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Mechanical Properties of Sustainable Mesocarp Fibre Reinforced Lightweight Foamed Concrete

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ABSTRACT

Foamed concrete has a tension weakness that can be mitigated by adding a suitable proportion of waste by-products such as mesocarp and trunk fibres. Accordingly, this study was conducted to explore the feasibility of using mesocarp fibre as a reinforcement in foamed concrete. Four varying percentages of mesocarp fibre were used: 0.2%, 0.4%, 0.6%, and 0.8% as an additive in foamed concrete. Two densities were cast and tested: 700 and 1400 kg/m^3. After that, all foamed concrete specimens were prepared and tested on 7, 28, and 56 days. Mechanical properties were investigated in this study. The results showed that adding mesocarp fibre to lightweight foamed concrete enhanced its compressive, flexural, and tensile strengths. Because a coarser surface allows mesocarp fibre and matrix interlocking in the cured cement matrix, the surface roughness of the mesocarp has been shown to be favourable for fibre-to-matrix interfacial bonding. According to the findings of this investigation, for a density of 700 kg/m^3, 0.4% volume fraction was the optimum quantity of foamed concrete applied to obtain the ideal mechanical properties while 0.6% of mesocarp was optimal for 1400 kg/m^3.

1. Introduction

Due to its numerous positive qualities, including its lighter weight, ease of fabrication, durability, and affordability, foamed concrete has recently attracted a lot of interest from the construction sector. Foamed concrete is a substance made of Portland cement paste or cement filler matrix that has been given a homogenous pore structure by adding air in the form of tiny bubbles [1]. A wide variety of densities (550 - 1850 kg/m^3) of foamed concrete can be generated with correct dose control and production procedures, allowing versatility for applications as structural components, partitions, insulating materials, and filler grades [2]. Foamed concrete has mostly been used as a filler material in civil engineering projects up to now. However, its tremendous potential as a material in building construction is shown by its good thermal and acoustic characteristics [3]. Indeed, it has been widely

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reported that foamed concrete has been used as structural components in the construction of homes, flats, and schools in nations including Indonesia, India, Libya, Russia, Malaysia and Singapore [4].

Construction companies have been using foamed concrete since it was first patented in 1923, albeit on a small scale. The material wasn't used in the Netherlands for ground engineering applications or void-filling projects until the late 1970s. In the United Kingdom (UK), a comprehensive evaluation of the use of foamed concrete for trench reinstatement was carried out in 1987. The success of this trial resulted in the widespread use of foamed concrete for trench reinstatement, and other applications soon followed [5]. Since then, foamed concrete as a building material has expanded in popularity and use, increasing its production and number of possible applications. Foamed concrete has been mainly used for bulk filling, trench reinstatements, backfill to retaining walls and bridge abutments, insulation to foundations and roof tiles, sound insulation, stabilising soils (especially in the construction of embankment slopes), grouting for tunnel works, sandwich filling for precast units, and pipeline infill over the past 20 years [6]. To capitalise on foamed concrete’s lightweight and excellent insulation qualities, there has been an increase in interest in using it as a lightweight semi-structural material in building construction over the past few years [7].

When subjected to typical stresses and impact loads, however, where its tensile strength is only about one-tenth that of its compressive strength, foamed concrete is known to be a relatively brittle material. Due to these characteristics, foamed concrete flexural members were unable to support the kinds of loads that typically occur during their service life. In the past, continuous reinforcing bars were used to reinforce foamed concrete members to help them withstand tensile stresses and make up for their lack of ductility and strength. Additionally, steel reinforcement was used to help foamed concrete members survive high-potential tensile and shear stresses at a crucial location [8]. Although adding steel reinforcement increases the strength of foamed concrete, it is still necessary to control the growth of microcracks to create concrete with uniform tensile properties. The density caused by foamed concrete's porosity has a considerable impact on the material's compressive strength. The development of air gaps brought on by the rising volume of foaming agents would result in the foamed concrete with a lower density having less strength due to the larger amount of foam. Compressive strength in proportion to density will also be influenced by the pores, air gaps, and matrix, which typically dictate the quality of the microstructure [9].

When the foamed concrete takes longer to cure, the strength gain increases. In addition to increasing the overall amount of water present in the pore spaces inside the concrete mass, or the water-to-binder ratio, they stated that adding foam to concrete results in air voids or pore spaces [10]. Tricalcium silicate (C3S) and dicalcium silicate (C2S) react to form calcium silicate hydrate (C-S-H), which is primarily crucial for the development of strength. The hydration of cement increases the water's alkalinity to pH 13 or even higher. In order to create foamed concrete with improved flexural and tensile strength - a new type of binder that can combine Portland cement in bonding with cement matrices - fibre is therefore seen as a potential solution [11]. The majority of the fibres are discontinuous and dispersed at random throughout the cement matrices [12]. Fibres are added to foamed concrete to prevent and delay the tensile cracking of composite material [13]. Thus, fibres convert the naturally unstable tensile crack propagation to controlled, slow crack growth. Flexural and shear cracking delays and their onset were strengthened by the fibre’s crack-controlling properties. It greatly improves the ductility of the composite and imparts extensive post-cracking behaviour. Fibres that are evenly distributed throughout the FC could effectively combat cracks and control shrinkage. These substances combine strength and energy absorption in exceptional ways. Fibre reinforcement is not a replacement for traditional steel reinforcement because both fibres and steel reinforcement have specific roles in foamed concrete technology and can be used in a variety of applications [14]. However, compared to traditional steel reinforcement, fibres are less effective at withstanding tensile stresses. Fibres are reinforced more closely than steel, which is better at preventing cracks and shrinkage [15]. Since fibres are more effective at controlling cracks, conventional steel reinforcements are used to increase the load-bearing capacity of the foamed concrete member. The expansion of oil palm plantations in Malaysia has resulted in significant waste products, particularly mesocarp fibre. Today, about 70% of Malaysia's total waste is made up of oil palm fibre waste [16]. Due to the low density and good tension of mesocarp fibre, scientists are actively exploring the use of mesocarp fibre in concrete. To determine the ideal composition of this concrete, the mesocarp fibre added to the concrete can also be applied to foamed concrete. Thus, this study explores how mesocarp fibre might be used in foamed concrete for strength enhancement.

2. Experimental Program

River sand, cement, mesocarp fibre, and water were utilised to create the basic mix. The sand was brought in from a river in the vicinity of Penang. Larger sand aggregates and harmful substances were removed by drying the sand in the open and sieving it with a 1.18mm sieve. Foams made for foamed concrete could be less stable if sand particles were larger. Sand has a fixed bulk density of 1.44 kg/m^3, a fineness modulus of 1.99, and a specific gravity of 2.59. The cement used was ordinary Portland cement. In terms of density, the cement has a bulk density of 1288 kg/m^3 and a specific gravity of 2.95. Tap water was used as a solvent for the base mix of the foamed concrete. When combined with the foaming ingredient, the tab water's PH of 6.97 makes for an ideal dilution. Mesocarp fibre was the primary additive in this study.

Raw mesocarp fibre was utilized for entire mixes. Table 1 shows the chemical composition of mesocarp fibre and Table 2 demonstrates the mechanical properties of mesocarp fibre. Figure 1 shows the raw mesocarp fibre utilized in the study. The foamed concrete production process additionally necessitates the use of a foaming agent in addition to the components used to create the base mix concrete. Noraite PA-1 protein foaming agent from DRN technologies was used as the foaming agent in this study. The protein-based foaming ingredient is what keeps the foam bubble from collapsing. Table 3 shows the foamed concrete mix design for 700 and 1400 kg/m^3 densities.

Table 1
Chemical composition of mesocarp fibre

Characterization	Percentage (%)
Cellulose	38.3
Hemicellulose	27.2
Lignin	23.8
Moisture	5.8
Ash	4.9

Table 2
Mechanical properties of mesocarp fibre

Properties	Value
Tensile strength	146 N/mm^2
Young’s modulus	14755 N/mm^2
Elongation at break (%)	10.56

Fig. 1. Raw mesocarp fibre

Table 3
Foamed concrete mix design for 700 kg/m^3 and 1400 kg/m^3 densities

Sample	Density (kg/m^3)	Mesocarp fibre (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)
Control	700	0.0	266.3	399.5	119.9
0.2% MF	700	1.7	266.3	399.5	119.9
0.4% MF	700	3.3	266.3	399.5	119.9
0.6% MF	700	5.0	266.3	399.5	119.9
0.8% MF	700	6.6	266.3	399.5	119.9
Control	1400	0.0	519.1	778.7	233.6
0.2% MF	1400	3.1	519.1	778.7	233.6
0.4% MF	1400	6.2	519.1	778.7	233.6
0.6% MF	1400	9.3	519.1	778.7	233.6
0.8% MF	1400	12.4	519.1	778.7	233.6

A compression test was conducted utilising GT-7001-BS300 universal testing equipment with a 300KN capacity. This evaluation is conducted in accordance with BS12390-3 [17] using a 100mm x 100mm x 100mm cube-shaped sample. The specimens were subjected to an axially compressive force that was acting at a rate of 0.15 Newtons per second before the failure occurred. The result was acquired, and the examination was carried out on days 7, 28, and 56 of the experiment. The compressive strength of the material is measured on an average basis using the three samples.

A rectangular beam with dimensions of 100mm x 100mm x 500mm was utilised for the flexural strength test. The examination was conducted in accordance with the requirements of BS EN 12390-5 [18]. The Go-Tech GT-7001-C10, which is a universal testing machine, was the machine that assisted in the execution of this testing programme. The roller allowed for unfettered horizontal movement, and the nominal distance between the supports was 300mm. The foamed concrete has exerted a steady load that is 0.15N/sec in magnitude. On the 7th, the 28th, and the 56th, respectively, the tests were carried out to achieve the outcome. Three different specimens are used to calculate the average flexural strength.

Next, the splitting tensile test aims to ascertain the load under which foamed concrete begins to fail. This phenomenon is referred to as tensile collapse. This test is guided by BS EN 12390-6 [19]. The configuration of splitting tensile strength is depicted in Figure 5. The specimens have a 100mm diameter and 200mm height, respectively. The machine utilised is the GOTECH GT 7001-BS300 universal testing machine. Prior to obtaining the result, the specimens are subjected to 0.15 N/sec. The examination was administered on the 7th, 28th, and 56th. Using three specimens, the average flexural strength is calculated.

3. Results and Discussion

3.1 Splitting Tensile Strength

Figures 2 and 3 depict the outcome of splitting the tensile strength of foamed concrete with the addition of mesocarp fibre at 700 kg/m^3 and 1400 kg/m^3 densities respectively. The foamed concrete without mesocarp fibre has a lower compressive strength than the foamed concrete with the addition of mesocarp fibre. The inclusion of 0.4% and 0.6% mesocarp fibre contributed to the maximum splitting tensile strength on day-56, which was 0.59 N/mm^2 for 700 kg/m^3 density and 0.89 N/mm2 for 1400 kg/m^3 density respectively. In addition, the lowest splitting tensile strength results for the control sample were 0.20 N/mm^2 for 700 kg/m^3 and 0.47 N/mm^2 for 1400 kg/m^3. The density of the foamed concrete also affected the splitting tensile strength. For 0.2% mesocarp fibre, the values are 0.24 N/mm^2 at 700 kg/m^3 and 0.55 N/mm^2 at 1400 kg/m^3 on day-56. For 0.8% mesocarp fibre, the values of splitting tensile strength dropped at 0.27 N/mm^2 for 700 kg/m^3 density and 0.67 N/mm^2 for 1400 kg/m^3 density on day-56. The optimal amount of mesocarp fibre inclusion and the build-up and irregular spreading of mesocarp fibre were identified, resulting in a decrease in tensile strength (beginning at 0.4% and 0.6% mesocarp fibre for 700 kg/m^3 and 1400 kg/m^3 densities respectively). As a result of the mesocarp fibre's enhancement of the foamed concrete's tensile strength, the splitting tensile strength improved. The addition of 0.4% and 0.6% mesocarp fibre for 700 kg/m^3 and 1400 kg/m^3 densities correspondingly increases the tensile strength of foamed concrete by boosting the optimum pozzolanic interactions with cement, resulting in the foamed concrete with a high-density [20]. This suggests that the addition of mesocarp fibre enhances the splitting tensile strength of foamed concrete.

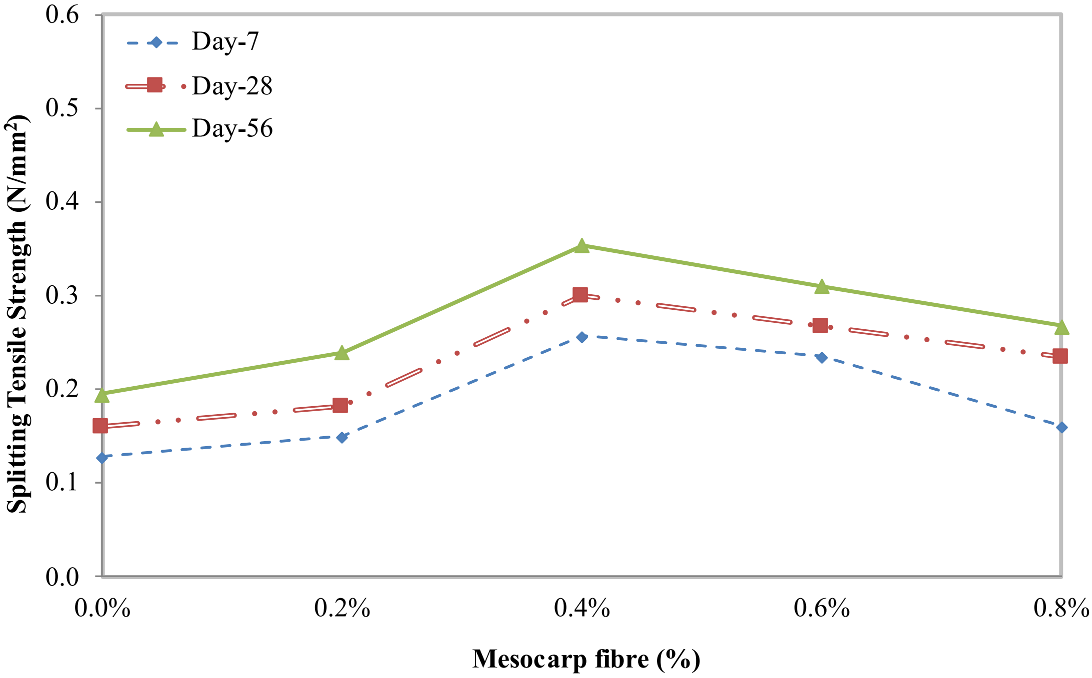

Fig. 2. Splitting tensile strength of 700 kg/m^3 density with varying percentages of mesocarp fibre

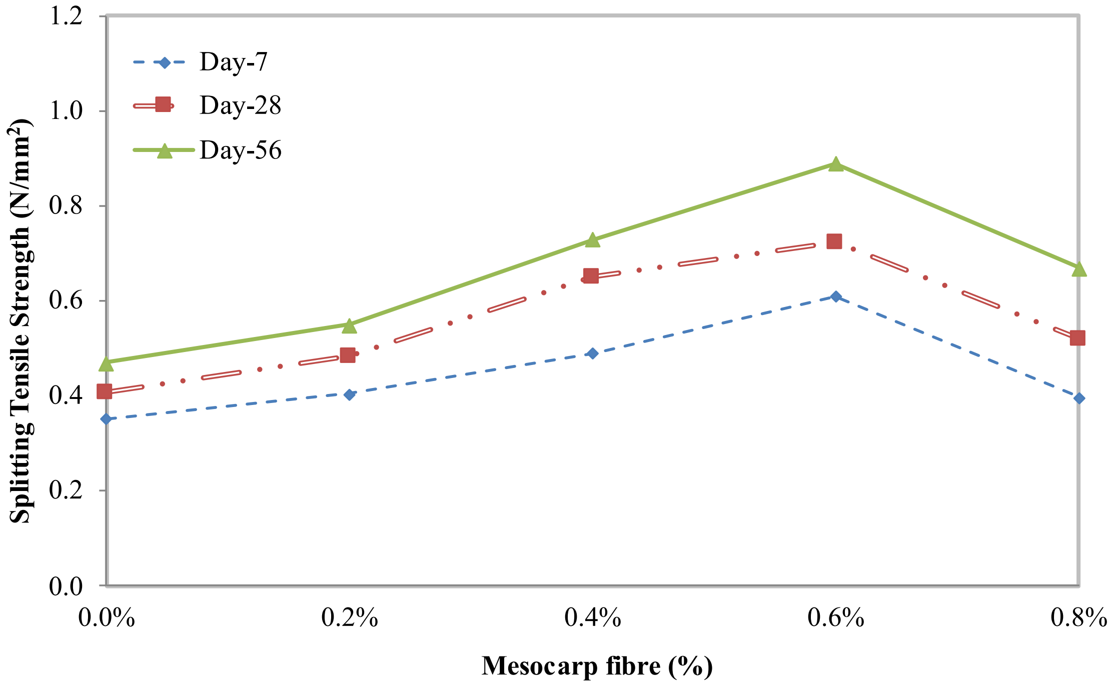

Fig. 3. Splitting tensile strength of 1400 kg/m^3 density with varying percentages of mesocarp fibre

3.2 Compressive Strength

Figures 4 and 5 illustrate the results of the control specimen and the foamed concrete's axial compressive strength with the addition of mesocarp fibre at densities of 700 kg/m^3 and 1400 kg/m^3. The control specimen (without the addition of mesocarp fibre) has a lower compressive strength than the foamed concrete with the addition of mesocarp fibre, as shown by these figures. From day 7 to day 56, there was an increase in compressive strength. From day 7 to day 56, an increase in compressive strength was seen. When compared to other mesocarp fibre percentages, 0.4% and 0.6% mesocarp fibre addition produced the highest compressive strength results for 700 kg/m^3 and 1400 kg/m^3 densities respectively. As a result, when the load was applied, the mesocarp fibre assisted in reducing the propagation of cracking in the cement matrix's plastic state. Additionally, the control specimen's compressive strength result was 1.66 N/mm^2 for 700 kg/m^3, and 4.76 N/mm^2 for 1400 kg/m^3 on day-56 correspondingly. Figures 4 and 5 clearly demonstrate that specimens containing 0.4% and 0.6% mesocarp fibre provide the best compressive strength for 700 kg/m^3 and 1400 kg/m^3 densities respectively, and that strength decreased as the mesocarp fibre level increased beyond the optimum level. The packing density of cement composite can be increased by adding a little quantity of fibre content, which will also raise the compressive strength. The formation of an air void within the mixture with a high fibre concentration may be what causes the drop in compressive strength when it reaches a particular fibre level [21]. As fibre content increased, the fibres clumped together and reduced compressive strength. Increased mesocarp fibre concentration may also result in less bonding and dissolution. In other words, a higher fibre concentration may result in a lower volume fraction of the matrix mix, which lowers compressive strength [22]. Since natural fibres have considerable resistance to compression, the foamed concrete with additional fibres often demonstrated greater compressive strength than the control specimen. According to the results, using foamed concrete with a higher density improves compressive strength.

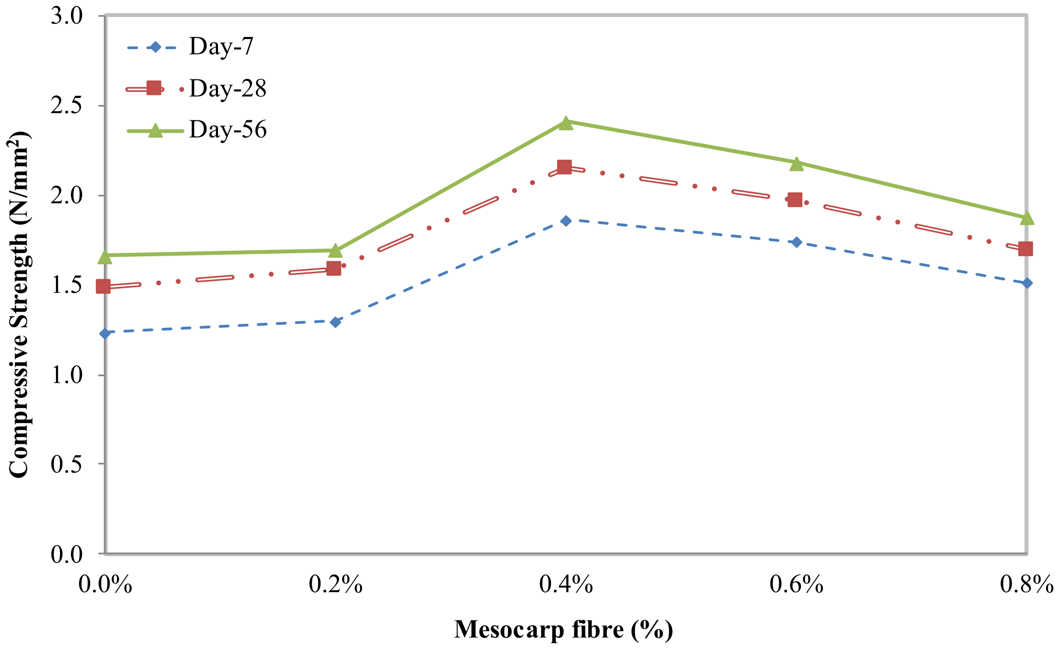

Fig. 4. Compressive strength of 700 kg/m^3 density with varying percentages of mesocarp fibre

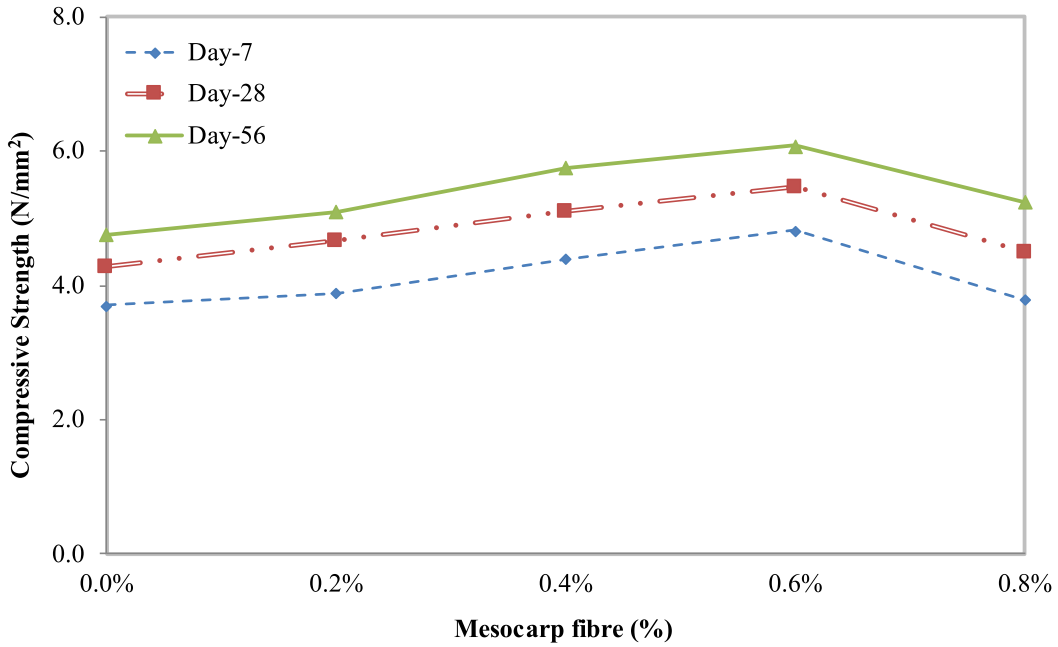

Fig. 5. Compressive strength of 1400 kg/m^3 density with varying percentages of mesocarp fibre

3.3 Flexural Strength

The flexural strength for both densities is shown in Figures 6 and 7. These both figures demonstrate that 0.4% and 0.6% mesocarp fibre was in control for the maximum flexural strength, which was 0.49 N/mm2 for a density of 700 kg/m^3 and 1.17 N/mm^2 for a density of 1400 kg/m^3 correspondingly. Due to mesocarp fibre's biodegradable qualities, it serves as a strengthening agent. High failure strain in mesocarp fibre resulted in better compatibility between the matrix and fibres. For both densities considered in this research, the increase in flexural strength increased the mesocarp fibre percentage. The flexural strength of foamed concrete, however, declines above 0.4%

and 0.6% for 700 kg/m^3 and 1400 kg/m^3 respectively. This is due to a composite that isn't complete. Additionally, the control specimen had the lowest flexural strength of 0.27 N/mm^2 for 700 kg/m^3 and 0.74 N/mm^2 for 1400 kg/m^3. Overall, it was determined that the foamed concrete was strong under flexural strength but brittle under compression. In light of this, it can be said that the addition of mesocarp fibre as concrete reinforcement increased the flexural strength of foamed concrete. The incorporation of mesocarp fibre into foamed concrete plays a significant part in both the strengthening of the foamed concrete matrix and the modification of the material properties from a brittle to a ductile state, respectively [23]. Mesocarp fibre contributes to an increase in the flexural strength of foamed concrete across the board [24]. Nevertheless, an uneven addition of mesocarp fibres, which caused the percentages to be greater than 0.4% and 0.6% for 700 kg/m^3 and 1400 kg/m^3 respectively, resulted in a reduced level of cohesiveness between the fibres and the matrix [25,26].

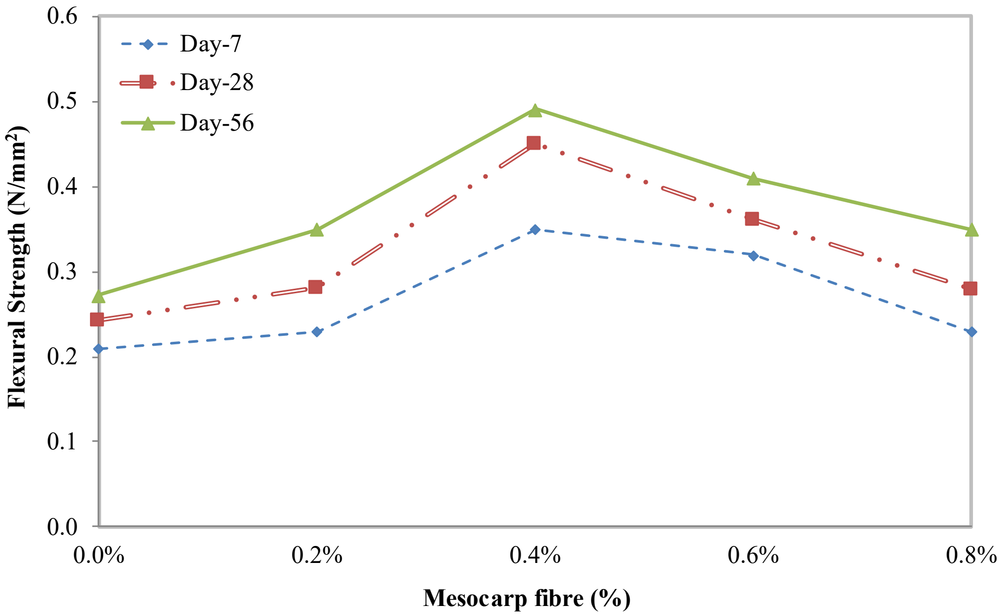

Fig. 6. Flexural strength of 700 kg/m^3 density with varying percentages of mesocarp fibre

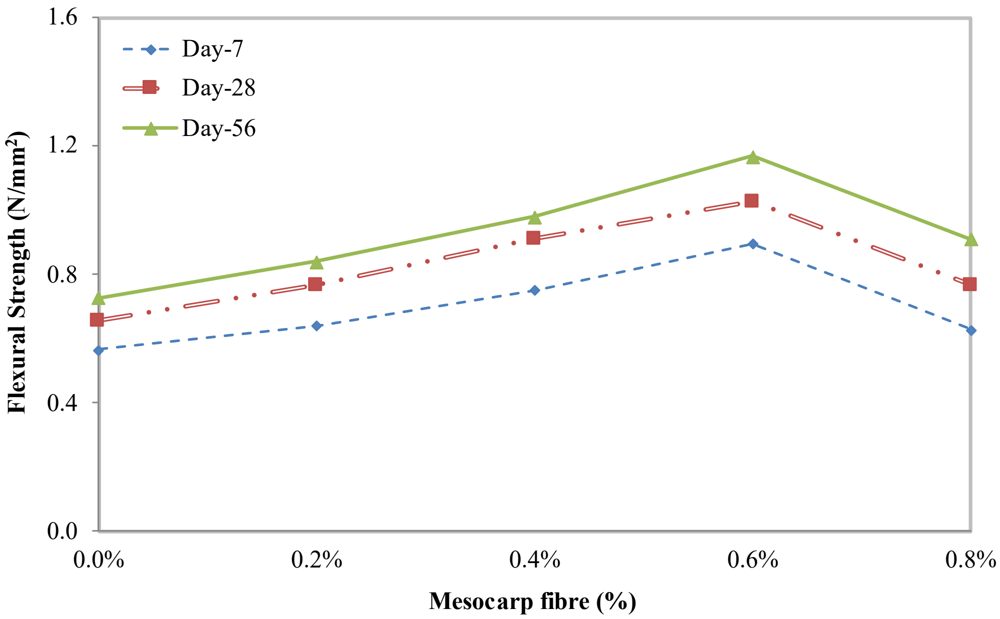

Fig. 7. Flexural strength of 1400 kg/m^3 density with varying percentages of mesocarp fibre

4. Conclusion

The incorporation of mesocarp fibre into the foamed concrete used in this study led to an increase in the material's overall strength. On the other hand, the mechanical characteristics of the foamed concrete were affected differently depending on the mesocarp fibre percentages that were added to the foamed concrete. In comparison to the other percentages that were used, the 0.4% and 0.6% mesocarp fibre in foamed concrete provided the best splitting tensile strength, compressive strength, and flexural strength for 700 kg/m^3 and 1400 kg/m^3 densities respectively. It is important to point out that the outermost layer of mesocarp fibre is rough, which enables the propagation of nodes and uneven stripes. Because of the surface roughness, fibre-matrix interface bonding, which is generally thought of as having a coarser surface, is useful. As a result, it strengthens both the mesocarp fibre and the matrix mechanical interlocking, which ultimately leads to an improvement in both foamed concrete's mechanical properties. The findings of this preliminary research could open the way for the manufacture of high-performance foamed concrete by including waste biomass from oil palm in the production process. The results of this research will provide a more in-depth understanding of the possibilities for the application of fibre derived from oil palm in foamed concrete.

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