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Effect of Sisal Fibre Length and Volume Fractions on Fibrous Concrete Performance

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Abstract: Sisal fiber has various advantages that make it a very promising concrete reinforcement material. These include its low cost, lightweight nature, excellent strength-to-weight ratio, lack of health hazards, and widespread availability in some places. To put its significance in context, roughly 4.5 million tons of sisal fiber are produced globally each year. The paper aimed to study the effect of length and proportions of sisal fibres on the characteristics of concrete. Compressive, tensile, bending strength, and water absorption were studied in the experimental program, in addition to the workability and microstructure of fibrous concrete. Short sisal fibres (SSFs) with lengths of 10 mm, 20mm, and 30mm, and different ratios of 0.4%, 0.8%, and 1.3% from cement weight were used. The results of the study indicated that Mix 9, which contains 30mm long SSFs with a percentage of 1.3%, showed the best results for compressive, tensile, and bending resistance of 37.52MPa, 37.52MPa, and 5.12MPa, respectively. Increasing the percentage of SSFs reduced workability, but in general, workability was acceptable, as sample M3 showed a slump of 9.8mm. The longer the fibres, the better the cohesion between the fibres and the cement paste, and this is reflected in the improvement of the results. Samples containing SSFs show a noticeable improvement in stress redistribution, crack arrest, and the microstructure of concrete.

[M.A Eita, Mohammed M. Attia. **Effect of Sisal Fibre Length and Volume Fractions on Fibrous Concrete Performance**. *J Am Sci* 2021;17(6):86-97]. ISSN 1545-1003 (print); ISSN 2375-7264 (online). http://www.jofamericanscience.org. 10. doi:10.7537/marsjas170621.10

Keywords: Sisal fibre; Natural fiber; Mechanical properties; Absorption; Fibrous concrete; SEM.

1. Introduction

Concrete is a popular construction material because to its great compressive strength, rigidity, and durability in various environments [1]. Concrete is brittle and has a low-tension strength. Plain concrete has two drawbacks: low tensile strength and low strain at fracture [2]. New materials have arisen to solve the constraints of traditional concrete, with distinct qualities that make them highly adaptable to a variety of environmental conditions. These materials have unique features that make them extremely responsive to their surroundings [3]. Fiber-reinforced concrete is a novel composite material that mixes concrete and short, equally distributed fibers to improve a variety of engineering properties. This includes increased flexural strength, shear strength, fatigue, and impact resistance, as well as crack avoidance due to temperature and shrinkage. The addition of these fibers to the concrete matrix transforms its overall performance and durability [4]. Steel, polypropylene, glass, synthetic, and natural fibres are commonly used.

Natural fibers encompass a wide range of materials that are derived from plants, animals, and geological processes. Natural fibres are inexpensive and readily available in many nations [5]. Using natural fibers as a construction material can significantly improve the characteristics of composites while keeping costs down [6]. Plant fibers have emerged as a viable alternative to steel and synthetic fibers in composite materials such as cement paste, mortar, and concrete due to their potential to improve strength qualities. These natural fibers include coir, sisal, jute, Hibiscus cannabinus, eucalyptus grandis pulp, malva, ramie bast, pineapple leaf, kenaf bast, sansevieria leaf, abaca leaf, vakka, date, bamboo, palm, banana, hemp, flax, cotton, and sugarcane. Incorporating these natural fibers into composites provides various benefits, including increased mechanical characteristics and sustainability [7]. Natural fibers' suppleness adds to their ease of usage and handling. However, complications may occur when a large number of fibers are required, as is the case with steel fibers. While natural fibers' elasticity makes them easier to incorporate into composites, logistics become more problematic when a high fraction of fibers is required. This is especially important when using steel fibers since their stiffness might cause issues during the mixing and positioning processes. Thus, significant consideration is required to optimize the handling and distribution of fibers in composites to ensure consistency and effectiveness [8]. To use high percentages of fibres, a casting technology must be developed fiber content and volume fraction are terms used to quantify the amount of fibres in a composite material [9]. R.D. Tolêdo Filho[10] conducted a study to investigate the impact of low modulus sisal, coconut, and polypropylene fibers on free plastic shrinkage and cracking sensitivity during the early drying of mortars. The study also examined the influence of crack control on the corrosion of steel bars, which are susceptible to cracks in the matrix. The findings indicated that low-volume sisal and polypropylene fibers were particularly effective in minimizing free plastic shrinkage, delaying the appearance of the first crack, and limiting fracture growth. This is attributed to the fact that the elastic modulus of these fibers is higher than that of the cementitious matrix at an early age. Emma Boghossian et al, [11] conducted a study to assess the plastic shrinkage parameters of mortar specimens reinforced with short flax fibers. The study examined the effectiveness of flax fibers compared to commercially available polypropylene and glass fibers in controlling restrained plastic shrinkage cracking. The researchers varied the volume of flax fibers from 0.05% to 0.3% in the mortar mixture. The evaluation was based on the number of cracks, total crack area, and maximum crack widths observed within the first 24 hours after casting and exposure to hot, dry, and windy conditions. The findings of the study indicated that flax fibers were slightly more effective than polypropylene and glass fibers in controlling restrained plastic shrinkage cracking in the specific mortar mixture studied. This conclusion was based on the observed reduction in the number of cracks, total crack area, and maximum crack widths. The incorporation of flax fibers showed promise in mitigating the effects of shrinkage and improving the performance of the mortar under challenging environmental conditions. Venkateshwaran. S et al, [12] conducted the mechanical properties of fibrous concrete. They compared the properties of fibrous concrete with different SSFs volume fractions (0.5%, 1%, and 1.5%) and an aspect ratio of 1:20, to those of ordinary M25 concrete. The results showed that the SSFs replacements had a significant impact on the concrete's performance. The study found that the compressive strength of fibrous concrete increased at 28 days. The increase was 13.8%, 21%, and 16.3% for SSFs replacements of 0.5%, 1%, and 1.5% respectively, compared to standard concrete. This indicates that the addition of SSFs improved the concrete's ability to withstand compressive forces. Additionally, the split tensile strength of the fibrous concrete also increased significantly. At 28 days, the split tensile strength increased by 24%, 56%, and 80% for SSFs replacements of 0.5%, 1%, and 1.5% respectively, compared to normal M25 concrete. This suggests that the SSFs enhanced the concrete's resistance to tensile stress. Furthermore, the study examined the early cracking load in flexure of the fibrous concrete. The results showed that the addition of SSFs improved the concrete's ability to resist cracking. At 28 days, the early cracking load in flexure increased by 12.5%, 27.5%, and 20% for SSFs replacements of 0.5%, 1%, and 1.5% respectively, compared to normal M25 concrete. M Kalaivani et al. [13] focused on jute fibre reinforced concrete and its potential for partial replacement of fine aggregate using plastic waste. Jute fibre was added in quantities of 0.25, 0.5, 0.75, and 1% by volume to optimum plastic waste concrete. It has been found that natural fibres in concrete improve their strength. Gizachew Markos Makebo et al. [14] investigated the effect of banana fiber in typical C-25 grade concrete. The aim of this study was to estimate the workability, unit weight, compressive strength, and splitting strength of concrete after 7, 28 days of curing. The study looked at 0%, 0.5%, 1%, 1.5%, and 2% banana fibre in concrete manufacture and determined its effect on fresh and cured concrete. It was established that the mechanical properties of waste banana fibered concrete, and flexural strength tests with various percentages ranging from 0 to 2%, produced satisfactory results. Zhijian Li et al. [15] investigated the characteristics of hemp fibre on fibrous concrete. The experimental study's variables included mixing method, fibre content by weight, aggregate size, and fibre length. It is found that fibre content by weight is the key component that impacts the compressive and flexural properties of HFRC, regardless of the mixing method used.

Finally, it is important to note that the specific impacts of volume fraction and fiber length on concrete qualities might differ based on factors such as fiber type, concrete mix design, and testing methodologies used. On the other hand, Sisal fibre is regarded environmentally beneficial, and its use is consistent with the growing public awareness of the benefits of natural fibres. So, the paper aimed to study the effect of length and ratio of SSFs on the compressive, tensile, bending strength, and water absorption, in addition to the workability and microstructure of fibrous concrete.

2. Experimental Program

2.1 Materials

In this study, Ordinary Portland cement (OPC) CEM I 42.5 N from the Cement Suez Company was used. The physical parameters and chemical compositions of the cement to meet the ASTM [16] are presented in Table 1. For the fine aggregate, siliceous sand was used. It had a specific gravity of 2.53 g/cm^3 and a water absorption of 1.62%. As for the coarse aggregate, crushed stone with a maximum nominal size of 12 mm was used. It had a water absorption of 1.11% and a specific gravity of 2.51 gm/cm^3. A sieve analysis test of the fine and coarse aggregates was conducted in line with the ASTM [17]. The results of this test are depicted in Fig. 1. To enhance the workability of concrete, the study utilized Sika Visco-Crete 3425. This product is a dual-action liquid super-plasticizer that can be used to create free-flowing concrete or as a significant water-reducing agent for achieving high strength and early strength development. It has a specific gravity of 1.08 and is added at a rate of 2.3% of the cement content. Sika Visco-Crete 3425 conforms to [18].

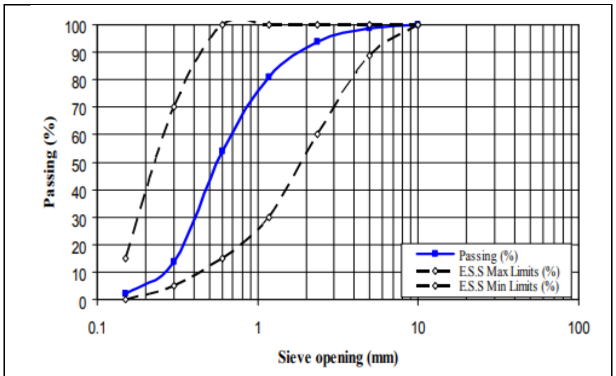
Table 1: Properties of Cement

Physical properties	CEM I
Specific gravity	3.13
Blaine surface area (cm^2/g)	3350
Color	Gray
Chemical Composition	
SiO2	21.89
Al2O3	4.68
Fe2O3	3.84
CaO	62.01
MgO	1.95
SO3	1.82
Na2O	0.2
K2O	0.2
L.O.I	1.89

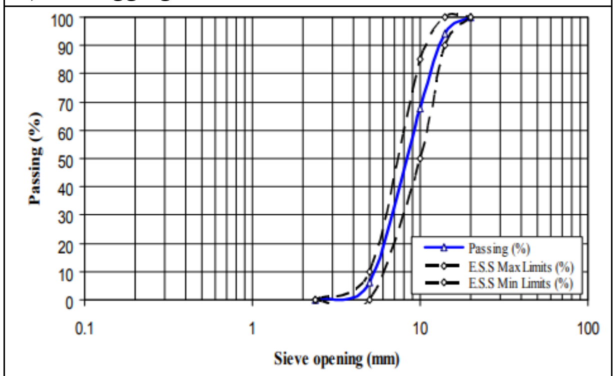
Table 2. Characteristics of SSFs

Properties	SSFs
Mechanical properties	
Tensile strength (MPa)	450
Young's Modulus (GPa)	38
L/D ratio	150
Physical properties	
Moisture content (%)	10
Density kg/cm^3	1450

The properties of SSFs which were used in the study are listed in Table 2 and shown in Fig. 2. These fibers were sliced to the desired length. To analyze the SSFs, scanning electron microscopy (SEM) scans were conducted, and the key elements present in the fibers were determined using energy-dispersive X-ray (EDX) spectrum analysis through spot scan EDX, as shown in Fig. 3, 4 respectively. The SSFs are soaked in NaOH solution for approximately 24 hours and then dried for approximately 24 hours before mixing with concrete.



a) Fine aggregate



b) Coarse aggregate

Fig. 1: Sieve analysis of aggregates

2.2 Mixing Procedure

Table 3 displays the design proportions for the different mixtures. The ACI [19], [20] was utilized to determine the mix design for mix with and without fibres. The addition of SSFs of varying lengths and VFs was the primary variation between the mixes. In this study, three fibre lengths of 10mm, 20mm and 30 mm were used at various ratio of cement weights of 0.4%, 0.8%, and 1.3%. Concrete was mixed in accordance with ACI [19], [20], which comprised adding aggregates, sand, and cement to the mixer and dry mixing for 1 minutes. The mixing water, which contained a superplasticizer additive, was added to the mixture, and mixed for another 1.5 minutes. Finally, the SSFs were carefully distributed throughout the mixture, and mixing was maintained to guarantee complete homogeneity. In fibrous concrete, the prior technique was critical for achieving good fibre dispersion, resulting in a homogeneous composite, and preventing the balling effect, which would otherwise result in the formation of fibre balls during concrete mixing.

Table 3. Proportions of concrete mixtures

No	SSFs (%)	SSFs Length (mm)	Cement (Kg)	Fine Agg. (Kg)	Coarse Agg. (Kg)	Water (Liter)	Admixture (Liter)
0	0	0	450	895	1392	180	9
1	0.4	10	450	895	1392	180	9
2	0.8	10	450	895	1392	180	9
3	1.3	10	450	895	1392	180	9
4	0.4	20	450	895	1392	180	9
5	0.8	20	450	895	1392	180	9
6	1.3	20	450	895	1392	180	9
7	0.4	30	450	895	1392	180	9
8	0.8	30	450	895	1392	180	9
9	1.3	30	450	895	1392	180	9

Fig. 2: Short Sisal fibres (SSFs)

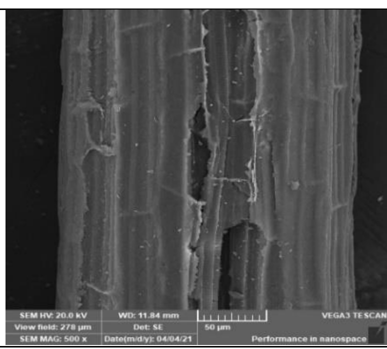


Fig. 3: SEM image of SSFs

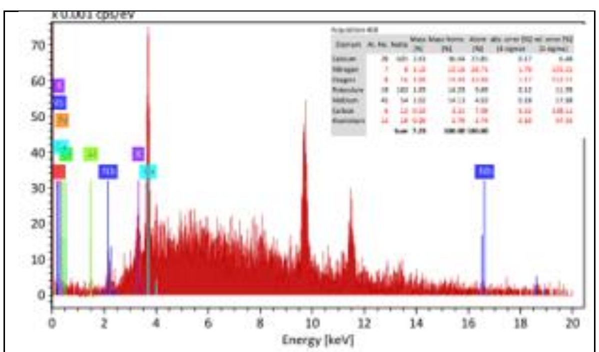


Fig. 4: EDX of SSFs

2.3 Testing Procedure

The characteristic of mixtures was measured in both fresh and hardened conditions. The slump test was performed according to the ASTM [21]. The compressive, tensile, bond stress and flexural strengths of the mixtures were determined. Compression tests were performed on cubic samples measuring 150 × 150 × 150 mm on days 3, 7, and 28 by BS [22] The compressive test was performed using a Testing Machine with a maximum capacity of 2000 kN and a loading rate of 0.6 MPa/s, as seen in Fig. 5-a. To comply with ASTM [23], cylinder specimens of 150 mm in diameter and 300 mm in length conducted an indirect splitting tensile test on day 28 as shown Fig. 5-b. The following formula was used to get the concrete's splitting tensile strength (ft):

$$ft = (2 \cdot P)/(\pi \cdot d \cdot L) \text{ MPa} \quad \text{Eq.1}$$

where P = Peak load indicated by testing machine, (N). d = Diameter of the specimen, (mm). L = Length of the specimen, (mm).

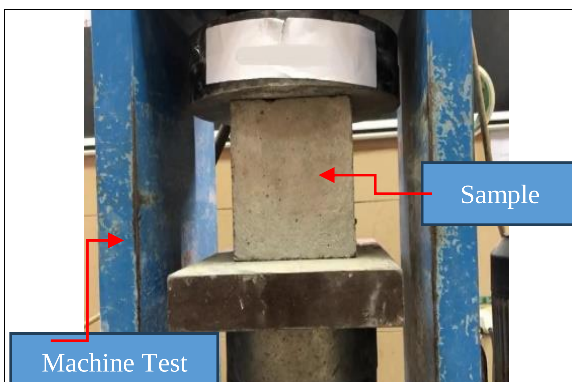


Fig. 5: a) Compressive test

As shown Fig. 5-c, prism samples of 100 x 100 x 500 mm were subjected to a flexural test on day 28 to meet the ASTM [24]. One point loading at the middle of the beam was applied to the specimens until failed. The following formula was used to get the modulus of rupture (Fr):

$$f_r = (3\cdot P\cdot L)/(2\cdot b\cdot d^2)\ \text{MPa} \qquad \text{Eq.2}$$

where P = Peak load indicated by testing machine, (N). b, d = Width and depth of beam, (mm). L = Span Length of the specimen, (mm).

For the absorption test, three cubical specimens of 70 x 70 x 70 mm were utilized, and the procedure was followed to meet ASTM [25]. Samples were subjected to microscopic morphology using a Variable Pressure Scanning Electron Microscope (SEM).

b) c)

Fig. 5: b) tensile test, c) bending test

3. Results and Discussions

3.1 Workability

Fig. 6 shows the slump test results which used to estimate the workability for all samples. The control sample, which was without fibres, recorded a slump of 16mm. In the samples containing fibres with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the slump decreases at a successive rate of 18.7%, 28.12%, and 40.6% compared to the control sample, while of the samples containing fibres with a length of 20 mm the slump decreases of 13.41%, 20.12%, and 35.6%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the slump decreases up to 22.56% compared to the control sample. The results show that increasing the percentage of fibre decreases the slump. This observed phenomenon can be attributed to the fibrous nature of sisal, which imparts structural changes within the concrete mix. As the concentration of SSFs rises, their interaction with the cement matrix creates a composite material with diminished fluidity. The three-dimensional network formed by the fibres hinders the movement of particles within the mix, limiting its ability to deform easily under compaction. Furthermore, the surface characteristics of sisal fibres contribute to increased frictional forces within the mix, further impeding particle flow. Consequently, the slump test values decrease proportionally with higher percentages of sisal fibres, reflecting a decrease in the workability of the concrete mix. Understanding this relationship is crucial for optimizing concrete mix designs that balance the benefits of sisal fibre reinforcement with the necessary workability for practical construction applications.

The slump value reduced with the addition of fibres and increased with the usage of long fibres relative to short fibres with the same amount of fibre. Samples containing 0.4% fibres and fibres with lengths of 10mm, 20mm, and 30 mm had a successive decrease in slump value of 18.7%, 13.12%, and 7.31% compared to the control sample, while with fibre ratio 0.8% increases the fibre length from 10mm to 30mm the slump was reduced 12.8%. Samples containing 1.3% fibre and fibres with lengths of 10mm, 20mm, and 30 mm a reduction in slump value of 40.24%, 35.98%, and 22.56% compared to the control sample. The results reveal that an increase in the length of sisal fibres corresponds to a notable improvement in the workability of the concrete. This improvement can be attributed to the enhanced reinforcement and distribution of fibres within the cement matrix. Longer sisal fibres contribute to a more interconnected and robust three-dimensional network within the concrete, affording better support and alignment. This network facilitates the movement of particles, allowing for improved deformability during compaction. Moreover, longer fibres inherently possess a higher aspect ratio, promoting efficient stress transfer between the fibres and the cement matrix. This, in turn, enhances the overall integrity and structural performance of the concrete. The improved workability associated with longer sisal fibres not only streamlines the construction process but also positively influences other mechanical properties, such as tensile strength and durability. Thus, optimizing sisal fibre length in concrete formulations emerges as a pivotal consideration in the quest for materials with superior workability and enhanced mechanical performance in construction applications.

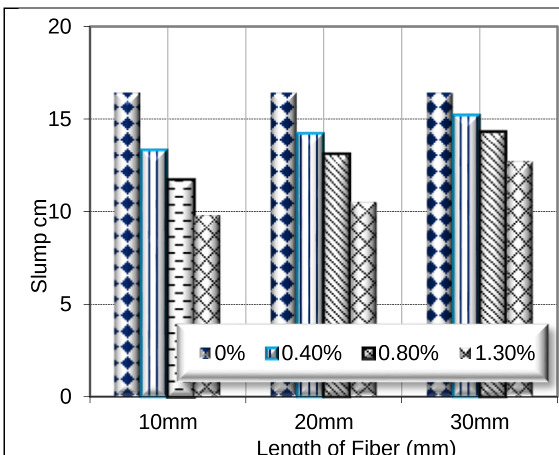


Fig. 6: Effect of Length and Ratio of SSFs on workability

3.2 Compressive Strength

Fig. 7 displays the compressive test findings for all samples versus the ratio and fibre length. By increasing the proportion and length of the SSFs, the compressive strength improves satisfactorily, and the samples containing the fibres show higher compressive strength than the control sample. This phenomenon can be attributed to the reinforcing effects of the fibres within the cement matrix. SSFs, characterized by their high tensile strength and stiffness, effectively augment the composite material's resistance to axial loads. The three-dimensional network formed by the fibres acts as an internal reinforcement system, mitigating crack propagation and enhancing the overall structural integrity of the concrete. The increased density of the fibrous matrix contributes to improved load distribution and stress transfer mechanisms, thereby fortifying the material against compressive forces. The control sample showed a compressive strength of 30.62 MPa. In the samples containing SSFs with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the compressive strength increases of 2.93%, 9.51%, and 14.3% compared to the control sample, while of the samples containing SSFs with a length of 20 mm the strength increases of 5.1%, 9.90%, and 17.99%, respectively. In the sample with a length of 30mm and ratio of SSFs 0.4%, 0.8%, and 1.3% the compressive increases up to 22.52%.

Fiber length significantly influences concrete strength. Longer fibres enhance structural integrity by reinforcing the matrix and promoting efficient stress transfer. This contributes to improved load-bearing capacity and crack resistance, highlighting the crucial role of fibre length in enhancing the overall strength of concrete strength. The samples with SSFs ratio of 1.3% and lengths of 10, 20 mm, and 30 mm showed the higher compressive strength of 35.02MPa, 36.13MPa, and 37.52MPa with improved14.36 % 17.1%, and 22.52%, respectively, compared to control mix. The samples containing SSFs with a ratio of 0.4% illustrated improved in compressive strength of 2.9%, 5.1%, and 10.1% with length of SSFs 10mm, 20mm, 30mm, respectively, compared to control mix, while of the sample with 0.8% were 9.53%, 9.87%, and 12.41%.

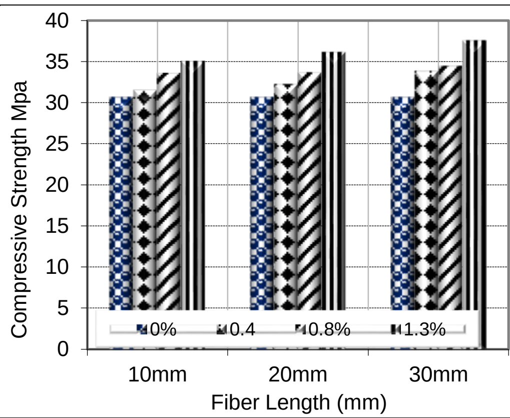


Fig. 7: Effect of Length and Ratio of SSFs on compressive strength

Curing age positively impacts concrete strength due to ongoing hydration reactions. As time progresses, the continuous formation and maturation of calcium silicate hydrates enhance interparticle bonding, reduce microcracks, and optimize the material's microstructure, resulting in improved overall strength and durability. Concrete increases significantly in compressive strength over the first six days of curing. It reached its maximum resistance after 28 days as it kept getting harder through cement hydration. The effects of curing age on samples with fibre lengths of 10, 20, and 30 mm, respectively, are displayed in Figs. 8–10. For instance, at 3d, 7d, and 28d, the samples with 10mm and 0.5% SSFs had compressive strengths of 15.91MPa, 22.28MPa, and 31.52MPa, respectively. From 3d to 28d, the samples' compressive strength grew progressively to 96.03%.

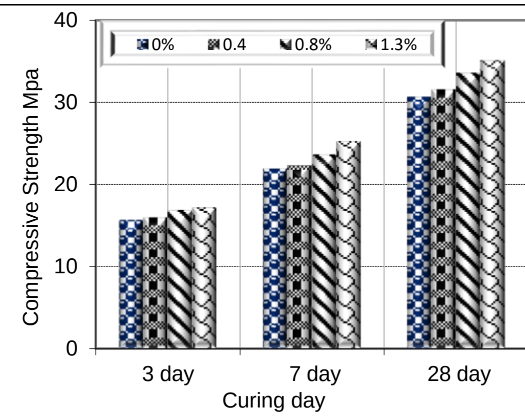


Fig. 8: Compressive strength vs curing day of 10 mm fibres

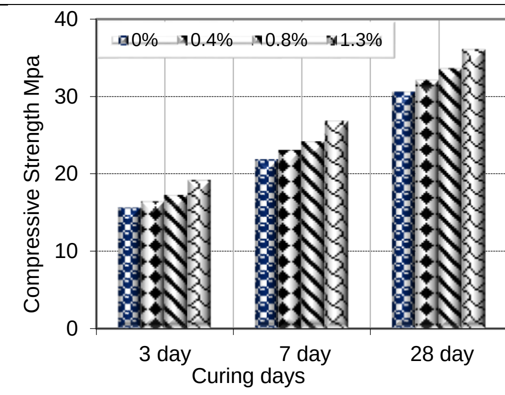


Fig. 9: Compressive strength vs curing day of 20 mm fibres

3.3 Tensile Strength

Fig. 11 shows the splitting tensile test results for all samples. The control sample, which was without fibres, recorded a tensile strength of 2.56MPa. The percentage of SSFs in concrete directly influences its tensile strength. As the fibre content increases, a reinforcing network forms, mitigating crack propagation and enhancing the material's ability to withstand tensile forces. Optimizing the sisal fibre percentage is critical in achieving improved tensile strength and contributing to the overall durability and performance of the concrete in various applications. In the samples containing fibres with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the tensile strength increases at a successive rate of 4.30%, 9.41%, and 12.94% compared to the control sample, while of the samples containing fibres with a length of 20 mm the tensile strength increases of 10.58%, 15.29%, and 22.35%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the slump decreases up to 28.24% compared to the control sample.

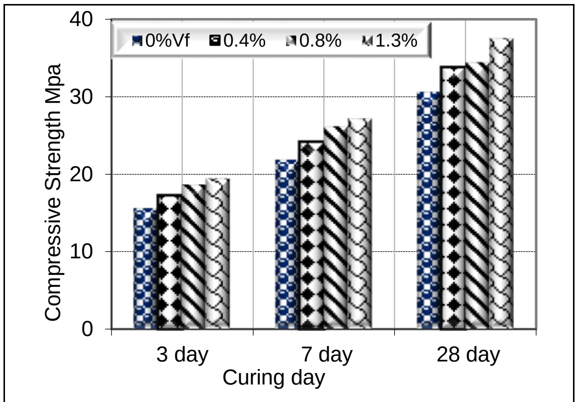


Fig. 10: Compressive strength vs curing day of 30 mm fibres

Increased lengths of SSFs in concrete lead to a proportional improvement in tensile strength. The extended fibres enhance the material's resistance to tensile forces by fostering a more efficient load-bearing structure, facilitating effective stress transfer, and reducing the likelihood of cracking. The samples with SSFs ratio of 1.3% and lengths of 10, 20 mm, and 30 mm showed the higher tensile strength of 2.88MPa, 3.12MPa, and 3.27 MPa with improved12.9 %, 22.35%, and 28.24%, respectively, compared to control mix. The samples containing SSFs with a ratio of 0.4% illustrated improved in tensile strength of 4.7%, 10.55%, and 16.86% with length of SSFs 10mm, 20mm, 30mm, respectively, compared to control mix, while of the sample with 0.8% were 9.40%, 15.29%, and 23.51%.

The inclusion of SSFs in concrete establishes a noteworthy relationship between compressive and tensile strengths. SSFs enhance the concrete's tensile strength by creating a reinforcing network, reducing the likelihood of cracks. This, in turn, positively impacts the compressive strength as the material becomes more resistant to the internal forces that lead to structural failure. Fig. 12 displays the splitting tensile strength vs compressive strength. The sample with 1.3% of SSFs and 30 mm length had the maximum tensile strength, outperforming the control sample without SSFs by 28.24%. An R-squared value of 0.95 was discovered for the second-order polynomial association that describes the splitting tensile strength of cylindrical specimens measuring 150 × 300 mm.

The relationship between splitting tensile strength and compressive strength is shown in Eq. (3):

$$F_t = 0.0056\, f_c^2 - 0.2872\, f_c + 6.174 \qquad \text{Eq.3}$$

where F_t the splitting tensile strength of the sample, and f_c refer to the compressive strength of the cube sample.

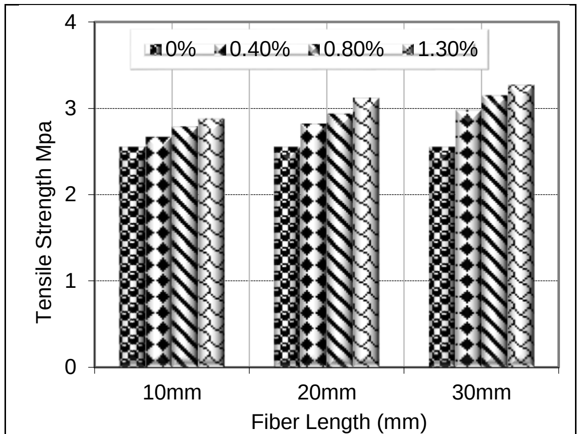


Fig. 11: Effect of Length and Ratio of SSFs on tensile strength

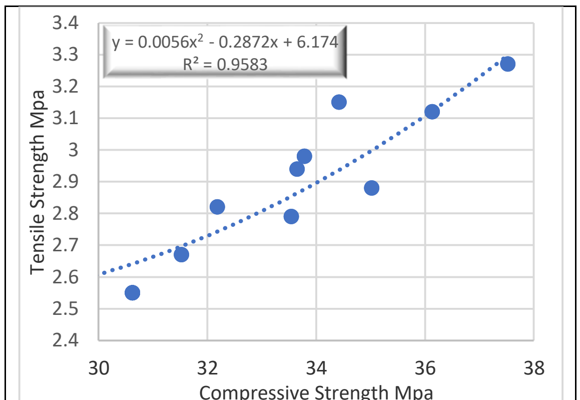


Fig 12: Tensile strength vs compressive strength

3.4 Flexural Strength

Fig. 13 displays the flexural test findings for all samples versus the ratio and fibre length. The control sample, which was without fibres, recorded a flexural strength of 3.93 MPa. In the samples containing fibres with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the flexural strength increases at a successive rate of 6.60%, 10.65%, and 13.49% compared to the control sample, while of the samples containing fibres with a length of 20 mm the flexural strength increases of 11.96%, 15.01%, and 18.83%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the flexural strength decreases up to 30.27% compared to the control sample.

The samples with SSFs ratio of 1.3% and lengths of 10mm, 20mm, and 30mm showed the higher flexural strength of 4.46MPa, 4.67MPa, and 5.12MPa with improved 13.49%, 18.83%, and 16.68%, respectively, compared to control mix. The samples containing SSFs with a ratio of 0.4% illustrated improved in flexural strength of 6.6%, 11.96%, and 16.53% with length of SSFs 10mm, 20mm, 30mm, respectively, compared to control mix, while of the sample with 0.8% were 10.68%, 15.05%, and 22.1%.

The relationship between compressive and flexural strengths is shown in Fig. 14. When SSFs increased compressive strength, so did their flexural strength in a monotonic manner. The sample with the highest flexural strength, measuring 30 mm in length and 1.3% SSFs, outperformed the control sample without fibres by 30.27%. An R-squared value of 0.88 was discovered for a second-order polynomial connection, indicating a high degree of agreement between the fitting and experimental data. The relationship between compressive and flexural strength is shown in Eq :(4) .

$$F_b = -0.0022\, f_c^2 + 0.5346\, f_c - 7.0785 \qquad \text{Eq.4}$$

where F_b refer to the flexural strength of the prismatic sample, and f_c refer to the compressive strength of the cube sample.

Conversely, the link between flexural strength and tensile strength is shown in Fig. 15. For the splitting tensile strength of cylindrical specimens (150 × 300 mm) and the flexural strength of prismatic samples (100 × 100 × 500 mm), a second-order polynomial correlation was discovered, with an R-squared value of 0.975. The relationship between splitting tensile strength and flexural strength is shown in Eq :(5) .

$$F_b = 0.0763\, f_t^2 + 1.4937\, f_t + 0.1594 \qquad \text{Eq.5}$$

where F_b, the flexural strength of the prismatic sample, and f_t, the splitting tensile strength of the cylindrical sample.

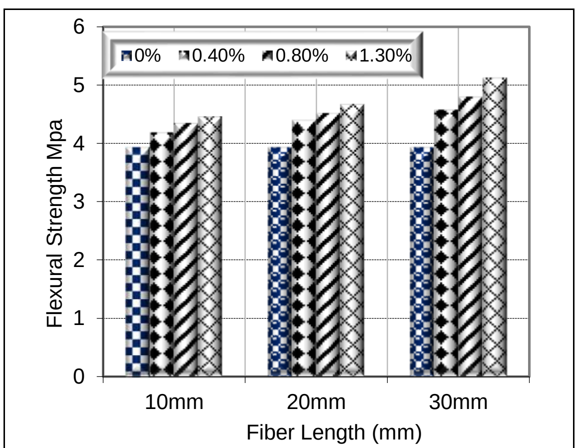


Fig. 13: Effect of Length and Ratio of SSFs on flexural strength

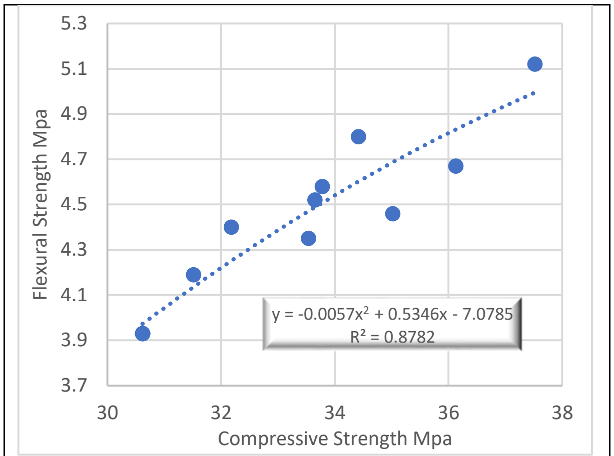


Fig 14: Flexural strength vs. compressive strength

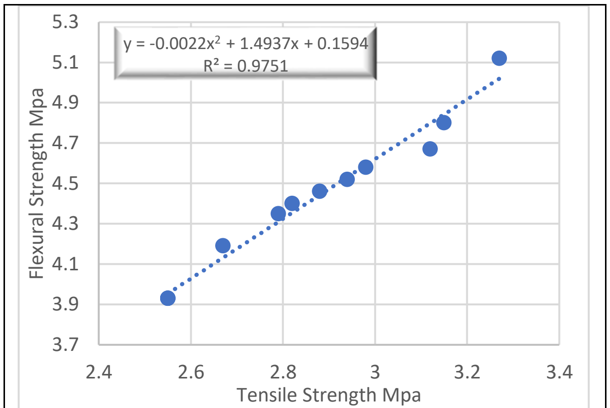


Fig 15: Flexural strength vs. tensile strength

3.5 Absorption Characteristic

The effect of the SSF_S ratio on each specimen's water absorption is shown in Fig. 16. The control sample, which was without fibres, recorded a water absorption of 3.72%. In the samples containing fibres with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the water absorption increases at of 22.58%, 29.03%, and 37.63% compared to the control sample, while of the samples containing fibres with a length of 20 mm the flexural strength increases of 17.70%, 22.58%, and 33.01%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the slump decreases up to 26.88% compared to the control sample. The samples with SSFs ratio of 1.3% and lengths of 10mm, 20 mm, and 30 mm showed the higher water absorption of 5.12%, 4.95%, and 4.72% with increases 37.63%, 33.01%, and 26.88%, respectively, compared to control mix. The samples containing SSFs with a ratio of 0.4% illustrated increase in water absorption of 22.58%, 17.71%, and 14.51% with length of SSFs 10mm, 20mm, 30mm, respectively, compared to control mix, while of the sample with 0.8% were 29.03%, 22.58%, and 19.35%.

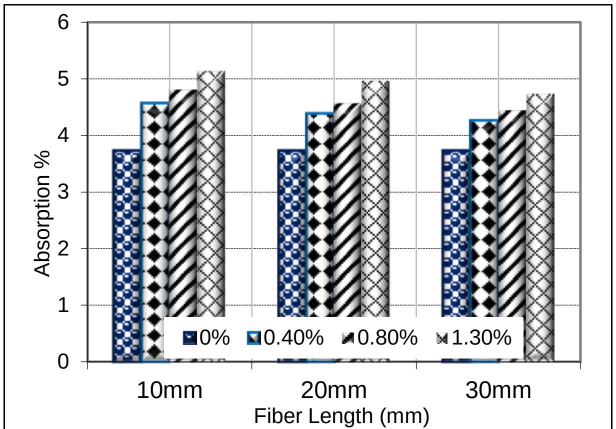
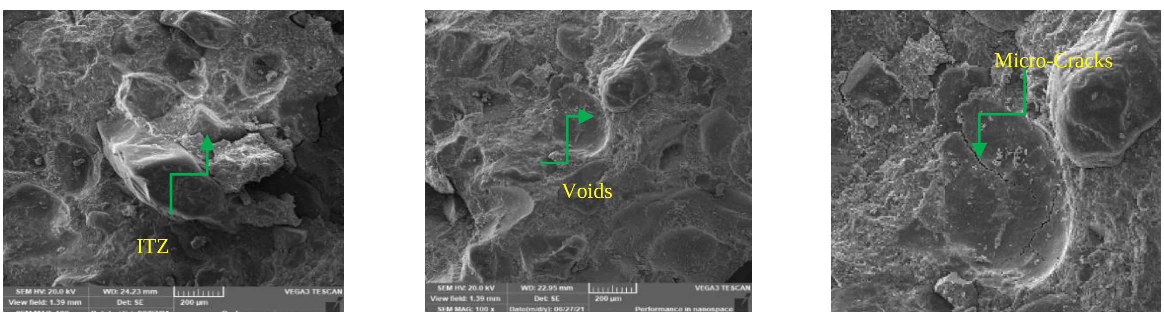


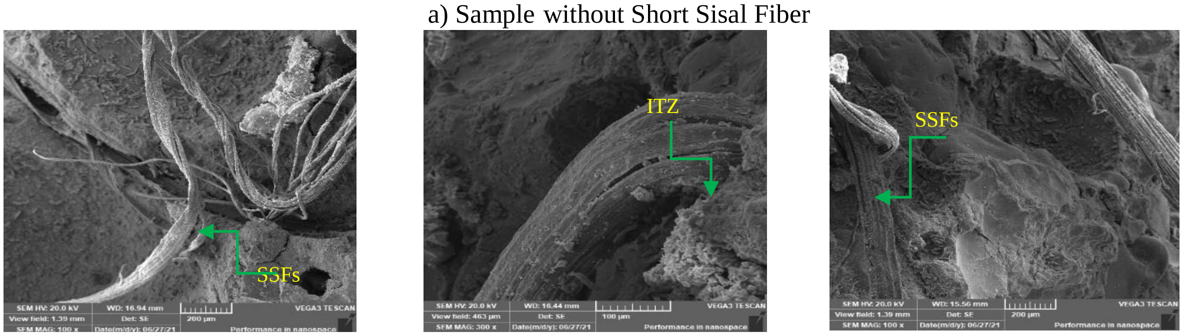
Fig. 16: Effect of Length and Ratio of SSFs on absorption

3.6 Microstructure Analysis

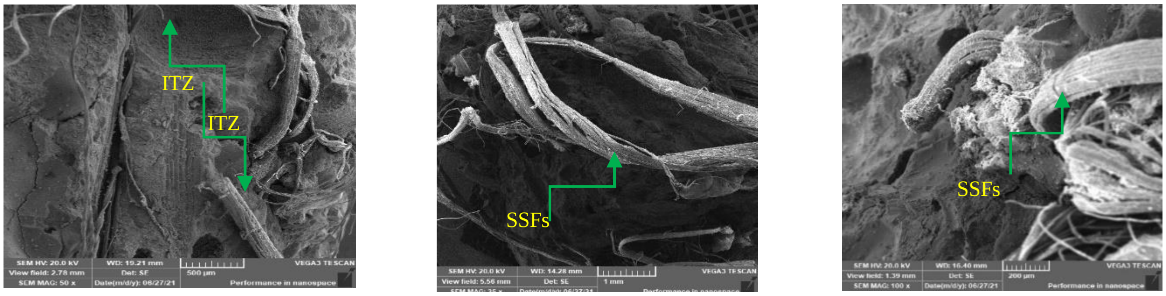
The examination of concrete morphology through Scanning Electron Microscopy (SEM) was undertaken to elucidate the influence of fibres on various aspects, including Interfacial Transition Zones (ITZs), micro-cracks, and their propagation within the matrix connecting fibre-cement paste and aggregate-cement paste. By employing SEM, the study aimed to gain insights into the intricate details of these interfacial regions, shedding light on how fibres interacted with the surrounding matrix. Specimens, with diameters ranging from 5 to 10 mm, were meticulously extracted from cubes subjected to compressive tests, ensuring a focused investigation into the microstructural features critical for understanding the mechanical behaviour and performance of fibre-reinforced concrete. Fig. 17-a depicts SEM images of the mixture without SSFs. The observed porosity resulted from initial water absorption, which impacted the rate of hydration. As shown in Figs. 17-b and d, the combination with SSFs had larger pores within the matrix. The existence of a prominent Interfacial Transition Zone (ITZ) between the SSFs and the paste was clearly visible, making the fibres easily identifiable. Furthermore, microcracks were discovered in the control composite, but no visible microcracks were found in the SSFs-containing mixtures. This can be ascribed to the inclusion of fibres, which reduced the production of micro-cracks and slowed their spread. These results are consistent with the mechanical parameters of the concrete mixtures, which include compressive, splitting tensile, and flexural strengths, as previously stated. Furthermore, the SSFs were found to be immersed in the cement paste, which increased matrix strength via a stress transfer mechanism between the matrix and SSFs. This effect, together with the fibers' ability to resist tensile stresses caused by external loads, led to the maintenance of the microstructure by preventing fracture growth.



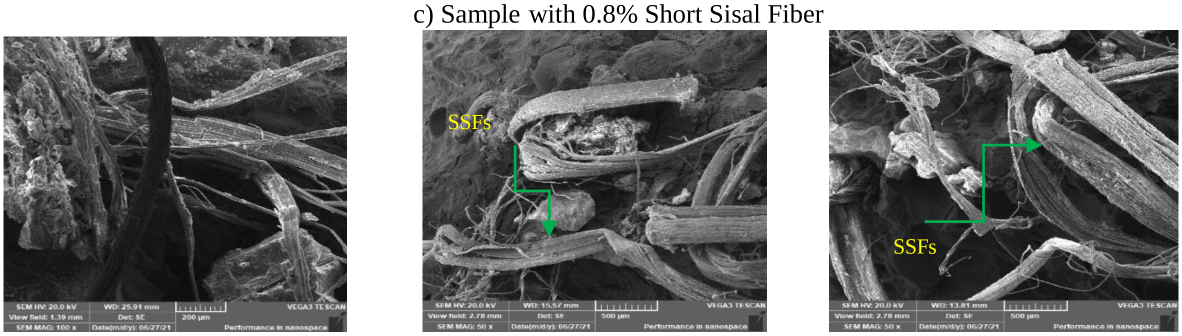
a) Sample without Short Sisal Fiber



b) Sample with 0.4% Short Sisal Fiber



c) Sample with 0.8% Short Sisal Fiber



d) Sample with 1.3% Short Sisal Fiber

Fig. 17: SEM of all specimens with and without Short Sisal Fiber

4. Conclusion

The study concludes that the inclusion of fibres in concrete derived from agricultural activities in construction materials improves the cracking behaviour of concrete and cement matrices. Based on the results, the following conclusions can be drawn: -

- The results showed that by increasing the percentage of SSFs, the slump decreased, and the sample M_3 with a length of 10 mm and a ratio of 1.3% recorded the lowest slump with a value of 9.8, which is considered an acceptable value for concrete workability. On the other hand, increasing the length of the SSFs reduces the loss rate of the slump.
- Increasing the percentage of SSFs leads to an increase in compressive strength, and the sample M_9 which had SSFs with length 30mm and ratio 1.3% recorded the highest compressive strength of compared to all samples 37.52MPa. While increasing the length of the SSFs leads to an improvement in compressive strength compared to shorter lengths.
- In the samples containing fibres with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the tensile strength increases at a successive rate of 4.30%, 9.41%, and 12.94% compared to the control sample, while of the samples containing fibres with a length of 20 mm the tensile strength increases of 10.58%, 15.29%, and 22.35%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the slump decreases up to 28.24% compared to the control sample. It can be noted that the highest value of tensile strength was for the sample M9, which contains SSFs with a length of 30mm and a ratio of 1.3%.
- In the samples containing fibres with a length of 10 mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the flexural strength increases at a successive rate of 6.60%, 10.65%, and 13.49% compared to the control sample, while of the samples containing fibres with a length of 20 mm the flexural strength increases of 11.96%, 15.01%, and 18.83%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the slump decreases up to 30.27% compared to the control sample. The samples containing SSFs with a ratio of 0.4% illustrated improved in flexural strength of 6.6%, 11.96%, and 16.53% with length of SSFs 10mm, 20mm, 30mm, respectively, compared to control mix, while of the sample with 0.8% were 10.68%, 15.05%, and 22.1%. The samples with SSFs ratio of 1.3% and lengths of 10mm, 20 mm, and 30 mm showed the higher flexural strength of 4.46MPa, 4.67MPa, and 5.12MPa with improved 13.49%, 18.83%, and 16.68%, respectively, compared to control mix.
- In the samples containing fibres with a length of 10

mm and the percentage of fibre 0.4%, 0.8%, and 1.3% the water absorption increases at of 22.58%, 29.03%, and 37.63% compared to the control sample, while of the samples containing fibres with a length of 20 mm the flexural strength increases of 17.70%, 22.58%, and 33.01%, respectively. The samples containing fibres with a length of 30 mm and the percentage from 0.4%, to 1.3% the slump decreases up to 26.88% compared to the control sample. Increasing the length of the SSFs leads to a decrease in water absorption compared to shorter samples at the same percentage, while increasing the percentage of SSFs leads to an increase in water absorption with the length constant of SSFs.

- The incorporation of the developed SSFs enhanced the microstructure of the concrete by promoting cohesiveness between the Basalt Fibers (BFs) and the matrix. This interaction led to a reduction in the size of the Interfacial Transition Zone (ITZ). Consequently, the presence of the SSFs filled the pores within the matrix, resulting in a decrease in porosity. This improvement in the microstructure played a significant role in enhancing the mechanical properties of the composite, as evidenced by the observed results.

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6/25/2021