU is synthesized from a diverse range of starting monomers, making it a class of polymers rather than a single compound. This chemical diversity enables the production of polyurethanes with widely varying properties, supporting an equally broad range of applications. They may be thermosetting or thermoplastic, as well as rigid and hard or flexible and soft foams. PU is composed of two main components: an isocyanate and a diol, which can be either a polyether end-capped diol or a polyester end-capped diol. The primary monomers used in polyurethane synthesis are di-isocyanates and polyols.

Common reagents used in PU production include polyols, isocyanates, catalysts, water, blowing agents, surfactants, pigments, and various additives. Polyurethane formation generally occurs in three stages. First, excess isocyanate reacts with a low molecular weight polyol to produce an isocyanate pre-polymer. In the second stage, these pre-polymers are combined with a diol during molding to form polyurethane. Amines act as catalysts, promoting both the gelling and blowing reactions. Foamed PU structures are created through chemical blowing using water, where excess isocyanate reacts with water to form unstable carbamic acid. This intermediate decomposes into an amine and carbon dioxide, the latter expanding the PU into foam [18].

The properties of polyurethanes are largely determined by the structure of their polymer backbone, allowing them to be engineered for high strength, rigidity, flexibility, or toughness. Most exhibit good resistance to oil, oxygen, and ozone. In the medical field, they are widely used as adhesives and coatings, with their strength, favorable properties, and moldability making them ideal for manufacturing orthopedic casts. However, PU has two main disadvantages: susceptibility to microbial degradation and a tendency to discolor (yellow) upon exposure to UV light.

2.5. Research Gaps

From this review, it is evident that plaster casts remain dominant in most hospitals despite their disadvantages. It is also clear that synthetic casts have better strength properties at minimum density, which is a major concern in the design of casts. The high cost of synthetic casts is what makes them uncommon in this application.

However, very little has been revealed in past studies about the use of bio-fibers coated with polymeric resins in the manufacturing of casts [19]. Glass fibers used in manufacturing synthetic casts are associated with relatively high density, difficulties in the machining process and non-biodegradability as seen in the discussion. Scientific research shows that non-wood cellulosic fibers could be a better alternative for applications in which glass fibers are used. Common examples of these fibers include banana, sisal [20], jute, cotton (Sathishkumar et al., 2016), flax, among others. Composites made from these fibers as the reinforcement material have low density, hence a higher specific strength, good thermal and dimensional stability, lower costs, low coefficient of friction and are biodegradable [21].

2.6. Survey of Common Cellulosic Fibers

A preliminary survey was conducted on common cellulosic fibers from banana, cotton and sisal cotton to determine their suitability for an alternative material for casting, based on their cost and availability. The findings are presented in Table 3.

From the findings recorded in Table 3, it can be observed that banana fibers have a density ranging from 0.75 g/cm^3 to 0.95 g/cm^3, the lowest among the three. The average tensile strength of this fiber is 1090 N/mm^2, the highest among the three and a Young's modulus of 3.48 GPa, the lowest among the three fibers. This fiber has the lowest Young's modulus value and the lowest stiffness, which is a desirable property for this design. This ruled out the use of banana fiber in this application. Cotton fibers have the highest average density of 1.54 g/cm^3. Its tensile strength ranges from 287 MPa to 840 MPa. The average Young's modulus of the fiber ranges from 5 GPa to 19 GPa, the highest among the three fibers. For this application, the density of this type of fiber renders it inapplicable since the design aims at using reinforcement fibers with minimum density.

Table 3. Summary of the properties of the cellulosic fibers considered for analysis

Properties / Fibers	Banana fibers	Cotton fibers	Sisal fibers
Density (g/cm^3)	0.75- 0.95	1.54	1.45
Tensile strength	1090 N/mm^2	287 to 840N/mm^2	529 to 914 N/mm^2
Young's modulus	3.48 GPa	5-19 GPa	3.8 GPa

Sisal fibers have an average density of 1.45 g/cm^3 [22], the second lowest after banana fibers. The fiber also has the second-highest tensile strength, ranging from 519 N/mm^2 to 914 N/mm^2, after banana fiber. The average Young's modulus of the fiber is 3.8 GPa, slightly above that of banana fiber. This means that the fiber is stiffer than banana fiber. From the analysis above, it is evident that the most appropriate cellulose fiber for this application is sisal. Sisal fiber provided the optimal balance of physical and mechanical properties for the design. When used in mat form, its bi-directional fiber orientation enhances the strength and stiffness of the resulting structure. Hence, further analyses were done using sisal reinforced fibre. The research gap lies in the limited exploration of using bio-fibers coated with polymeric resins, such as sisal, in cast manufacturing as a low-cost, lightweight, and biodegradable alternative to high-density, non-biodegradable glass fiber-based synthetic casts. Hence, the purpose of this study is to address these issues.

2.7. Rationale of the Study

Plaster of Paris casts, though affordable and easily moldable, suffer from drawbacks such as heaviness, susceptibility to water damage, and non-biodegradability. Fiberglass casts address many of these limitations by offering a superior strength-to-weight ratio, improved durability, and faster curing times. However, their high production cost, non-biodegradable nature, and limited moldability restrict widespread adoption in hospitals. These contrasting strengths and weaknesses highlight the need for an alternative material that combines the affordability, availability, and workability of POP with the superior mechanical performance of fiberglass, while also being lightweight, eco-friendly, and cost-effective-thus providing the rationale for developing a sisal-reinforced polymeric cast.

3. Materials and Methods

Sisal cellulosic fibres were selected for analysis in this research. These fibres were chosen mainly due to their lower cost and availability within the study area.

3.1. Extraction of Cellulose Fibre

The sisal plant is a perennial crop that is widely cultivated in the tropical and subtropical zones of the globe. The fibers were extracted from the leaf of the plant in a process known as decortication. The leaves were repeatedly pulled through a wooden plank and blunt knives so that only fibers remained. Fibers free from impurities or damage were dried. Treating the fibers with a sodium hydroxide solution is essential to enhance the bond between the fibers and the resin in sisal-reinforced composites. Sisal fibers are antistatic, a property that is beneficial in certain applications since the fibers do not absorb dust and moisture [23].

3.2. Resin for Manufacturing

Unsaturated Polyester Resin (UPR) was used to impregnate the manufactured fabric casts. The choice of this resin was attributed to its availability and low cost [4]. The major properties of this resin include a specific gravity of 1.12, viscosity of 500 CPS at 250 °C, an acid value (mg KOH/g) of 17, a gel time of 17 minutes at room temperature and 59% solid content.

3.3. Experimental Design

This involved the fabrication of composite samples with varying fiber and resin mass fraction ratios, using a simple hand lay-up technique followed by press molding during curing. The fabricated samples had fiber mass fraction ratios ranging from 10% to 25% (Mbeche et al., 2020). Table 4 gives the experimental design for determining the sample with the optimum mechanical strength properties as cited by [24].

Table 4. Experimental design for varying fiber and resin mass fractions

Sisal fibre (%)	Unsaturated polyester resin (%)
10	90
15	85
20	80
25	75

3.4. Fabrication of Composites

A mild steel rectangular mold of dimensions 300 mm by 150 mm by 20 mm was fabricated. The mold's inner surface was cleaned using an acetone solution prior to the manufacturing of the cast. Next, wax or a release agent was applied to the mold's inner surface and left to dry. The mold's inner bottom surface was covered by a thin plastic film with a layer of wax to allow for easy demolding, as shown in Figure 2.

Fig. 2 Mild steel rectangular mould

Sisal mats measuring 280 mm by 130 mm were cut out and weighed using a digital weighing balance. Unsaturated polyester resin and MEKP hardener were mixed and stirred so that the mixture contained 98% unsaturated polyester resin and 2% of the hardener. A single ply of sisal mat was placed in the mold and impregnated with resin using a brush, as illustrated in Figure 3.

Fig. 3 Laying up of the sisal mat and impregnation with UP resin

This process was then followed by continuous rolling of a steel roller on a wetted mat to entrap all air bubbles and allow uniform flow of the resin. Thereafter, the composite was covered by the mold lid and allowed to be cured for 12 hours under compressive loads of 25 kg, after which they were demolded. The composite samples were left to condition at room temperature for 48 hours before testing.

3.5. Mechanical Properties

The samples prepared were cut into specimens of various standard sizes, which were subjected to three mechanical tests, namely, tensile, compression and flexural tests. These tests are briefly described hereafter.

3.5.1. Tensile Testing

Three tensile test specimens from each sample were prepared in accordance with ASTM D638, the standard method for tensile testing. The specimens had a length of 165 mm, a width of 13mm and a thickness of about 3 mm. The specimens were mounted on a universal testing machine and stretched at a crosshead speed of 2 mm/min until they fractured. A digital data acquisition system was used to continuously record the load and deflection for each tested specimen. The load (N) and elongation (mm) at fracture were given in this data sheet. The results computed from the load-elongation graphs were tabulated [25]. Tensile strength was determined by dividing the maximum load sustained before failure by the cross-sectional area under load, as derived from the load-elongation graphs. Three tests were carried out on each specimen, and their results were averaged to obtain the final results.

3.5.2. Compression Testing

Three compression test specimens from each sample were prepared in accordance with ASTM D695, the standard method for compression testing, and tested on the Universal Testing Machine (UTM). The specimens were loaded under uniaxial compression loading at a speed of 5 mm/min until the fracture point. The ultimate compressive strength was computed by dividing the average maximum load prior to failure by the cross-sectional area under load.

3.5.3. Flexural Testing

Three flexural test specimens from each sample were prepared following the ASTM D790 standard for flexural testing. Each specimen measured 48 mm × 12.7 mm × 3 mm and was tested under a three-point bending setup on the UTM. Positioned between two supports, each specimen was loaded at its midpoint at a speed of 5 mm/min. A digital data acquisition system continuously recorded the load and deflection during testing. The flexural strength for the samples was calculated using the formula $\sigma = 3PL / (2bd^2)$. Here, P represents the maximum load, L is the specimen length, b is its width, and d is its thickness. [25]

3.6. Bulky Density for the Fabricated Cast

The density test for the sample with the best strength properties was carried out in accordance with ASTM D792-13, the standard test method for density. Five test specimens from the optimally selected sample test were prepared and tested.

4. Results and Discussion

4.1. Fabricated Sisal-Reinforced Cast

The samples obtained from the fabrication process are shown in Figure 4.

Fig. 4 Samples with varying sisal fiber and UP resin mass fractions

4.2. Mechanical Properties

Figure 5 presents the samples' tensile, compressive, and flexural properties with different fiber mass fractions. Tensile strength was observed to increase with fiber mass fraction up to 20%. A drop in tensile strength was noted in the sample with 25% sisal fiber and 75% unsaturated polyester resin. The sample with 20% sisal fiber and 80% unsaturated polyester resin had the highest tensile strength of 12.85 MPa. Fibers have good tensile properties due to their large aspect (length to diameter) ratio. This explains the continuous increase in tensile strength up to 20% sisal mass fraction. The drastic drop in tensile strength in samples with 25% sisal can be attributed to misalignment and poor fixation of the mat within the resin. The smaller amount of resin in this sample could not cover the total surface of the mat. This resulted in the formation of voids in the composite, which might have resulted in low strength.

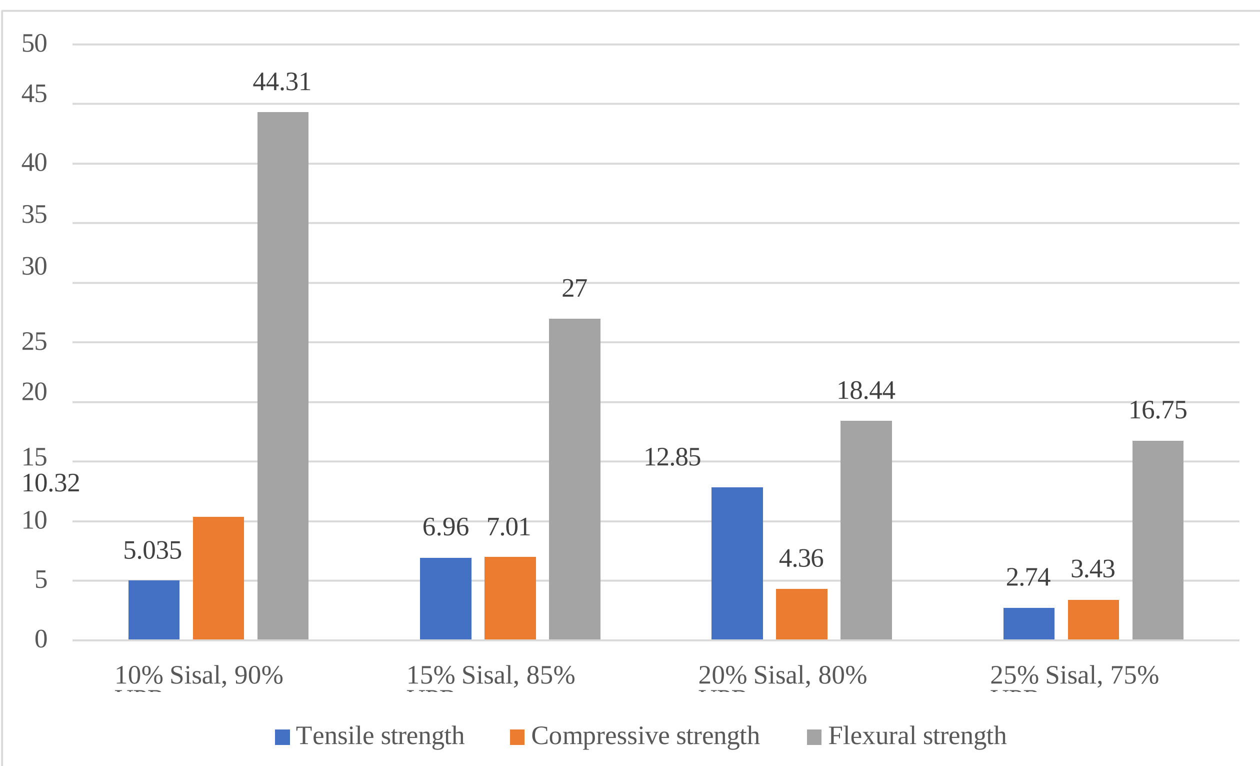

Fig. 5 Mechanical properties

4.2.1. Compressive Strength

Figure 5 shows that compressive strength decreased with an increase in sisal fiber mass fraction. The sample with 10% sisal and 90% unsaturated polyester resin had the highest recorded compressive strength of 10.32 MPa. Fibers have poor compressive properties owing to their flexibility. To possess good compressive properties, fibers need to be fixed and aligned. This setup is formed by applying the resin, where the bond between the reinforcement fibers and the solidified resin creates the composite interface. The resin meets fibers to develop a good interface in these structures. A lesser amount of resin results in poor bonding between these two constituents. This explains the decrease in compressive strength with increased fiber mass fraction ratios.

4.2.2. Flexural Strength

Also, flexural strength decreased with an increase in sisal fiber mass fractions. The sample with 10% sisal and 90% unsaturated polyester resin had the highest recorded flexural strength of 44.31 MPa. This occurrence can be attributed to the amount of resin in the samples. The stiffness of structures laminated with polymeric resins is directly proportional to the resin mass fraction. In this case, the higher the UPR mass fraction in a sample, the stiffer the resultant composite and vice versa. From these analyses, samples with 10% sisal and 90% unsaturated polyester resin had the highest compression and flexural strength values. This sample had an average tensile strength of about 5 MPa and was therefore selected as the optimal sisal composite cast.

4.2.3. Bulk Density

The results for the bulky density test done on the optimal sisal composite cast samples are tabulated in Table 5. The average density of the fabricated cast was found to be 0.84 g/cm^3.

Table 5. Bulk density test

Sample	1	2	3	4	5
Mass (grammes)	19	22	20	20	19
Volume (cm^3)	23.735	25	24	23.76	22.5
Density (g/cm^3)	0.8	0.88	0.83	0.84	0.84

4.3. General Discussion on the Properties of the Fabricated Sisal Composite Cast

Properties of the optimally fabricated sisal composite cast were compared with those made from fiberglass and plaster of Paris casts to determine their suitability, as shown in Table 6. The compressive strength of the sisal-reinforced UP cast was found to be four times greater than that of the POP cast. Its tensile strength was slightly above that of POP casts, while its flexural strength was almost thrice that of POP casts. This alternative cast also had a slightly lower density than the POP cast. From the analysis, the sisal reinforced UP cast had better physical and mechanical properties than the POP cast. Sisal-reinforced UP cast had a higher compressive strength than that of the fiberglass cast. This feature is a very important advantage of this alternative cast over fiberglass cast. Sisal reinforced UP cast was up to four times weaker than fiberglass cast from the analysis of their tensile strength values. This cast also had lower flexural strength as compared to the fiberglass cast, and a slightly higher density than the fiberglass cast. These results clearly confirm that fiberglass casts remain physically and mechanically superior to the two casts, that is, POP and sisal reinforced UP casts.

Table 6. Comparison of the mechanical and physical properties of the design to similar properties of the reviewed casts

Property	Fiberglass cast (Wytch et al., 1987)	Plaster of Paris cast (Olosho et al., 2018)	Sisal reinforced UPR cast
Compressive strength (MPa)	7.22	2.407	10.32
Tensile (MPa) strength (MPa)	22	4	5.035
Flexural strength (MPa)	70	15	44.31
Density (g/cm^3)	0.58	1.15	0.84

4.4. Advantages and Disadvantages of the Types of Cast

Table 7 shows the advantages and disadvantages of each type of cast.

Table 7. Advantages and disadvantages

Cast Type	Advantages	Disadvantages
Plaster of Paris (POP)	Low cost; Easy availability; Excellent moldability; Few allergic reactions; Widely used and familiar in hospitals.	Heavy and uncomfortable; Low strength-to-weight ratio; Causes pressure sores and numbness; Absorbs moisture, leading to cracking; Non-biodegradable; Environmentally unfriendly disposal.
Fiberglass (Synthetic)	High strength-to-weight ratio; Lighter than POP; More radiolucent; Shorter curing time; Stronger construct; Improved breathability.	High manufacturing cost due to machining difficulty of glass fibers; Limited moldability; Non-biodegradable; Not eco-friendly; Less common in hospitals despite better mechanical properties.

5. Conclusion

Therefore, the following issues were identified based on the results of this study. Firstly, a reinforced unsaturated polyester cast made with an optimum mass fraction of 10% sisal and 90% UP resin gave the best strength properties. This cast had better tensile, flexural and compressive strength than a plaster cast. It also proved to be lighter than a plaster cast from the analysis of their densities.

Secondly, in comparison to fiberglass cast, sisal reinforced UP cast showed lower tensile strength and flexural strength as compared to fiberglass cast. It also proved to be denser than fiberglass cast. These results show that fiberglass cast remains superior among the three casts in terms of the physical and mechanical properties under consideration in this study. However, this new cast proved to have the best compressive strength, a key property in this application, as compared to the two casts.

It can therefore be concluded that single ply sisal mat reinforced unsaturated polyester is satisfactorily strong and light enough to be used in the manufacturing of orthopaedic casts for managing bone fractures. However, the new sisal-reinforced polymeric cast faces limitations, including potential moisture absorption, susceptibility to microbial attack, UV-induced discoloration, and the need for further optimization to match or exceed fiberglass's long-term durability and strength.

5.1. Future Research Directions

Future research could focus on enhancing sisal-reinforced polymeric casts by improving moisture resistance, optimizing fiber-resin bonding, and exploring hybrid bio-fiber composites for better tensile and flexural performance. Studies could also assess long-term durability, biodegradability, and patient comfort under real clinical conditions, aiming to create an eco-friendly, cost-effective alternative to fiberglass and plaster casts without compromising mechanical strength.

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