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Preliminary studies on the development of sustainable lightweight foamed concrete reinforced with natural fibres for mechanical properties enhancement

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ABSTRACT

Although foamed concrete was originally developed for void filling and insulation, today's society is gradually shifting its focus to structural qualities. The findings of an experimental investigation that was conducted to determine the impact of various densities and additives on the mechanical properties of foamed concrete are presented in this paper. Additionally, control foamed concrete samples with various densities (600kg/m3, 1200kg/m3, and 1800kg/m3) and additives were created separately to evaluate the effects of each on the mechanical qualities. Coir fibre, sisal fibre, kenaf fibre and flax fibre were used as additives in foamed concrete. According to this study, the density of foamed concrete was influenced by its density due to the volume of porosity. On the other hand, it was discovered that foamed concrete samples with the inclusion of kenaf fibre produced better improvements to the mechanical properties compared to other types of fibre. Since kenaf fibre has a high failure strain and is suitable for use as reinforcement in foamed concrete, it can improve compatibility between the fibres and matrix. The results of this study will help us understand how natural fibres might be used in foamed concrete.

1. Introduction

Due to its promising characteristics, including reduced weight, higher thermal insulation, and long-lasting performance, foamed concrete is increasingly needed and used as a building material [1]. Concrete that has been foamed is lighter than regular concrete because foaming agents can artificially trap air bubbles in cement mortar [2]. There is no use for coarse aggregate in the production of foamed concrete, and fine aggregate (sand) can be replaced by renewable resources

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including pulverised fuel ash, silica fume, and coconut fibres in part or in full [3]. Additionally, foamed concrete offers a great deal of potential as a structural material [4]. Typically, the strength value for foamed concrete ranges from $1.5N/mm^2$ to $14.5N/mm^2$ for densities between $450kg/m^3$ and $1850kg/m^3$ [5]. It should be noted that density and porosity are key factors in determining how strong foamed concrete will be. Since the dawn of civilisation, pozzolan minerals have been used either naturally or synthetically to replace cement or sand in concrete [6]. It has been demonstrated to improve the strength of foamed concrete because its inherent strength is poor, in addition to economic and environmental considerations [7]. One of the essential areas that have to be studied is mechanical characteristics, yet little is known about how different types of additives affect the mechanical properties of foamed concrete [8].

Despite extensive research, various drawbacks, such as low flexural strength, continue to limit the uses of lightweight foamed concrete [9]. Different cementitious materials, cement dosage, mix proportion, water-cement ratio, foam volume, foaming agent, curing process, additive, and addition of waste by-products all affect the strength of foamed concrete [10]. The strength of foamed concrete is somewhat controlled by density. In order to enhance strength while minimising density as much as possible, it is necessary to constantly seek a balance between the two [11]. Sometimes, this can be accomplished by choosing premium foaming agents and ultralight aggregates, as well as optimising cementitious materials [12]. When concrete density is fixed, the types of fillers and the addition of oil palm biomass will affect the water-solid ratios, and the reduction of sand particle size will aid to increase strength [13].

The secondary cement hydration product, Ca(OH)2 (calcium hydroxide, also known as portlandite), reacts with fibre biomass waste to produce more C-S-H gel (secondary C-S-H). As the Ca:Si molar ratio of C-S-H decreases during the pozzolanic reaction, the longer silicate chains are created [14]. This secondary C-S-H boosts the strength, density, and ion diffusion resistance of foamed concrete by decreasing porosity in bulk cement paste and strengthening the interfacial binding between aggregate particles and fibre [15]. Due to its superior thermal and mechanical characteristics, including high flowability, low self-weight, good thermal performance, and sound insulation capabilities, foamed concrete has recently attracted a lot of interest from industrial players and construction material makers [16]. In addition, foamed concrete is an eco-friendly building material due to its low aggregate usage and a high potential for waste material integration, such as natural fibres. Foamed concrete, which can be thought of as self-compacting material, is a mixture of cement paste (slurry) and homogenous foam introduced using a suitable foaming agent [17]. Foamed concrete differs from highly air-entrained materials by having an air content of more than 25% by volume. Foamed concrete has received more attention globally, however, its use in the context of the Malaysian building sector is still in its infancy. In Malaysia, it has, however, been used in several housing and void-filling projects. Consequently, this study was carried out to examine the potential use of additives in foamed concrete to enhance its mechanical qualities.

2. Experimental Program

2.1 Materials and Mix Design

Ordinary Portland cement (OPC), fine sand, a foaming agent, water, and 4 different types of fibres were the 5 major components utilised to create foamed concrete. YTL Castle Cement Marketing provided the OPC. All of the cement was in good shape and was kept under cover. Natural fine sand that was purchased from a local provider was used in this study. This fine sand passed through a 600-micron sieve with a passing of 60% to 90% and a maximum width of 2mm. Sand's suitability adhered to BS822:1992. A protein-based foaming agent, specifically Noraite PA-1, was employed to create stable foam. The foam was created using the Portafoam TM-1 portable foaming generating unit. This study included a variety of natural fibres, including Coir fibre, sisal fibre, kenaf fibre and flax fibre. These natural fibre weight fractions inclusion was set at 0.2%. Table 1 shows the chemical composition of the natural fibres employed in this research while Table 2 demonstrates its mechanical properties. The sand-cement ratio was kept constant at 1:1.5 for all 9 mixes, while the water-cement ratio was set at 0.45. Table 3 displays the foamed concrete mix design with various types of natural fibres.

Table 1
Chemical composition of natural fibres

Characterization	Coir	Sisal	Kenaf	Sisal
Cellulose (%)	44.9	67.3	71.2	68.9
Hemicellulose (%)	0.5	14.3	9.7	13.6
Lignin (%)	46.5	10.5	13.5	10.1
Moisture (%)	5.7	4.4	3.5	4.7
Ash (%)	2.4	3.5	2.1	2.7

Table 2
Mechanical properties of natural fibres

Characterization	Coir	Sisal	Kenaf	Flax
Tensile strength (MPa)	349	551	597	481
Young's Modulus (GPa)	5.8	14.5	24.8	12.6
Elongation at break (%)	17.8	5.6	2.1	8.9

Table 3
Foamed mortar mix design

Sample	Density (kg/m^3)	Fibre (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)
Control	600	0.0	230	345	104
FC-COIR	600	1.4	230	345	104
FC-SISAL	600	1.4	230	345	104
FC-KENAF	600	1.4	230	345	104
FC-FLAX	600	1.4	230	345	104
Control	1200	0.0	447	670	201
FC-COIR	1200	2.7	447	670	201
FC-SISAL	1200	2.7	447	670	201
FC-KENAF	1200	2.7	447	670	201
FC-FLAX	1200	2.7	447	670	201
Control	1800	0.0	664	995	299
FC-COIR	1800	3.9	664	995	299
FC-SISAL	1800	3.9	664	995	299
FC-KENAF	1800	3.9	664	995	299
FC-FLAX	1800	3.9	664	995	299

2.2 Experimental Program

The testing included flexural, compression, and splitting tensile tests to investigate the mechanical properties with the use of various types of additives.

2.2.1 Compression test

The compression test was performed on a 100mm x 100mm x 100mm cube in accordance with the BS EN 12390-3 [18] standard. The average compressive test result from three specimens was chosen as the final result.

2.2.2 Flexural test

A prism measuring 100mm x 100mm x 500mm was used for the flexural test in accordance with BS EN 12390-5 [19]. To determine the flexural strength of foamed concrete, a three-point flexural test was used. Three specimens were made, and the average flexural test result was used as the final result.

2.2.3 Splitting tensile test

For splitting tensile strength, an BS EN 12390-6 [20] cylinder of 100mm diameter x 200mm height was evaluated. Three specimens were made and tested, with the average reading from the three flexural test findings used as the final result.

3. Results and Discussion

3.1 Compressive strength

Figures 1-3 depict the compressive strength of foamed concrete of 600, 1200 and 1800 densities with the addition of different types of natural fibres, where there is a discernible increase in the compressive strength of foamed concrete commencing on day-7 and continuing until day-180. It can be seen that foamed concrete without the addition of any natural fibres has the lowest compressive strength in comparison to other mixes. At day-28, foamed concrete with the addition of kenaf fibre had the highest compressive strength (97% increase over the control specimen), followed by foamed concrete with the addition of sisal fibre (75% increase) for 600 kg/m^3 density. In addition, the compressive strength of 62%, and 47% of foamed concrete specimens, including the flax and coir fibres, increases significantly by day-28.

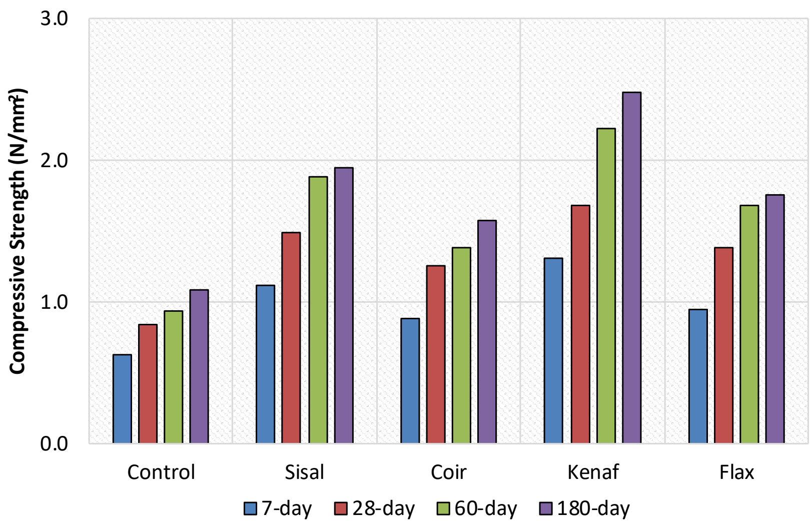

Fig. 1. Compressive strength of 600 kg/m^3 density with varying types of natural fibre

For all the mixes, the natural fibres and cement matrix achieved great compaction, resulting in a homogeneous mix containing a 0.2% weight fraction of fibres. It was anticipated that these results would correlate with Young's modulus of the natural fibres. In this study, kenaf fibre had the greatest Young's modulus, at 24.8 GPa, compared to other fibres investigated. Regarding the tensile strength of the single fibre in Table 2, kenaf fibre has the greatest value of 597 MPa, followed by sisal (551 MPa), flax (481 MPa), and coir (349 MPa), therefore contributing directly to the increased compressive strength of foamed concrete. By incorporating kenaf fibre, which possesses tensile strength and Young's modulus, into foamed concrete, the composite's resistance has been reduced [21,22]. This result may be explained by the fact that fibres with stronger Young's modulus and tensile strength provide greater stiffness to the matrix of foamed concrete [23,24].

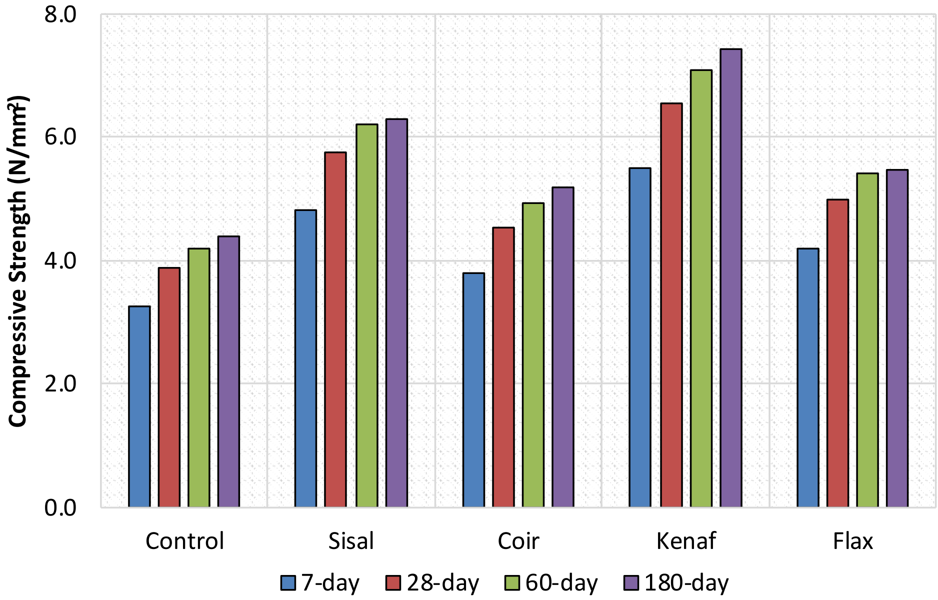

Fig. 2. Compressive strength of 1200 kg/m^3 density with varying types of natural fibre

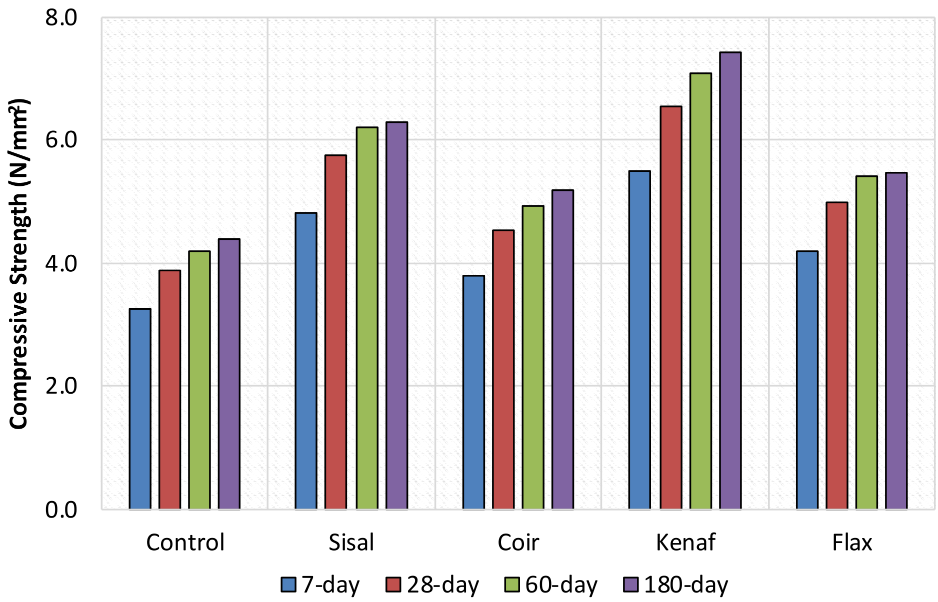

Fig. 3. Compressive strength of 1800 kg/m^3 density with varying types of natural fibre

3.2 Flexural strength

Figures 4-6 show the results of testing the flexural strength of foamed concrete specimens made using a variety of fibre types and each of the three densities that were taken into consideration for this study. In comparison to the other combinations, the foamed concrete specimens that contained kenaf fibre showed the highest flexural strength. The control mix showed just a minor increase in flexural strength as the testing age progressed. This mix had the lowest flexural strength of all the mixes tested. However, specimens of foamed concrete that were supplemented with natural fibres of any kind demonstrated a considerable increase in their flexural strength along with the testing age. Furthermore, there is a discernible rise of compressive strength at 135%, 94%, 76%, and 65% of the foamed concrete specimens, including kenaf fibre, sisal fibre, flax fibre, and coir fibre, respectively, at day-28 in comparison to the control specimen for the 600 kg/m^3 density. The incorporation of kenaf fibre resulted in the achievement of the greatest flexural strength after 28 days. It is quite likely that the tensile strength of the fibres, as is shown in Table 1, was connected to these results. In this study, the tensile strength of kenaf fibre was found to be 597 MPa, making it the natural material with the highest measured value. The ability of a single fibre to withstand a force that has the potential to tear it in two is what is meant when we talk about the fibre's tensile strength. Therefore, the stronger fibre entanglement, such as that of kenaf fibre, will sturdily maintain the fibres together and provide a tougher fibre–matrix adhesion, which ultimately leads to good flexural strength qualities in the foamed concrete specimens under the applied load. In the meantime, the tensile strength of coir fibre is the weakest (349 MPa), followed by flax fibre (481 MPa) and sisal fibre (551 MPa). Because of the comparatively low transverse stiffness of the fibre, weak planes of failure are created for a considerably stiffer matrix, which results in the matrix exhibiting the lowest percentage of flexural strength augmentation [25,26]. Therefore, the findings obtained to strengthen the likelihood that kenaf fibre is the most effective type of fibre that can provide stronger fibre gripping over a longer period, thereby delaying the onset of fracture in composites when subjected to flexural loading at the beginning of day-7 [27,28].

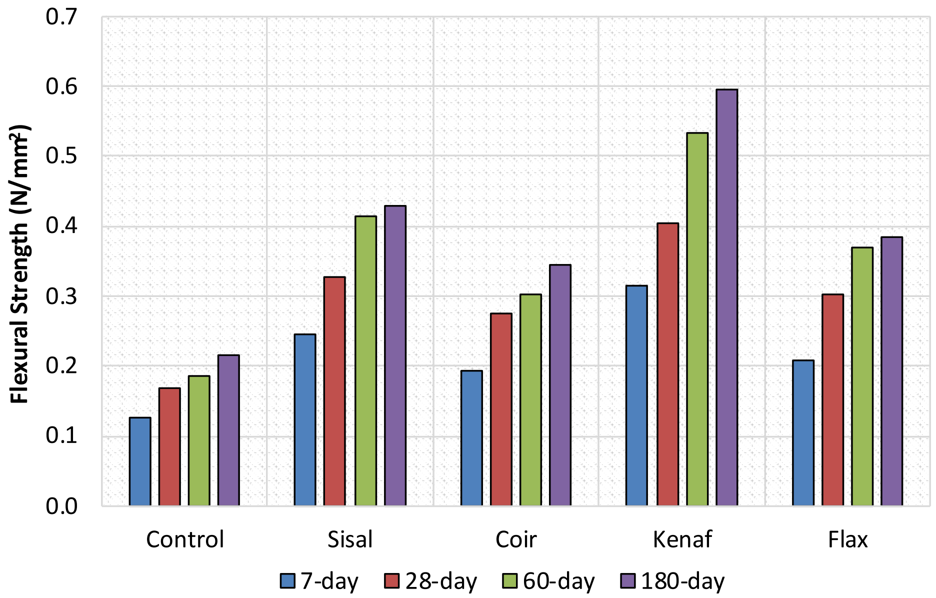

Fig. 4. Flexural strength of 600 kg/m^3 density with varying types of natural fibre

The incorporation of kenaf fibre resulted in the achievement of the greatest flexural strength after 28 days. It is quite likely that the tensile strength of the fibres, as is shown in Table 1, was connected to these results. In this study, the tensile strength of kenaf fibre was found to be 597 MPa, making it the natural material with the highest measured value. The ability of a single fibre to withstand a force that has the potential to tear it in two is what is meant when we talk about the fibre's tensile strength. Therefore, the stronger fibre entanglement, such as that of kenaf fibre, will sturdily maintain the fibres together and provide a tougher fibre–matrix adhesion, which ultimately leads to good flexural strength qualities in the foamed concrete specimens under the applied load. In the meantime, the tensile strength of coir fibre is the weakest (349 MPa), followed by flax fibre (481 MPa) and sisal fibre (551 MPa).

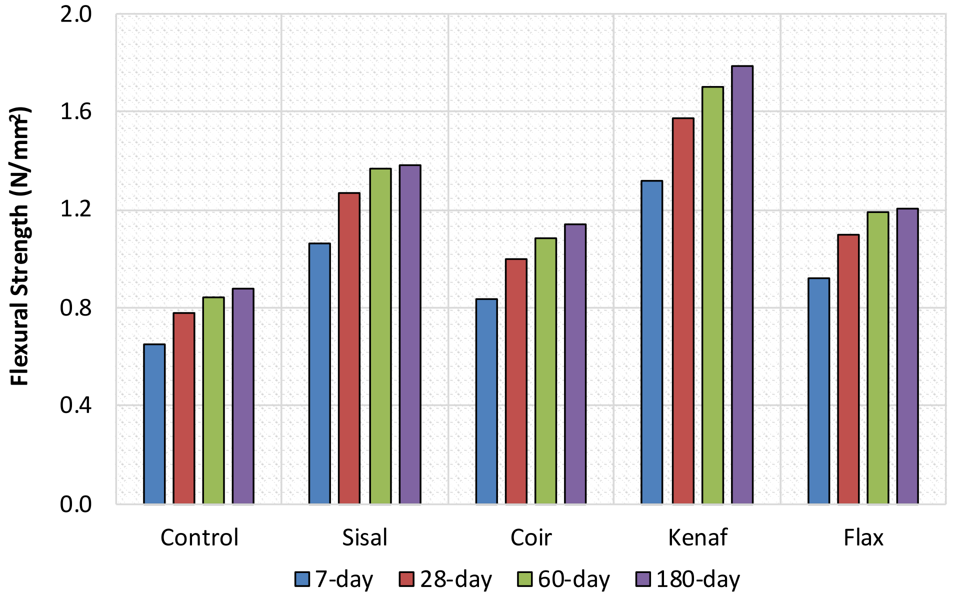

Fig.5. Flexural strength of 1200 kg/m^3 density with varying types of natural fibre

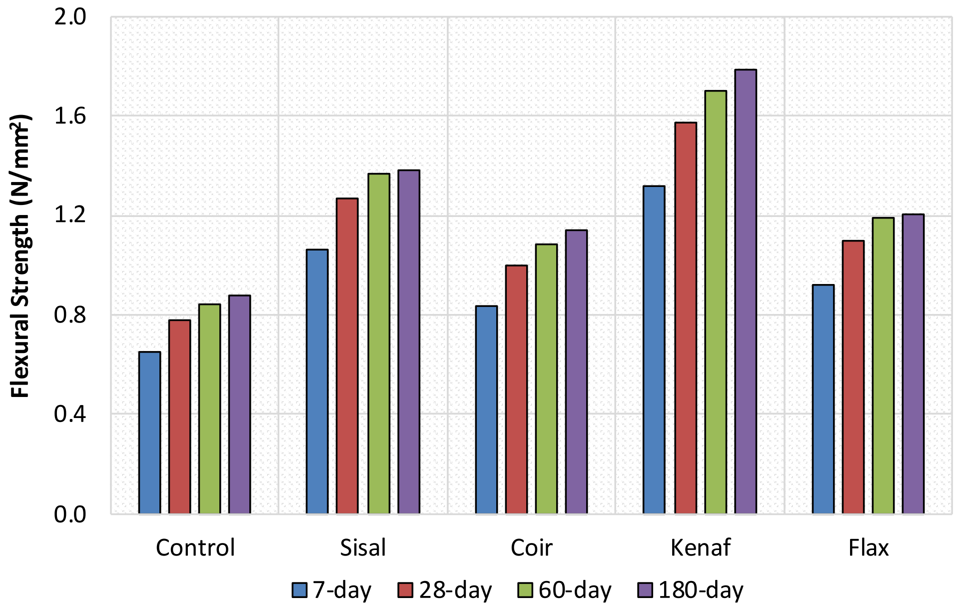

Fig. 6. Flexural strength of 1800 kg/m^3 density with varying types of natural fibre

Because of the comparatively low transverse stiffness of the fibre, weak planes of failure are created for a considerably stiffer matrix, which results in the matrix exhibiting the lowest percentage of flexural strength augmentation. Therefore, the findings obtained strengthen the likelihood that kenaf fibre is the most effective type of fibre that can provide stronger fibre gripping over a longer period, thereby delaying the onset of fracture in composites when subjected to flexural loading at the beginning of day-7.

3.3 Tensile Strength

The trend of rising splitting tensile strength in foamed concrete, encompassing various types of natural fibres, is displayed in Figure 7-9. According to the findings, the foamed concrete specimens that contained kenaf fibre accomplished the highest tensile strength, whereas the control mix attained the lowest possible tensile strength. Regarding the other specimens, each mixture accomplished a discernible increase in tensile strength at 92%, 75%, and 58% of foamed concrete with the addition of sisal fibre, flax fibre, and coir fibre, respectively, on day-28 with a density of 600 kg/m^3; this was the case for all the specimens. According to the findings of this study, the flexural strength of foamed concrete was approximately 70% of its splitting tensile strength. As can be seen in Table 1, kenaf fibre has a relatively low elongation at break, which contributes to its exceptionally high tensile strength. The ability of a fibre to withstand changes in shape without developing cracks can be measured by measuring its elongation at break. Because natural fibres such as kenaf fibre are stiffer, their splitting tensile strength is significantly increased. The tensile strength and brittle nature of foamed concrete are well-known characteristics of this material. On the other hand, it was discovered through the course of this research that the inclusion of natural fibres led to an increase in the tensile strength of the material.

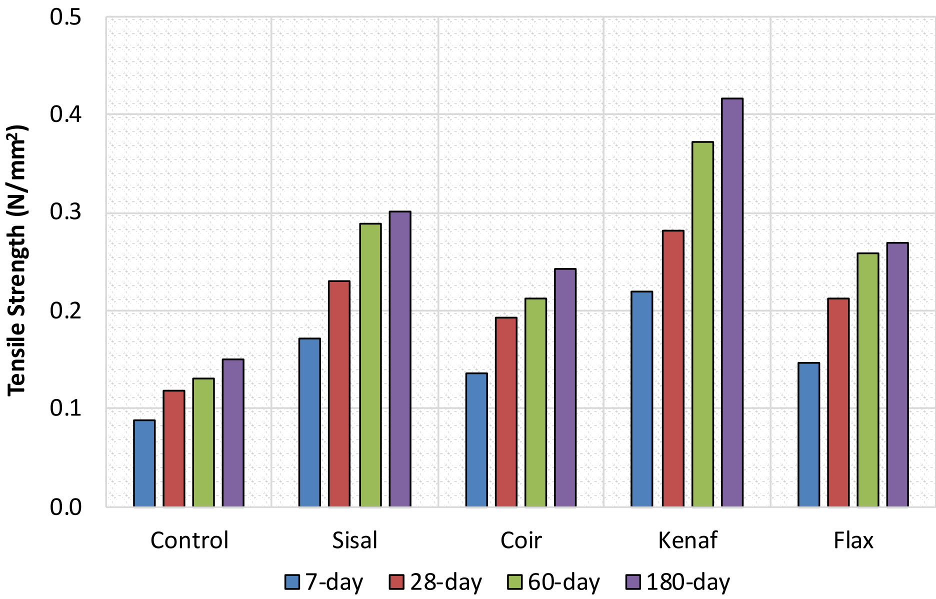

Fig.7. Tensile strength of 600 kg/m^3 density with varying types of natural fibre

The presence of natural fibres causes an increase in the toughness of concrete, which in turn causes an increase in the tensile strength of the concrete. The addition of 0.2% fibre content increases the increment of tensile strength in foamed concrete by promoting an optimal pozzolanic reaction with the OPC content, which ultimately results in the production of denser and more durable concrete [29]. According to the findings of this research, the incorporation of natural fibres into foamed concrete results in an increase in that material's tensile strength.

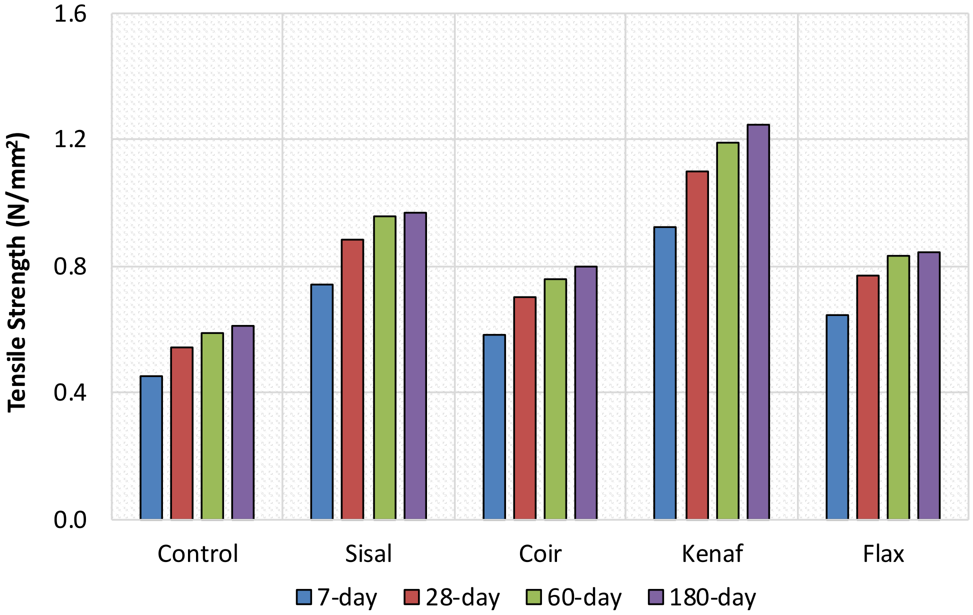

Fig. 8. Tensile strength of 1200 kg/m^3 density with varying types of natural fibre

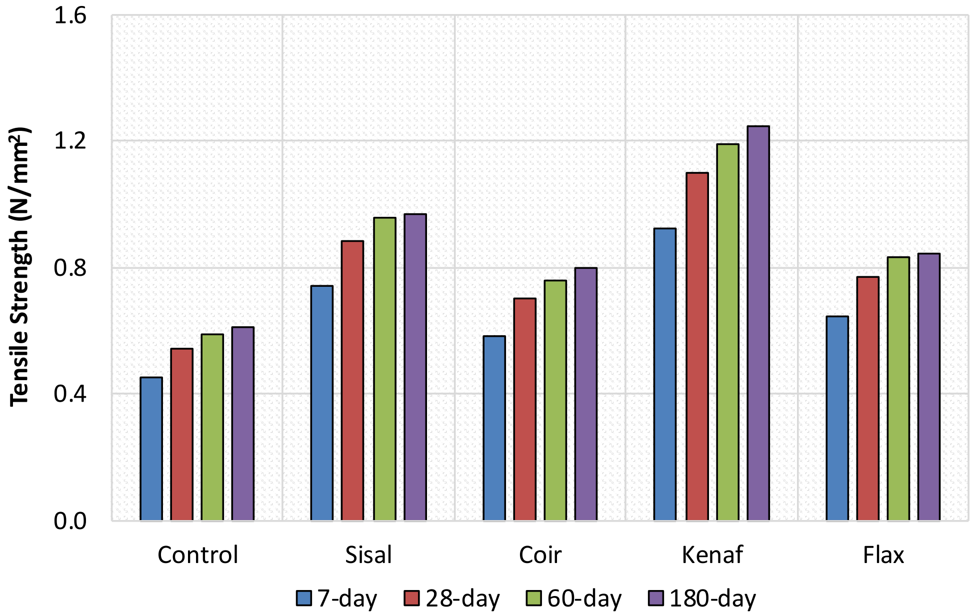

Fig. 9. Tensile strength of 1800 kg/m^3 density with varying types of natural fibre

4. Conclusion

This study investigated the possibility of using natural fibres in foamed concrete to improve their mechanical qualities. Three densities, 600, 1200, and 1800 kg/m^3, were cast and tested. Compressive strength, flexural strength, and splitting tensile strength were three mechanical parameters that were assessed. This study showed that adding natural fibres to foamed concrete can improve its qualities by achieving exceptional outcomes with the addition of kenaf fibre. Comparing the different mixes, the foamed concrete without oil palm fibre had the lowest compressive strength. foamed concrete had the maximum compressive strength with the inclusion of kenaf fibre, then sisal, flax, and coir fibres. In this case, it was anticipated that the fibres and cement matrix would achieve strong compaction, resulting in good homogeneity in the mixture with 0.2% fibre inclusion. The addition of fibre to foamed concrete makes the bulk of the material stronger and changes the material's basic properties from fragile to ductile elastic-plastic. As a result, the addition of fibre helps to improve foamed concrete's flexural strength. However, a high fibre concentration can cause bonding to be reduced and disintegration to occur.

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