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Effect of Sisal and Steel Fibers on the Properties of Lightweight Concrete

Meeaad Mohammed Ali[1], Eethar Thanoon Dawood[1]
[1] Building and Construction Engineering, Technical College of Mosul, Northern Technical University, Iraq,
meeaad.mohammed@ntu.edu.iq, eethar2005@yahoo.com

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Corresponding author:
Name: Meeaad Mohammed Ali
Affiliation:Northern Technical University
Email:
meeaad.mohammed@ntu.edu.iq

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OPC: Ordinary Portland cement, ML: Lightweight Concrete Mix, MLN: Lightweight Concrete Mix with Sisal Fiber, MLS: Lightweight Concrete Mix with Steel Fiber

A B S T R A C T

The research examined how sisal natural fibers combined with steel fibers with hooked ends influence the mechanical and physical properties of lightweight concrete. The lightweight quality of pumice made it a suitable alternative to regular aggregates, which supported environmental initiatives through insulation applications and partition panels. 70% of natural sand grains were substituted with fine and coarse pumice stock. The testing process separated the pumice into two fractions: the coarse elements stayed on the 12.5 mm screen while the fine pumice material fit through a 4.75 mm screen. Tensile and compressive strength evaluations were performed as well as flexural strength, modulus of elasticity, and dry density testing. The experimental samples included various volume combinations of sisal fibers at 0.25%, 0.5%, and 0.75% together with steel fibers at 1%, 1.25%, and 1.5% levels. The combination of sisal at 0.5% content delivered elevated tensile and flexural strength results, and performance declined due to increased porosity levels. 1.5% steel fibers exhibited the best performance in terms of compressive and flexural strength, which demonstrates their powerful reinforcement properties. Compressive strength decreased because sisal fibers did not bond well with the cement matrix and created additional holes inside the material. When 0.5% sisal particles were added to concrete instead of the standard mix, the tensile strength went up by 5.1% and the flexural strength went up by 7.8%. Concrete reinforced with 1.5% steel fibers showed strength gains of 10.5% and 26.9%, with minor decreases in workability and density. The experimental outcomes identified the best fiber-to-concrete ratio, offering an ideal combination of strength improvement and environmentally friendly practices in lightweight concrete.

1. Introduction

The rapid growth in the global population has led to increased demand for both residential and industrial infrastructure to accommodate societal expansion. In the construction sector, concrete is the preferred material due to the availability of raw materials, its cost-effectiveness, and its properties, including high compressive strength and durability. The material possesses high density, low tensile strength, brittleness, and inadequate durability. To address evolving construction needs, there is a growing emphasis on the development of lightweight concrete composites capable of reducing structural load while maintaining performance.

Life cycle thinking demanded immediate attention together with sustainable resource use and existing infrastructure changes for less energy-consuming product manufacturing. Traditional concrete served as the dominant construction material [1, 2]. Pumice has been widely investigated as a lightweight aggregate in numerous studies due to its porous structure, which contributes to lower density in concrete mixes.

During volcanic eruptions, cooling magma creates small gaps in pumice because gas release produces a porous structure. Multiple investigations into lightweight concrete mixes and their properties show evidence that their weight reduction capabilities match acceptable strength levels. The improvement of concrete thermal insulation through pumice use is demonstrated in both Al-Khayat and Al-Haq's work [3] and Kılıç et al.'s study [4]. The addition of fibers into concrete material enhances durability and ductility by increasing mechanical strength for addressing brittleness. Synthetic fiber additions, specifically steel fibers, address concrete cracking by creating crack bridges and distributing structural loads. Research confirms that steel fibers generate superior compressive strength and longevity outcomes thanks to their crack-shrinking capability and structural stabilizing effects [5, 6]. Concrete structures benefit from the use of steel fibers with designed curved ends, which provide maximum enhancement to both tensile strength and bending strength [7]. Sisal fiber, derived from Agave sisalana, represents a sustainable and cost-effective alternative to synthetic reinforcement materials in concrete applications.

The Agave sisalana wild plants in subtropical and tropical regions produce sisal fibers that maintain excellent tensile strength together with durability and sustainability attributes. Several studies have confirmed that sisal fibers enhance the tensile and flexural behavior of concrete; however, their hydrophilic nature may compromise long-term durability by accelerating moisture-related degradation [8, 9].

Ganesan et al. researched how sisal fibers strengthen concrete properties without compromising its sustainability benefits [10]. The combination of sustainable materials with concrete creation results in stronger frameworks conserves resources, and lowers emission levels [11]. Because environmentally friendly mineral additives present economic opportunities along with environmental benefits [12]. This research explores the individual effects of pumice as a lightweight material and sisal fibers and steel as reinforcing agents. The research project investigates the impact of these materials on the development of compressive strength as well as the examination of flexural and tensile strength, dry density, and modulus of elasticity. The research intends to fill this knowledge gap by assessing these materials' performance in lightweight concrete methods according to references [13, 14]. This research will enhance lightweight concrete development through mechanical property improvements, which will benefit practical applications. The study holds great importance for the development of non-structural construction elements such as insulation layers and lightweight panels because weight reduction with maintained strength remains essential. The findings possess value for building structural elements because they enhance both compressive strength and elastic moduli performance. The research achieves sustainability through natural-synthetic materials integration that strengthens durability and minimizes environmental burden, suitable for green buildings along with modern infrastructure needs. The research provides guidelines for to use of natural along synthetic fibers within lightweight concrete mix designs to develop sustainable construction specifications that operate efficiently [15, 16]. The research identifies weight restrictions of lightweight concrete because of its reduced density combined with its thermal insulating capabilities, despite this making it suitable for many building needs. The goal of the research was to evaluate steel and sisal fibers as possible lightweight concrete ingredients for reinforcing concrete while gaining a better understanding of their combined strength and sustainable benefit ratios [13, 14].

2. Text Formatting

2.1 Materials and properties

The reference mix followed designs from ACI 318 and ACI 211 Standards, together with previous studies [17, 18] on lightweight concrete. The mix proportions were determined by optimizing the strength, workability, and density balance. The water-cement (W/C) ratio was modified by adding a superplasticizer (SP-175) to minimize water content and ensure sufficient workability and strength. Aggregate sizes and gradations were selected to ensure uniform particle distribution, minimize voids, and enhance cohesion within the matrix. Pumice was used as a lightweight aggregate, replacing sand and gravel in specific proportions to achieve a lightweight mix with good strength.

Locally available OPC cement was used in this research, sourced from the Badush factory in Nineveh province. Natural river gravel and sand were used in all mixtures in this study obtained from the Kanhash area of Mosul, Iraq. The sand and gravel were thoroughly washed with multiple water rinses to remove impurities and clay lumps. After that, they were spread and left to air dry until they reached a saturated surface dry state. The sand was then sieved to ensure that it passed through a 4.75 mm sieve. The physical properties of the sand, according to ASTM C 33-02 and ASTM C128 [19, 20], were the dry bulk density and absorption of this sand of 2.62 and 1.9%, respectively. Natural river gravel with a maximum aggregate size of 12.5 mm was used, with a specific density of 2.65 and absorption of 0.81% according to ASTM C127 [21]. Tap water was used to mix the components, free of oils, organic matter, and other potentially harmful components. Sisal is a natural fiber characterized by high modulus of elasticity, excellent tensile strength, affordability, ease of accessibility, recyclability, and good durability with minimal maintenance. ASTM D3822, [22]. Defines the standardized approach for determining individual fiber mechanical properties. Tensile strength and elongation measurements of sisal fibers can be tested using this specification. The density measurement of sisal follows ASTM D3800, [23]. The typical dry density values for sisal fibers extend between 1.45 g/ cm³ and 1.55 g/ cm³. The density value used in this study was 1.510 g/cm³. Volumetric ratios of 0.25%, 0.5%, and 0.75% of the mixture volume were added to the lightweight concrete mixture, and the physical properties of sisal fibers are shown in Table (1). Steel fibers with hooked ends were used in all types of concrete mixes with a length of 35 mm, a diameter of 0.3 mm, and a density of 8750 kg/m³. The properties of steel fibers are shown in Table (2), where volume ratios of 1%, 1.25%, and 1.5% of the mixture volume were added to the ordinary concrete mix. To obtain lightweight concrete, pumice was used and crushed to a sand gradation passing through a sieve No. 4.75 mm to replace sand and crushed to a gradation passing through a 12.5 mm sieve to replace coarse gravel. The physical properties of pumice can be observed as shown in Table (3). To obtain higher workability, we reduced the water ratio in the mix, and to obtain higher strength, superplasticizer (SP.175) was added at a rate of 1%, and its specifications are mentioned in Table (4) according to ASTM C494 [24]. Figure (1) shows the Pumice used in the experiment while Figure (2) displays the poured samples.

Fig. 1. Fine and coarse pumice.

Fig. 2. Poured samples.

Table 1. Physical properties of sisal fibers.

Property	Value
Specific Gravity	1.51
Length	35mm
Diameter:	0.1 to 0.5 mm
Elongation percentage %	14.80%
Tensile strength	31-221 N/ mm²
Absorption/24 hours	28%

Table 2. Properties of Hooked-End Glued Steel Fibers.

Property	Value
Specific Gravity	7.850
Length	35 mm
Diameter	0.3 mm
L/D Ratio	11.67%
Tensile Strength	2600 MPa
Type	Hooked end glued

Table 3. Physical Properties of Pumice Aggregate.

Properties	Result	Specification
Specific Gravity (dry)	1.066	ASTM C 127 [21]
Specific Gravity Coarse (S.S.D) (Pass Sieve 12.5mm)	1.201	ASTM C 127 [21]
Specific Gravity	1.322	ASTM C 127 [21]

Fine (S.S.D) (Pass Sieve 4.75mm)		
Water Absorption (%)	32%	ASTM C 127 [21]

Table 4. Properties of Superplasticizer.

Technical Properties @ 25ºC	
Color:	Yellowish liquid
pH:	6 ± 1.0
Specific Gravity	1.07 ± 0.02
Chloride Content	None

2.2 Mix properties

The research started by adopting the initial mixture (ML0), which was a conventional concrete mix and achieved a compressive strength of 31 MPa at the age of 28 days and 34 MPa at the age of 90 days, as shown in the mixing ratios in Table (5). An attempt was made to replace sand and gravel with fine and coarse pumice at rates of 50%, 60%, and 70% to produce lightweight concrete with reduced density targeting a strength of 25 MPa. Mixture (ML) was adopted, where 70% of the volume of sand and gravel was replaced with pumice to produce lightweight concrete, as shown in detail in Table (6). Natural fibers (sisal) were added at volumetric ratios of 0.25%, 0.5%, and 0.75%, while synthetic fibers, and steel fibers at volumetric ratios (1%, 1.25%, 1.5%), as shown in Table (7). The reference mix volume was determined as shown in Table (8) to calculate the added fiber weights as shown in Table (9) and the mixing and replacement ratios were within the limits of ACI 318 and ACI 211, [17,18] for lightweight concrete.

Table 5. Initial mix ratio ML0.

Martial	Ratio	Weight kg	Specific Gravity	Volume m³
Cement	1	350	3.15	0.11
Sand	2.28	800	2.62	0.31
Gravel	3.28	1150	2.65	0.43
Water	0.3	105	1	0.11
superplasticizer	1%	3.85	1.1	0.00
The total volume of Mix				0.96

Table 6. Reference Mix lightweight concrete ratio (ML).

Mix ID	ML
Replacement Ratio	70%
Cement Kg	350
Fine Aggregate Kg	240
Fine Pumice Kg	282.6
Coarse Aggregate Kg	345
Coarse Pumice Kg	364.8
Water-Liter	105
Superplasticizer Liter	3.85
Slump mm	80
Compressive Strength 7-day (MPa)	20.2
Compressive Strength 28-day MPa	26.3

Table 7. Mix properties for Reference Mix Lightweight concrete (ML) adding % of fiber.

Mix ID	Cement Kg	Fine Aggregate Kg	Fine Pumice kg	Coarse Aggregate Kg	Coarse pumice kg	Water Litre	Natural Fiber %Volume	Steel Fiber % Volume
ML	350	240	282.56	345	364.83	105	0	
MLN1	350	240	282.56	345	364.83	105	0.25%	
MLN2	350	240	282.56	345	364.83	105	0.5%	
MLN3	350	240	282.56	345	364.83	105	0.75%	
MLS1	350	240	282.56	345	364.83	105		1%
MLS2	350	240	282.56	345	364.83	105		1.25%
MLS3	350	240	282.56	345	364.83	105		1. 5%

Table 8. Calculate the Volume of the lightweight concrete Mix.

Material	Weight kg	Specific Gravity	Volume m³
Cement	350	3.15	0.11
Sand	240	2.62	0.09
Fine Pumice	282.56	1.322	0.21
Gravel	345	2.65	0.13
Coarse Pumice	364.83	1.201	0.30
Water	105	1	0.11
S.P 175	3.85	1.1	0.01
Volume of Mix			0.96

Table 9. Calculate the weight of % fibers for lightweight concrete mix.

Sisal	Volume m³	Specific Gravity Sisal	Weight kg
0.25 %	0.96	1510	3.63
0.50 %	0.96	1510	7.26
0.75 %	0.96	1510	10.89
steel	Volume m³	Specific Gravity steel	Weight kg
1.00 %	0.96	7850	75.46
1.25 %	0.96	7850	94.32
1.50 %	0.96	7850	113.19

3. Test and Result

3.1. Compressive strength

The lightweight concrete compressive strength measurements used the ASTM C-39 [25] standard to test 100 × 100 × 100 mm cubic specimens as illustrated in Figure (3). A reference lightweight concrete mixture received an addition of both steel and sisal fibers. Table (10) contains test results of lightweight cement starting from 7 days through 28 days up to 90 days. Sisal fibers enhanced the compressive strength of concrete by 4.7% to 5.7% at their lowest suggested dosage levels when tested on day seven. The strength diminished at 0.75% fiber content because of expanded voids within the concrete matrix. The data revealed that steel fibers led to a substantial strength elevation, which surpassed 19.6% at a 1.5% inclusion rate. Sisal fibers had the greatest impact on compressive strength at 28 days, increasing it by approximately 2.3% compared to the control mix. Steel fibers added at 1.5% brought a major strength boost to 21.4%. The compressive strength measurement reached a 6.4% elevation with the introduction of 0.5% sisal fibers during the 90-day testing period. The blend of materials reached its best performance with 1.5% steel segment reinforcement, resulting in a 24% increase as illustrated in Figure (4). The study demonstrates that moderate sisal fiber addition enhances strength, but excess amounts reduce performance because of growing void contents.

Steel fibers provide superior compressive strength performance because of their stiffness coupled with their ability to fill cracks in addition to enhancing structural applications that require increased strength and load-bearing capabilities. The inclusion of fibers offers key benefits over the reference mix, which typically suffers from reduced compressive strength due to the porous nature of pumice aggregate. Plain lightweight concrete without fiber support shows weak mechanical capabilities, which limits its design potential. Concrete showed modest strength gains with sisal fibers, while steel fibers significantly improved strength, making the material more suitable for heavy-duty structural uses. The combination of 0.5% sisal fibers exhibits strong durability and strength enhancement attributes, but 1.5% steel fibers offer superior structural integrity for sustainable use. Results showed that steel fibers provided superior compressive strength enhancement to the material when compared to natural sisal fibers. Research findings exposed that concrete containing 1.5% steel fibers achieved its peak compressive strength because these fibers produced effective crack prevention and proper stress distribution.

Concrete material gained less strength augmentation when sisal fibers were introduced compared to steel fibers as reinforcement. Tensile and flexural strengths increased more from sisal fiber incorporation than compressive strengths did. The highest compressive strength was recorded with 1.25% steel fibers, while the optimal strength-to-workability balance was achieved with 0.5% sisal fibers. Experimental data confirms the research objective since steel fibers demonstrate higher effectiveness at enhancing lightweight concrete compressive abilities. The inclusion of sisal fibers produced minimal improvements within compressive strength measurements up to 0.5% usage, according to this research study. Raising the sisal fiber content led to greater concrete open spaces and inferior bonding between the matrix and fibers, thus compromising the overall concrete quality. Ganesan and Raghavan [9] agreed with these findings, indicating that proper selection of fiber content produces balanced toughness and strength results. Steel fibers increase compressive strength when added to concrete because they regulate the formation of cracks and their spread. The end-hook fibers developed superior mechanical interlocking properties with cement molecules while stopping cracks from widening. Research conducted by Zhang and Malhotra [5] along with Sivakumar and Arumairaj [7] established that compressive strength grows when using fiber contents between 1% and 1.5%. The findings of this research match these previous studies.

Fig. 3. Compressive Strength Test of Lightweight Concrete.

Table 10. Compressive Strength results.

Mix Number	Sisal %	Steel Fiber%	Compressive Strength 7-day (MPa)	Compressive Strength 28-day (MPa)	Compressive Strength 90-day (MPa)
ML	0		20.15	26.3	28.3
MLN1	0.25%		21.1	26.7	29.6
MLN2	0.5%		21.3	26.9	30.1
MLN3	0.75%		21.2	26.8	29.6
MLS1		1%	22.6	29.8	32.3
MLS2		1.25%	23.2	31.2	33.8
MLS3		1. 5%	24.1	31.9	35.1

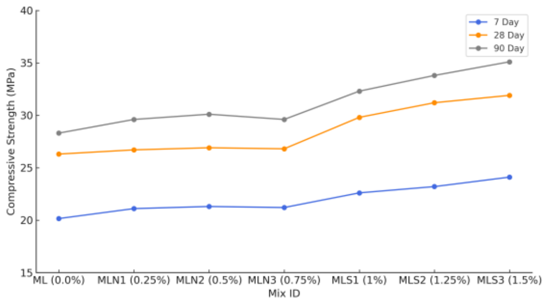

Fig. 4. Effect of Fiber Percentage on Compressive Strength at 7, 28, and 90 Days (MPa).

3.2. Dry density

ASTM C642 [26] provides the methodology for 28 and 90-day dry density calculations. The inclusion of sisal fibers reduced the overall density of the concrete at every fiber mixture ratio due to the relatively low density of sisal fibers (1510 kg/m³). The density values declined consistently as the amount of sisal fibers in the concrete mix increased. However, at 90 days, a slight increase in density of 0.34% was observed compared to 28 days, indicating a stabilization trend over time. The addition of steel fibers resulted in a significant increase in density, because of their high unit weight (7850 kg/m³). The increase reached 123 kg/m3 when adding 1.5% steel fibers compared to the reference mixture. At 90 days, the density continued to increase, ranging from 1.08% to 1.61% with increasing fiber content. Table (11) presents the results, and Figure (5) shows the comparison. When these results were compared to a reference lightweight concrete, which typically has a lower density due to the use of lightweight materials, sisal fibers resulted in a reduction in overall density, which can be beneficial for applications requiring lightweight materials but at the expense of slightly lower mechanical properties. Steel fibers contributed to increased density and significantly enhanced mechanical performance. Steel fibers enhance both density and mechanical performance due to their rigidity and crack-bridging capacity, making them suitable for structural applications where strength is prioritized over weight reduction. The choice of fiber type depends on the balance between reducing density and improving strength, with sisal fibers being preferred for weight-sensitive applications. Steel fibers represent the best choice when strength becomes a primary application requirement. The utilization of pumice as lightweight aggregate produced concrete with a lower dry density than normal concrete while meeting our objective of designing a reduced-density mix. The steel fibers heightened dry density levels although their density remained higher than concrete density. Sisal fibers maintained relatively stable dry density but slightly reduced workability. Sisal fibers slightly affected dry density and reduced workability due to their high water absorption capacity. This discovery is essential for lightweight construction applications because of a favorable balance between reduced self-weight and enhanced long-term performance.

Table 11. The dry density results (kg/m³).

Mix Number	Sisal %	Steel Fiber%	Dry Density 28Day	Dry Density 90Day
ML	0		1764	1775
MLN1	0.25%		1758	1764
MLN2	0.5%		1749	1755
MLN3	0.75%		1740	1746
MLS1		1%	1845	1865
MLS2		1.25%	1861	1891
MLS3		1. 5%	1882	1905

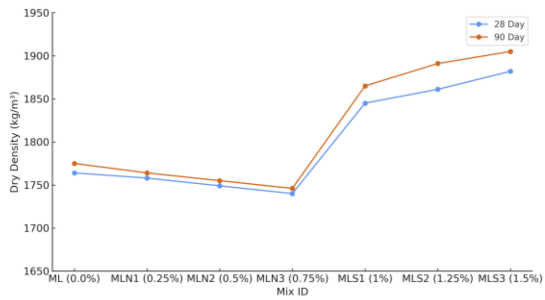

Fig. 5. Compares the dry density between 28 and 90 days. (Kg/m³)

3.3. Flexural strength test

The ASTM C78/C78M specifications guided the evaluation of the test specimen measuring 100×100×400 mm [27]. Application of sisal fibers to concrete led to a moderate increase in flexural strength; however, a slight decline was observed at 0.75% sisal content. The dispersion of fibers and their water absorption contributed to increased matrix porosity, leading to reduced strength. The introduction of steel fibers into the mixture led to higher flexural strength results by 16% when using 1.5% steel fibers compared to the reference mixture on day 28. The flexural strength decreased by 3.4% at 90 days when 0.75% sisal fiber was incorporated into the mixture relative to 28 days. Sisal fibers experience natural strength degradation over time due to environmental exposure, which diminishes their mechanical performance [28]. The use of steel fibers resulted in a 4% improvement over the reference values recorded at 28 days. Table (12) shows the results, and Figure (6) compares the ages of 28 and 90 days. When using sisal fibers, the optimum ratio for the best improvement in flexural strength was 0.5%, while higher ratios had a negative effect at 90 days. For steel fibers, increasing the ratio resulted in better flexural strength. When compared to the reference mixture, sisal fiber addition yielded a slight improvement in flexural strength at 0.5% content. The addition of steel fibers indicates an increase in flexural strength due to its effectiveness in enhancing crack resistance and load distribution, making it suitable for construction applications requiring higher durability. On the other hand, the decrease in strength observed in sisal fiber reinforced concrete at 90 days indicates potential fiber degradation, highlighting the need for further studies on its performance with age and possible treatments. Steel and sisal fibers showed improved flexural strength. Steel fibers provide a bridging effect across cracks, delaying their propagation and improving toughness. A 1.5% steel fiber content yielded the highest flexural strength, supporting previous research indicating that steel fibers improve post-crack behavior. Sisal fibers also improved flexural strength but to a lesser extent. Their stress-distribution capability contributed to lowering brittleness in the concrete matrix. However, adding a content of >0.5% resulted in fiber agglomeration, reducing overall workability and compromising uniform fiber distribution. These results emphasize the need to optimize fiber dosage for practical concrete applications. These findings fulfill the study's goal by illustrating the comparative effectiveness of fiber additions on flexural performance and enhancing the potential of steel fiber addition in construction applications.

Table 12. The dry density results (kg/m^3).

Mix Number	Sisal%	Steel %	Flexural strength 28Day (MPa)	Flexural strength 90Day (MPa)
ML	0		3.49	3.81
MLN1	0.25%		3.63	3.95
MLN2	0.5%		3.78	4.11
MLN3	0.75%		3.42	3.68
MLS1		1%	3.84	4.14
MLS2		1.25%	3.93	4.16
MLS3		1. 5%	4.05	4.21

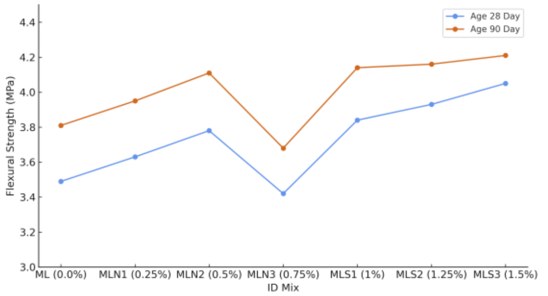

Fig. 6. Effect of Fiber Percentage on Flexural Strength at 28 and 90 Days (MPa)

3.4. Splitting strength

The splitting tensile strength test of lightweight concrete was performed using a 100 × 200 mm cylinder according to ASTM C496/C496M [29], as shown in Fig (7) A moderate improvement in tensile strength was observed when sisal fiber was added up to 0.5%. However, increasing the percentage beyond 0.5% resulted in performance deterioration due to increased void formation and fiber agglomeration. The addition of steel fibers resulted in an approximate 19% increase in tensile strength compared to the reference mixture at 28 days. An increase in the split tensile value was also observed at 7 days, which can be attributed to the water-holding properties of pumice, which supports prolonged hydration and strength development. The use of a superplasticizer (S.P 175) accelerated the hardening process. At 90 days, an increase of 25% was observed compared to 28 days. Table (13) shows the results, and Figure (8) shows the comparison across different curing ages. To analyze the results compared to the reference mixture, which showed low tensile strength and brittle behavior, the addition of sisal fibers and steel enhanced ductility and minimized surface cracking. The addition of 0.5% sisal fibers enhanced tensile strength while maintaining workability, but the addition of more sisal fibers lowered mechanical performance due to void formation and fiber clustering. Steel fibers showed consistent improvement in tensile properties without significantly compromising density or strength. The results suggest that fiber reinforcement, especially steel fibers, effectively addresses the inherent brittleness of lightweight concrete, making it more applicable to applications requiring better tensile performance, such as structural panels and load-bearing components. Splitting tensile strength is a recognized limitation in lightweight concrete; however, a slight improvement was observed with fiber incorporation. Steel fibers achieved the highest increase in split tensile strength due to their excellent bonding capacity with the cement matrix and their ability to suppress cracking. This increase was significantly evident at steel fiber ratios of 1.25% and 1.5%. The effect of sisal fibers was also positive up to 0.5% due to their ability to improve ductility and resistance to sudden collapse Adding a higher percentage caused fiber clustering, resulting in stress concentrations and weak zones within the matrix. This result confirms that fiber incorporation is effective in mitigating the natural brittleness of lightweight concrete, supporting the goal of improving its mechanical properties.

Fig. 7. Splitting strength test

Table 13. Splitting tensile strength Result (MPa)

Mix Number	Sisal %	Steel Fiber%	splitting strength 7Day	splitting strength 28Day	splitting strength 90Day
ML	0		2.24	2.61	3.12
MLN1	0.25%		2.31	2.75	3.23
MLN2	0.5%		2.40	2.81	3.28
MLN3	0.75%		2.46	2.71	3.06
MLS1		1%	2.41	2.88	3.55
MLS2		1.25%	2.57	2.98	3.71
MLS3		1. 5%	2.68	3.1	3.96

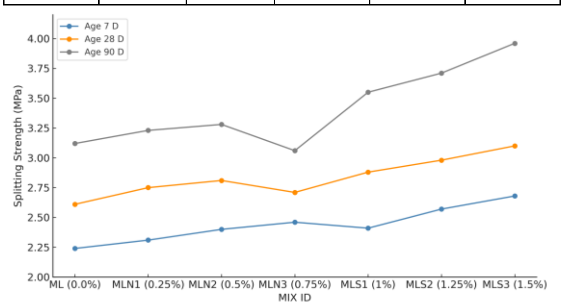

Fig. 8. Comparison of Splitting Tensile Strength at 7, 28, and 90 Days (MPa)

3.5. Modules of Elasticity Test

The Modulus of Elasticity test was performed using a 100 × 200 mm cylinder according to ASTM C469/C469M [30], as illustrated in Figure (9). An improvement was observed when 0.5% sisal fiber was added at 28 days, while a decrease was observed when 0.75% was added. The increase in voids in concrete containing sisal fiber was attributed to raising the sisal content beyond 0.5%, leading to negative results. The addition of steel fibers resulted in a 4.9% increase in modulus of elasticity (N/mm²) at 28 days compared to the reference mixture. Table (14) shows the results, and Figure (10) shows the effect of adding different percentages of fibers. The Modulus of Elasticity results show that the addition of steel fibers contributed to improved stiffness and load-bearing capacity. The highest values were recorded at steel fiber contents of 1.25% and 1.5%, indicating improved energy absorption and elastic recovery. Meanwhile, sisal fiber reinforcement exhibited a more ductile behavior, making it suitable for applications requiring flexibility rather than stiffness. Sisal fibers are a biodegradable and cost-effective alternative.

Fig. 9. Modulus of Elasticity Test

Table 14. Modulus of elasticity results (GPa)

Mix Number	Sisal %	Steel Fiber%	Modules of Elasticity 28Day(GPa)
ML	0		12.7
MLN1	0.25%		12.65
MLN2	0.5%		12.62
MLN3	0.75%		12.57
MLS1		1%	13.05
MLS2		1.25%	13.17
MLS3		1. 5%	13.32

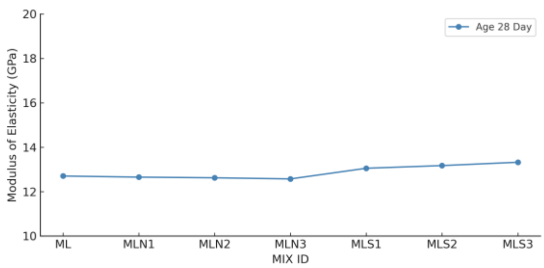

Fig. 10. Effect of Fiber Percentage on Modulus of Elasticity at 28 Days (GPa)

4. Conclusion

This study examines the outcomes of adding natural sisal and synthetic steel fibers to concrete made from 70% pumice to replace typical aggregates in construction. Sisal fiber additions at 0.5% improved flexural and tensile strength slightly, although higher amounts caused strength reduction through increased material porosity together with uneven fiber distribution. The combination of improved properties through sisal fibers at low concentration levels was limited by their high water absorption and inadequate bonding with the cement matrix at elevated dosages. Sisal fibers offer sustainability advantages for non-structural elements, although their mechanical performance is lower than that of steel fibers. The research discovered that steel fibers set at a volume fraction of 1.5% produced remarkable increases in mechanical aspects, including compressive strength by 24%, tension strength by 26.9%, and flexural strength improvement. The main limitation of this study is the lack of long-term durability assessments, particularly concerning fiber degradation and performance under aggressive environmental conditions. Further research is needed to evaluate hybrid composite fibers' effects as well as the impact of alternative durable natural fibers and surface treatments of the fibers for enhanced bonding. The application of steel fibers between 1.25% and 1.5% suits structural projects with high-performance needs, but sisal fibers at 0.5% work best for sustainable non-load-bearing components. The research findings contribute to sustainable high-performance lightweight concrete development by simultaneously improving mechanical strength and environmental performance and supporting more resilient and sustainable building solutions.

References

[1] A. M. Neville, *Properties of Concrete*, 5th ed. Pearson Education, 2012.

[2] P. K. Mehta and P. J. M. Monteiro, *Concrete: Microstructure, Properties, and Materials*, 4th ed. McGraw-Hill, 2014.

[3] K. H. Al-Khayat and M. Haq, "The use of pumice aggregate in lightweight concrete," *Construction and Building Materials*, vol. 23, no. 3, pp. 1195–1201, 2009.

[4] A. Kılıç, İ. Durmuş, and S. Yılmaz, "Lightweight concrete using pumice aggregate: Performance evaluation," *Construction and Building Materials*, vol. 134, pp. 556–563, 2017.

[5] M. H. Zhang and V. M. Malhotra, "High-performance concrete with steel fibers," *Cement and Concrete Composites*, vol. 18, no. 2, pp. 91–97, 1996.

[6] R. Fazael and M. Ramli, "Effect of steel fiber on mechanical properties of concrete," *Journal of Civil Engineering and Architecture*, vol. 6, no. 2, pp. 248–254, 2012.

[7] R. Sivakumar and P. Arumairaj, "Influence of steel fibers on concrete's compressive and flexural strength," *International Journal of Engineering Science and Technology*, vol. 7, no. 6, pp. 67–75, 2015.

[8] A. Kumar and P. Singh, "Use of sisal fibers in concrete," *International Journal of Advanced Engineering Technology*, vol. 2, no. 4, pp. 187–192, 2011.

[9] N. Ganesan and S. Raghavan, "Properties of concrete with natural fibers," *Construction and Building Materials*, vol. 49, pp. 38–45, 2014.

[10] M. M. Islam and M. Ali, "Durability of concrete with sisal fibers," *Materials Science and Engineering A*, vol. 708, pp. 161–167, 2017.

[11] A. Radhi Taha, D. A. Abbas Al-Attar, and H. Mohammed Ahmed, "the Effect of Different Design Ratios on the Compressive Strength of Geopolymer Concrete: a Parametric Study Using the Taguchi Method," NTU J. Eng. Technol., vol. 2, no. 4, pp. 1–11, 2023, doi: 10.56286/ntujet.v2i4.682.

[12] M. Faisal Khalil and E. Thanon Dawood, "The Effects of Using Eco-friendly Materials for the Production of High Strength Mortar," NTU J. Eng. Technol., vol. 2, no. 3, pp. 17–26, 2023, doi: 10.56286/ntujet.v2i3.612.

[13] T. Uygunoglu and E. Yilmaz, "Combined effects of pumice and fiber reinforcement in concrete," *Construction and Building Materials*, vol. 68, pp. 103–110, 2014.

[14] S. A. Akinmoladun and L. F. Olanrewaju, "Effects of natural and synthetic fibers in lightweight concrete," *Journal of Materials Science and Engineering*, vol. 7, no. 8, pp. 239–245, 2019.

[15] S. Amudhavalli and T. Sundararajan, "Sustainability in construction: Use of fibers in concrete," *Journal of Sustainable Building and Infrastructure*, vol. 4, no. 1, pp. 15–22, 2016.

[16] R. Dhahran and R. Kumar, "Optimizing concrete mix designs with natural and synthetic fibers," *International Journal of Environmental Science and Engineering*, vol. 12, no. 6, pp. 75–81, 2019.

[17] *ACI 318-19: Building Code Requirements for Structural Concrete and Commentary*, 2019. Available: *https://doi.org/10.14359/51716937*

[18] *ACI 211.1-91: Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete, 1991. Available:* https://www.concrete.org/store/productdetail.aspx?ItemID=211191

[19] ASTM C33, *Specification for Concrete Aggregates*, *Annual Book of ASTM Standards*, ASTM International, 2018, doi: 10.1520/C0033.

[20] ASTM C128, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate*, *Annual Book of ASTM Standards*, ASTM International, 2015, doi: 10.1520/C0128-15.2.

[21] ASTM C127, *Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate*, *Annual Book of ASTM Standards*, ASTM International, 2018, doi: 10.1520/C0127-15.2.

[22] ASTM D3822, *Standard Test Method for Tensile Properties of Single Textile Fibers*, ASTM International. Available: https://www.astm.org/d3822_d3822m-14r20.html.

[23] ASTM D3800-22, *Standard Test Method for Density of High-Modulus Fibers*, ASTM International. Available: https://standards.iteh.ai/catalog/standards/astm/a7512c63-e2bd-4b37-ae3a-a2b76ab6c7bb/astm-d3800-22.

[24] ASTM C494, *Standard Specification for Chemical Admixtures for Concrete*, *Annual Book of ASTM Standards*, ASTM International, 2018, doi: 10.1520/C0494.

[25] ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, *Annual Book of ASTM Standards*, ASTM International, 2015, doi: 10.1520/C0039.

[26] ASTM C642, *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*, *Annual Book of ASTM Standards*, ASTM International, 2016, doi: 10.1520/C0642-13.5.

[27] ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, *Annual Book of ASTM Standards*, ASTM International, 2018, doi: 10.1520/C0078.

[28] F. P. Teixeira, O. da F. M. Gomes, and F. de A. Silva, "Degradation mechanisms of curious, hemp, and sisal fibers exposed to elevated temperatures," *BioResources*, vol. 14, no. 1, pp. 1494–1511, 2019, doi: 10.15376/biores.14.1.1494-1511.

[29] ASTM C496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*, *Annual Book of ASTM Standards*, ASTM International, 2020, doi: 10.1520/C0496.

[30] ASTM C469, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*, *Annual Book of ASTM Standards*, ASTM International, 2014.