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# OPTIMIZATION OF MECHANICAL PROPERTIES OF RAW AGAVE FIBRE-REINFORCED LIGHTWEIGHT FOAMED CONCRETE

The utilization of readily accessible natural fibres in lightweight foamed concrete (LWFC), which is already a widely used building material, can have a substantial positive impact on the environment. Therefore, the mechanical characteristics might be increased by using a correct mix proportion of fibre-reinforced LWFC. Innovative LWFC-agave fibre (AF) composites were created in this experiment. In order to get the best mechanical qualities, this investigation set out to establish the correct weight fraction of AF to be added to LWFC. Two LWFC densities of 750 and 1500 kg/m$^3$ were produced with the addition of several weight fractions of AF, precisely 0.0%, 1.5%, 3.0%, 4.5%, 6.0%, and 7.5%, were used. To establish the mechanical characteristics of LWFC-AF composites, flexural tests, tensile strength tests, axial compression tests, and ultrasonic pulse velocity tests were carried out. Test results revealed that the combination of LWFC together with a weight fraction of 4.5% of AF exhibited superior mechanical properties. Beyond 4.5% of AF's weight fraction, the mechanical properties started to deteriorate. This study gives insight and crucial data on the mechanical characteristics of LWFC-AF composites therefore it will enable future researchers to explore other properties of LWFC reinforced with AF.

*Keywords:* lightweight foamed concrete; agave fibre; flexural, tensile; compression

## 1. Introduction

In the present day, there has emerged a pressing need to undertake comprehensive investigations pertaining to the ecological impact of the construction sector on the concept of sustainability, while simultaneously formulating effective methodologies to alleviate possible threats to sustainability [1]. The primary objective of these methods of mitigation is to safeguard the integrity of natural resources while simultaneously curbing the generation of waste materials [2]. The examination of the life cycle assessment pertaining to buildings has emerged as a prominent field of study, primarily driven by the detrimental ecological ramifications associated with the materials employed in construction, with concrete being of particular concern [3]. Inquiring about the precise impact of material utilisation on the phenomenon of global warming, as well as the influence it exerts on the preferences of consumers for energy-efficient and ecologically conscious constructions [4,5].

Lightweight foamed concrete (LWFC) is a widely recognized building material that facilitates the creation and utilization of lightweight constructions. The removal of coarse components from LWFC mixtures allows to produce mixtures that are highly malleable [6]. The LWFC exhibits a significant degree of fluidity, which is attained through the amalgamation of a mortar slurry containing cement with pre-made foam [7]. The utilisation of specific combinations of materials can offer notable benefits in construction projects located in areas with challenging soil conditions, where the load exerted on building foundations tends to be relatively low [8]. Nevertheless, the growth of LWFC technology may face obstacles due to environmental degradation resulting

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from the release of harmful substances and concerns about sustainability arising from the extraction of natural aggregates [9]. The application of natural fibres in the enhancement of properties of low-fluorinated compounds during the production of concrete has resulted in a significant range of potential outcomes [10].

The deployment of LWFC can exhibit variability contingent upon the optimization of the constituent combination [11]. The unit weight of LWFC can significantly impact the characteristics and properties of the material [12]. According to earlier studies, the density of LWFC varies from 450 to 1900 kg/m$^3$ [13]. Furthermore, LWFC exhibits fire-resistant properties and possesses thermal and acoustic insulation capabilities, rendering it is extremely appropriate for various uses, including flooring and insulation on roofs., as well as void filling [14]. Furthermore, it has the potential to be utilised for the restoration of trenches. In addition, LWFC can be effectively utilised for various applications such as filling for underground pipeline, blocks, and insulation boards [15-22].

It is crucial to acknowledge that LWFC has faced multiple obstacles in its progression as a feasible material within the building sector. The issues involve multiple facets, including brittleness, reduced bending and tensile strengths, increased drying shrinkage, enhanced water absorption capacity, and limited fracture prevention features. Moreover, the issue of brittleness has been recognized as a noteworthy worry [23]. The issues pertaining to the diminished fracture toughness of LWFC are alleviated when the material is enhanced by the incorporation of polymer fibers derived from various origins [24]. The uniform dispersion of both natural and synthetic fibres within a fibre composite can lead to a substantial enhancement in the strength of a previously weak matrix [25]. As a result of this phenomenon, LWFC exhibits behaviour that resembles that of a composite material rather than an unreinforced LWFC [26].

It is noteworthy to mention that synthetic fibres are commonly employed as the primary choice for reinforcing concrete. However, there is a growing trend towards the utilisation of natural plant fibres [27]. There has been an increasing apprehension surrounding the utilisation of materials that are strengthened by natural plant fibres. The utilisation of natural plant fibres is crucial due to their inherent characteristics of sustainability, renewability, and biodegradability. Given the substantial environmental consequences associated with synthetic fibres, it is plausible to consider substituting them with natural plant fibres. The degradation of natural fibres and the subsequent reduction in their elasticity and deformation ability can be attributed to the alkalinity of the matrix. The deprivation of natural fibre cell walls can occur when they are subjected to highly alkaline conditions, primarily due to the limited stability of lignin and hemicellulose. The determination of the fractional composition of fibres, binder, filler, water, and surfactant present in the mixture is of significant importance. Natural fibres exhibit respective advantages over synthetic fibres in various aspects, for instance their capacity for natural decomposition, lower density, and increased resistance to melting when exposed to elevated temperatures [28]. The incorporation of natural fibres in cementitious materials has been found to enhance their strength, making them particularly advantageous in the manufacturing and advancement of construction materials. Numerous researchers have dedicated significant efforts towards investigating the durability properties of LWFC that have been enhanced with both natural and synthetic fibres. A scarcity of studies has been conducted to ascertain the effects of AF in LWFC. The primary objective of this study is to investigate the potential application of raw AF in LWFC with the aim of improving its mechanical properties.

## 2. Experimental setup

### 2.1. Materials

In order to fabricate LWFC samples, five essential components were necessary. These components encompassed cement, which served as the binding agent, fine river sand, utilized as a fine filler, clean water and a surfactant. The utilization of AF as an addition was implemented in the FC base mixture. The cement utilized in the research was Portland cement, more precisely Ordinary Portland Cement (OPC), which was selected based on the specifications provided in the BS197-1 standard. The compressive strength of conventional Portland cement is determined to be 52.5 MPa, the initial setting time is measured to be 50 minutes, and the soundness is found to be 12 mm. The present study utilized fine sand. The sand in question was obtained from a provider located in close proximity. The choice of fine river sand was made due to its characteristics of homogeneity and gradation, which contribute to the enhanced workability of LWFC. Fig. 1 demonstrates the sand sieve result which was in line with ASTM C33-03. According to the BS-3148 standard, the process of mixing and curing the FC involves the use of potable water that is devoid of any impurities. The implementation of Noraite PA-1, a surfactant derived from proteins, was carried out. The foam solutions demonstrated the ability to

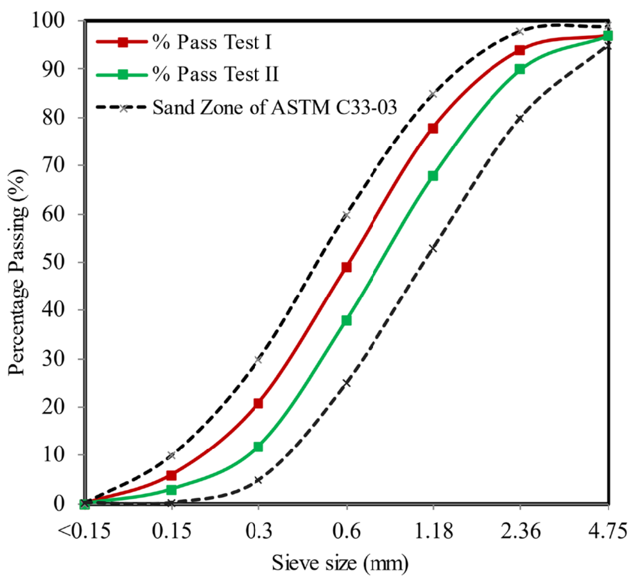


Fig. 1. Sand sieve analysis result

attain a density of 70 ± 5 kg/m$^3$ following the process of aeration. The pre-foaming technique was utilized in order to manufacture foam, making use of a foam generator known as TM-1. The AF consumed was provided by DRN Technologies, as shown in Fig. 2. The acquired raw material was thoroughly rinsed and cleaned to effectively remove any impurities and debris. Then it was left dried under the sun for 48 hours. Subsequently, the raw AF material was chopped to a length of 19 mm. The SEM micrograph of raw AF is shown in Fig. 3.

Fig. 2. Physical appearance of raw AF employed in this study

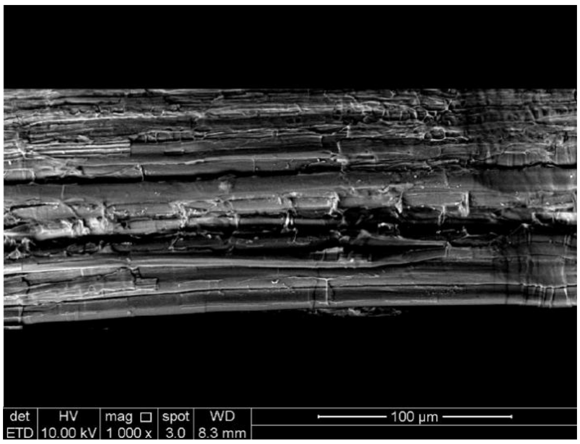


Fig. 3. SEM micrograph of raw AF

### 2.2. Mix design

A total of six LWFC blends were developed. Two densities of LWFC specifically 750 and 1500 kg/m$^3$ were manufactured. The LWFC mixes were added with AF at various weight fractions, specifically 0.0%, 1.5%, 3.0%, 4.5%, 6.0%, and 7.5%. In each mix, a sand-cement fraction of 1:1.5 was used, whereas the water-cement proportion was consistently maintained at a value of 0.45. The LWFC mix design in the present investigation is displayed in TABLE 1.

TABLE 1

LWFC mix design

| Mix | AF (%) | AF (kg/m$^3$) | Sand (kg/m$^3$) | Cement (kg/m$^3$) | Water (kg/m$^3$) | Foam (kg/m$^3$) |
|---|---|---|---|---|---|---|
| AF700-0.0 | 0.0 | 0.0 | 420 | 280 | 140 | 38 |
| AF700-1.5 | 1.5 | 12.6 | 420 | 280 | 140 | 38 |
| AF700-3.0 | 3.0 | 25.2 | 420 | 280 | 140 | 38 |
| AF700-4.5 | 4.5 | 37.8 | 420 | 280 | 140 | 38 |
| AF700-6.0 | 6.0 | 50.3 | 420 | 280 | 140 | 38 |
| AF700-7.5 | 7.5 | 62.9 | 420 | 280 | 140 | 38 |
| AF1500-0.0 | 0.0 | 0.0 | 819 | 546 | 273 | 15 |
| AF1500-1.5 | 1.5 | 24.6 | 819 | 546 | 273 | 15 |
| AF1500-3.0 | 3.0 | 49.1 | 819 | 546 | 273 | 15 |
| AF1500-4.5 | 4.5 | 73.7 | 819 | 546 | 273 | 15 |
| AF1500-6.0 | 6.0 | 98.3 | 819 | 546 | 273 | 15 |
| AF1500-7.5 | 7.5 | 122.8 | 819 | 546 | 273 | 15 |

### 2.3. Experimental setup

A series of strength property tests were achieved, including the compression, flexural, split tensile, and modulus of elasticity tests. The standard for compressive strength tests, BS12390-3, was adopted with a load speed of 0.5 MPa/second. A total of three samples were subjected to testing during each specified period of curing. To ascertain the compressive strength, a sample in the form of a cube measuring 100×100×100 mm was employed. The study employed a GOTECH-7001 apparatus, renowned for its capacity to withstand forces up to 3000 kilonewtons. The flexural strength test was conducted utilizing a GoTech GT-7001-C10 universal flexural testing equipment, in accordance with the protocols outlined in the BS12390-5 standard. The study employed prisms measuring 100×100×500 mm. The LWFC specimens underwent split tensile strength testing using the GT7001 device, following the guidelines outlined in the ASTM C496 standard. The sample utilized for the purpose of this investigation was a cylindrical shape with dimensions of 100×200 mm. The modulus of elasticity of LWFC was measured using the methods specified in ASTM C469, employing 100×200 mm cylinders and conducting the test at 28 days.

## 3. Results and discussion

This section will provide a summary of the results of the laboratory evaluation performed to evaluate the strength properties of LWFC.

### 3.1. Compressive strength

The compressive strength findings for densities of 750 and 1500 kg/m$^3$ are depicted in Figs. 4 and 5, correspondingly. Overall, it is evident from the presented data that the inclusion of AF in LWFC has resulted in enhanced compressive strength, regardless of the AF weight fraction. The mixtures exhibited superior compressive strength when matched to the control sample. The optimal weight fraction of the AF was determined to be 0.45%. The maximum strength attained on day 28 was 2.97 MPa for specimens having a density of 750 kg/m$^3$ and 18.19 MPa for specimens having a density of 1500 kg/m$^3$, when a weight fraction of 0.45% of AF was present. In comparison, the control specimen, which did not have AF inclusion, only attained compressive strengths of 1.75 N/mm$^2$ (for a density of 750 kg/m$^3$) and 12.01 N/mm$^2$ (for 1500 kg/m$^3$density). Furthermore, it was revealed that the presence of agglomeration and uneven dispersion of fibres resulted in a reduction in compressive strength when the weight percentage of AF fibres reached 0.60%. The incorporation of AF fibres at a weight fraction of 0.45% resulted in a notable enhancement in the compaction of both the fibres and the cement matrix, ultimately leading to a desirable level of mix homogeneity [29-33].

### 3.2. Flexural strength

In general, the inclusion of AF in LWFC led to a notable enhancement in flexural strength, irrespective of the density or weight fraction of AF incorporated into the LWFC combination. The figures presented in Figs. 6 and 7 illustrate the flexural strength results obtained for densities of 750 and 1500 kg/m$^3$, respectively. The control mixture, including of lightweight fine aggregate concrete (LWFC) without the inclusion of an admixture (AF), demonstrated the lowest flexural strength. However, the incorporation of AF in LWFC specimens leads to a significant enhancement in flexural strength as time progresses. On the 28th day, the flexural strength of the control lightweight fiber-reinforced concrete (LWFC) was measured to be 0.40 MPa for the standard density. However, for the LWFC with densities of 750 and 1500 kg/m$^3$, the flexural strength values were found to be 2.68 MPa and 2.68 MPa, respectively. The investigation

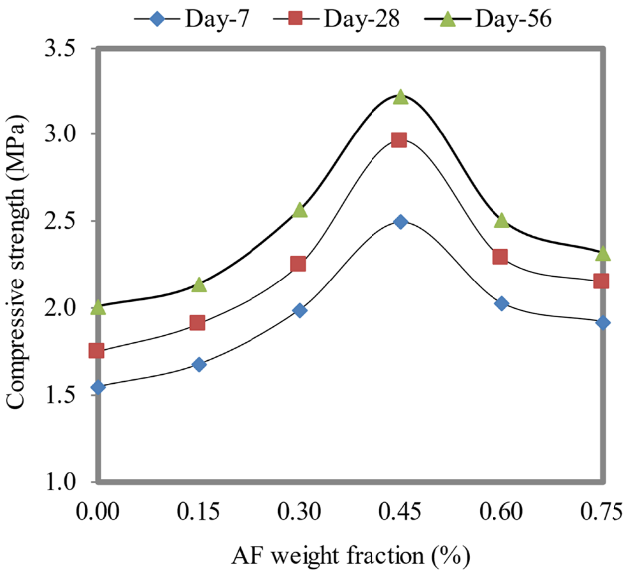


Fig. 4. Compressive strength of 750 kg/m$^3$ LWFC

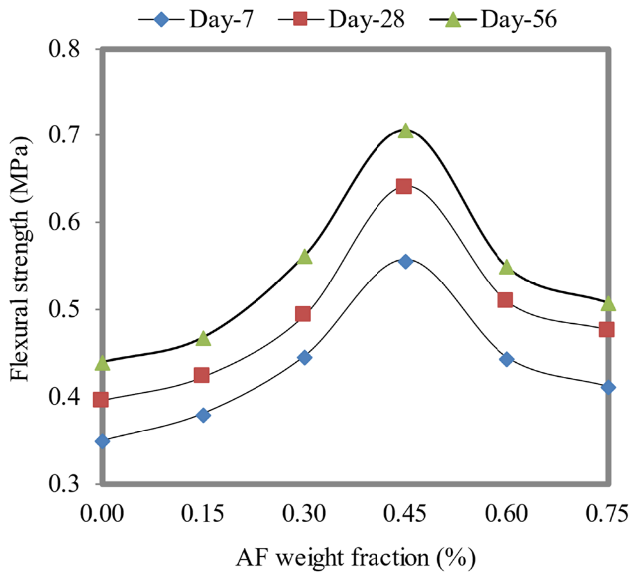


Fig. 6. Flexural strength of 750 kg/m$^3$ LWFC

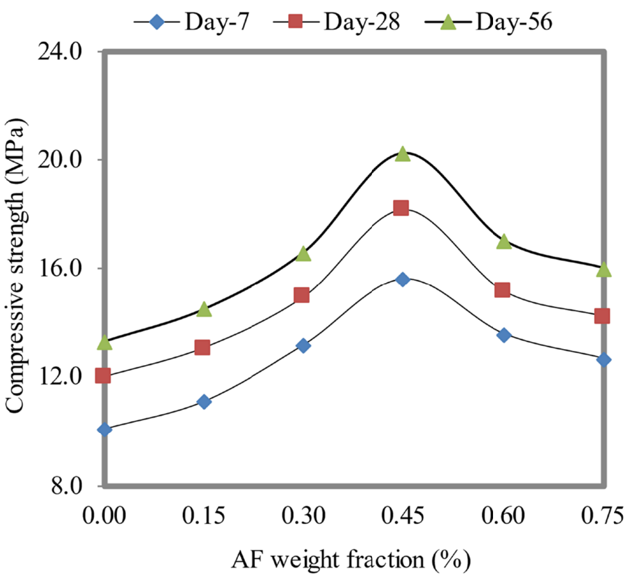


Fig. 5. Compressive strength of 1500 kg/m$^3$ LWFC

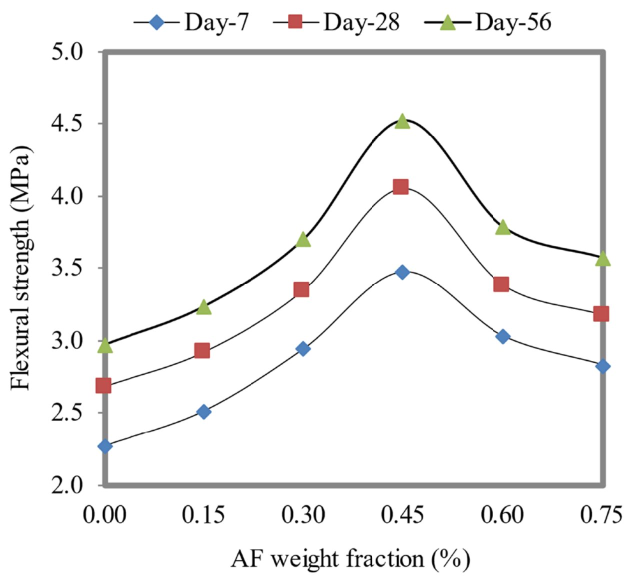


Fig. 7. Flexural strength of 1500 kg/m$^3$ LWFC

revealed that, akin to the compressive strength, the flexural strength exhibited the most advantageous results when the appropriate weight fraction of AF was discovered to be 0.45%. The flexural strengths achieved at the 28th day were recorded as 0.64 MPa and 4.06 MPa, respectively. The incorporation of AF fibre in LWFC is a considerable factor in enhancing the strength of the LWFC and transforming its material properties from being brittle to exhibiting ductile elastic-plastic behaviour [34-37]. Nevertheless, the incorporation of an excessive weight fraction of AF into LWFC (exceeding 0.45%) can potentially result in a decrease in the bonding intensity of the composites.

### 3.3. Split tensile strength

The results of the split tensile strength assessment for the two densities investigated in this research are illustrated in Figs. 8 and 9. The aforementioned investigation revealed a consistent pattern, wherein the optimal outcomes for split tensile strength were achieved when the weight fraction of AF inclusion amounted to 0.45%. The split tensile strengths achieved on day 28 for densities of 750 and 1500 kg/m$^3$ were 0.44 MPa and 2.92 MPa, respectively, as shown in Figs. 8 and 9. These values were obtained in the presence of 0.45% AF. After exceeding the recommended amount of AF addition, it was seen that there was an accumulation of fibres and an uneven distribution, resulting in a decrease in strength (at 0.6% AF). The enhanced toughness observed in LWFC, leading to an increase in split tensile strength, can be attributed to the incorporation of AF [38]. The incorporation of a fibre content of 0.45% in LWFC enhances the tensile strength by facilitating an optimal pozzolanic reaction with OPC. The chemical reaction leads to the formation of a denser and LWFC.

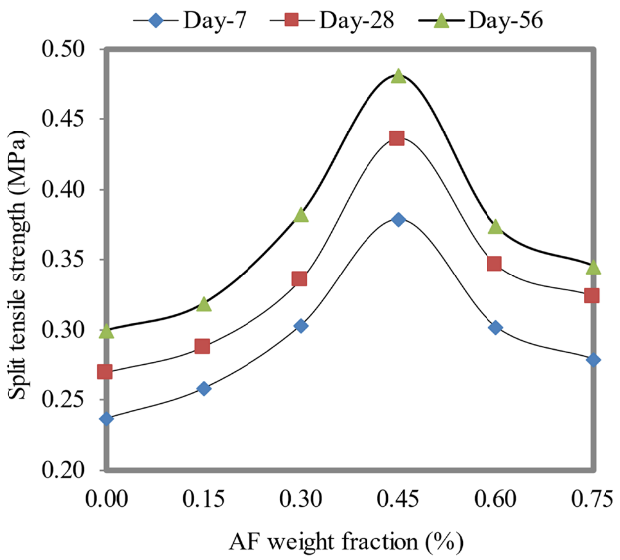


Fig. 8. Split tensile strength of 750 kg/m$^3$ LWFC

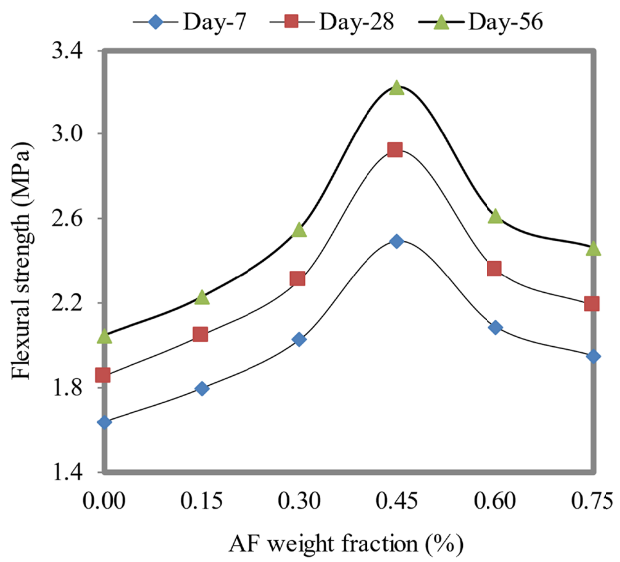


Fig. 9. Split tensile strength of 1500 kg/m$^3$ LWFC

### 3.4. Modulus of elasticity

The results for the modulus of elasticity for both densities examined in this study are presented in Fig. 10. The data presented in Fig. 10 demonstrates that the most favourable outcomes were achieved when incorporating a weight fraction of 0.45% of AF. The modulus of elasticity demonstrated an increasing pattern as the substitution rate reached a weight fraction of 0.45% of AF. Nevertheless, an observable decrease in the elastic modulus of the LWFC was noted as the replacement rate was raised to 0.60% and subsequently to 0.75%. The notable expansion in compressive strength of the LWFC mixtures can be credited to an upsurge in the elastic modulus.

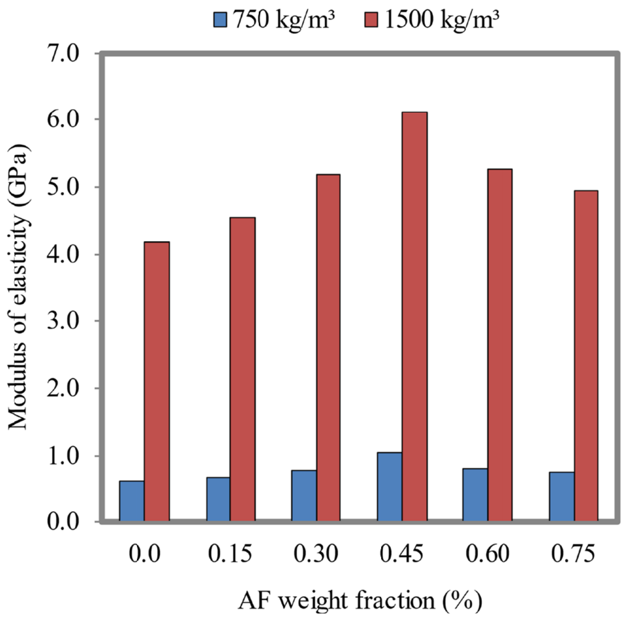


Fig. 10. Modulus of elasticity of LWFC

## 4. Conclusions

This study aimed to empirically examine the efficacy of incorporating AF in two distinct densities of LWFC, namely

750 kg/m$^3$ and 1500 kg/m$^3$, to augment its mechanical characteristics. The weight fractions of AF incorporated in LWFC mixes were 0.00%, 0.15%, 0.30%, 0.45%, 0.60%, and 0.75%. The present study provides a summary of its findings as follows:

i. The incorporation of 0.45% of AF in LWFC has been found to yield optimal outcomes in terms of compressive, flexural, and split tensile strengths, as well as the modulus of elasticity.
ii. The addition of AF serves to fill voids and connect small fractures within the LWFC, thereby contributing to its enhanced strength, particularly when subjected to flexural and tensile forces.
iii. The presence of AF in the LWFC cementitious matrix contributed to the prevention of crack formation in the plastic state.
iv. In spite of this, it was observed that beyond the ideal AF weight fraction (0.45%), there was a tendency for accumulation and non-unvaryingdispersal of fibres, preceding to a decline in LWFC strength.

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