



# Challenge Journal

## OF CONCRETE RESEARCH LETTERS

### Research Article

## Enhancing mechanical properties of foam concrete with sisal fiber reinforcement: An experimental investigation

Mehmet Uzun<sup>a,\*</sup> 

<sup>a</sup> Department of Civil Engineering, Karamanoğlu Mehmetbey University, 70200 Karaman, Türkiye

### ABSTRACT

In this study, we explore the possibility of using sisal fibers as an environmentally-friendly reinforcing agent for foam concrete. We aim to improve its physical properties by combining environmental friendliness with engineering practicality to create a durable material that can be used safely today and a supplier of ecological sustainability for tomorrow. Known for being lightweight and thermally insulating, foam concrete has very low tensile strength and ductility as compared with other materials. This is why its application is often limited in scope. We naturally think that adding sisal fibers, which are a high-performance and renewable resource in themselves, will improve these properties. It is well known that they have a tensile strength of more than 400 kg/cm, and their long, stiff lamellae further increase this advantage. As a result, we integrated sisal fibers at different mixing rates: 0 (no Sisal), 0.25g, 0.5g and so on up to 1% volume. After the test specimens were standardized like this they went into the hence examining each of these properties in turn. With a reasonable content of fibres, the mechanical properties of foam concrete improved significantly. It was observed that the properties of fresh concrete decreased slightly in the samples where 0.50% sisal fiber was used. However, the compressive strength increased by 12.9% compared to the reference sample, and the flexural strength increased by 2.85 times compared to the reference sample. This study not only confirms the feasibility of using sisal fibers to reinforce foam concrete theoretically, but it will also serve as a useful reference for the development of more sustainable scientific building materials. The author provides a discussion of their results and future directions for research on construction materials, highlighting environmental and economic benefits from incorporating natural fibers into these materials.

### ARTICLE INFO

*Article history:*

Received 22 March 2024

Revised 18 April 2024

Accepted 29 April 2024

*Keywords:*

Natural fibers

Sisal fibers

Foam concrete

Mechanical properties



This is an open access article distributed under the CC BY licence.

© 2024 by the Author.

### 1. Introduction

Foam concrete is an ideal construction material, characterized by its cellular structure made of a mixture of cement, sand, water, and foaming agent, that combines the best of lightweight form, thermal insulation, and sound absorption (Raj et al. 2019; Shi et al. 2021; Tran et al. 2022; Shaheen et al. 2023). Traditionally, it has been applied in construction for non-load-bearing walls, insulation panels, and void filling, as a result of the relatively low density and good thermal performance it brings (Hamada et al. 2023). However, despite these advantages,

foam concrete has its weaknesses in mechanical strength and durability that confine its use to parts of a building structure that are not bearing considerable load (Falliano et al. 2018).

Foam concrete's intrinsic properties, such as low density and high thermal insulation, make it an attractive choice for specific construction applications. However, its broader use is hampered by limited mechanical strength and durability. Studies exploring ways to enhance these properties have focused on various admixtures and reinforcements (Huang et al. 2015; Ji et al. 2015; Oren et al. 2020). For instance, Jones and McCarthy (2005) demon-

\* Corresponding author. Tel.: +90-338-226-2200 E-mail address: mehmetuzun@kmu.edu.tr (M. Uzun)

strated that the inclusion of synthetic fibers could marginally improve the compressive strength of foam concrete. Similarly, a study by Renjith et al. (2021) explored the use of micro-silica to enhance the material's mechanical properties, noting improvements in both compressive and flexural strengths. Despite these advancements, the environmental impact of synthetic reinforcements remains a concern. This has led researchers to explore natural, sustainable alternatives that would not compromise the material's performance (Jones and McCarthy 2005). The exploration of natural fibers as reinforcement in construction materials has surged due to their environmental benefits over synthetic fibers. Natural fibers, including bamboo, hemp, flax, and sisal, have been investigated for their potential to enhance the mechanical properties of construction materials (Coutts and Ni 1995; Frydrych et al. 2019; Netinger Grubeša et al. 2018; Okeola et al. 2018). In addition to their ability to deliver high structural performance, low density, high acoustic damping and reduced industrial fuel expense, the use of natural fiber-reinforced composite materials has been proposed to provide optimal recyclability and biodegradability (Çakıroğlu and Bekdaş 2021; Gultekin 2023). Wang et al. (2023) provided an extensive review of the mechanical properties of natural fiber-reinforced concrete, emphasizing the positive impact of natural fibers on improving tensile strength, flexural strength, and crack resistance. Due to the high mechanical properties of natural fibers, natural fiber added concretes are preferred not only in structural elements but also in non-structural elements. Due to its high tensile strength, it is very common to use it as a wall element, as a superstructure element for roads, and in underground systems. Sisal fiber stands out due to its availability, cost-effectiveness, and mechanical properties. Its application in construction materials has been limited but promising, with studies showing its potential to improve not only the mechanical properties but also the thermal and acoustical insulation of composites (Shalwan et al. 2017).

The construction industry, today a major cause of global carbon emissions, is under increasing pressure to shift towards more sustainable practices. Part of this shift involves seeking out green building materials which not only meet structural requirements but also reduce the environmental effects of their production and use. In this context, natural fibers used for reinforcement in construction materials make sense. Renewable, biodegradable and having a low carbon footprint, natural fibers are well partnered with the aims of sustainable construction (Zini and Scandola 2011).

One method to enhance the mechanical properties of concrete is by adding fibers to the concrete mix (Canbaz et al. 2022). Of the natural fibers available, sisal, in particular, has attracted attention because it has high tensile strength, durability and resistance to degradation in harsh environments (Ahmad et al. 2022). In this way, it is suitable for use in buildings where it may be exposed to chemicals and some similar harsh conditions. Sisal fiber derived from the *Agave sisalana* plant is traditionally employed in the manufacture of rope or twine but has been more recently proposed as reinforcement for polymer composites and building materials (Sabarish et al. 2020).

Sisal fiber's potential in reinforcing construction materials, particularly in foam concrete, has garnered attention in recent years. A pivotal study by Zhang et al. (2024) investigated the effects of sisal fiber on the compressive and tensile strengths of foam concrete. They found that small additions of sisal fibers could significantly enhance the material's ductility while marginally improving its compressive strength. This study laid the groundwork for further exploration into the optimal percentage of sisal fiber inclusion for maximizing mechanical benefits.

Moreover, a recent research has begun to address the long-term durability of sisal fiber-reinforced foam concrete under various environmental conditions. Naik et al. (2024) explored the effects of moisture and microwaves on the mechanical properties of sisal fiber-reinforced composites, highlighting the fibers' resilience and the composite's maintained integrity over time.

The utilization of natural fiber, such as sisal, is an environmentally friendly way to improve the mechanical properties of composite materials due to its excellent properties. However, specific records of how this fine product should for the best parameters used in foam concrete construction do not exist. Addressing this gap has both theoretical and practical worth, benefiting the environment too. This paper fills this area, promoting in greater depth a better understanding of renewable materials in construction-able objects, and thereby furthering on sustainable development of our construction. In this study, sisal fiber-added foam concrete samples were prepared. Fiber ratios of 0.25, 0.50, 0.75 and 1.00% by volume were used in the samples. The effect of the amount of fiber changing on the fresh and hardened concrete properties of foam concrete was examined.

## 2. Experimental Program

River sand with a specific gravity of  $1.68 \text{ g/cm}^3$  was used as fine aggregate for the concrete mixture. Fine aggregate gradation is presented in Fig. 1.

Mixtures were prepared with CEM I 42.5R type cement, whose specific gravity and specific surface area are  $3.02 \text{ g/cm}^3$  and  $3150 \text{ cm}^2/\text{g}$ , respectively (TS-EN-197-1 2000). The physical and chemical properties of cement are given in Table 1.

Foaming agents and foam stabilizers were used to produce foam concrete. The foaming agent is a material that facilitates foam formation. Foam stabilizer makes the foams in fresh concrete long-lasting. In this way, the porous structure in foam concrete is preserved during the concrete setting. A foam stabilizer based on Calcium stearate was used for the production of foam concrete. A protein-based foaming agent was also used for foam production. The production of foam concrete is presented in Fig. 2.

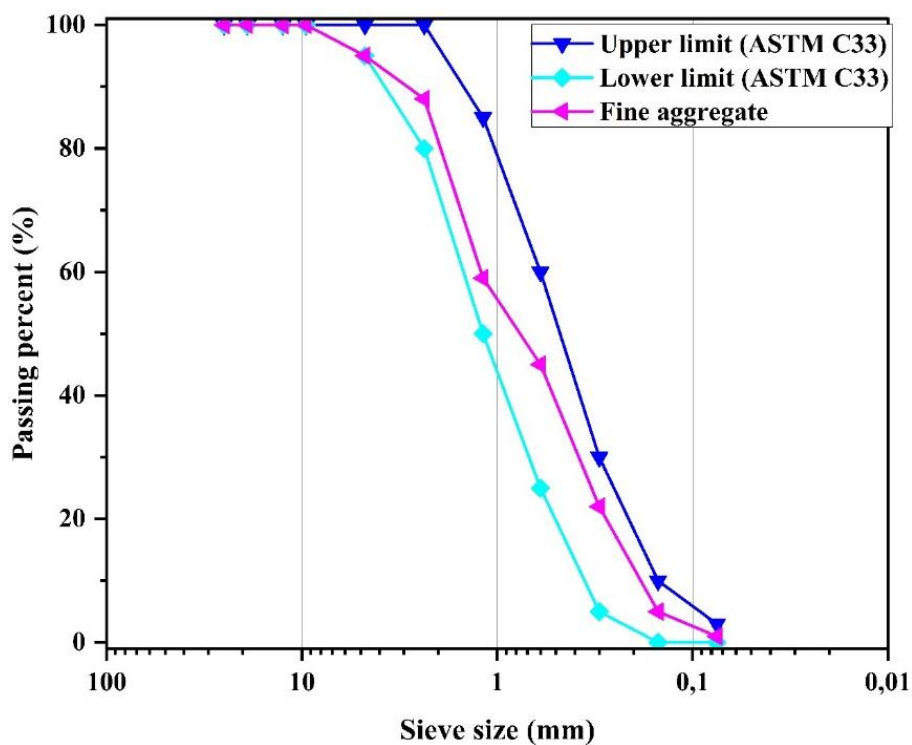
Sisal fiber was used to increase the mechanical properties of foam concrete. Sisal fiber is a type of natural fiber obtained from the *Agave sisalana* plant. *Agave sisalana* plant is a plant native to Kenya, Tanzania and Brazil. Sisal leaves are dark green and have straight flesh. Sisal leaves are crushed with a smooth-edged stick until they are separated into fibers. The fibers are then

cleaned with plenty of water to get rid of dust and waste. The cleaned fibers are air-dried. Sisal fiber is presented

in Fig. 3. The physical and chemical properties of sisal fiber are given in Table 2.

**Table 1.** Physical and chemical properties of cement.

Chemical properties (%)		Physical and mechanical properties	
SO <sub>3</sub>	4.12	Initial setting time (min.)	165
CaO	69.51	Final setting time (min.)	210
SiO <sub>2</sub>	13.45	2-days compressive strength (MPa)	34.3
MgO	1.03	28-days compressive strength (MPa)	51.8
Fe <sub>2</sub> O <sub>3</sub>	7.34	Specific gravity (g/cm <sup>3</sup> )	3.02
Na <sub>2</sub> O	0.59	Specific surface (cm <sup>2</sup> /g)	3150
Al <sub>2</sub> O <sub>3</sub>	3.94		



**Fig. 1.** Aggregate gradation.

**Table 2.** Physical and chemical properties of sisal fiber.

Chemical properties (%)		Physical and mechanical properties	
Hemicellulose	12.3-14.6	Density (g/cm <sup>3</sup> )	1.36-1.41
Cellulose	66.0-74.0	Diameter (mm)	0.10-0.13
Pectin	10.0	Tensile strength (MPa)	540-720
Wax	2.0	Elasticity modulus (GPa)	9.0-12.4
Lignin	7.4-10.3		



**Fig. 2.** Foamed concrete production.



**Fig. 3.** Agave sisalana plant and sisal fiber.

The samples using different proportions of sisal fiber were prepared to examine the effect of sisal fiber on the fresh and mechanical properties of concrete. Fresh and hardened concrete properties were examined for samples to which sisal fiber was added at 0.25, 0.50, 0.75 and 1.00% by volume. The mixtures are given in Table 3.

**Table 3.** Mix design.

Mix	Sisal fiber % (by volume)	Cement (kg)	W/C	Fine aggregate (kg)	Foaming agent and stabilizer (kg)
R	0	720	0.48	230	2.2/1.4
SF0.25	0.25	720	0.48	230	2.2/1.4
SF0.50	0.50	720	0.48	230	2.2/1.4
SF0.75	0.75	720	0.48	230	2.2/1.4
SF1.00	1.00	720	0.48	230	2.2/1.4

The mini-slump test was performed to measure the spreading diameter of fresh concrete, according to TS-EN 1170-1 (TS-EN-1170-1 1999), as shown in Fig. 4.



**Fig. 4.** The spread diameter test.

The cubic samples with dimensions of 150x150x150 mm were prepared to determine the compressive strength of foamed concrete. The samples were tested by TS-EN 12390-3 (TS EN 12390-3 2002). The compressive strength test is presented in Fig. 5. The samples were kept in the mold for 16 hours and were then placed in curing pools at 20 °C. Compressive strength test samples were tested at the end of 7 and 28-day cures.



**Fig. 5.** The compressive strength test.

Prismatic samples measuring 40x40x160 mm were prepared for the flexural test. The samples were tested according to the TS-EN 12390-5 (TS EN 12390-5 2019), as seen in Fig. 6. The density of foam concrete was measured according to TS-EN 12390-7 (TS-EN-12390-7 2010).



Fig. 6. The flexural strength test.

### 3. Results and Discussion

A mini slump test was applied to evaluate the workability of samples prepared according to different sisal fi-

ber ratios. Foam concrete was filled into the cylindrical mold with a height and diameter of 80 mm. The cylindrical mold was then removed to allow the foamed concrete to spread. After the foam concrete became stable, the spreading diameter was measured. Workability in foam concrete is affected by many parameters (amount and type of foaming agent, amount of fiber, water/cement ratio, etc.) (Amran et al. 2015; Kearsley and Mostert 2005; Nambiar and Ramamurthy 2006; Rooholamini et al. 2018). Increasing the amount of fiber in foam concrete increases stability, as workability decreases (Yildizel 2020). Increasing the fiber ratio in the mixture increases the internal resistance of the mixture. Therefore, while the stability in the mixture increases, the fluidity decreases. Additionally, there is a decrease in workability due to natural fibers absorbing water. Mini slump test results are presented in Fig. 7. The increase in the amount of fiber causes the spreading diameter to decrease. However, while the loss in workability was less in samples containing 0.25% and 0.50% fiber, the workability decreased more in samples containing 0.75% and 1.00% fiber. The results are consistent with the literature (Calis et al. 2021; Gencil et al. 2022; Hanafi et al. 2020).

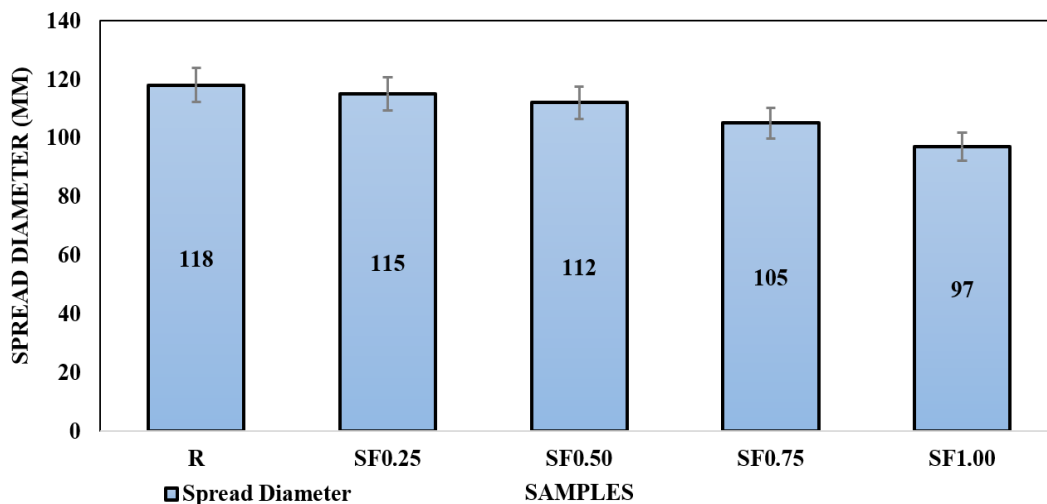


Fig. 7. The mini-slump test results.

The change in density in fiber-added foam concrete depends on the amount of fiber. Increasing the amount of fiber causes the number of solids in the mixture to increase. The increase in the number of solids increases the density of concrete (Mydin et al. 2023). In this study, it was observed that the density increased in samples with an increasing fiber ratio. In addition, increasing the fiber ratio may cause changes in the foam structure in the concrete. Fibers in concrete can affect the stability and size distribution of air bubbles, causing the density of the concrete to change. Deterioration of the foam structure causes the density of the concrete to increase. Fresh and hardened foam concrete densities are given in Fig. 8. The increase in fiber content caused the density of foam concrete to increase. The increase in the amount of fiber increased the amount of solid matter in the mixture, causing the density to increase slightly. However, the difference was not significant.

The compressive strengths of the samples depending on different fiber ratios are presented in Fig. 9 for 7 and 28 days. The highest compressive strength was obtained in the sample with a fiber content of 0.50%. The compressive strength of SF0.50 increased by 12.9% compared to the reference sample. Foamed concrete mechanical properties depend on the concrete matrix and the microstructure of the concrete. Adding fiber to the concrete matrix increased the compressive strength of foam concrete. In fiber-added foam concrete, fibers contribute to the concrete compressive strength by reducing crack propagation (Mahzabin et al. 2018; Serri et al. 2014). In addition, the fibers caused the air bubbles in the foam concrete to break down, thus reducing the voids in the concrete. This also contributed to the increase in compressive strength in foam concrete (Yildizel and Calis 2019). Fiber content greater than 0.50% caused the foam concrete strength to decrease.

The reason for this is that the hydration water decreases as a result of the fibers absorbing the water in the concrete. The large surface area of the fibers increases their water absorption (Farzarian et al. 2016; Pourjavadi et al.

2013). Hydration water was insufficient due to the amount of fiber in the mixture being more than a certain ratio. The results are compatible with the literature (Amran et al. 2015; ArdHIRA et al. 2023).

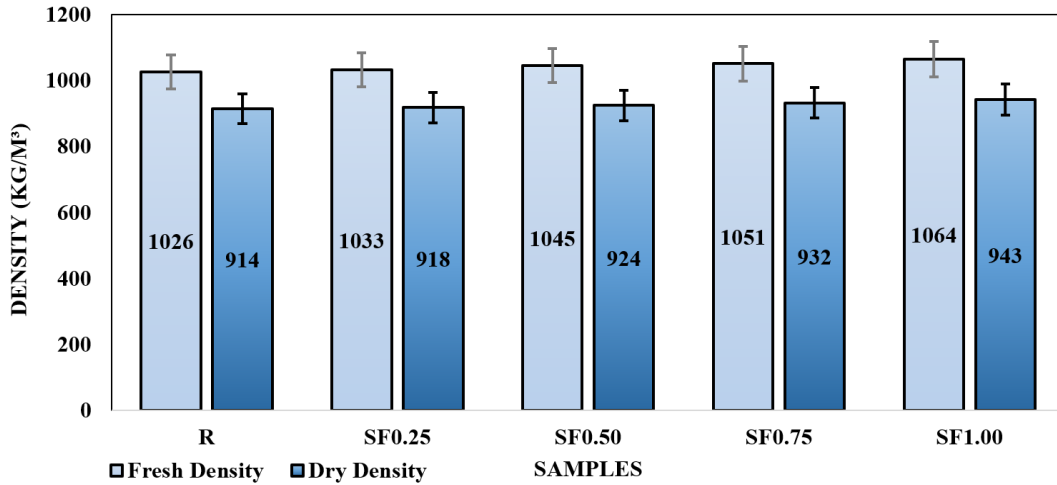


Fig. 8. Fresh and dry density values.

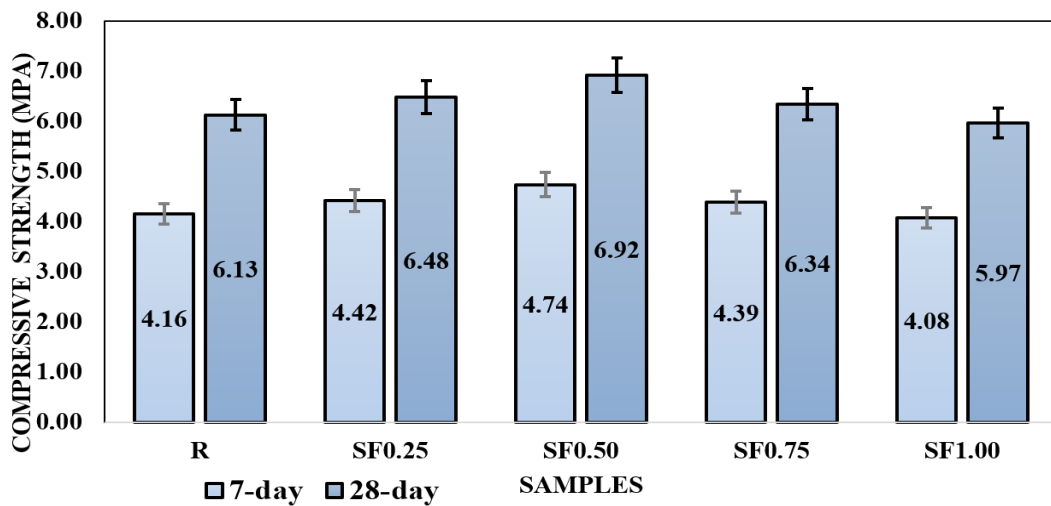


Fig. 9. The compressive strength test results.

Flexural strength test results are shown in Fig. 10. While the increase in the amount of fiber increased the flexural strength up to a certain ratio, more than a certain ratio caused the strength to decrease. The highest flexural strength was obtained in the SF0.50 sample. The flexural strength of the SF0.50 sample is 2.85 times higher than the reference sample. Due to the high tensile strength of sisal fibers, adding them to concrete at a certain ratio increases flexural strength (Castillo-Lara et al. 2020; Raj et al. 2020). Fiber content greater than 0.50% caused a decrease in strength. Using more than a certain amount affects the distribution of fibers in the mixture due to the increase in fiber concentration (Raj et al. 2020).

Although the increase in fiber amount causes the fiber distribution in the matrix to deteriorate, even SF0.75 and SF1.00 samples have more flexural strength than the reference sample. Due to the high tensile strength of sisal fiber, it improves the flexural strength of concrete com-

pared to the reference sample even when used in high amounts. Because the flexural strength of conventional concrete is quite weak. Natural fibers, especially sisal fiber, have very high water absorption. Therefore, it absorbs the hydration water in the concrete. Decreasing hydration water reduces the ultimate strength of concrete. Therefore, the use of high fiber reduces flexural strength. To use high amounts of fiber, the surface of the fibers should be coated.

#### 4. Conclusions

In this study, the properties of sisal fiber-added foam concrete were examined. The foamed concrete samples with different sisal fiber ratios were prepared. Workability was evaluated for each mixture. The mechanical properties of the samples were examined. The findings obtained based on the test results are as follows:

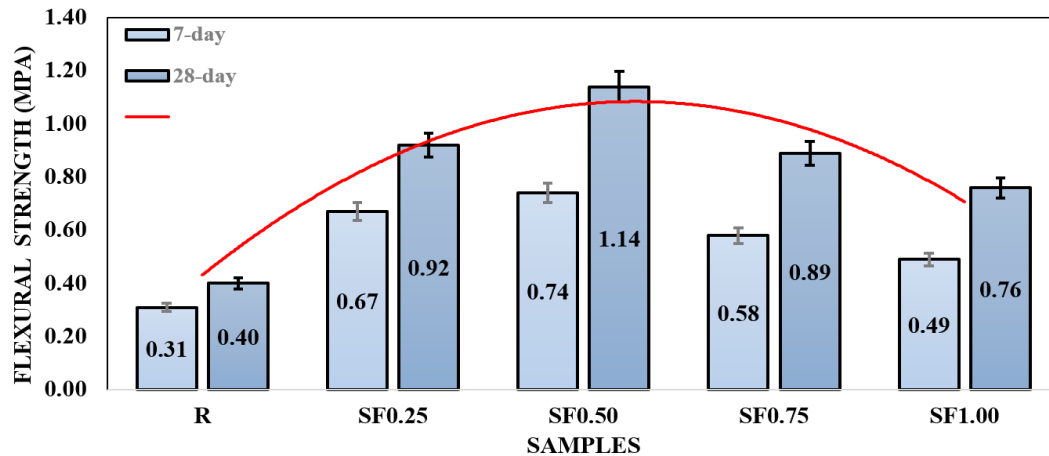


Fig. 10. The flexural strength test results.

- Sisal fiber improved the compressive strength of foam concrete due to its uniform distribution in the concrete matrix. An increase in the amount of sisal fiber up to 0.50% increased the compressive strength of foam concrete. The use of more than %0.50 sisal fiber reduced the compressive strength as it greatly increased the concentration within the concrete matrix.
- Approximately a 12.9% increase in compressive strength was achieved in samples using 0.50% sisal fiber. In addition, there were no significant losses in the workability of samples added %0.50 sisal fiber.
- Sisal fiber with high tensile strength contributed to the flexural strength of foam concrete. However, the use of more than 0.50% sisal fiber decreased flexural strength.
- In samples with 0.50% sisal fiber added, the flexural strength increased 2.85 times compared to the reference sample.
- Excessive use of sisal fiber absorbs the hydration water in the concrete. Therefore, the sisal fibers should be coated with waterproof materials to use large amounts of sisal fiber in concrete mixture. There are many surface coating methods such as polyester resin and bio-based shellac. Before these coating methods, some treatment methods can be applied to clean the fiber surface from organic substances. There are many treatment methods recommended in the literature, such as hornification, alkaline treatment and polymer impregnation.
- Even if the workability decreases in foam concretes with sisal fiber addition, the use of 0.50% or fewer sisal fibers provides acceptable workability.
- Foam concrete is used as a non-structural member in buildings with its high heat and sound insulation properties. If the mechanical properties obtained in fiber-added foam concrete are improved, it will also be possible to use it as a structural member.

Foam concrete is preferred in non-structural elements because of its lightweight and high sound and thermal insulation properties. However, its mechanical properties are not sufficient for use as a structural element. Future studies should aim to improve the mechanical properties of foam concrete without increasing its density. In this way, it will be possible to use foam concrete as structural elements.

#### Acknowledgements

None declared.

#### Funding

The author received no financial support for the research, authorship, and/or publication of this manuscript.

#### Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

#### Data Availability

The datasets created and/or analyzed during the current study are not publicly available, but are available from the corresponding author upon reasonable request.

#### REFERENCES

- Ahmad J, Majdi A, Deifalla AF, Ben Kahla N, El-Shorbagy MA (2022). Concrete reinforced with sisal fibers (SSF): Overview of mechanical and physical properties. *Crystals*, 12(7), 952.
- Amran YHM, Farzadnia N, Abang Ali AA (2015). Properties and applications of foamed concrete; a review. *Construction and Building Materials*, 101, 990–1005.
- Ardhira PJ, Ardra R, Harika M, Sathyan D (2023). Study on fibre reinforced foam concrete-a review. *Materials Today: Proceedings*, In Press.
- Calis G, Yildizel SA, Erzin S, Tayeh BA (2021). Evaluation and optimisation of foam concrete containing ground calcium carbonate and glass fibre (experimental and modelling study). *Case Studies in Construction Materials*, 15, e00625.
- Canbaz M, Bensaoud M, Erol H, Şenge, H (2022). Effect of carbon fibers on the mechanical properties of steam-cured concrete. *Challenge Journal of Structural Mechanics*, 8(2), 38–46.
- Castillo-Lara JF, Flores-Johnson EA, Valadez-Gonzalez A, Herrera-Franco PJ, Carrillo JG, Gonzalez-Chi PI, Li QM (2020). Mechanical properties of natural fiber reinforced foamed concrete. *Materials*, 13(14), 3060.
- Coutts RSP, Ni Y (1995). Autoclaved bamboo pulp fibre reinforced cement. *Cement and Concrete Composites*, 17(2), 99–106.
- Çakıroğlu C, Bekdaş G (2021). Buckling analysis of natural fiber reinforced composites. *Challenge Journal of Structural Mechanics*, 7(2), 58–63.
- Falliano D, De Domenico D, Ricciardi G, Gugliandolo E (2018). Experimental investigation on the compressive strength of foamed concrete: Effect of curing conditions, cement type, foaming agent and dry density. *Construction and Building Materials*, 165, 735–749.

- Farzarian K, Pimenta Teixeira K, Perdigão Rocha I, De Sa Carneiro L, Ghahremaninezhad A (2016). The mechanical strength, degree of hydration, and electrical resistivity of cement pastes modified with superabsorbent polymers. *Construction and Building Materials*, 109, 156–165.
- Frydrych M, Hýšek Š, Fridrichová L, Le Van S, Herclík M, Pechočiaková M, Le Chi H, Louda P (2019). Impact of flax and basalt fibre reinforcement on selected properties of geopolymer composites. *Sustainability*, 12(1), 118.
- Gencil O, Nodehi M, Yavuz Bayraktar O, Kaplan G, Benli A, Gholampour A, Ozbakkaloglu T (2022). Basalt fiber-reinforced foam concrete containing silica fume: An experimental study. *Construction and Building Materials*, 326, 126861.
- Gultekin A (2023). Effect of hemp and basalt fiber on fracture energy of cement-based composites: a comparative study. *Challenge Journal of Concrete Research Letters*, 14(4), 107-117.
- Hamada HM, Shi J, Abed F, Humada AM, Majdi A (2023). Recycling solid waste to produce eco-friendly foamed concrete: A comprehensive review of approaches. *Journal of Environmental Chemical Engineering*, 11(6), 111353.
- Hanafi M, Aydin E, Ekinici A (2020). Engineering properties of basalt fiber-reinforced bottom ash cement paste composites. *Materials*, 13(8), 1952.
- Huang Z, Zhang T, Wen Z (2015). Proportioning and characterization of Portland cement-based ultra-lightweight foam concretes. *Construction and Building Materials*, 79, 390–396.
- Ji R, He Y, Zhang Z, Liu L, Wang X (2015). Preparation and modeling of energy-saving building materials by using industrial solid waste. *Energy and Buildings*, 97, 6–12.
- Jones MR, McCarthy A (2005). Preliminary views on the potential of foamed concrete as a structural material. *Magazine of Concrete Research*, 57(1), 21–31.
- Kearsley EP, Mostert HF (2005). Designing mix composition of foamed concrete with high fly ash contents. *Proceedings of the International Conference on the Use of Foamed Concrete in Construction*.
- Mahzabin MS, Hock LJ, Hossain MS, Kang LS (2018). The influence of addition of treated kenaf fibre in the production and properties of fibre reinforced foamed composite. *Construction and Building Materials*, 178, 518–528.
- Mydin MAO, Abdullah MMAB, Hamah Sor N, Omar R, Dulaimi A, Awoyera PO, Althoey F, Deifalla AF (2023). Thermal conductivity, microstructure and hardened characteristics of foamed concrete composite reinforced with raffia fiber. *Journal of Materials Research and Technology*, 26, 850–864.
- Naik TP, Gairola S, Singh I, Sharma AK (2024). Microwave-assisted alkali treatment of sisal fiber for fabricating composite as non-structural building materials. *Construction and Building Materials*, 411, 134651.
- Nambiar EKK, Ramamurthy K (2006). Influence of filler type on the properties of foam concrete. *Cement and Concrete Composites*, 28(5), 475–480.
- Netinger Grubeša I, Marković B, Gojević A, Brdarić J (2018). Effect of hemp fibers on fire resistance of concrete. *Construction and Building Materials*, 184, 473–484.
- Okeola A, Abuodha S, Mwero J (2018). Experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete. *Fibers*, 6(3), 53.
- Oren OH, Gholampour A, Gencil O, Ozbakkaloglu T (2020). Physical and mechanical properties of foam concretes containing granulated blast furnace slag as fine aggregate. *Construction and Building Materials*, 238, 117774.
- Pourjavadi A, Fakoorpoor SM, Hosseini P, Khaloo A (2013). Interactions between superabsorbent polymers and cement-based composites incorporating colloidal silica nanoparticles. *Cement and Concrete Composites*, 37, 196–204.
- Raj A, Sathyan D, Mini KM (2019). Physical and functional characteristics of foam concrete: A review. *Construction and Building Materials*, 221, 787–799.
- Raj B, Sathyan D, Madhavan MK, Raj A (2020). Mechanical and durability properties of hybrid fiber reinforced foam concrete. *Construction and Building Materials*, 245, 118373.
- Renjith PK, Sarathchandran C, Sivanandan Achary V, Chandramohanakumar N, Sekkar V (2021). Micro-cellular polymer foam supported silica aerogel: Eco-friendly tool for petroleum oil spill cleanup. *Journal of Hazardous Materials*, 415, 125548.
- Rooholamini H, Hassani A, Aliha MRM (2018). Evaluating the effect of macro-synthetic fibre on the mechanical properties of roller-compacted concrete pavement using response surface methodology. *Construction and Building Materials*, 159, 517–529.
- Sabarish KV, Paul P, Bhuvaneshwari, Jones J (2020). An experimental investigation on properties of sisal fiber used in the concrete. *Materials Today: Proceedings*, 22, 439–443.
- Serri E, Suleiman MZ, Mydin MAO (2014). The effects of oil palm shell aggregate shape on the thermal properties and density of concrete. *Advanced Materials Research*, 935, 172–175.
- Shaheen Y, Etman Z, Kandil D (2023). Performance of light weight ferrocement composite walls. *Challenge Journal of Concrete Research Letters*, 14(3), 69-88.
- Shalwan A, Alajmi M, Alajmi A (2017). Insulation characteristics of sisal fibre/epoxy composites. *International Journal of Polymer Science*, 2017, 1–6.
- Shi J, Liu B, He Z, Liu Y, Jiang J, Xiong T, Shi J (2021). A green ultra-lightweight chemically foamed concrete for building exterior: A feasibility study. *Journal of Cleaner Production*, 288, 125085.
- Tran NP, Nguyen TN, Ngo TD, Le PK, Le TA (2022). Strategic progress in foam stabilization towards high-performance foam concrete for building sustainability: A state-of-the-art review. *Journal of Cleaner Production*, 375, 133939.
- TS-EN-197-1 (2000). Cement–Composition, Specifications and Conformity Criteria–Part 1: Common Cements. Turkish Standard Institute, Ankara, Türkiye.
- TS-EN-1170-1 (1999). Precast concrete products–Test method for glass-fibre reinforced cement–Part 1: Measuring the consistency of the matrix “Slump test” method. Turkish Standard Institute, Ankara, Türkiye.
- TS EN 12390-3 (2002). Testing hardened concrete–Part 3: Compressive strength of test specimens. Turkish Standard Institute, Ankara, Türkiye.
- TS EN 12390-5 (2019). Testing hardened concrete–Part 5: Flexural strength of test specimens. Turkish Standard Institute, Ankara, Türkiye.
- TS-EN-12390-7 (2010). Testing hardened concrete–Part 7: Density of hardened concrete. Turkish Standard Institute, Ankara, Türkiye.
- Wang W, Zhang Y, Mo Z, Chou N, Jayaraman K, Xu Z (2023). A critical review on the properties of natural fibre reinforced concrete composites subjected to impact loading. *Journal of Building Engineering*, 77, 107497.
- Yildizel SA (2020). Material properties of basalt-fiber-reinforced gypsum-based composites made with metakaolin and silica sand. *Mechanics of Composite Materials*, 56(3), 379–388.
- Yildizel SA, Calis G (2019). Design and optimization of basalt fiber added lightweight pumice concrete using Taguchi method. *Revista Romana de Materiale/ Romanian Journal of Materials*, 49(4), 544–553.
- Zhang A, Liu K, Li J, Song R, Guo T (2024). Static and dynamic tensile properties of ultra-high performance concrete (UHPC) reinforced with hybrid sisal fibers. *Construction and Building Materials*, 411, 134492.
- Zini E, Scandola M (2011). Green composites: An overview. *Polymer Composites*, 32(12), 1905–1915.