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ELASTIC AND PLASTIC BEHAVIOUR OF SISAL FIBRE FOR CONCRETE REINFORCEMENT

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Abstract: *This study investigated the mechanical properties of sisal fibre-reinforced concrete, with a focus on its elastic and plastic behaviour under tensile loading. The experimental procedure involved a series of tensile tests, during which the elongation, force, and tensile stress of the sisal fibre were measured and recorded. The results showed a linear elastic behaviour, followed by elastic and plastic deformation, with a significant increase in tensile stress with increasing force, indicating that the sisal fibre-reinforced concrete exhibited a promising mechanical behaviour. The strain-stress relationship revealed a consistent linear pattern, emphasizing the material's elasticity and reliability in structural applications. The tensile strength analysis demonstrated a progressive increase in tensile stress with increasing force, surpassing the minimum requirement specified in the BS EN ISO 13934-1: (2013) standard, suggesting that the sisal fibre-reinforced concrete had the potential to enhance the tensile strength and crack resistance of concrete structures. The force-elongation relationship demonstrated a positive correlation between force and elongation, highlighting the material's resilience and ductility. Furthermore, the time-elongation relationship showed a consistent pattern of elongation with increasing time, indicating the material's ability to withstand stress over prolonged durations.*

Keywords: Durability. Deformation, Elasticity, Fibre, Plasticity, Sustainability,

1.0 Introduction

The use of natural fibers as reinforcement in concrete has gained significant attention in recent years due to their eco-friendly nature, cost-effectiveness, and potential to enhance the mechanical properties of concrete composites. Among these natural fibers, sisal fiber has emerged as a promising candidate due to its high tensile strength, availability, and biodegradability (Tolêdo Filho *et al.,* 2000). The elastic and plastic behavior of sisal fiber plays a critical role in determining the performance of fiber-reinforced concrete, particularly in terms of crack resistance, ductility, and energy absorption. Elastic behavior refers to the ability of the material to return to its original shape after deformation, while plastic behavior describes the permanent deformation that occurs beyond the material's elastic limit. Understanding these properties is essential for optimizing the use of sisal fiber in concrete reinforcement, especially in applications requiring improved toughness and durability (Silva *et al*., 2010).

Research has shown that the incorporation of sisal fibers into concrete can significantly alter its stress-strain response, enhancing both its elastic modulus and post-cracking plastic deformation capacity (Savastano *et al.,* 2003). The elastic behavior of sisal fiber-reinforced concrete is influenced by factors such as fiber-matrix adhesion, fiber content, and curing conditions, while the plastic behavior is closely related to the fiber's ability to bridge cracks and redistribute stress (Tolêdo Filho *et al.,* 2003). However, challenges such as fiber degradation in alkaline environments and variability in fiber properties must be addressed to fully harness the potential of sisal fiber in concrete reinforcement. This study aims to explore the elastic and plastic behavior of sisal fiber in concrete, providing insights into its mechanical performance and deformation characteristics.

The incorporation of sisal fibers into concrete has been extensively studied to enhance the mechanical properties of concrete, particularly its plastic behavior. Research by Joseph, Kuruvilla, and Thomas (1999) demonstrated that sisal fiber-reinforced composites are promising materials for structural applications, highlighting their ability to improve plastic deformation characteristics. The study emphasized that sisal fibers can enhance concrete ductility, thereby increasing its resistance to cracking and sudden brittle failure.

Further studies have explored the impact of sisal fiber content on concrete's mechanical properties. Elinwa and Mahmood (2003) observed that the optimal performance of sisal fiber-reinforced concrete was achieved at a 3% fiber volume fraction with a water-cement ratio of 0.6. They attributed the improved plastic behavior to the fibers' ability to bridge cracks, distribute stress evenly, and delay crack propagation under loading conditions. The findings reinforced the importance of selecting the appropriate fiber content to maximize performance.

Moreover, the role of sisal fibers in reducing plastic shrinkage cracking has been highlighted by Woldesenbet (2023). This study demonstrated that concrete reinforced with sisal fibers showed a significant reduction in plastic shrinkage cracks, particularly in environments with high temperatures. The fibers allowed the concrete to better accommodate shrinkage strains, resulting in enhanced durability and performance. Collectively, these studies underscore the value of sisal fibers in improving the plastic behavior and durability of concrete composites.

2.0 Research Methods

The experimental procedure was designed to evaluate the mechanical properties of sisal fiber, focusing on its elastic and plastic behaviour under tensile loading. The procedure involved several key steps, including the preparation of sisal fiber specimens, tensile testing setup, data acquisition, and analysis of the stress-strain curve.

Sisal fiber specimens were carefully prepared to ensure uniformity in dimensions and properties. The fibers were cleaned, dried, and cut to a standardized length and diameter to minimize variability in the test results. Each specimen was securely mounted on the grips of a universal testing machine (UTM) to ensure proper alignment and prevent slippage during testing. The tensile test was conducted using a UTM equipped with a load cell and an extensometer, at a constant crosshead speed of 1 mm/min.

The load and elongation data were continuously recorded using a data acquisition system, which captured real-time measurements and enabled the generation of a force-elongation curve. The data was then used to calculate stress and strain values, which are essential for analyzing the fiber's mechanical properties. The stress-strain curve provided critical insights into the mechanical behavior of the sisal fiber, including its modulus of elasticity, yield point, ultimate tensile strength, and elongation at break.

3.0 Results and Discussion

The elastic and plastic behaviour of sisal fibre in concrete reinforcement were examined through a series of tests, during which the elongation of the fibre increased steadily from 1.411 mm to 2.419 mm over a period of 20 minutes, indicating both elastic and plastic deformation. Correspondingly, the force exerted on the fibre increased from 0.197 N to 5.002 N. Initially, the stress on the fibre rose from 98.5 N/mm^2 to 2501 N/mm^2, while the strain increased from 2.351% to 4.031%. Notably, the tensile stress experienced by the fibre ranged from 6.355 N/mm^2 to 161.355 N/mm^2, showcasing its ability to withstand substantial loads. These properties were observed through recording intervals, starting from 0.017 minutes, where the initial values were measured. As time progressed, both force and stress increased steadily, leading to higher tensile stress values, indicating the material's ability to withstand greater forces without failure. Overall, the sisal fibre-reinforced concrete demonstrated promising mechanical properties, suggesting its potential for various structural applications.

3.1 Force-Tensile Relationship of Sisal Fibre

The force-tensile relationship of sisal fibre exhibits distinct phases, beginning with an initial phase where the fibre displays linear elastic behaviour. At 0.017 minutes, the fibre shows an elongation of 1.411 mm, a force of 0.197 N, and a tensile stress of 6.355 N/mm^2. As the fibre continues to stretch, it enters the elastic region, where stress and strain increase proportionally, indicating elastic deformation. This region is characterized by a gradual increase in elongation and force, with the fibre stretching up to 1.893 mm, with a force of 2.845 N, and a tensile stress of 91.774 N/mm^2.

As the fibre transitions to the plastic region, the stress increases at a slower rate, indicating the start of plastic deformation. In this region, significant elongation occurs with increasing force, showing plastic deformation. The fibre continues to stretch until it approaches its ultimate tensile strength, with high stress and strain values indicating possible fibre failure. At 0.028 minutes, the fibre shows an elongation of 2.419 mm, a force of 5.002 N, and a tensile stress of 161.355 N/mm^2, marking the final phase of its deformation

Furthermore, the tensile strength analysis of sisal fibre reinforcement revealed a progressive increase in tensile stress as the force applied to the fibres increased as seen in Figure 1. Starting at 6.355 N/mm^2 for a force of 98.5 N, the tensile stress reached 161.355 N/mm^2 at a force of 2501 N. The relationship between force and tensile strength indicated that the sisal fibres demonstrated considerable strength, with their performance improving consistently under greater stress. When compared to the BS EN ISO 13934-1: (2013) standard, which specifies a minimum tensile strength requirement of 80 N/mm^2 for natural fibre textiles, the sisal fibres significantly surpassed this limit, particularly in the higher force range, demonstrating their potential suitability for reinforcement purposes in various applications.

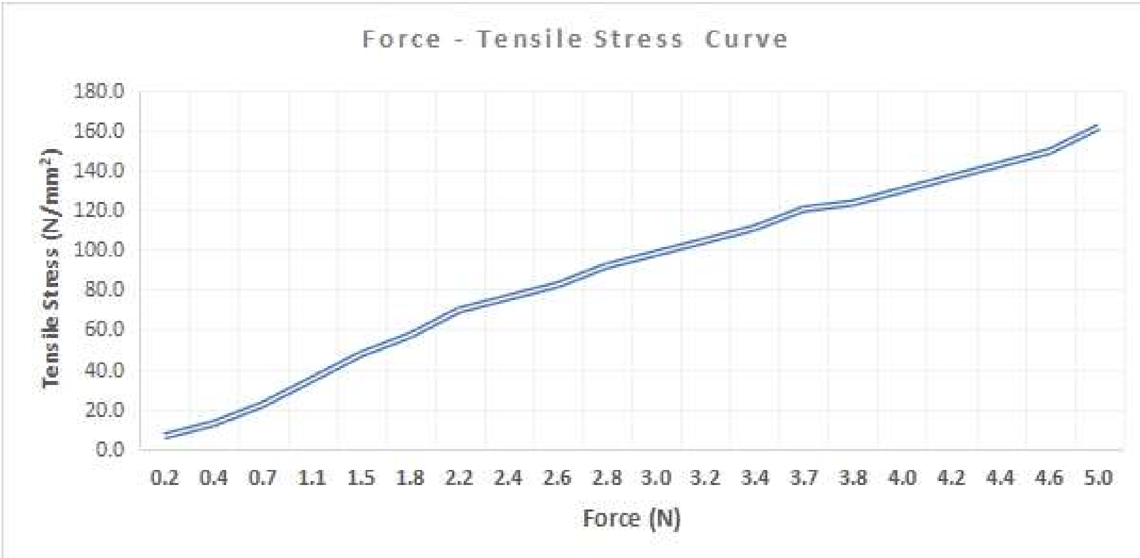

Figure 1: Force Tensile Stress Relationship Curve

3.2 Strain-Stress Relationship

The analysis revealed a consistent relationship between force, stress, and strain, indicative of the fiber's linear elastic behaviour as can be seen in Figure 2. As the force increases, stress and strain exhibit a linear growth pattern, emphasizing the material's elasticity. The stress-strain curve demonstrated uniform deformation characteristics, essential for predicting the fibre's behaviour under varying loads within the elastic limit. This linear relationship between stress and strain is a key indicator of the material's reliability in structural applications, as it ensures that the fibre will return to its original form once the load is removed, thus maintaining the integrity of the concrete structure. Understanding sisal fibre's elastic behaviour is paramount for its effective utilisation in concrete reinforcement. The linear stress-strain relationship and consistent elastic modulus highlight the material's ability to withstand loading without undergoing plastic deformation. Incorporating sisal fibre into concrete matrices could enhance structural integrity by mitigating cracking and improving load-bearing capacity, thus offering a sustainable alternative to conventional steel reinforcement materials.

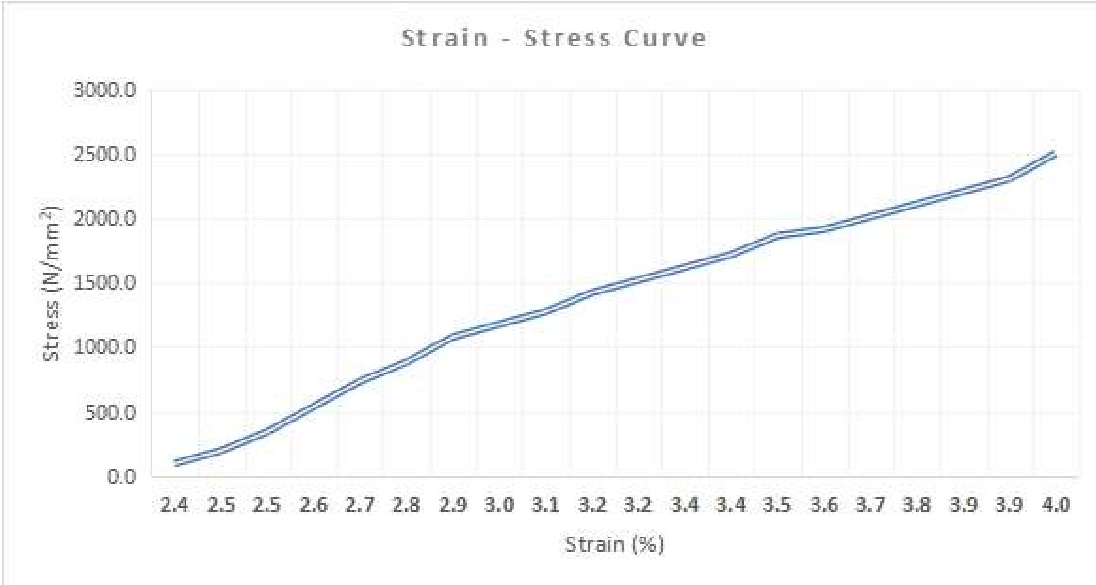

Figure 2: Strain - Stress Relationship Curve

3.3 Relationship Between Force and Elongation

From Figure 3, the relationship between force and elongation in sisal fibre concrete reinforcement materials revealed essential insights into their mechanical properties. As force increases, elongation also tends to increase, demonstrating the material's ability to withstand greater stress before reaching its breaking point. This positive correlation between force and elongation highlights the material's resilience and ductility, essential characteristics for concrete reinforcement applications where the material is subjected to varying loads and stresses. Analysing the data, it's evident that as force increases, elongation progressively rises, indicating the material's ability to deform plastically without sudden failure. Understanding this relationship is key for designing durable and reliable concrete structures reinforced with sisal fibre, ensuring they can effectively withstand the demands of real-world applications while maintaining structural integrity.

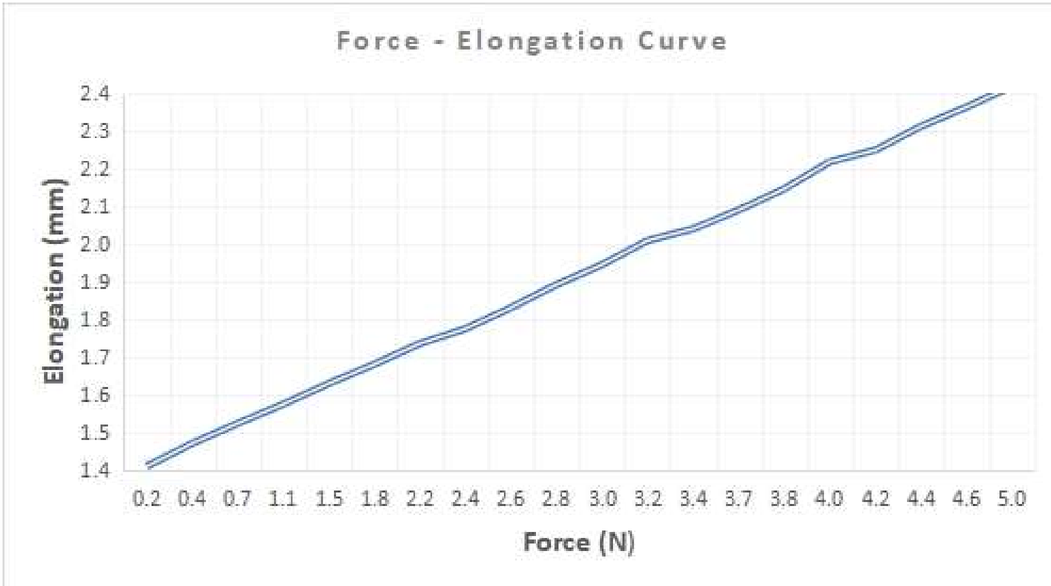

Figure 3: Force - Elongation Relationship

3.4 Time-Elongation Relationship

The relationship between time and elongation for sisal fibre reinforcement revealed a consistent pattern of elongation with increasing time (Figure 4), indicative of the fibres' ability to withstand stress over prolonged durations. As time progressed, elongation increased steadily, suggesting a favourable creep resistance characteristic. When compared to the force and tensile stress metrics, it's evident that the elongation behaviour aligns with the fibres' capacity to endure higher forces while maintaining structural integrity. Considering the BS EN 14889-2:(2018) standard for natural fibre usage in concrete reinforcement, which typically requires fibres to exhibit elongation properties conducive to concrete's deformation behaviour, the sisal fibres showcased promising elongation characteristics suitable for such applications. This suggests their potential efficacy in enhancing concrete's tensile strength and crack resistance,

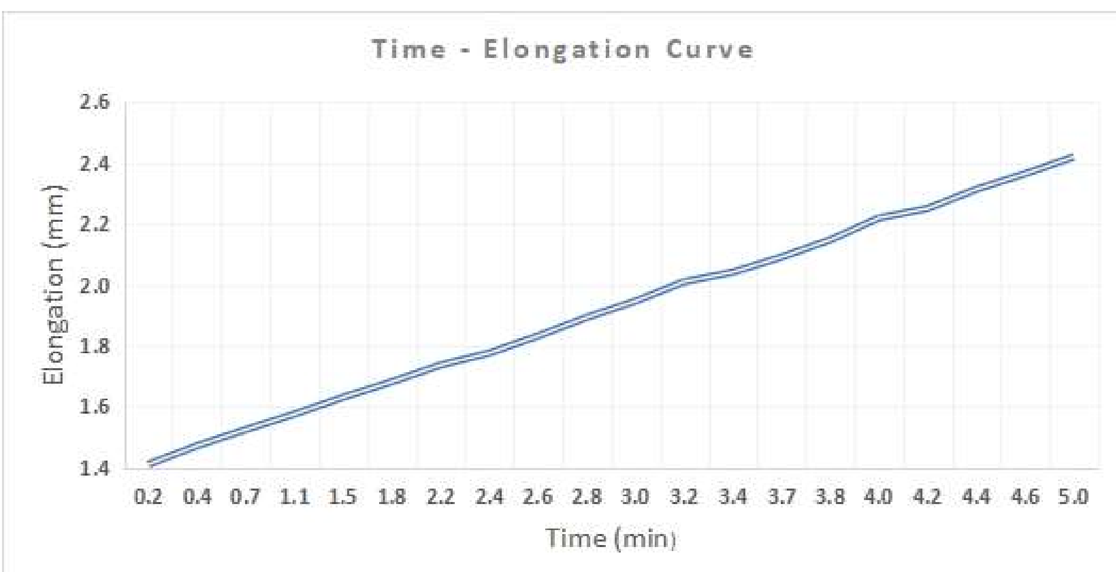

Figure 4: Time - Elongation Relationship

4,0 Conclusion

The experimental investigation of sisal fibre-reinforced concrete has yielded significant insights into the material's mechanical properties and behaviour under tensile loading. The results demonstrated that sisal fibre-reinforced concrete exhibited a linear elastic behaviour, followed by elastic and plastic deformation, with a significant increase in tensile stress with increasing force. This behaviour is indicative of the material's ability to withstand substantial loads without failing.

The strain-stress relationship revealed a consistent linear pattern, emphasizing the material's elasticity and reliability in structural applications. The force-elongation relationship demonstrated a positive correlation between force and elongation, highlighting the material's resilience and ductility. Furthermore, the time-elongation relationship showed a consistent pattern of elongation with increasing time, indicating the material's ability to withstand stress over prolonged durations.

The tensile strength analysis demonstrated a progressive increase in tensile stress with increasing force, surpassing the minimum requirement specified in the BS EN ISO 13934-1: (2013) standard.

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