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Optimization of Sisal Fibre Content in The Production of Gypsum Bio composites

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Abstract: *The mechanical efficiency of fibre-reinforced composites largely depends on the fibre volume fraction, and improper optimization of fibre content often results in poor stress transfer. Imported sisal fibre (ISF) was utilized to reinforce gypsum bio composite to improve its mechanical properties. Gypsum composites are always brittle materials that do not withstand tension load. In this study, Plaster of Paris (POP) cement used was characterized in accordance with ASTM C472. The ISF exhibited a tensile strength of 273.10MPa, Young's modulus of 22.4 GPa, elongation of 4.89 mm, water absorption of 12.8%, and a density of 0.12 g/cm³. The chemical properties also include cellulose at 63.46%, hemicellulose at 22.6% and lignin at 6.7%. Composite samples were produced using the POP cement to gypsum ratio of 0.48 which was determined as the consistency of the POP cement, with fibre contents varied at 0%, 0.5%, 1.0%, 1.5%, and 2.0%. The maximum flexural strength of the composites was recorded as 8.9MPa and 11.6MPa after 3 and 7 days of curing, respectively, satisfying the requirements specified in ASTM C473. The maximum fibre reinforcement was observed at 1.0%. Water absorption increased with the addition of fibre content, ranging from 18.4% to 21.9%, while composite density decreased from 1.33 g/cm³ to 1.07 g/cm³ as the fibre content increases this is due to the increase of more porous within the matrix. However, the results showed that incorporating ISF as reinforcement enhanced the mechanical properties of gypsum-based composites, highlighting their potential for lightweight applications.*

Keywords: *Gypsum bio composite, Imported Sisal Fibre, Mechanical properties*

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1. INTRODUCTION

Plaster of Paris (POP) cement originates from a natural raw material known as gypsum, which has been widely utilized as a building and construction material since ancient times. Gypsum plasters are extensively used in ceiling designs, partition walls, and wall coverings due to their versatility and ease of application. Gypsum-based materials, including mortars, composites, and boards, are increasingly favored in modern construction for their exceptional fire resistance, thermal insulation, and sound absorption properties (Ghouleh & Shao, 2018). Gypsum plaster boards are particularly popular for interior walls and ceilings because of their simple manufacturing process, environmental friendliness, aesthetic appeal, affordability, and excellent performance characteristics (Al-Rifaie & Al-Niami, 2016). The integration of gypsum in interior finishing has also been driven by the growing need for lightweight, energy-efficient, and sustainable materials in building design. Ceilings, as horizontal non-structural members that cover the upper section of a building's interior space, play important functional and aesthetic roles. Despite being non-structural, they often support attachments such as lighting fixtures, security cameras, and smoke detectors; thus, they must be capable of bearing self-weight, dust accumulation, and the weight of attached fittings (Anowai *et al*., 2020). Achieving such strength while maintaining a lightweight profile has proven challenging with conventional materials, thereby stimulating global interest in composite materials for improved mechanical performance—a trend also evident in aviation, marine, and construction industries (Yildizhan *et al*., 2025). Although gypsum exhibits several advantageous physical and chemical properties, its mechanical performance is relatively low, as it tends to be brittle in nature (Alcaraz *et al.,* 2019). Fibre reinforcement has been identified as an effective approach to overcoming this limitation, enhancing both the strength and durability of gypsum-based composites. If such reinforcement can be achieved using locally available fibres, it will not only improve the mechanical behavior of the composite but also reduce the cost of the final product (Ngaaje, 2021). Reinforcements in the form of fibres function by carrying the applied load, thereby providing additional strength and support to the composite structure. Indeed, fibres have been reported to bear more than 70% of the applied load within composites (Gu, 2009). The effectiveness of reinforcement depends on several parameters, including the type, length, concentration, distribution, and bonding of the fibres within the gypsum matrix, all of which significantly influence mechanical properties [8]. However, the optimal volume fractions of specific fibres in given resins for maximum performance remain inadequately defined (An *et al*., 2023). Natural fibres—sourced from plants, animals, and minerals—are increasingly recognized as sustainable alternatives to synthetic fibres due to their lower cost, lighter weight, biodegradability, and impressive mechanical characteristics (Elfaleh *et al*., 2023). Their utilization provides cost-effective solutions across diverse sectors, including aerospace, construction, consumer goods, automotive, marine, and medical industries, while also supporting rural economies (Puttegowda, 2025). Prior studies have demonstrated that both natural and glass fibres can effectively distribute stress loads within gypsum composites, thereby addressing issues such as low flexural strength (Kuqo & Mai, 2021). However, the properties of gypsum-based materials can be modified by incorporating various particulate additives such as sand, perlite, or lightweight aggregates—to alter parameters like density, thermal conductivity, and acoustic insulation. Such modifications enable tailored performance suitable for diverse construction and interior design applications (Doleželová *et al*., 2021).

II. METHODOLOGY

A. MATERIAL PREPARATION AND CHARACTERIZATION

The materials involve include but not limited to the POP cement and ISF which were bought from a major distributer. The materials were characterized in accordance to relevant international standards. The gypsum composite was produced using POP cement-to-water ratio for dispersion as 0.48. A 450 x 100 x 12.5 mm mold was lubricated with oil and half filled with the dispersion, and different percentages of the ISF by weight of the POP cement was evenly spread/distributed at from 0%, 0.5%, 1%, 1.5%, and 2%. The second dispersion was applied and allow to set in the mold. The composites were produced in the order below

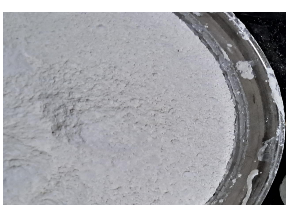


Plate 1. POP cement


Plate 2. Water


Plate 3. ISF


Plate 4. Gypsum bio

A. FLEXURAL STRENGTH

Flexural strength is defined as the maximum stress that a material can withstand without failing or breaking when subjected to a bending load. The test was carried out according to [14]. ASTM C473-19, using Universal Testing Machine. The flexural strength was calculated using equation 1 below.

$$\text{Flexural Strength} = \frac{3FL}{2bd^2} \qquad 1$$

Where F=maximum Load, L = Length of the Sample, b = width of the sample, d = thickness

B. WATER ABSORPTION (WA)

The water absorption test for the produced sample was done in conformity with ASTM C473. The samples of sizes 100mm x 25mm x 12.5mm were weighed to get the dry weight, immersed in distilled water for 2 hours. It was removed, surface dried and re-weighed to get the soaked weight. The percentage of water absorption was calculated using Equation 2 below.

$$WA\% = \frac{M2-M1}{M1} X\,100 \qquad \textbf{2}$$

Where M2= saturated surface dried mass, M1= Oven dried mass

C. DENSITY

Density test is the ratio of sample weight to its volume according to ASTM C473, and it is measured in kg/m^3. The density test was carried by weighing each sample on a weighing balance and the measured sample weight was divided by the volume of the used mold. The density was calculated using the equation 3 below.

$$\rho = \frac{M}{V} \qquad \textbf{3}$$

Where ρ= density, M= mass of the sample V= volume of the mold

D. HARDNESS

This test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. The surface hardness values were measured using 5019D Shore D hardness tester.

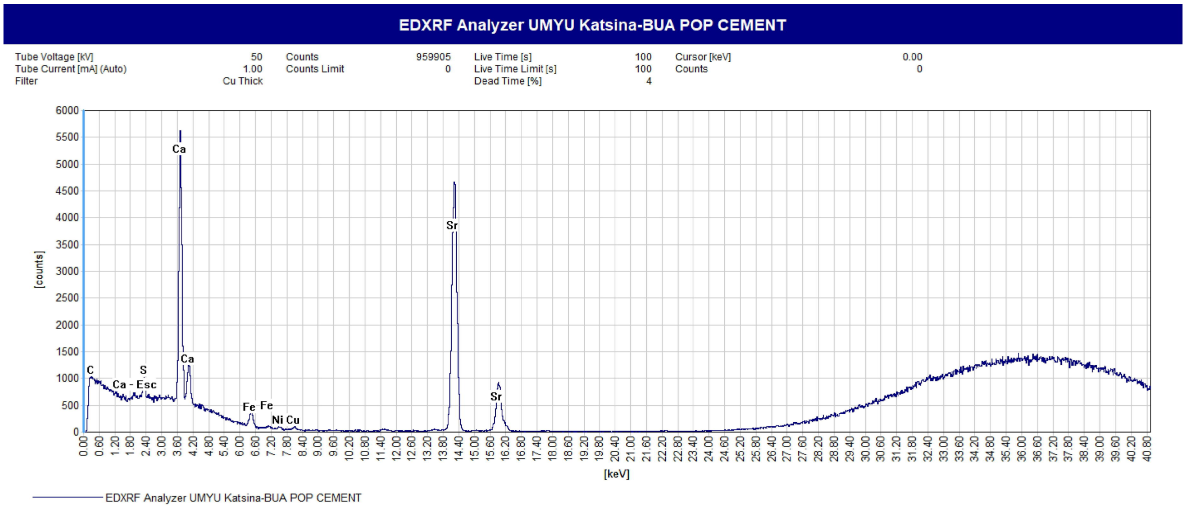
III. RESULTS AND DISCUSSION

A. MATERIALS CHARACTERIZATIONS

From table 1 and figure 1 indicated the elemental oxide concentration and their spectra respectively. The percentage concentration of SO_3 is less than the recommended percentage of 35, the CaO and MgO have satisfied the required percentage and can described as POP cement which is in line with IS 2547-1 (1976). The ISF chemical and mechanical properties has fall within the range suggested by Elfaleh *et al.*, 2023, to be used as reinforcements.

Table 1. Chemical oxide composition of POP cement

S/N	ELEMENT	CONCENTRATION (%)
A	SO_3	25.6
B	SiO_2	12.5
C	CaO	40.89
D	Al_2O_3	0.93
E	MgO	0.76



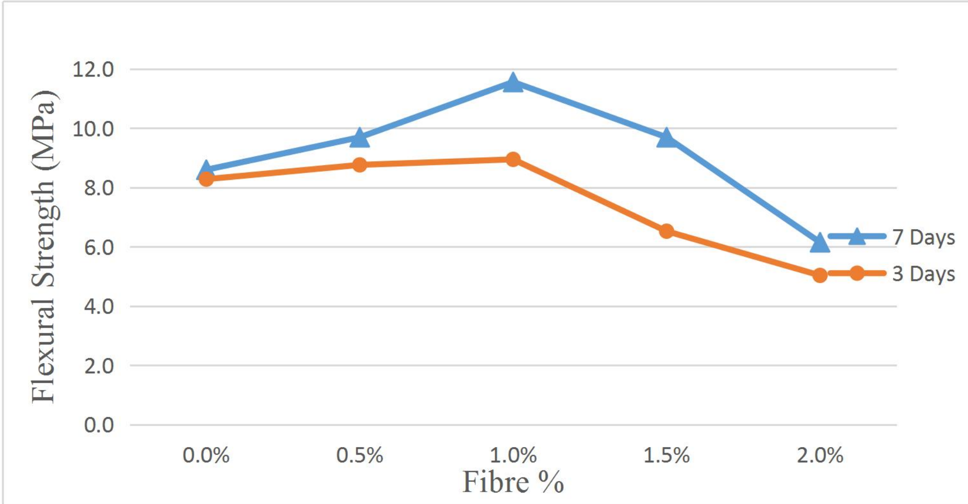
1: The Spectra of the X-Ray Fluorescence Results

Table 4.8: Chemical and Mechanical properties of ISF

Description	ISF
Hemicellulose (%)	22.6
Cellulose (%)	63.46
Lignin (%)	6.70
Young Modulus (GPa)	22.4
Tensile strength (MPa)	273.10
Elongation (mm)	4.89

B. FLEXURAL STRENGTH

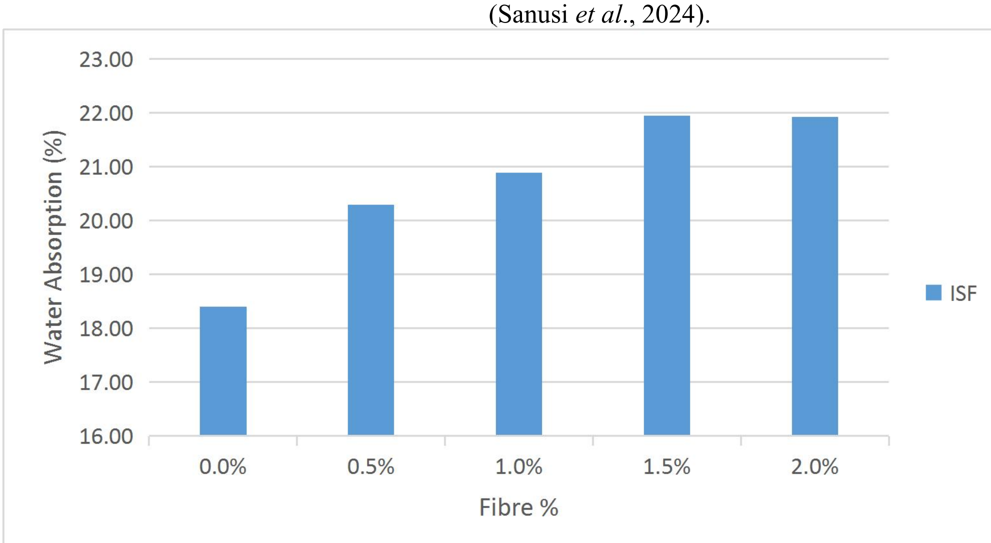
The flexural strength results of the ISF composites produced with varying the fibre contents are presented in the figures 2 below. The result for the maximum flexural strength for ISF reinforced composites are 10.5MPa & 10.8MPa at 1% fibre content for 3days and 7days early strength respectively. The increase in strength is as a result of addition of fibre to the matrix and the POP cement serves as coating to the fibre and increases the fibre matrix adhesion, as the fibre content increases, the fibre adhesion decreases and the flexural strength decreases, this is true from the research of (Madueke *et al*., 2022). He reported that definite increase in the fibre loading does not result to definite increase in the tensile properties of the composite because there exists a critical volume above which further increase in the volume of the fibres results to decrease in the tensile properties.



2: Variation of reinforcement on flexural strength of the ISF composites.

C. WATER ABSORPTION

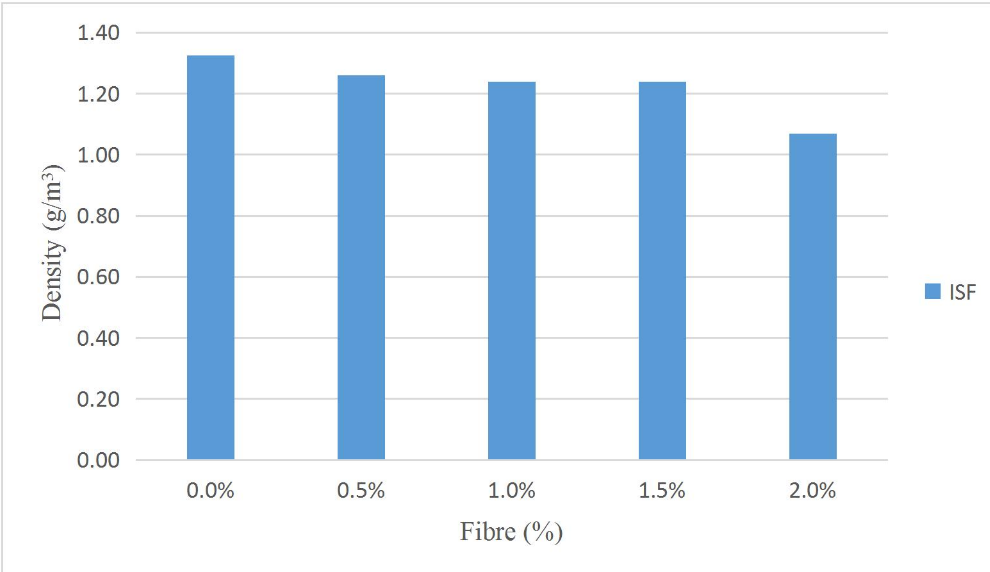
The results of the WA test are presented in figure 3 below. The WA for ISF and NJF composites produced ranges between 18.4% to 21.92%. The composite with 0% fibre has the lowest water absorption and composite with 2% fibre has the highest values. The lowest WA value recorded could be attributed due to the none present of fibre in the composite as the natural fibres contributes to the water absorption capacity of the natural fibre reinforced composites (NFRCs) this statement is in line with the report of (Prasad *et al.*, 2022), who reported that an increase in fibre content increased the water adsorption of NFRCs attributed to water penetration between the fibre and matrix gap, lumen, and shell wall. As the fibre content increases the content of cellulose, hemicellulose and lignin increases which are responsible for WA as reported by (Sanusi *et al.*, 2024).



3: Variation of water absorption with fibre percentage

D. DENSITY

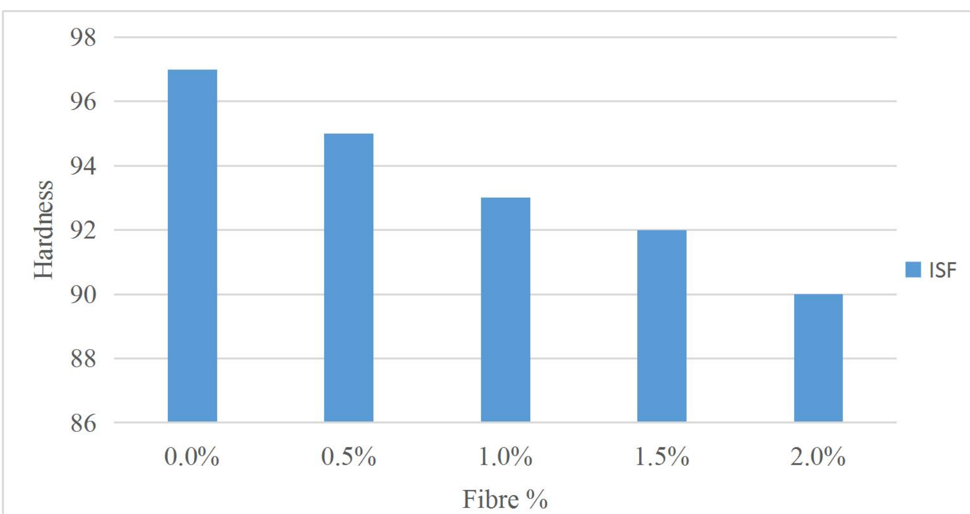
The density test results of the produced POP composites with ISF for different fibre content are shown in figure 4 below. The result of the densities ranges between 1.07kg/m^3 to 1.33kg/m^3 which is lower than the result obtained by (Sanusi *et al.*, 2024). as the author adopted a different method of mixing when producing the composites which reduces the porosity of the composites. The lower densities indicated a good choice for lightweight applications. There is decline in the density as the fibre content increases this is due to the increase in the porosity of the composites and this is in line with the statement that increased fibre loading, the porosity of the NFRCs rises due to an increase in fibre matrix compatibilization (Prasad *et al*., 2022). The porosity in the NFRCs can be reduced during the fabrication with the proper precautions and high pressure (Patel *et al*., 2023).



4: Variation in density with Fibre percentages

E. HARDNESS

The hardness test results are presented in figure 5 below for variation in fibre content. The hardness values of the composites reduce as the fibre content and water-to-POP cement ratio increases, this is due to the increase in porosity and viscoelastic behaviour of the composite which reduces its stiffness.



5: Variation in hardness with Fibre percentages

IV. CONCLUSION

The POP cement and the ISF fibre were characterized and have satisfied some requirement to be used as POP cement and as reinforcement in lightweight applications. The addition of ISF improves the mechanical properties of the brittle POP/gypsum composite and has satisfied the requirement of [14] to be used as a ceiling board in building construction applications.

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