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Development and Analysis of Sisal and Plantain Fibre Hybrid Composites for Pipeline Flange Applications

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Abstract - **This study investigates the creation of a pipeline flange using a hybrid polymer composite made from sisal and plantain fibre particles. Sisal/plantain hybrid composites are affordable, lightweight, and exhibit adequate mechanical properties, making them accessible and user-friendly. These natural fibres serve as effective alternatives to synthetic options and hold considerable potential to replace traditional steel materials. The sisal and plantain fibres were processed into particles sized between 300-500 µm. The hybrid composites were fabricated using the traditional hand layup technique, incorporating various percentage combinations of sisal and plantain fibres in laminates made from unsaturated polyester resin. The resulting laminate samples underwent a series of tests, including tensile, flexural, impact, compressive, and hardness tests, to evaluate their mechanical properties based on different fibre ratios. A ratio of 75% sisal to 25% plantain fibres yielded optimal performance, achieving a tensile strength of 10.2 MPa, a compression strength of 96.7 MPa, and a Rockwell hardness number of C19, indicating strong resistance to brittle fractures. The sisal/plantain fibre polyester composite flange produced at this ratio was further analyzed using Finite Element Analysis (FEA), providing insights into its structural behavior under varying pressure conditions. As pressure increased from 30 psi to 300 psi, the maximum von Mises stress in the flange rose steadily, peaking at 7.894 MPa at 300 psi. This result indicates a proportional response to mechanical loads, demonstrating that the hybrid materials significantly enhance the flange's structural integrity. Energy Dispersive Spectroscopy (EDS) analysis identified silicon (Si) as the predominant element in the sisal/plantain hybrid composite, whereas the cast iron sample was primarily composed of iron (Fe). Additionally, observations under Scanning Electron Microscopy (SEM) revealed a strong interfacial bond in the sisal/plantain fibre hybrid polyester composites, confirming their suitability for flange production. The standard sisal/plantain polymer hybrid flange was fabricated using the traditional hand layup method. It features a diameter of 150 mm, four bolts, 16 mm diameter holes, and a flange thickness of 25.4 mm, based on the 75%:25% fibre ratio.**

Keywords: **Hybrid Polymer Composite, Sisal/Plantain Fibres, Finite Element Analysis (FEA), Mechanical Properties, Hand Layup Technique**

I. INTRODUCTION

High-Density Polyethylene (HDPE) pipes are flexible plastic pipes used for fluid and gas transfer and are often employed to replace aging concrete or steel main pipelines. Their high impermeability and strong molecular bonds make them suitable for pipeline applications. HDPE pipes are in high demand in the oil and gas industries due to their excellent strength and corrosion resistance. These pipes are typically connected using flanges. However, flanges are expensive, and Nigeria currently lacks the capacity to produce them locally.

Composite materials have emerged as a solution to achieving a high strength-to-weight ratio. Advanced developments in petrochemical-based polymers have provided significant benefits to mankind. However, the environmental impact of non-degradable plastic materials, particularly disposable plastics, is becoming increasingly evident. These materials contribute substantially to environmental degradation, harming terrestrial and aquatic ecosystems. The accumulation of plastic waste poses serious threats to wildlife and disrupts natural habitats, causing long-term damage that is difficult to reverse [1], [2].

There is growing urgency to convert agricultural by-products and crop surpluses into profitable and sustainable products. The increasing emphasis on environmental conservation has renewed scientific interest in exploring the potential of natural fibres as reinforcement in biopolymer matrices. This shift aims to develop technologies that align with ecological preservation by integrating sustainable materials into composite production. Natural fibre-based composites demonstrate good mechanical properties while reducing dependence on fossil-based, non-renewable materials, resulting in both economic and environmental benefits. Natural fibres offer advantages over synthetic fibres, such as low cost, low density, acceptable strength properties, ease of separation, carbon sequestration, and biodegradability.

Sisal (*Agave sisalana*) is a tall, perennial monocot plant that originates from southern Mexico but is now widely cultivated worldwide. The plant's leaves contain stiff fibres used in the production of various products, while its young central buds can be consumed as vegetables. Sisal has a growth cycle of 7 to 12 years, producing 120-180 leaves depending on environmental conditions. Due to its limited production of viable seeds, sisal is primarily propagated through vegetative methods, such as bulbils from the inflorescence or suckers. After flowering, the plant dies and must be replaced. The fibres constitute only about 4% of the plant's total weight. As a tropical and subtropical species, sisal thrives in temperatures above 25°C and requires abundant sunlight. The increasing demand for sisal across industries highlights the importance of understanding its properties [3], [4].

II. LITERATURE REVIEW

Adeniyi *et al.,* [5] stated that crops like plantain produce significant waste that is currently considered worthless. Non-wood fibres extracted mechanically from the pseudo-stem of plantain plants can serve as reinforcing materials in polyester composites.

A pipe flange is a circular, disc-shaped component that connects to a pipe, allowing for the attachment of other components such as valves, nozzles, and specialized fittings. Flanges are one of the most common methods for joining piping components after welding, particularly when disassembly is required for maintenance, inspection, or replacement. Flanged joints, which use bolts and gaskets to prevent leaks, are preferred in such situations. The choice of piping flanges is determined based on pressure-temperature ratings and pipe class, following the guidelines specified in ASME B16.5 or ASME B16.47 standards. While custom flanges can be fabricated, they are less common in industrial applications. Flanges are typically manufactured through the forging process.

HDPE pipes, on the other hand, are flexible plastic options used for transporting fluids and gases, often replacing older steel pipelines. Their impermeability and robust molecular structure make them ideal for high-pressure systems. HDPE pipes are particularly popular in the oil and gas sector due to their superior strength and resistance to corrosion. Natural fibre-reinforced polymer composites made from sisal and plantain fibres offer a cost-effective and environmentally friendly solution to corrosion issues. These composites provide good mechanical properties, a long lifespan, and a sustainable alternative.

HDPE pipes exhibit high strength, flexibility, and resilience, as well as resistance to impacts, corrosion, and chemicals. The HDPE pipe market is segmented into HDPE 63, HDPE 83, and HDPE 100 based on type, and further categorized into applications such as oil and gas, irrigation, water supply, sewerage systems, and others. A market study conducted in 2023 valued the global HDPE pipe market at $21.7 billion in 2022, with a projected compound annual growth rate (CAGR) of 5.1% from 2023 to 2032, potentially reaching $35.4 billion [6].

There is an increasing emphasis on sustainability and environmental consciousness within the oil and gas industry. High-Density Polyethylene (HDPE) pipes align with these trends as they are recyclable, have a long service life, and require less energy for manufacturing compared to traditional materials. The focus on eco-friendly practices is driving the demand for HDPE pipes as a preferred choice over other piping options.

The use of conventional materials, such as steel, has resulted in increased weight for steel flanges. To fully transition to environmentally friendly solutions, more effort is required in the processing and manufacturing of natural fibre composites. This transition is essential not only for ecological reasons but also to ensure that these products remain affordable and accessible to consumers.

The research community faces the challenging task of developing innovative technologies and methods for treating solid waste, particularly non-biodegradable polymers. Reinforcing polymers with natural fibres has emerged as a more sustainable alternative. Additionally, there is a growing need for solutions that rely on manpower with minimal tooling requirements.

In this context, sisal/plantain fibre particle hybrid polymer reinforced composites are being explored as alternatives to metal alloys for pipeline flange production due to their lightweight nature and low initial capital investment. This study investigates the development of a pipeline flange made from sisal/plantain fibre particle hybrid polymer composites [7].

Oluwagbenga *et al.,* [8] investigated hybrid plantain fibre/calcite particle-reinforced polyvinyl chloride biocomposites for automobile applications. Plantain fibre (PF) and calcite particles (CP) were used as reinforcements, with weight percentages ranging from 3% to 15%. The mixtures underwent compounding and compression molding at 150°C for 10 minutes. The mechanical and thermal properties of the resulting composites were analyzed, and their fracture surfaces were examined using Scanning Electron Microscopy (SEM). The findings revealed that the addition of these reinforcements significantly enhanced the properties of the composites compared to unreinforced samples, with the hybrid composites demonstrating superior performance.

Optimal compositions were identified within the ranges of 6-8 wt.% plantain fibre (PF) and 3-4 wt.% calcite particles (CP). Specifically, the composite containing 6 wt.% PF and 3 wt.% CP achieved the highest ultimate tensile strength of 63.77 MPa, optimal elongation at break, and the best thermal insulating property of 0.24 W/m·K. In contrast, the composite with 8 wt.% PF and 4 wt.% CP exhibited the highest tensile modulus of 4.79 GPa, a flexural strength of 91.35 MPa, and a flexural modulus of 8.2 GPa. The peak impact strength was observed at 10 wt.% PF and 5 wt.% CP, reaching 107.02 J/m². These results suggest that the developed hybrid reinforced biocomposite compositions are promising candidates for various automotive applications.

Mulenga *et al.,* [9] examined the mechanical properties of a new hybrid composite material combining bio-epoxy reinforced with sisal fibre and enhanced with fly ash nano-fillers. The experimental results indicated significant improvements in the composite's mechanical characteristics due to the addition of fly ash nano-fillers. Specifically, the tensile strength increased by 6.3%, while the flexural strength showed a remarkable rise of 68%. Additionally, the impact strength improved by 28%, and scratch hardness increased by 17%, all achieved with a 20% fibre weight fraction and a 5% fly ash weight fraction. These results underscore the considerable potential of hybrid fibre-reinforced bio-epoxy composites with fly ash nano-fillers as environmentally friendly alternatives to conventional synthetic composites. The enhancements in mechanical properties suggest that this composite is well-suited for a variety of engineering applications, including automotive components, construction materials, and consumer products.

Kumar *et al.,* [11] investigated the mechanical properties of okra, sisal fibre, and polyester-based hybrid composites. They conducted experimental development and characterization of hybrid natural fibre composites by reinforcing okra/sisal fibres with polyester resin using the hand layup method. Natural fibres were extracted through manual retting and combing processes. The hybrid composites were formulated using okra and sisal fibres at weight ratios of 30/70, 50/50, and 70/30, with varying fibre weights of 0.4, 0.8, 1.2, 1.6, and 2 grams. Subsequent testing of the tensile and impact properties revealed that both tensile strength and impact strength increased with rising fibre weight.

Rodrigues Pereira de Paula *et al.,* [12] investigated the development and characterization of sawdust and sisal fibre-reinforced vegetable-based polyurethane foam hybrid composites. The composites were produced in five different proportions and were analyzed using imaging, mechanical, and physical tests. Composites with 50% foam, 37.5% sawdust, and 12.5% sisal exhibited the highest bending resistance of 11.31 MPa and the best results after 2 hours of immersion. These composites were deemed suitable for furniture and craft applications.

Numerous studies have investigated the use of sisal, jute, and banana fibres as reinforcements in polymer matrices. Jayaraman and Parandaman [13] analyzed the mechanical properties of Jute/Sisal/Glass (JSG) and Jute/Banana/Glass (JBG) hybrid composite materials with epoxy resin. Their study evaluated the effects of hybridizing natural fibres with glass fibres on mechanical behavior, including tensile, hardness, and impact strengths. For JSG, the results showed a tensile modulus of 23.29 MPa, flexural strength of 59.8 MPa, and impact strength of 15.01 kJ/m². In comparison, JBG demonstrated superior performance with a maximum tensile modulus of 42.24 MPa, maximum flexural strength of 72.93 MPa, and maximum impact strength of 26.35 kJ/m².

The properties of hybrid Oil Palm Empty Bunch Fibre (OPEBF)/banana/glass fibre-reinforced unsaturated polyester composites were systematically investigated. The authors performed mechanical tests, including tensile, flexural, impact, and hardness assessments. Results indicated that increasing banana fibre content led to a decline in flexural strength, while an increase in glass fibre content enhanced flexural strength. The composite containing 5 wt.% OPEBF, 10 wt.% banana fibre, and 10 wt.% glass fibre exhibited a high impact strength of 55.5 J/m², representing a 1568.67% improvement over virgin unsaturated polyester. Furthermore, the hybrid composite with 15 wt.% banana fibre and 5 wt.% glass fibre demonstrated the highest hardness of 3.55 HV, reflecting a 136.67% improvement compared to the polyester hardness of 1.5 HV. The study concluded that the hardness of the samples was significantly influenced by the increase in banana fibre content, making banana fibre composites suitable for applications requiring high impact strength, such as automotive components [14].

The compressive and impact strengths of plantain fibre-reinforced polyester composites were assessed in another study. The evaluation aimed to determine how the incorporation of plantain fibres affects the mechanical performance of the polyester matrix. Results indicated that the addition of plantain fibres significantly enhanced both compressive and impact strengths, highlighting the potential of natural fibres for improving mechanical properties in polyester composites. The study concluded that increasing the volume fraction of plantain fibre substantially enhanced compressive and impact strengths, demonstrating their suitability for automobile fender production [15].

The impact behavior and analysis of sisal/jute and glass fibre-reinforced hybrid composites were also investigated [16]. The study found that incorporating sisal and jute fibres into glass fibre-reinforced polymer (GFRP) composites improved impact properties. The properties and behavior of different plant fibres reinforced in polymer matrices have been extensively reviewed and studied [17]-[22]. However, from the literature, it is evident that limited work has been conducted on polyester reinforced with locally grown sisal/plantain hybrid fibres for flange production. This study investigates the development of a pipeline flange using sisal/plantain fibre particle hybrid polymer composites.

III. MATERIALS AND METHOD

A. Materials

The materials employed in the preparation of the composite included unsaturated polyester resin as the matrix, methyl ethyl ketone peroxide as the catalyst, cobalt naphthalate as the accelerator, and Vaseline as the mould-releasing agent. Additionally, sisal plant fibre and plantain plant fibre were utilized as reinforcing components.

B. Method

The plantain pseudostem and sisal leaves were subjected to water retting for 30 days. The retting process allows bacteria to act on the soaked plantain pseudostem and sisal leaves. Figure 1 shows the sisal plant, and Figure 2 shows the plantain plant. The retted fibres were thoroughly washed with water and re-soaked to ensure the complete removal of lignin, pectin, cellulose, and hemicellulose present in the fibres. The fibres were dried, brushed, and sorted into various grades. Figure 3 shows the sisal fibre, and Figure 4 shows the plantain fibre extracted from the pseudostem of the plantain.

The materials used for the hand layup process included sisal and plantain fibre strands shredded to a range of 300-500 µm, unsaturated polyester resin, methyl ethyl ketone peroxide catalyst, and cobalt accelerator at a ratio of 10:1:0.5. The different composites were produced in the form of laminates for tensile, flexural, compression, and hardness tests. Each composite was loaded with a 0.40 volume fraction, and the particulate fibre combination percentages for sisal to plantain were as follows: 50:50, 67:33, 33:67, 75:25, 25:75, sisal alone, and plantain alone.

The composite samples were cured at room temperature and consolidated with a roller load weight of 50 g for 4 hours before being removed from the mould. The specimens were then further cured in the air for another 12 hours after demoulding.

Test specimens were subjected to mechanical tests as per ASTM standards using an Instron Universal Testing Machine. The tests included the tensile test (ASTM D638), three-point flexural test (ASTM D790), compression test (ASTM C790), and impact test. The microstructure of the composites was investigated using SEM-EDS. All specimen preparations and mechanical tests were conducted at a room temperature of approximately 37 °C.

Figure 5 shows the compression test samples, while Figure 6 shows the flexural test samples. Figure 7 shows the tensile test samples, and Figure 8 shows the hardness test samples. Figure 9 illustrates the SEM/EDS test samples, and Figure 10 displays the mould developed for the flange. The flange produced is shown in Figure 11.


Fig. 1 Sisal


Fig. 2 Plantain


Fig. 3 Extracted Sisal fibre


Fig. 4 Extracted Plantain fibre.


Fig. 5 Compression test samples


Fig. 6 Flexural test samples


Fig. 7 Tensile test samples


Fig. 8 Hardness test samples


Fig. 9 SEM/EDS test samples


Fig. 10 The Flange mould


Fig. 11 The Flange produced

The prepared samples consist of a volume of fibres (sisal/plantain) and a volume of the matrix material. For a composite material composed of fibres and matrix material, the total volume of the composite material is equal to the sum of the volume of the fibres and the volume of the matrix.

Therefore

$$V_c = V_f + V_m \tag{1}$$

Where,

V_c = volume of composite material

V_f = volume of fibre

V_m = volume of matrix

Let, the fibre volume fraction V_f and the matrix volume fraction V_m be defined as

$$V_f = \frac{v_f}{v_c} \tag{2}$$

$$V_m = \frac{V_m}{V_c} \tag{3}$$

such that the sum of volume fractions is

$$V_f + V_m = 1 \tag{4}$$

IV. RESULTS AND DISCUSSION

A. Tensile Test

The tensile strength of the unreinforced specimen, designated T0, was measured to be 13.4 MPa. The specimen designated T4, with a sisal:plantain fibre ratio of 75%:25%, exhibited the second-highest tensile strength of 10.2 MPa. The tensile test results for the laminates indicated an optimal tensile strength of 10.2 MPa, suggesting their suitability for producing HDPE flanges.

The HDPE PE100 pipe currently used in the oil and gas industry possesses the following optimal properties: minimum required strength (MRS) of 10.0 MPa (1450 psi), allowable compressive strength of 7.93 MPa, tensile strength at yield of 23 MPa, modulus of elasticity (over 50 years) of 200 MPa, and flexural modulus of 100 MPa. Figure 12 illustrates the tensile strength results of the samples analyzed. The results for sample T4 are consistent with the properties of the HDPE PE100 pipe used in the oil and gas sector.

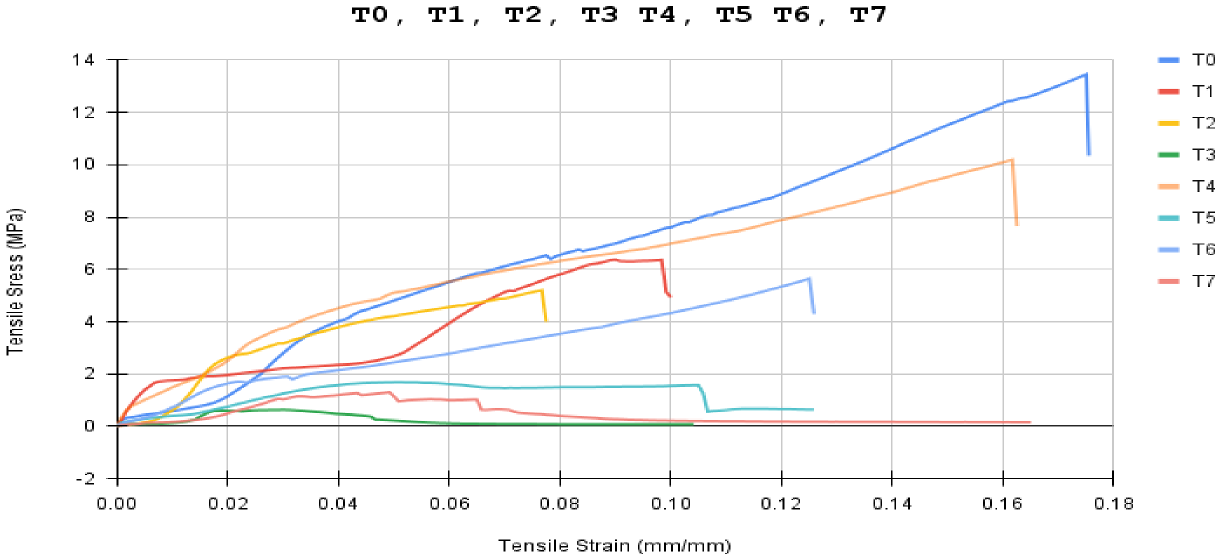


Fig. 12 Graph of Tensile Test Results

B. Compression Test

The compression test was performed on all composite samples in accordance with ASTM C790 using an Instron Universal Testing Machine. Each specimen was cylindrical, with a height and diameter of 20 mm. The compressive strength of the unreinforced specimen, designated C0, was measured to be 73.6 MPa. The specimen designated C3, composed of a sisal:plantain fibre ratio of 67%:33%, exhibited a compressive strength of 68.4 MPa. Figure 13 illustrates the results obtained from the compression test.

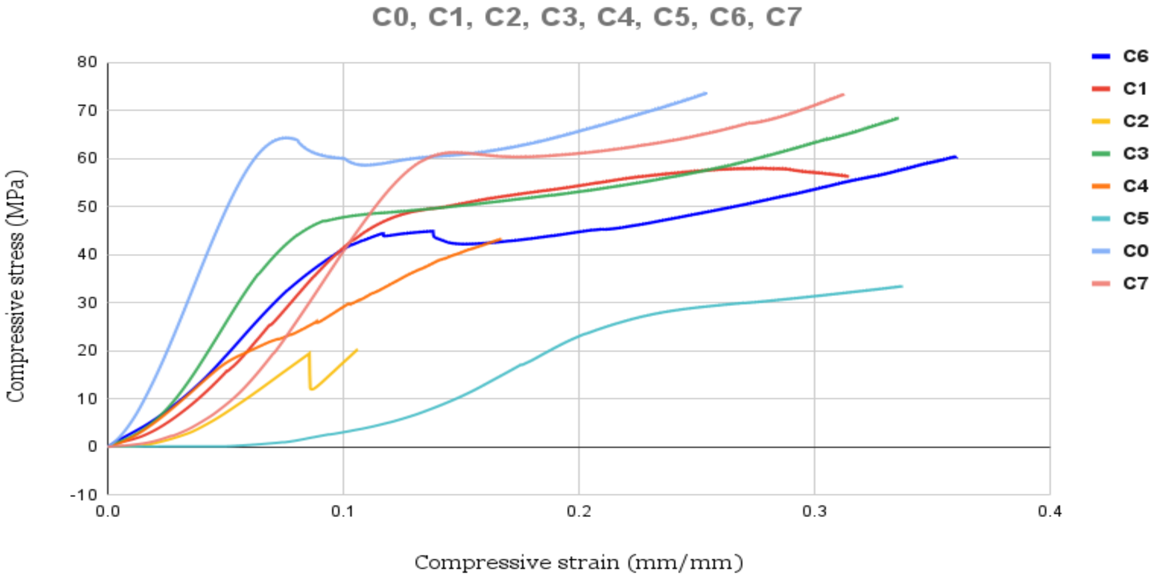


Fig. 13 Graph of Compressive Test Results

C. Flexural Test

The three-point flexural test was performed on all composite samples in accordance with ASTM D790 using an Instron Universal Testing Machine. Each specimen measured 120 mm × 20 mm × 5 mm, with a maintained span length of 100 mm. As shown in Figure 14, the unreinforced specimen, designated F0, exhibited the highest flexural strength of 153 MPa. This was followed by specimen F4, which had a sisal:plantain composite ratio of 75%:25%, demonstrating a flexural strength of 96.7 MPa.

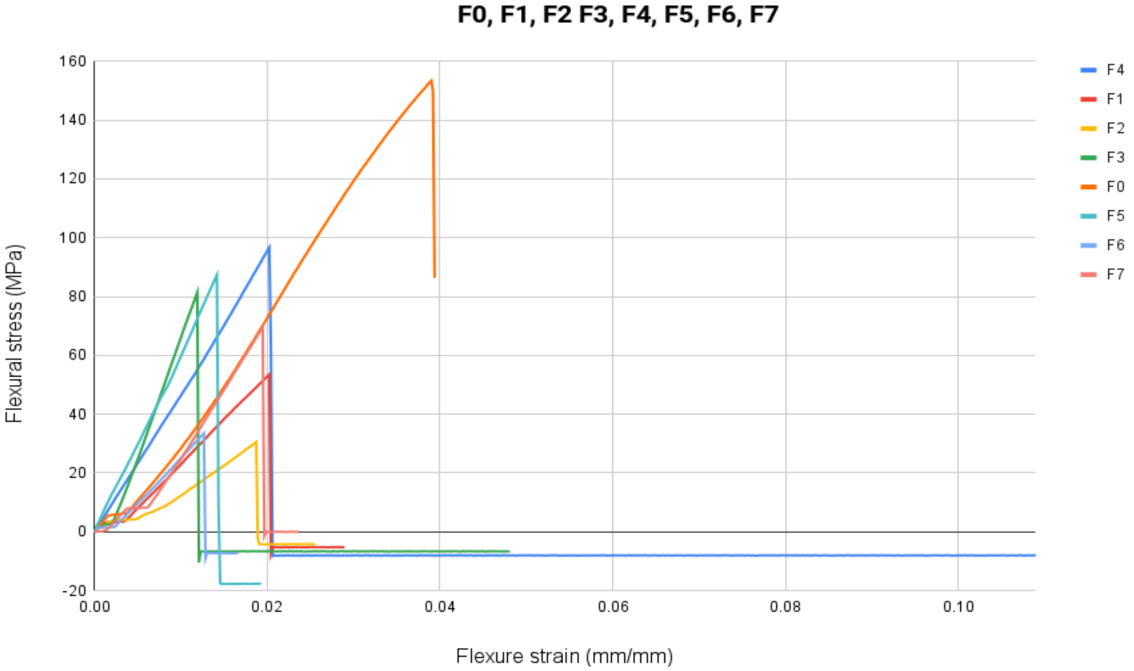


Fig. 14 Graph of Flexural Test Result

D. Hardness Test

The Rockwell hardness test evaluates a material's resistance to brittle fracture and toughness, which are crucial for assessing a material's durability. According to the results shown in Figure 15, the unreinforced specimen, designated H0, exhibited a hardness of 7. In contrast, specimen H4, which comprises a sisal:plantain composite ratio of 75%:25%, achieved the highest Rockwell hardness number of 19, indicating superior resistance to brittle fractures.

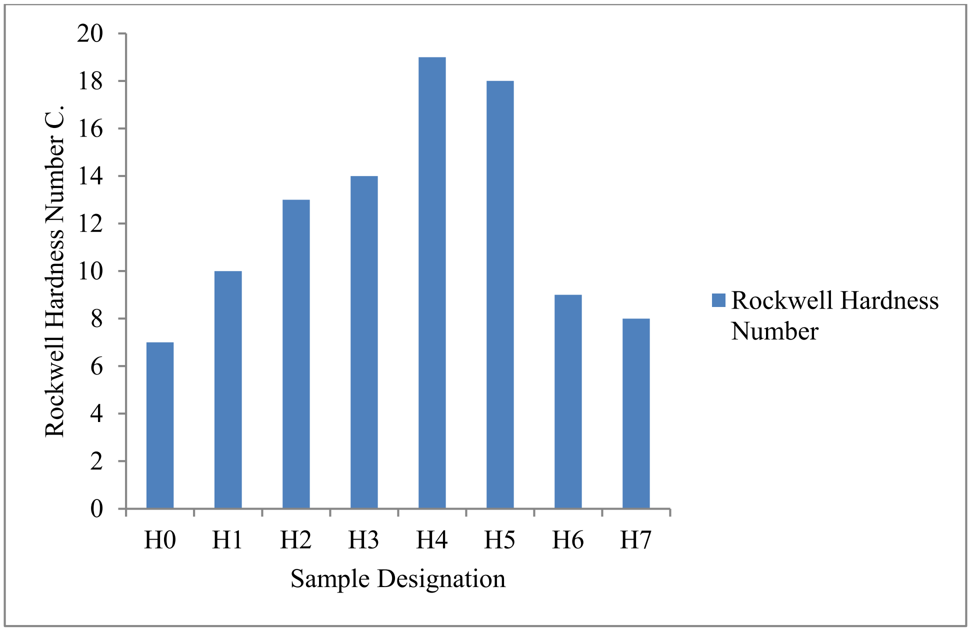


Fig. 15 Graph of Rockwell Hardness Test Results

E. Comparative Analysis of the Properties of Conventional Cast Iron Flange, Sisal/Plantain Hybrid Polymer Flange, and HDPE PE100 Pipe

Table I presents a comparative analysis of the conventional cast iron flange, the sisal/plantain hybrid polymer composite flange, and the HDPE PE100 pipe. The optimal strength properties of the developed sisal/plantain hybrid polymer composite flange, along with its weight and cost advantages, confirm its suitability for use in the development of flanges for HDPE pipes.

TABLE I COMPARATIVE ANALYSIS OF THE PROPERTIES OF CONVENTIONAL CAST IRON FLANGE, SISAL/PLANTAIN HYBRID POLYMER FLANGE AND HDPE PE 100 PIPE

Properties	Gray Cast Iron Flange	Developed Sisal/ Plantain Flange	HDPE PE 100 Pipe Properties
Rockwell Hardness C	14.4 - 29.0	19	
Tensile Strength	115 - 700 MPa	10.2 MPa	10 - 23 MPa
Flexural Strength	421 - 641 MPa	96.7 MPa	80 - 1000 MPa
Compressive Strength	572 - 1380 MPa	68.4 MPa	≤ 7.93 MPa
Density	6.80 - 7.34 g/cm³	1.20 g/cm³	0.950 g/cm³
Cost	\$10 - \$25	\$5	

F. Simulation Analysis

The simulation results for the “Sisal and Plantain Fibres Polyester Composite” flange provide essential insights into its structural behavior under varying operating pressures. As the pressure increases from 30 to 300 psi, the maximum von Mises stress in the flange consistently rises, peaking at 7.894 MPa at 300 psi. This stress progression indicates a proportional response to the applied mechanical loads (operating pressure), demonstrating that the material properties effectively contribute to the flange's structural integrity. A significant observation is the declining trend in the Factor of Safety (FOS) as pressure surpasses 240 psi, dropping sharply to 0.095 at 270 psi. This highlights a critical pressure threshold where the safety margin considerably decreases, emphasizing the need for careful evaluation and potential modifications to enhance reliability. Additionally, the maximum displacement values show a gradual increase with rising pressure, reaching 0.053 mm at 300 psi, which reflects the deformation experienced by the flange under applied loads. While the flange remains within its tensile strength limits, the decreasing FOS underscores the necessity for further optimization to ensure long-term structural reliability and safety in practical applications.

1. Model Details

Figures 16 and 17 provide the dimensional details and an exploded view of the designed flange model. The flange design is a Class 150 slip-on flange with a diameter of 2 inches, in accordance with ASME B16.5 standards.

2. Boundary Conditions

The simulation model includes two flanges bolted together using ISO 3640-M16 fasteners. While the material properties of the fasteners were suppressed, the tightening torque was activated and calibrated to 1.5 Nm in the boundary setup, as illustrated in Figure 20. The outer face of the slip-on flange - designated as the region where the HDPE pipe will be welded by fusion (shown in Figure 19) - was set as a fixture. The working or operating pressure was applied to the interior faces of the two flanges, where fluid flow occurs, as indicated in Figure 19.

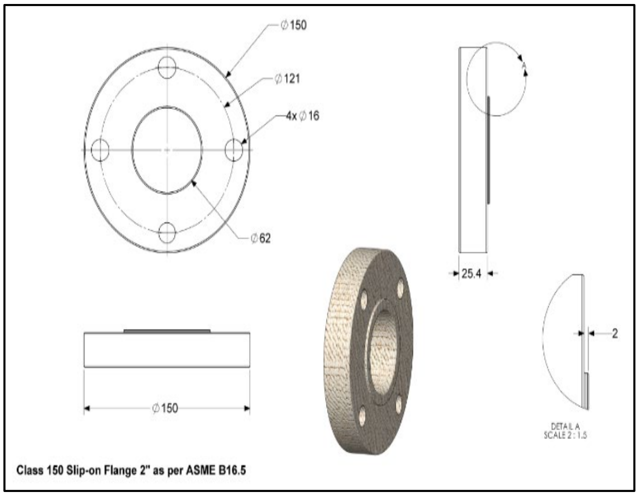
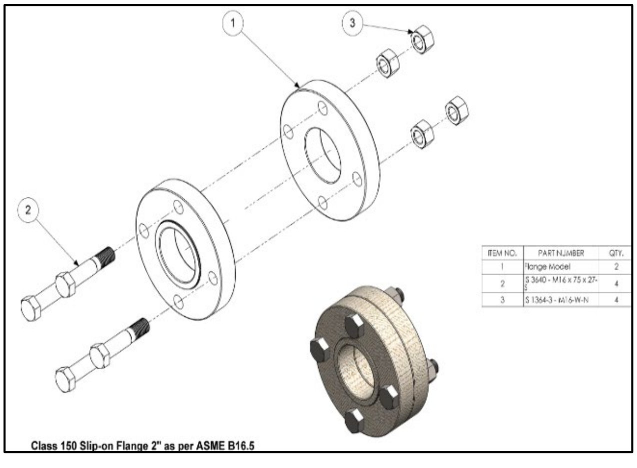


Fig. 16 Dimensional Details of the Flange



ITEM NO.	PART NJMBER	QTY.
1	Flange Model	2
2	S 3640 - M16 x 75 x 27-S	4
3	S 1364-3 - M16-W-N	4

Fig. 17 Exploded View of the Flange Assembly

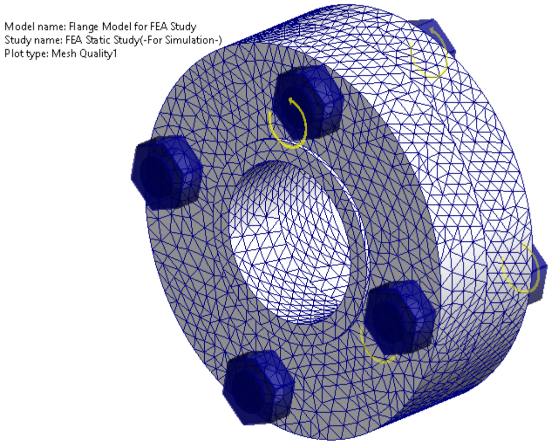
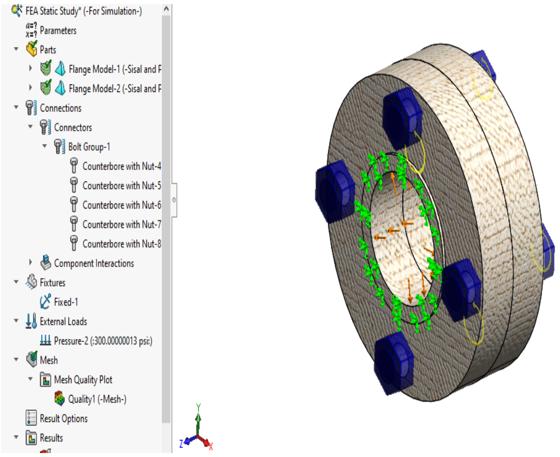
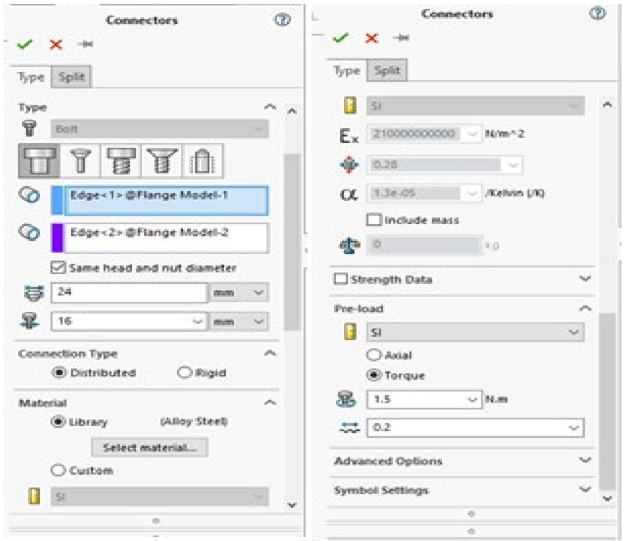


Fig. 18 Meshed Model of the Flange Assembly



FEA Static Study* (-For Simulation-)
- Parameters
- Parts
  - Flange Model-1 (-Sisal and P
  - Flange Model-2 (-Sisal and P
- Connections
  - Connectors
    - Bolt Group-1
      - Counterbore with Nut-4
      - Counterbore with Nut-5
      - Counterbore with Nut-6
      - Counterbore with Nut-7
      - Counterbore with Nut-8
  - Component Interactions
- Fixtures
  - Fixed-1
- External Loads
  - Pressure-2 (:300.0000013 psi:)
- Mesh
  - Mesh Quality Plot
    - Quality1 (-Mesh-)
- Result Options
- Results

Fig. 19 Simulation Setup Summary



Connectors

Type | Split

Type
Bolt
Edge<1>@Flange Model-1
Edge<2>@Flange Model-2
☑ Same head and nut diameter
24 mm
16 mm

Connection Type
● Distributed ○ Rigid

Material
● Library (Alloy Steel)
Select material...
○ Custom
SI

Connectors

Type | Split

SI
E_x 210000000000 N/m^2
0.28
α 1.3e-05 /Kelvin (/K)
☐ Include mass
0 kg

☐ Strength Data

Pre-load
SI
○ Axial
● Torque
1.5 N.m
0.2

Advanced Options

Symbol Settings

Fig. 20 Fasteners: Bolts connection setup

Figure 18 illustrates the meshed model of the designed flange. The simulation setup for the Finite Element Analysis (FEA) of the flange is displayed in Figure 19, while the configuration for the fasteners and bolt connections is shown in Figure 20. The stress distribution of the flange at 60 psi is presented in Figure 21, revealing that the maximum von Mises stress at this pressure reached 5.04 MPa. Figure 22 depicts the deformation of the flange at 60 psi, with a maximum deformation of 0.023 mm, which is considered negligible. Finally, Figure 23 presents the shear stress distribution of the developed flange, with a yield strength measured at 7.50 MPa.

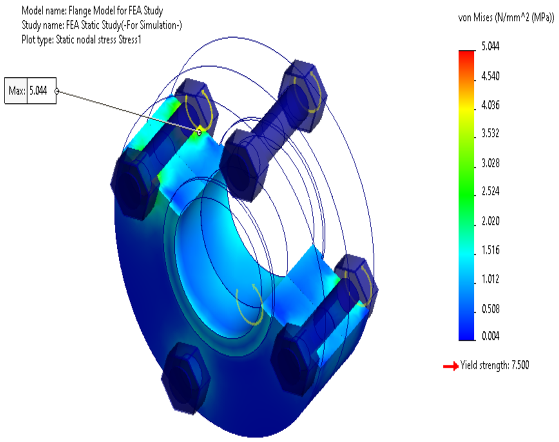


Fig. 21 Stress Distribution Operating at 60 psi

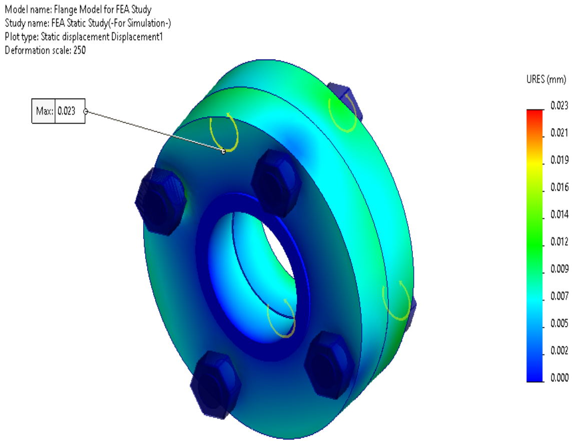


Fig. 22 Deformation Contour of the Flange at 60 psi

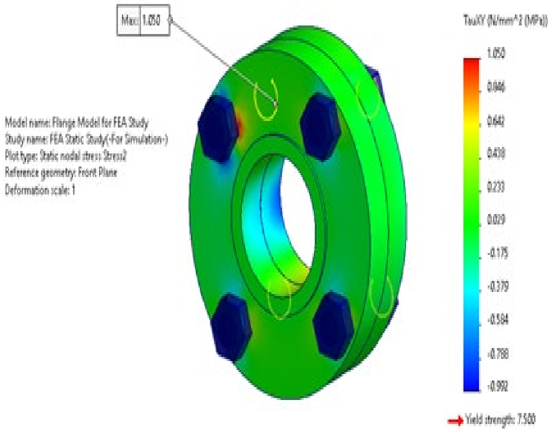


Fig. 23 Shear Stress Distribution while operating at 60 psi

The summary of the simulation conducted on the developed flange is shown in Table II.

TABLE II SUMMARY OF THE SIMULATION RESULTS

Operating Pressure (psi)	Maximum von Mises (MPa)	Maximum Displacement (mm)	FOS
30	4.843	0.020	1.549
60	5.044	0.023	1.487
90	5.293	0.027	1.417
120	5.584	0.027	1.34
150	5.909	0.0341	1.26
180	6.265	0.038	1.19
210	6.645	0.038	1.12
240	7.045	0.046	1.065
270	7.452	0.050	0.095
300	7.894	0.053	0.95

G. SEM-EDS Results

The Scanning Electron Microscopy (SEM) results of the samples at various magnifications are presented in Figures 24-27, while the Energy Dispersive X-Ray Spectroscopy (EDS) results are shown in Figures 28-31. The sample designated as Es in the SEM (Figure 24) is cast iron. The micrograph displays the main constituents-iron and carbon-with dark and white flakes of the iron-carbon bond evenly arranged in a crystalline structure. The EDS analysis for this sample (Figure 28) reveals that iron is the predominant element, comprising 54 wt.%, followed by oxygen (20.2%), zinc (7%), carbon (3%), and silicon (3.22%). Figures 25 and 29 depict the SEM and EDS results for the sample designated E0, which is pure virgin polyester without sisal or jute fibre reinforcements. The matrix in Figure 25 shows the absence of fibre reinforcements. Additionally, Figure 29 indicates the main constituents as follows: silicon (55%), carbon (7.2%), and aluminum (6.5%) by weight. The sample designated E4, illustrated in Figures 26 and 30, contains 75% sisal fibre and 25% plantain fibre. Figure 26 reveals fibre agglomeration within the polymer matrix, with a void present, indicating a defect around the bond in the specimen. Figure 30 lists the main constituents as silicon (50.2%), oxygen (20%), and aluminum (8.2%) by weight. Finally, Figures 27 and 31 present the SEM and EDS results for the sample designated E6, which consists of 100% sisal fibre and 0% plantain fibre. In Figure 27, fibre agglomeration is observed with no voids present. Figure 31 indicates the main constituents as silicon (68.2%), oxygen (15%), and aluminum (4.3%) by weight.

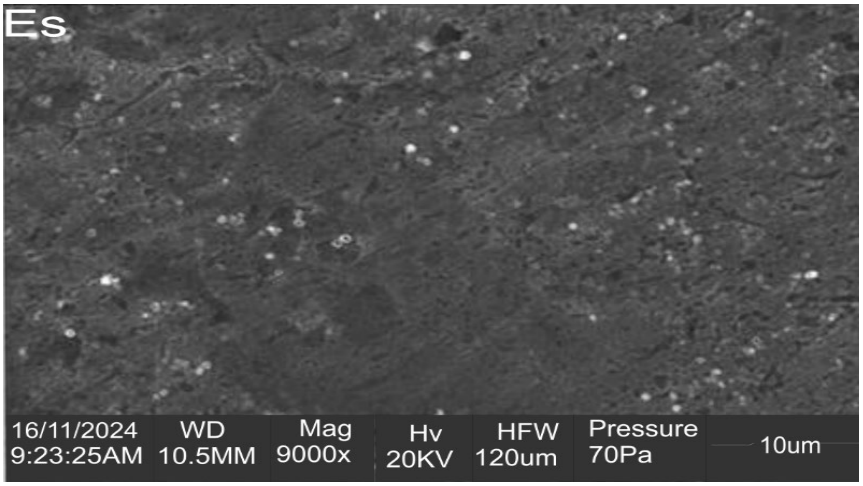


Fig. 24 Scanning Electron Microscope (SEM) at magnification x9000 for sample Es

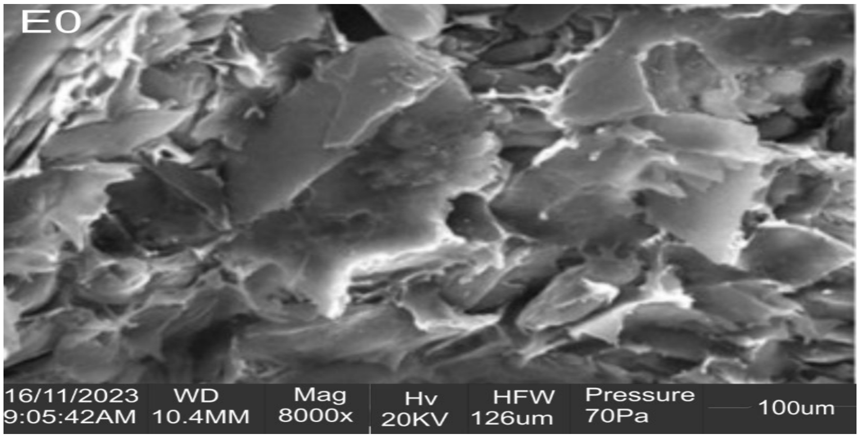


Fig. 25 Scanning Electron Microscope (SEM) at magnification x8000 for sample E0

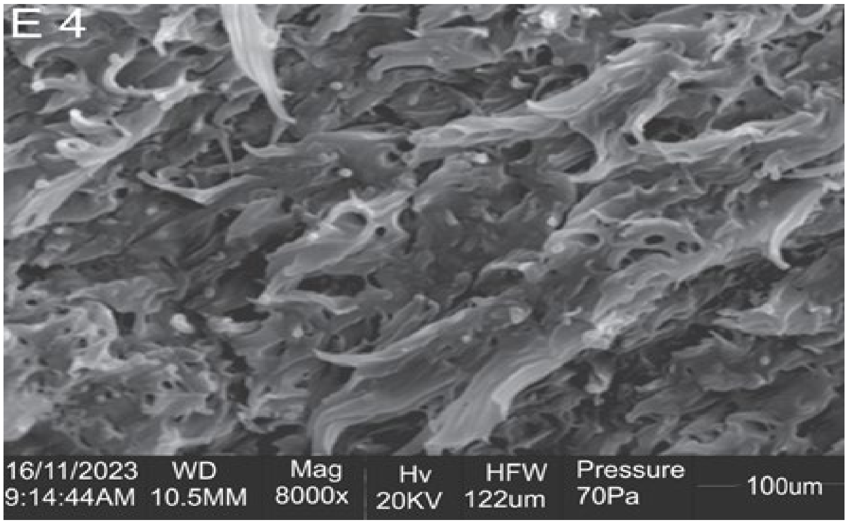


Fig. 26 Scanning Electron Microscope (SEM) at magnification x8000 for sample E4

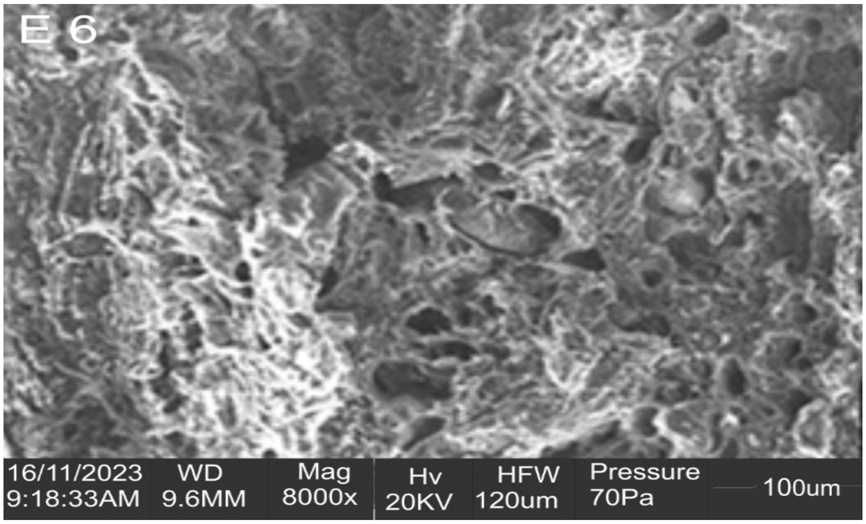
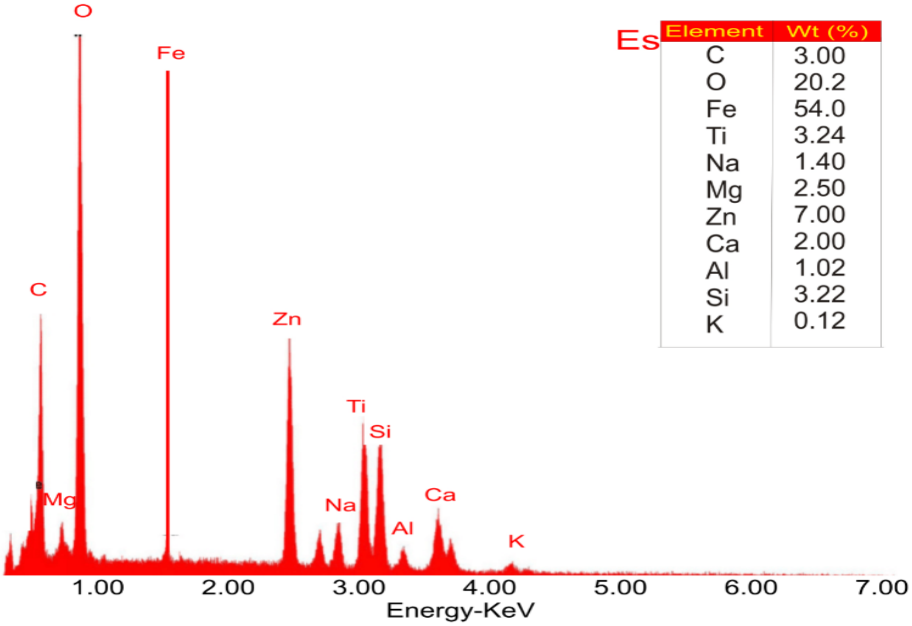
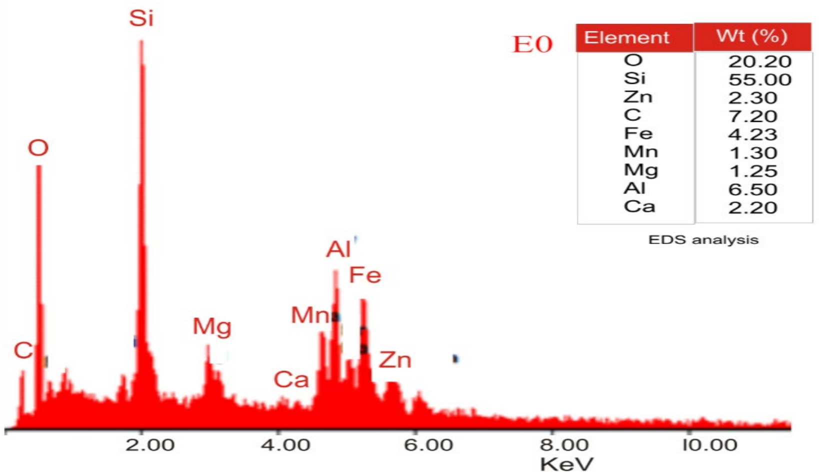


Fig. 27 Scanning Electron Microscope (SEM) at magnification x8000 for sample E6



Element	Wt (%)
C	3.00
O	20.2
Fe	54.0
Ti	3.24
Na	1.40
Mg	2.50
Zn	7.00
Ca	2.00
Al	1.02
Si	3.22
K	0.12

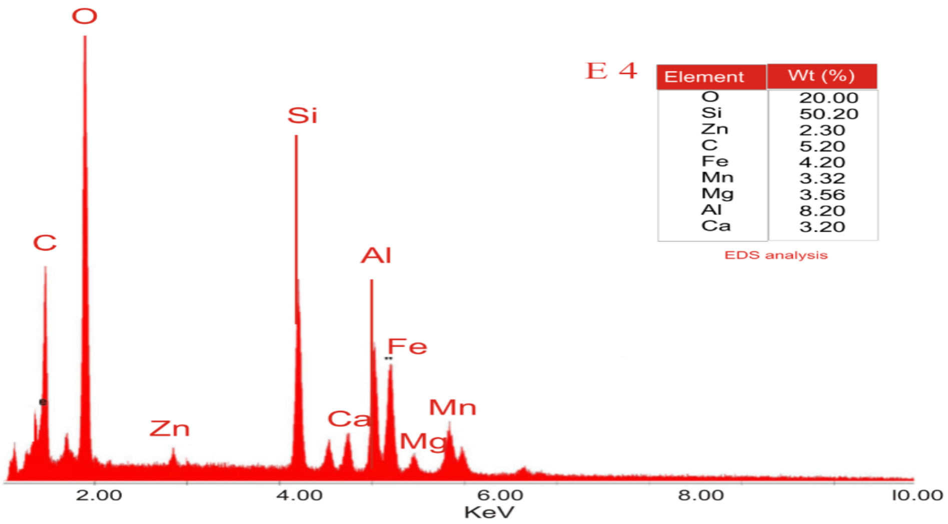
Fig. 28 Sample designated Es Energy Dispersion Spectroscope (EDS)



Element	Wt (%)
O	20.20
Si	55.00
Zn	2.30
C	7.20
Fe	4.23
Mn	1.30
Mg	1.25
Al	6.50
Ca	2.20

EDS analysis

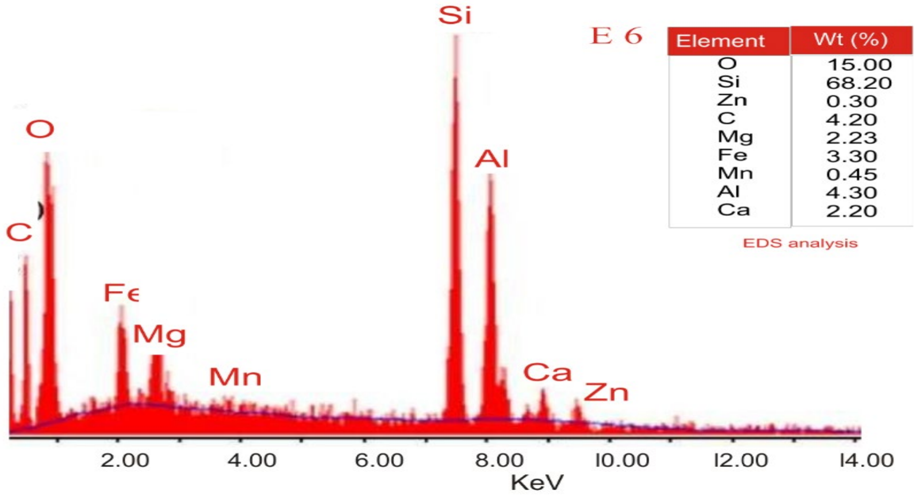
Fig. 29 Sample designated E0 Energy Dispersion Spectroscope (EDS)



Element	Wt (%)
O	20.00
Si	50.20
Zn	2.30
C	5.20
Fe	4.20
Mn	3.32
Mg	3.56
Al	8.20
Ca	3.20

EDS analysis

Fig. 30 Sample designated E4 Energy Dispersion Spectroscope (EDS)



Element	Wt (%)
O	15.00
Si	68.20
Zn	0.30
C	4.20
Mg	2.23
Fe	3.30
Mn	0.45
Al	4.30
Ca	2.20

EDS analysis

Fig. 31 Sample designated E4 Energy Dispersion Spectroscope (EDS)

V. CONCLUSION

This research focused on the development of a pipeline flange using a sisal/plantain fibre polymer hybrid composite. Sisal/plantain fibre hybrid polymer composites are cost-effective, lightweight, and possess satisfactory mechanical properties, making them both accessible and user-friendly. These fibres have emerged as viable alternatives to synthetic fibres and have the potential to replace conventional steel as preferred materials, thanks to recent advancements in composite technology. The sisal and plantain fibres used as reinforcements were shredded to a range of 300-500 μm. The hybrid composites were created using the hand layup technique, based on various percentage combinations of sisal and plantain fibres in the form of laminates prepared from unsaturated polyester resin. The laminate samples underwent tensile, flexural, impact, compressive, and hardness tests to evaluate their strengths based on the fibre percentage combinations. The sisal/plantain fibre combination ratio of 75%:25% demonstrated an optimum tensile strength of 10.2 MPa. The combination ratio of 67%:33% (designated as C3) exhibited a compressive strength of 68.4 MPa, while the ratio of 75%:25% (designated as F4) showed a compressive strength of 96.7 MPa. Sample H4, with the same fibre percentage combination, achieved a Rockwell hardness number of C19, indicating strong resistance to brittle fractures. The simulation results for the sisal/plantain fibre polyester composite flange provide valuable insights into its structural behavior under varying operating pressures. As the pressure increases from 30 psi to 300 psi, the maximum von Mises stress in the flange steadily rises, reaching 7.894 MPa at 300 psi. This stress evolution reflects a proportional response to the applied mechanical loads, demonstrating that the hybrid components effectively contribute to the structural strength and integrity of the flange. Energy Dispersive Spectroscopy (EDS) analysis reveals that the primary constituent element in the sisal/plantain fibre hybrid composite sample is silicon (Si), while the cast iron sample is predominantly composed of iron (Fe). The microstructure of the sisal/plantain hybrid, observed under Scanning Electron Microscopy (SEM), indicates strong interfacial bonding, making it suitable for flange production. The hand layup method was employed to produce a standard sisal/plantain fibre polymer hybrid flange with a diameter of 150 mm, featuring 4 bolts, 16 mm diameter holes, and a flange thickness of 25.4 mm, utilizing a sisal/plantain fibre percentage combination of 75%:25%.

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