

Exploring the performance of steel fiber reinforced lightweight concrete: A case study review

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ABSTRACT

This review paper aims to investigate the prior research on incorporating steel fibres into lightweight concrete (SF-LWC) to produce sustainable and environmentally friendly concrete. The objectives of the study are to analyse the chemical composition and physical characteristics of SF-LWC and examine its hardened properties such as compressive and flexural strengths. The research also focuses on the impact of steel fibres on the longevity of lightweight concrete and explores various properties such as the failure mode, stress-strain behaviour, ductility, and modulus of elasticity. A comprehensive literature review was conducted to evaluate the prior studies on the use of steel fibres in LWC. The findings of the previous studies were analysed and compared to determine the physical and durability properties of SF-LWC. The results of the literature review showed that steel fibres have a length range of 30–36 mm and a diameter range of 0.5–0.92 mm, with a smooth surface and high tensile strength of 1100–3000 MPa. The addition of steel fibres to LWC was found to improve compressive and flexural strengths and increase ductility. The review also highlights the impact of steel fibres on the durability and longevity of the concrete. The original contribution of this research lies in its comprehensive analysis of previous studies that have used steel fibres as a partial replacement for cement in lightweight concrete. The findings of this study provide valuable insights into the properties and performance of sustainable SF-LWC and offer suggestions for future research. By presenting a critical evaluation of prior research, this study advances the field and lays a solid foundation for further investigation. This paper offers recommendations for future studies and provides valuable insights into the properties and performance of SF-LWC, contributing to the advancement of sustainable and energy-efficient construction methods.

1. Introduction

Owing to its straightforward manufacturing process, low cost, and accessibility of raw materials [1], concrete measured as one of the most widely utilized building works worldwide [2]. Its exceptional flexibility, toughness, and adaptability meet the requirements

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of conventional constructions [3,4]. Conservative concrete also has the drawbacks of being heavy on its own, having a low tensile strength, being extremely brittle, and having poor toughness [5]. Due to these flaws, standard concrete is inappropriate for use in the construction of unique structures and buildings, including bridge decks, offshore oil platforms, and field-fabricated beams [6,7].

It is needed to progress a concrete composite that is lighter on its own and with superior mechanical capabilities in order to meet the demand for buildings and constructions of this type [8,9]. With the introduction of lifecycle thinking into the engineering civic [10], there has been a shift away from the use of less cement and waste-based materials and near the use of greener [11], and sustainable materials [12,13]. As the world's natural resources continue to be depleted [14], it is imperative that the existing technological infrastructure be modified to produce goods that use less energy to produce [15]. Not only will this help the environment today, but it will also help future generations [16]. Since conventional concrete is still one of the most common building materials, strategies that result in a less energy-intensive product will have a big worldwide influence [17–19].

Due to the huge potential for employment in the construction field, interest in lightened concretes has increased significantly over the past 30 years, and as a result, they are now used extensively all over the world. This interest is primarily driven by the necessity to use more environmentally friendly materials in the construction industry than are currently used, while simultaneously pursuing a number of other goals, such as lightening structures, conserving energy, minimalizing the use of key resources, increasing resource efficiency, dropping embodied energy and embodied carbon in a life cycle method to the product, and all of these things while still maintaining high technical performance. These are just some of the goals that are being pursued by this interest [20].

In order to achieve non-structural functions that are thought to be considerably more remarkable, for example, insulation against heat and sound, reduction of dead load, dampening of vibration, and protection against fire are all provided by this material, one of the main objectives is centered on dropping the density. In fact, these vital features rise as density falls, and they are impacted not only by air volume but moreover by the properties of air voids [21,22].

Portland cement manufacture results in severe environmental damage and high energy consumption, contributing to around 8% of the world's CO₂ emissions [23]. In order to lessen the environmental impact of cement manufacture, extensive research has been focused on creating alternative cementing combinations employing leftovers [24–28]. In contrast to traditional concrete, which fails at the matrix-aggregate interface, lightweight concrete fractures as a result of aggregate rupture [29,30], making it fewer resistant to fracture and to flexural loads.

Different kinds of fibers can be used as an additional material to concrete, especially lightweight mixtures, to increase its energy absorption capacity following matrix breaking, so resolving this drawback. Fibers increase the fatigue strength of a material by reducing the crack opening [29]. The greatest deformation of the specimen and the width of the fracture in the matrix rupture both have an effect on the elasticity modulus in the post-cracking zone of the cyclically stressed fiber reinforced concrete. This is because both of these factors contribute to the rupture of the matrix. When it comes to fiber-reinforced concrete, the amount of energy required to break through the fiber reinforcing mechanisms that were put in place after the matrix cracked is substantially greater than the volume of energy that was absorbed when the matrix broke. The primary attribute that gains from fiber reinforcement is hence energy absorption capacity [30]. Modern structures have also become taller, deeper, and wider as a result of the rising need for living space [31]. In the past 20 years, new, lightweight concrete with great strength has been created to satisfy these needs [32,33].

Lightweight cement concrete (LCC), a recently developed material, has adequate compressive strength and a relatively little density [34,35], as well as worthy durability [36], thermal resistance [37], and impermeability. LCC has drawn more attention as a result of its numerous potential uses in civil and offshore structures [38]. In general, adding air/bubble or lightweight materials or eliminating concrete fines can reduce the weight of concrete, but doing so also greatly reduces its strength [39,40]. To achieve a high specific strength of LCCs, it is effective to add micro-lightweight aggregates to cement [41]. The features of LCCs have recently been the subject of several studies on the creation of high-performance construction materials, counting the impact of water/binder ratios [42], additives [37], curing conditions, and micro-lightweight aggregates [43,44].

Using lightweight concrete (LWC) as a structural component has a number of benefits [45]. The production of more compact and lightweight structural components is made possible by the use of LWC, which lowers the structures' dead loads and increases their ability to withstand earthquakes. In addition, precast concrete members with smaller and lighter components are preferable because they are simpler to pull, more buoyant, and require less expensive handling and carrying systems. Consequently, the use of LWC for floating constructions has slowly gained popularity [46].

Similar to other cementitious materials, lightweight concrete can also be thought of as brittle [47], but when shear is the major failure mode, the relatively low strength of the light aggregates raises additional doubts concerning the brittleness of the LWC [48]. This is especially true when the shear mode of failure is prominent. To make these materials suitable for use as structural materials that have desirable physical and mechanical qualities, the brittleness of these materials must be increased [49]. This is the key to achieving this goal [47]. Numerous studies have demonstrated that discrete fibers provide an efficient and affordable reinforcement to transform cementitious material into a resistant and ductile end product [47]. Additionally, the fibers in the mixture form a network structure that effectively prevents the segregation of lightweight aggregates and prevents cracks from forming as a result of plastic shrinkage, particularly the fibers with a relatively low elasticity modulus and/or strong adhesion to binder materials [50].

Furthermore, concrete is known to be harmed by freeze-thaw cycles and to function less durably in harsh weather circumstances. External stresses and environmental damage induce deterioration in concrete quality over time [51,52]. Concrete must possess durability in order to survive a variety of climatic chemical attacks, conditions, and abrasion over an extended period of time [53]. Concrete can expand by around 9–10% in volume when water is dropped inside of it. Concrete pores experience pressure as a result of the freezing of the water within the concrete. The expansion of pores, expansion of fractures, scaling, and crumbling of concrete are all affected by repetitive freezing and thawing cycles. The addition of fibers to the concrete mix, as well as a reduction in the ratio of water to cement in the mix, both give to an improvement in the concrete's strength and resistance to the freeze-thaw degradation that can

occur [54]. Fiber-reinforced concrete offers various benefits when used. Improved tensile and flexural strength, less air and water voids, less bleeding from newly laid concrete, the arrest of crack propagation, and a notable increase in durability are a few of these [52,55–57].

In order to create structures that are energy efficient, lightweight concrete is essential. According to Samson, et al. [58] that underlines the necessity to discover building materials that can be used for both insulation and partial load-bearing in the current environmental and economic context. In order to create structures that are energy efficient, lightweight concrete is essential. According to Real, et al. [59], the heating energy requirements for lightweight aggregate concrete (LWAC) are 15% lower than those for standard weight concrete (NWC), although cooling energy requirements in Europe did not significantly differ between the two types of concrete. LWC is a broad name for all varieties of lightweight concrete, including foamed concrete and autoclaved aerated concrete. Lightweight aggregate concrete, on the other hand, uses particles that have a lower density than typical aggregates [60].

Because steel reinforcement corrodes more quickly, reinforced concrete structures must be expensively repaired or completely rebuilt. Due to its outstanding corrosion resistance, light weight, and high tensile strength features, fiber-reinforced polymer (FRP) bars are being used more and more in construction constructions [61–63]. Because natural aggregates cannot be renewed, there has been a lot of interest in lightweight aggregates as a sustainable and long-lasting alternative material. This is due to the fact that natural

Table 1

A summary of previous works on incorporating fiber into lightweight concrete.

Reference	Country	Field of Use
Aslani and Kelin[17]	Australia	High-performance lightweight self-compacting concrete reinforced with fibers using recycled crumb rubber particles exposed to high temperatures
Rasheed and Prakash[81]	India	Lightweight concrete with hybrid synthetic fiber reinforcement under uniaxial tension
Guler and Akbulut[82]	Turkey	3D, 4D and 5D steel fiber-reinforced concrete exposed to high temperatures.
Yang, et al.[83]	China	Fibers in lightweight aggregate concrete
Balamuralikrishnan and Saravanan[84]	Oman	Effect of alcofine on cement mortar.
Zhang, et al.[44]	China	Fibers' effects on lightweight cement concrete
Choi, et al.[46]	South Korea	Fiber-reinforced lightweight concrete
Guler and Akbulut[85]	Turkey	The impact of temperature swings on the durability of 3D/4D/5D steel fiber-reinforced concrete.
Guler, et al.[86]	Turkey	Strength prediction for steel, synthetic, and hybrid fiber reinforced concretes.
Frazão, et al.[50]	Portugal	Sandwich panels using fiber lightweight concrete
Doostmohamadi, et al.[87]	Iran	Anchorage system and polyolefin macro fibers on self-compacting light concrete
Williams, et al.[88]	India	The Mechanical Properties of Green Concrete.
Onyelowe, et al.[89]	Uganda	Green Concrete Based on Life Cycle Assessment Considerations.
Zhang, et al.[33]	China	Effects of fibers on dynamic behavior and microstructures of ultra-lightweight high strength concrete
Liu, et al.[90]	China	The dynamic behavior of bridge approach backfilled with lightweight fiber-reinforced concrete
Cunha, et al.[30]	Brazil	Concrete with fiber reinforcement
Sun, et al.[91]	Australia	Lightweight fiber-reinforced engineered cementitious composites
Alhassan, et al.[92]	Jordan	Lightweight concrete beams with different macro synthetic fiber and steel ratio doses
Shaiksha Vali and Bala Murugan [93]	India	Artificial fiber aggregate's effect on the creation of lightweight concrete
Karamloo, et al.[94]	Iran	Effects of varying polyolefin macro-fiber quantities of self compacting lightweight concrete
Amin, et al.[95]	Egypt	Lightweight fiber concrete in hot environments
Mastali, et al.[96]	Finland	Fiber alkali-activated slag foam concrete
Rustamov, et al.[52]	South Korea	Lightweight fiber concrete for frozen and thawed.
Sahoo, et al.[97]	India	Lightweight fiber-reinforced concrete
Wu, et al.[57]	China	Lightweight aggregate concrete's mechanical characteristics and microstructure with and without fibers
Zeng, et al.[98]	China	After freeze-thaw process, fiber-reinforced lightweight aggregate concrete.
Jin, et al.[99]	China	Lightweight concrete beams without stirrups: Fiber ratio effects
Falliano, et al.[20]	Italy	Ultra-lightweight fiber-reinforced foamed concrete
Jagarapu and Eluru[100]	India	Lightweight fiber reinforced concrete from agriculture waste
Liu, et al.[101]	China	Fiber lightweight aggregate concrete
Ismael and Mohammed[102]	Iraq	Performance of fiber lightweight concrete slabs
Hossain, et al.[103]	Canada	Fiber lightweight self compacting concrete beams
Shafigh, et al.[104]	Malaysia	Fiber-reinforced structural lightweight concrete's thermomechanical effectiveness
Deifalla[105]	Egypt	An analysis of lightweight concrete beams with and without fibers
Zhao, et al.[106]	Australia	The strength and durability of steel fiber lightweight expanded-shale concrete
Wu, et al.[68]	China	Lightweight concrete reinforced with SF and pre-stressed
Xiang, et al.[80]	China	Self compacting lightweight concrete in square columns
Li, et al.[107]	China	Bending Behaviors of Steel Fiber Elasto Plastic
Badogiannis, et al.[108]	Greece	Pumice lightweight concrete reinforced with steel fibers.
Manharawy, et al.[73]	Egypt	Lightweight foamed concrete deep beams with steel fibers
Christidis, et al.[109]	Greece	End-hooked steel fibers lightweight pumice concrete
Liu, et al.[67]	China	Flexural fissures in lightweight concrete with steel fiber beams
Li, et al.[77]	China	Concrete with steel fiber reinforcement (self-compacts and uses lightweight aggregate)
Xiong, et al.[110]	China	Improving steel fiber lightweight concrete
Li, et al.[111]	China	The self-compacting lightweight concrete for steel fiber reinforcement
Salehi, et al.[112]	Iran	Microbiological stresses' effects on mechanical and robustness of polypropylene fiber lightweight concrete

aggregates are non-renewable [64,65]. In addition, the use of LWC is an extremely efficient method for reducing the internal forces of long-span bridges with a significant amount of dead load, while also reducing the amount of reinforcement that is required and increasing the seismic resistance capability [66]. A hybrid system that is built of these two materials might assist raise the strength-to-weight ratio of the structures while also lowering the total cost of maintaining the structures. Given the benefits of both FRP bars and LWC, this type of system could be quite beneficial [67].

Due to additional advantages such high fracture resistance and superior ductility, concrete with steel fiber reinforcement and lightweight aggregate (SFLWC) has attracted a lot of interest recently [57,68,69]. Where previous studies Ganesan and Indira [70], Balgude [71], S Manharawy, et al. [72] claimed that adding steel fibers to LWFC boosts its flexural and tensile strength as well as its resistance to dynamic and abrupt loading as well as its resistance to explosive effects. LWFC's load carrying ability is increased by the addition of steel fibers, bringing it closer to the strength of regular weight concrete. Additionally, it limits the spread of cracks and reduces their width. Additionally, the potential of deformation is diminished in order to get cost-effective solutions by lighter concrete [73].

In addition, adding SF to self-compacting lightweight concrete (SLC) alters the internal structure of SLC, which makes steel fiber-reinforced self-compacting lightweight concrete (SFSLC) an effective method for increasing the brittleness, tensile strength, and crack resistance of concrete. Modern studies have exposed that the bridging action of SFs can effectively limit the inner concrete matrix, stop the growth and spread of internal cracks, and ensure that the specimen maintains at least some degree of ductility after cracking. These benefits were discovered as a result of existing research [68,74–76]. By reducing the chance of fiber aggregation within the specimen, Where Li, et al. [77], Li, et al. [78] can assist in making the steel fibers more evenly dispersed throughout the specimen. It is possible that the incorporation of steel fiber into SLC will result in a substantial enhancement of the material's mechanical characteristics, including an increase in its compressive strength, tensile strength, and bending toughness. This illustrates that the two elements work well together to form a complementary whole. And Zhang [79] carried out experimental investigation on the mechanical characteristics and toughness of SLC specimens with 0%, 0.5%, and 1% steel fiber. They compared the results of their findings. He found that by including a particular quantity of steel fiber into SLC, the tensile strength of the material could be increased, the formation of cracks could be avoided, and the material's resistance to carbonation and shrinkage was greatly enhanced. In addition, he discovered that the hardness of the material may be improved by including steel fiber into the SLC [80].

In conclusion, one of the most widely employed building materials worldwide is concrete. The drawbacks of traditional concrete are its high self-weight, poor toughness, high brittleness, and low tensile strength. Because of these flaws, standard concrete cannot be used for prefabricated beams in the field, bridge decks, or offshore oil platforms. Lightweight concrete is less resistant to fracture and flexural loads than conventional concrete because fracture occurs as a result of aggregate rupture. A more recent invention with adequate compressive strength and a low density is lightweight cement concrete. To ensure a high specific strength of LCCs, it is useful to add micro-lightweight aggregates to cement. Because smaller, lighter structural elements may be created with lightweight concrete, structures have improved seismic resilience and have less dead weight. The use of LWC for floating constructions has increasingly drawn a lot of interest. Like other cementitious materials, lightweight concrete can be thought of as fragile. Because steel reinforcement corrodes more quickly, reinforced concrete structures must be expensively repaired or completely rebuilt. In order to create structures that are energy efficient, lightweight concrete is essential. Due to its additional advantages, steel fiber reinforced lightweight aggregate concrete has drawn a lot of interest. LWFC's load carrying ability is increased by the addition of steel fibers, bringing it closer to the strength of regular weight concrete. Additionally, it limits the spread of cracks and reduces their width. Additionally, by making the concrete lighter, it is possible to provide cost-effective solutions while limiting its capacity to deform. (Table 1).

Concrete is one of the most widely used building materials in the world due to its low cost, accessibility of raw materials, and straightforward manufacturing process. However, traditional concrete has several limitations such as high self-weight, low tensile strength, poor toughness, and high brittleness. This makes it unsuitable for unique structures such as bridge decks, offshore oil platforms, and field-fabricated beams. To address these limitations, the development of sustainable and energy-efficient lightweight concrete is crucial. This type of concrete has improved mechanical capabilities and is lighter in weight, making it suitable for a wide range of construction applications. The introduction of lifecycle thinking in engineering has resulted in a shift towards using greener and sustainable materials, which is essential as the world's natural resources continue to deplete.

This study aims to investigate the prior research on incorporating steel fiber into lightweight concrete to produce sustainable concrete. The study highlights the chemical composition and physical characteristics of sustainable lightweight concrete and examines the hardened properties such as compressive and flexural strengths. The research also focuses on the impact of steel fibers on the longevity of lightweight concrete and explores various properties such as the failure mode, stress-strain behavior, ductility, and modulus of elasticity.

The original value of this work lies in its comprehensive analysis of the previous studies that used steel fibers as a partial replacement for cement in lightweight concrete. The study offers several suggestions for future research and provides valuable insights into the properties and performance of sustainable lightweight concrete. By presenting a critical evaluation of the prior research, this study contributes to the advancement of the field and provides a solid foundation for further investigation.

2. Material Properties

Present paper provides a comprehensive review of what was mentioned in previous studies about the physical and chemical properties of steel fiber into lightweight concrete. The paper shows the properties in figures and tables in order to compare them and identify the most important components of steel fiber, also, the study of the material properties considers a very vital issue, as this is an essential step in order to know the importance of the material, how to benefit from it, and its applicability. The present paper will

provide an extensive review of the most important and recent references to the physical and chemical properties of steel fiber.

2.1. Physical and chemical properties

Güneyisi, et al. [113] mentioned that The physical properties and aspect ratios of the steel fibers are given as follow in Table 2. The steel fiber was utilized with three distinct aspect ratios of 55, 65, and 80 along with four distinct volume fractions (Vf) of 0.35%, 0.70%, 1.00%, and 1.50% as an additional component.

Where Wang and Wang [114] that the steel fibers had a breaking strength of 600 MPa and were made of cold-drawn steel with slightly expanded ends. The typical fiber had an aspect ratio of 50 and a length of 32 mm. Additionally, a superplasticizer based on naphtha was utilized in a 25% water solution. Additionally, Christidis, et al. [109] mentioned the use of end-hooked steel fibers (SF) in four distinct contents of 0.5%, 0.75%, 1.0%, and 1.5% by volume (Vf,%), resulting in eight FRLWC, in two different total lengths of 35 mm and 60 mm. Table 3 provides a summary of the geometrical properties of used fibers.

Liu, et al. [67] stated that SF with a volume fraction 0.6% were assimilated into the SFLWC, and the key properties of the SFs are shown in Table 4.

Salmasi and Mostofinejad [115] reported that in order to achieve the desired workability and greater strength, the water-to-cement ratio was decreased through the utilization of a superplasticizer based on poly-carboxylate at a dosage of 0.25% of the cement weight for the specimens that did not contain steel fibers, and at a dosage of 0.3% for the specimens that did contain steel fibers. The volume fraction of steel fibers employed as reinforcement was 1. Since steel fibers can be employed for anywhere between 0.5% and more than 2% of the concrete volume, this volume fraction was chosen at random as the average of conservative ranges. Table 5 details the qualities of steel fibers used as reinforcement, and Fig. 1 includes images of them.

The phrase "length-to-diameter ratio" is used to describe steel fibers. Slenderness is described by this ratio, which divides fiber length by fiber diameter. Steel fibers with a circular cross section and hooks are typically utilized for concrete reinforcement [116]. When compared to regular steel fibers, those generated with hooked ends exhibit better peeling behavior. In [117] steel fibers were mixed with fibers that were 60 mm long, 075 mm in diameter, and had a slenderness value of 80. The ideal steel fiber dose should be established, according to Altun and Aktaş [117] in order to evenly distribute steel fibers throughout the concrete. The chosen dosage is important for the concrete to behave like a homogeneous substance. Also highlighted by Hosen, et al. [116] was the use of steel fibers with hooked ends and bonded bundles in the mixtures for this lightweight concrete, and the percentage of fiber in the concrete varied from 0% to 1.50%. Table 6 displays the properties of steel fiber.

Most of studies [118,119] on the addition of SFs to concrete use somewhat longer fiber (>25 mm), concentrating largely on hooked end fibers, while few studies have done on straight micro fibers, which might have a less detrimental effect on the flow-ability of concrete. Due to their tiny size and lack of interlocking, straight micro steel fibers are predicted to have a less detrimental effect on the workability of concrete than longer hooked end and other irregularly shaped steel fibers [1].(Fig. 2).

Additionally, Xiong, et al. [110] reported using flat copper-plated steel fibers with dimensions of 13 mm in length, 0.175 mm in diameter, 3.008 GPa for ultimate tensile strength, and 7800 kg/m³ for apparent density as the reinforced material in their work. However, Li, et al. [111] reported using regular Portland cement with a density of 3.1 g/cm³. Fig. 3 illustrates the usage of brass-coated micro steel fiber (MSF) and long steel fiber (LSF) as reinforcement materials. Table 7 displays the mechanical and physical characteristics of steel fiber.

2.2. Microstructure Properties

Due of its porous structure and low strength, jun Li, et al. [69] found that the lightweight coarse aggregate played a major role in the LWC's strength. The SEM picture of the aggregate paste interfacial zone in traditional concrete is shown in Fig. 4(b). The interfacial zone amongst the aggregate and paste contained the apparent fissures. The loose and porous structure caused numerous aggregate-paste interfaces to debond under the final stress, and normal weight aggregates and cement paste were typically required for strength. This showed that the aggregate paste interfacial zone was typically the weakest part of traditional concrete. On other hand Fig. 4(c) depicts the fiber-paste interface's microstructure. The cracks in the fiber-paste interface were substantially wider than the cracks in the aggregate-paste interface at the same magnification, in contrast to the ITZ cracks between the aggregates and cement matrix illustrated in Fig. 4(a). The strength and durability of concrete were negatively impacted by the rise in porosity amongst the fibers and paste that was seen with the rise in SF dosage. This was one justification for selecting the best SF content.

The micro-scale interfaces between the cement matrix and SFs during conventional and vibrational mixing are depicted in Fig. 5(a and b) respectively, according to Xiong, et al. [110]. Fig. 5(a) depicted a specimen with a smooth fiber surface and limited hydration products evenly dispersed on the fiber surface. Fig. 5(b) on the other hand showed the specimen's rough fibrous surface while it was

Table 2
Physical properties of steel fibers, [113].

Fiber Mix	Aspect ratio (L/d)	Length (L) mm	Diameter (d) mm	Density (g/cm ³)
mix 1	80	60	0.75	7.85
mix 2	65	60	0.92	7.85
mix 3	55	30	0.55	7.85

Table 3
Geometrical characteristics of fibers, [109].

	Length, l (mm)	Diameter, d (mm)	Aspect ratio, l/d	Modulus of elasticity (MPa)
SF type 1	35	0.62	56	200,000
SF type 2	60	0.90	65	200,000

Table 4
Steel fibers' inherent characteristics, [67].

Type	Length (mm)	Diameter (μm)	Density ($\text{kg}\cdot\text{m}^{-3}$)	Tensile strength (MPa)	Shape	Surface
SF	13	200	7800	greater than 3000	Straight	Smooth

Table 5
Particularities of the fiber that was employed, [115].

Fiber	Hooked-end steel
Density (kg/m^3)	785
Tensile strength (MPa)	1000–1800
Length (mm)	36
Water absorption (%)	0



Fig. 1. The hooked-end steel fibers used, [115].

Table 6
Steel fibers' inherent chemical and physical characteristics, [116].

Fiber type	Length (mm)	Poisson's ratio	Aspect ratio	Nominal diameter (mm)	Density (kg/m^3)	Modulus of elasticity (GPa)	Ultimate tensile strength (MPa)
SF	35	0.28	65	0.54	7840	200	1130

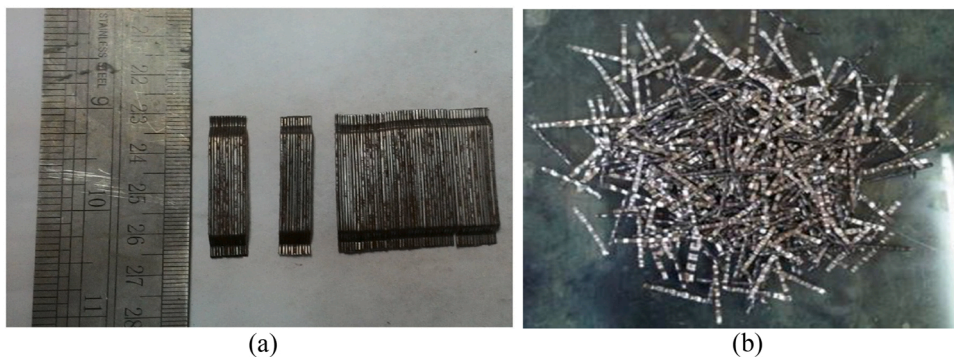


Fig. 2. (a) Hooked end steel fibers [116], (b) The SF shape [69].

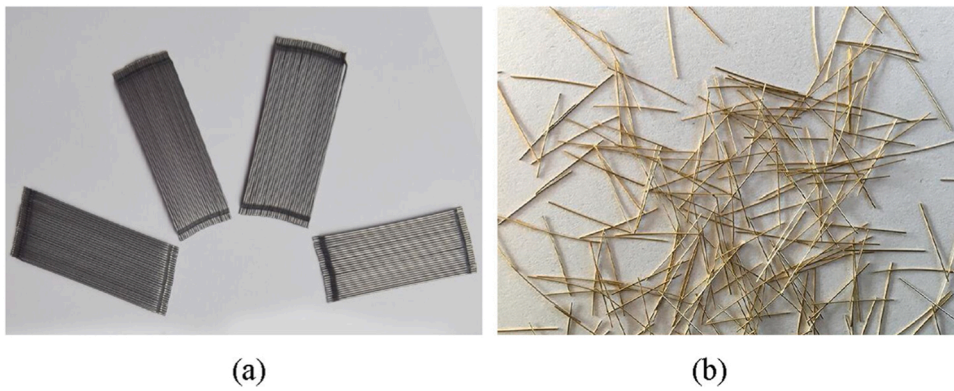


Fig. 3. The following are types of steel fiber: (a) LSF, (b) MSF, [111].

Table 7

Steel fibers' inherent characteristics, [111].

Type	Length (mm)	Aspect ratio	Density (g/cm ³)	Diameter (mm)	Quantity (root/kg)	Tensile strength (MPa)
MSF	13	65	7.80	0.2	83,000	2860
LSF	35	70	7.85	0.5	8100	> 1100

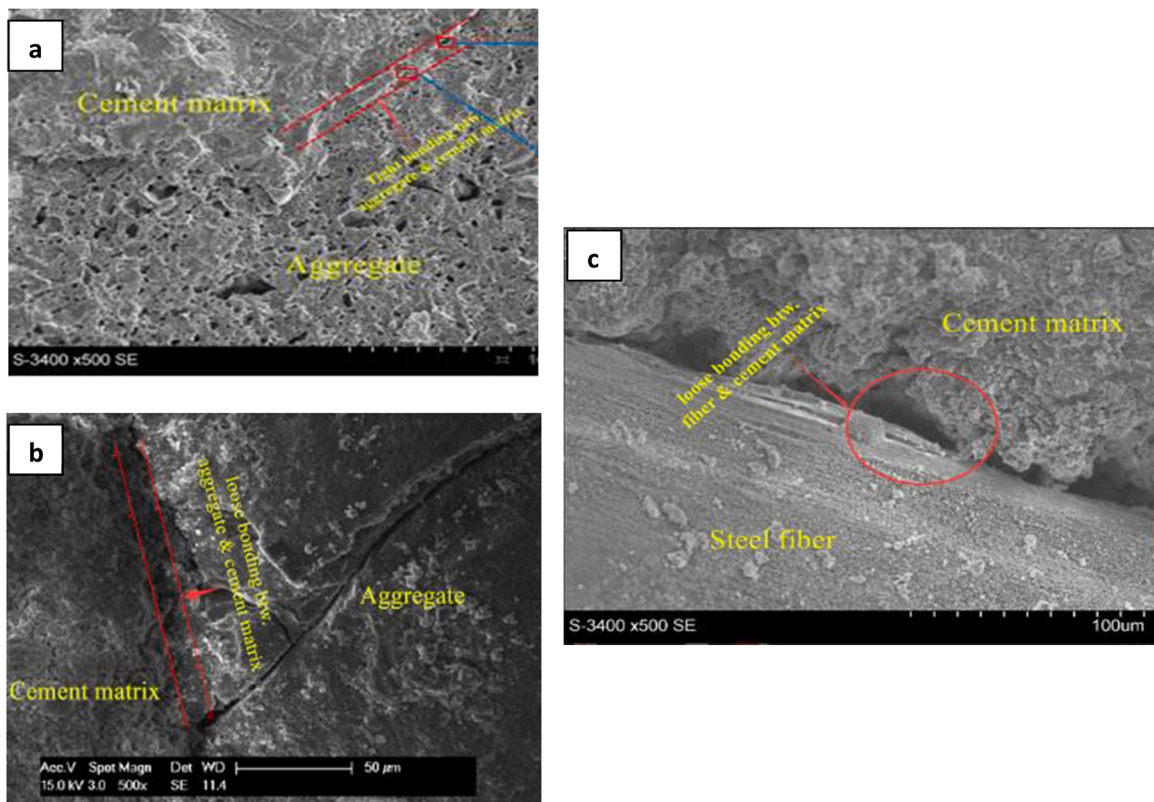


Fig. 4. (a) a scanning electron micrograph of the aggregate-paste interface in light weight concrete (b) a scanning electron micrograph of the aggregate-paste interface in conventional concrete (c) a scanning electron micrograph of the fiber-paste interface in steel fiber reinforced cement paste, [69].

being vibrated, demonstrating how the vibration action can strengthen the strong adhesive force to withstand fracture failure. SFs' copper plating peeled off during the process of fracture. In addition, it was simple to spot numerous hydration byproducts on the surface of SFs, including hexagonal sheet CH crystals and C-S-H gels. There are two explanations for these differences: (a) The concrete's load capacity was reduced as a result of the smooth SFs surface's weak adhesive bond, which was first broken (b). Under vibration mixing, the collected SFs are easily mixed and coated with low-yield stress fresh cement paste, forming a durable paste layer. The production and upgrading of C-S-H gels and CH crystals were helped by the free water present in the paste film [78]. The dense paste layer that covered the interface had a synergistic impact, enhancing the SFs' and the matrix's capacity for cohesiveness and toughening after cracking [78,110].

The lightweight coarse aggregate played a crucial part in determining the strength of the lightweight coarse aggregate (LWC) because of its porous structure and low strength. In traditional concrete, the zone of interface between the aggregate and the paste was frequently the weakest part of the material. When the amount of SF in the mixture was increased, it was seen that the porosity between the fibers and the paste also increased. This was one justification for selecting the best SF content. The concrete's load capacity was reduced as a result of the smooth SFs surface's weak adhesive bond, which was first broken. SFs' copper plating peeled off during the process of fracture. On the surface of SFs, see several hydration byproducts, including C-S-H gels and hexagonal sheet CH crystals.

3. Fresh concrete properties

Iqbal, et al. [120] It has been noted that the droop flow decreases as the fiber content grows, particularly after reaching a content of more than 0.75% SFs. The concrete blend that had a fiber percentage of 1.25 had a slump flow that was less than the permitted minimum of 600 millimeters. As a result, both the ratio of water to cement and the amount of powder in the mix were slightly increased so that it would be easier to work with. In addition, it is evident that the density of the fresh LWC increased by more air than it did in the past, despite the inclusion of steel fibers, which are substantially heavier than other components of the blend. Additionally, the rise in the proportion of SFs results in a decrease in workability while simultaneously leading to an increase in the percentage of air, see Table 8.

Yap, et al. [121] mentioned that to reach the vital slump for LWC, the use of superplasticizer in OPSC is requisite as the greatly irregular-shaped OPS prevent full compaction [122]. As a result, the incorporation of a superplasticizer into OPSC made it possible for that material to achieve a sufficient level of workability and compaction that was comparable to that of NWC. Instead, the results of the slump tests indicate that the incorporation of the SFs into the fresh concrete led to a sizeable reduction in the material's ability to be worked. It is possible to state that the addition of 0.50% steel fiber resulted in a lessening in the slump values of 40% and 70% respectively. The dispersion of the steel fiber in the freshly mixed concrete will result in the formation of a fiber-cement matrix network. This network will have a fiber-matrix interfacial connection because the cement mortar will wrap around the fiber. The new concrete's capacity to flow is hindered by the network's structure [123]. A greater droop reduction was achieved as a result of the synergistic effect of the addition of forms and surface roughness of fiber. Despite this, there was no correlation between the aspect ratio of the steel fiber and the reduction in slump in the mixtures [121].

Li, et al. [77] concluded that the filling and passing capacities diminished as the percentage of steel fiber in the material rose. When fibers were added to concrete, the high stiffness of steel fiber caused an increase in friction between the aggregates and the fibers. This resulted in a decrease in slump and a lengthening of the slump-flow period, both of which were accomplished by consuming energy from the mixture [6]. Additionally, the randomly positioned fibers limited the horizontal flow of coarse particles. On the other hand, the inclusion of steel fibers might increase the resistance to segregation. It was because more paste was required to cover the fiber's surface because its specific surface area was greater than that of the coarse aggregate, increasing the viscosity of the combination. Additionally, the mixture's overlapped fibers efficiently prevented the development of light-weight coarse aggregates and improved the uniformity of their spatial distribution [77].

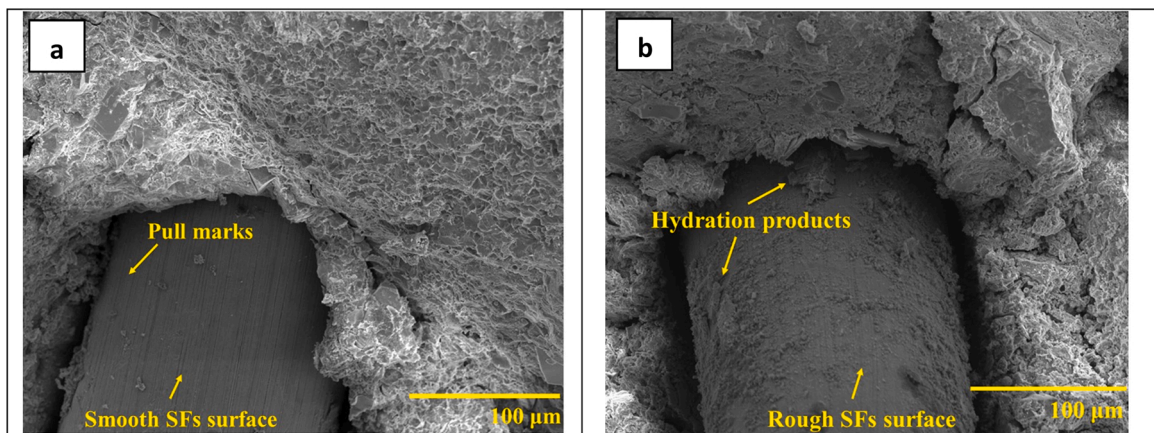


Fig. 5. (a) SF surface morphology under the ordinary mixing, (b) under the vibrational mixing, [110].

Table 8
Fresh state properties, [120].

SF %	Slump flow (mm)	Density (kg/m ³)	Air content (%)
0.5	725	1744	3.63
0.75	715	1749	4.17
1	620	1744	5.25
1.25	630	1746	5.32

Grabois, et al. [124] established that all mixes' slump flow spreads were in compliance with normal weight SCC criteria and requirements. During the V funnel testing, the fiber mixes took an excessive amount of time to flow, and none of the concretes displayed any sort of segregation, see Table 9. Also, Nahhab and Ketab [76] mentioned that the fresh density of SCLWC greater than before somewhat as the volume fractions of micro SFs greater than before, and the $T_{50\text{ cm}}$ and V-funnel flow time prolonged as the volume fraction of micro SFs better.

4. Hardened concrete properties

The hardened properties of concrete are determined by a number of factors, some of which include the chemical and physical characteristics of the concrete and the raw materials, the quantity of the binder and the raw materials, the type and quantity of coarse aggregate, the quantity and quality of fine aggregates, the total aggregates to mix proportion of the concrete, the mixing level of the concrete, the alkaline solution to binder content, the curing of the concrete, and the testing parameters. Other factors that determine the hardened properties of concrete include.

The current paper provides a comprehensive review of the most important results related to the hardened properties and analyzes the effect of adding or replacing steel fiber in lightweight concrete.

4.1. Compressive strength

Zhao, et al. [106] reported that despite the fact that the compressive strength of class 52.5 cement at 28 days was only 1.17 times that of class 42.5 cement, the f_{cu} of LAC with grade 52.5 cement was 1.44 times bigger than that of LAC with grade 42.5 cement when both had the same weight-to-volume ratio. Despite the fact that the compressive strength of grade 52.5 cement was only 1.17 times that of grade 42.5 cement, this was nevertheless the situation. This demonstrated that the higher cement grade utilized in this research worked well with the bigger shale, which is significant given that the adaptability of coarse aggregate to set cement paste is what controls the compressive strength of LAC [125,126]. W/b had slight effect on the f_{cu} of SFRELC with the similar cement when $V_f = 0.8\%$. When V_f grew from 0.4% to 2.0%, SFRELC's f_{cu} increased by 20.7% with cement of grade 42.5, but only by 10.1% with cement of grade 52.5.

This indicates a relationship between cement strength and the efficiency of SF augmentation on LAC's compressive strength [106]. The strength of LAC had reached a high level due to the higher cement strength, which prevented the steel fiber from further enhancing that strength. The enhancing impact of steel fibers on LAC was more pronounced when V_f was greater than 1.6%. This is because the resistance of SF caused a homogenous stress distribution, which caused the matrix to develop a number of tiny cracks, reducing the dependency of the compressive strength on the cement paste's strength [127,128]. As a result of the steel fibers significantly dispersion along the horizontal axis, the constraint that was placed on the transverse deformation that was taking place during the loading process was loosened [129], which occurred as the prism was cast horizontally [106].

Iqbal, et al. [1] mentioned that As the percentage of steel fiber in the concrete rises, there is a marginal drop in the material's compressive strength. This relationship may be seen in the compressive strength of the concrete at both 7 days and 28 days of age (see Fig. 6). The compressive strength of concrete that contains 0.5% SFs is 64.03 MPa, whereas the compressive strength of concrete that encloses 1.25% SF is 59.74 MPa. As a result, a decrease in compressive strength of roughly 7% occurs if there is a 0.75% point increase in the amount of steel fiber content.

This references found that higher cement grades can be used to increase the compressive strength of lightweight autoclaved aerated concrete, even when the compressive strength of the cement is only 1.17 times that of a lower grade. Steel fibers were also found to increase the compressive strength of LAC, but with diminishing returns as the percentage of steel fiber rises. At higher percentages of steel fiber, the resistance of the steel fibers caused a homogenous stress distribution and loosened the constraint that was placed on the transverse deformation of the concrete.

According to Shafigh, et al. [130] an increase in the volume percentage of steel fiber led to an increase in the compressive strength

Table 9
State of the concrete in its fresh form and its physical qualities, [124].

Mixes	Slump flow (mm)	V funnel time (s)	Inverted slump flow (mm)	Density (kg/m ³)	Water absorption (%)
0% SF	670	23	650	1764 (± 8.60)	3.9 (± 0.01)
30% SF	650	46	715	1822 (± 22.9)	5.6 (± 0.30)

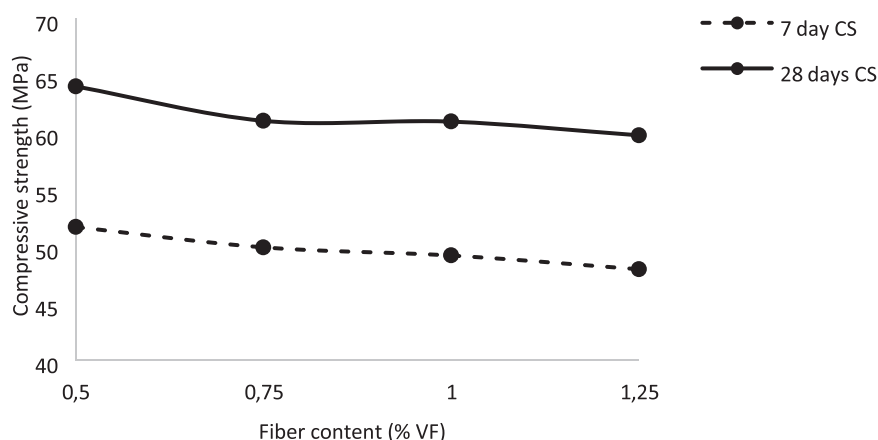


Fig. 6. Changes in the compressive strength of concrete with variation, [1].

of concrete at all ages. The steel fiber ratio was increased from 0% to 0.25%, 0.5%, 0.75%, and 1%, which resulted in an increase in compressive strength of approximately 1.7%, 2.5%, 7.8%, and 3% after three days, 6.1%, 4%, 9.1%, and 10% after seven days, 6.2%, 6.9%, 14%, and 14.3% after 28 days, and 5.3%, 8.9%, 16%, and 18.8% after 56 days, respectively. These results were achieved by increasing the steel fiber A comparison of the strength when it was young and when it was older demonstrates that the rate of strength development increased with age, particularly for concretes with a larger percentage of steel fiber content. It was also found that the percentage of strength decreased at 3 and 7 days, but increased at 56 days, when the steel fiber ratio increased. This occurred in conjunction with the previous observation. This occurs as a result of the increased rate of strength gain that occurs with advancing age in humans. For a steel fiber ratio of 1%, this rate is noteworthy. The performance of steel fiber in OPS concrete appears to get better with aging for all volume fractions.

There are a variety of reports available on the effect that steel fiber has on the compressive strength of LWAC. It was practical that the compressive strength of LWAC produced using pumice aggregate increased by approximately 21.1% [131] with an increase in SF. According to Tang [132] The high strength lightweight concrete (HSLC) that was made with extended clay aggregate did not see a substantial increase in its compressive strength as a consequence of the addition of SF.

The impact of steel fiber on the characteristics of lightweight expanded polystyrene (EPS) concrete was studied by Chen and Liu [133] According to their study's findings, the compressive strength of EPS concrete with silica fume became greater than before significantly after the adding of SF (25 mm length and aspect ratio of 60), while it declined somewhat without silica fume. According to a different study by Chen and Liu [134] the compressive strength of HSLC prepared with expanded clay aggregate bigger by up to 10% with the inclusion of 1% SF volume.

Additionally, Badogiannis, et al. [108] claimed that the introduction of SFs demonstrated to result in a material's compressive strength to be significantly increased. In comparison to the reference mixture, the SF mixtures' compressive strength values ranged from 16% to 76% greater. In view of the fact that the relationship between (regular) aggregates and paste is weaker than the link among fibers and paste, the observed strength increase does not conform with the literature. Because of this, it is not predicted that the addition of SF will have a particularly positive impact on the compressive strength, especially at higher contents of the additive [69].

The maximal growth ratio of 76% in steel fiber mixes is similar to the one (60%) reported by Libre, et al. [135]. However, Libre, et al. [135] discovered a comparable growth ratio that was independent of the fiber volume fraction. On the other hand, Gao, et al. [136] found that, while measuring a lesser rise in compressive strength, the volume fraction and aspect ratio increased proportionally.

According to Wang and Wang [114] both the 1d and 7d compressive strengths of the concrete in the 28d specimen were 67% and 84.1%, respectively. This is because of the utilization of early strength superplasticizers in conjunction with high early strength cement. Additionally, Wang and Wang [114] noted that as people age, the rise in compressive strength with an increase in steel fiber content becomes more and more noticeable. Also, Wang and Wang [114] reported that according to the findings, the compressive strength for the various fiber volume fractions ranged from 60.4–74.8 MPa, which is equivalent to an age of 28 days.

It is abundantly obvious that SF-HSLC has a far bigger impact than conventional concrete. In high-strength lightweight concrete, the coarse lightweight aggregate is the weakest component, not the transition zone between cement paste and lightweight aggregate or the solidified cement paste. Rather, the transition zone amongst cement and lightweight aggregate is the weakest component. The ultimate strength of the concrete is mostly determined by the strength of the lightweight coarse aggregate used in its construction. Under uniaxial compression, concrete compressive strength test specimens experienced both transverse tensile and vertical compressive strain, and the amount of concrete deformation steadily increased as the force applied to the specimens increased. When the transverse tensile strain of the coarse particles in concrete reached their ultimate tensile strain, cracks appeared in the aggregates [114].

Steel fiber is united into the matrix to boost the final compressive strength by stopping the growth of cracks based on the link between SF and cement paste. The test revealed that increasing the fiber volume fraction to 2.0% made it exceedingly difficult for the fibers to disperse, which prevented the concrete from being completely compacted. It is highlighted that the compressive strength of

this form of lightweight aggregate only reaches a particular threshold and does not benefit significantly from subsequent increases in matrix strength [114].

According to Li, et al. [111] regardless of the quantity or kind of fiber that was included, the compressive strength of the model improved when the length of time the material was subjected to the curing process was increased. It was necessary to extend the curing age in order to raise the compactness of the concrete matrix, the bond performance amongst fiber and cement paste. This was necessary because increasing the curing age increased the cement's degree of hydration, which in turn increased the bond performance.

Also, Li, et al. [111] noted that the incorporation of LSF into SLC did not have a discernible impact on the material's compressive strength. If we take the compressive strength after 28 days as an example, we can see that adding 0.25–0.75 vol% LSF to SLC results in a compressive strength that is between 2.8% and 4.7% higher. At 1.0 vol% LSF, the compressive strength was 53.9 MPa, which was lesser than the compressive strength of SLC. When compared to the SLC, the related specimen's compressive strength after 28 days was 10.3–16.7% higher than that of SLC when the MSF content was 0.25–1.0 vol%. When there was a concentration of fiber equal to one volume percent, the compressive strength was measured at 59.8 MPa. In relation to the poor compactness of the concrete matrix and fiber clumping brought on by excessive fiber concentration, the compressive strength showed a decreasing trend when LSF and MSF exceeded a particular content. This is because excessive fiber concentration leads to poor compactness of the concrete matrix [69].

Li, et al. [111] reports that it was discovered that MSF had a superior improvement effect on compressive strength than LSF. The following explanations might be given for the occurrences that were just described. (1) When comparing the number of MSF to the number of LSF with the same fiber volume fraction, the number of MSF was significantly larger. According to the hypothesis regarding fiber spacing, the bridging effect of MSF was significantly more substantial than that of LSF on cracks. (2) Since the MSF and LSF had differing specific surface areas, the bonding amongst the fiber and the cement paste was significantly enhanced as a result. (3) The coating of brass improved the performance of both the cement paste and the fiber bond [137].

Table 10

Summary of previous studies about the compressive strength of steel fiber lightweight concrete.

Reference	Field of Use	Mix Proportion	Steel Fiber	Compressive Strength (MPa)		
				7	28	90
Zhao, et al.[106]	Steel fiber reinforced expanded-shale	1: 1.52: 1.2: 0.35	0	–	32.2	–
			0.4	–	43.8	–
			0.8	–	45.4	–
			1.2	–	46.6	–
			1.6	–	53.1	–
			2	–	52.9	–
Wu, et al.[68]	Beams reinforced with steel fiber	1: 1.54: 1.75: 0.3	0	–	44.6	–
			0.3	–	47.8	–
			0.36	–	45.4	–
			0.42	–	40.2	–
Xiang, et al.[80]	Confined lightweight concrete with steel fiber reinforcement	1: 1.06: 1.08: 0.46	0	–	50.4	–
			0.5	–	52.6	–
			1	–	49.9	–
Iqbal, et al.[120]	Lightweight Self-Compacting High Strength Steel Fiber Concrete	1: 0.65: 1.12: 0.58	0.5	53	64.03	–
			0.75	51	61.01	–
			1	50	60.94	–
			1.25	49.5	59.74	–
Zhao, et al.[75]	Concrete reinforced with steel fiber	1: 1.46: 1.22: 0.35	0	31.5	38.5	–
			0.5	35	41	–
			1	36	44	–
			2	36.5	44.5	–
Li, et al.[111]	Self-compacting lightweight concrete	1: 1.70: 1.83: 0.49	0	35	55	–
			0.25	42	60	–
			0.5	45.5	64.5	–
			0.75	43	61.5	–
			1	41.5	61	–
Xiong, et al.[110]	SF reinforced lightweight aggregate concrete by vibrational mixing	–	0	–	57	–
			0.5	–	62.5	–
			1	–	66.5	–
			1.5	–	67.5	–
			2	–	68	–
			0	26.5	36	40
Prakash, et al. [138]	Concrete made of coconut shells and steel fibers that has some fly ash in it.	1: 0.72: 1.6: 0.33	0.25	31.5	40.5	47.25
			0.5	32.25	43	50.75
			0.75	34	47.5	54.5
			1	35	49.75	56.75
Hosen, et al.[139]	Fibrous-Reinforced High-Strength Lightweight Concrete	1: 1.29: 1.82: 0.45	0	–	54.16	–
			0.5	–	56.8	–
			1	–	61.2	–
			1.5	–	64.4	–

Also, as Nahhab and Ketab [76] mentioned, the results showed that mixes with 0.25% and 0.5% fiber inclusion had approximately equal compressive strengths, however mixes with the maximum fiber inclusion, 0.75%, had typically greater strength, especially at the maximum size of 10 mm. Other authors also found the increased compressive strength brought on by raising the volume percentages of micro-SF, but for vibrated lightweight concrete [32].

In conclusion, it is evident that steel fibers have a positive effect on the compressive strength of lightweight aggregate concrete. The addition of steel fibers resulted in an increase in compressive strength of approximately 1.7%, 2.5%, 7.8%, and 3% after three days, 6.1%, 4%, 9.1%, and 10% after seven days, 6.2%, 6.9%, 14%, and 14.3% after 28 days, and 5.3%, 8.9%, 16%, and 18.8% after 56 days, respectively. Furthermore, the compressive strength of the concrete increased with aging, particularly for concretes with a larger percentage of steel fiber content. It was also noted that micro-SF has a greater impact on compressive strength than large SF. The addition of steel fibers to LWAC also had a greater impact on compressive strength than the addition of silica fume and extended clay aggregates. (Table 10 and Table 11).

4.2. Flexural strength

According to Zhao, et al. [106], the flexural strength of SFRELC was considered by using the test beam's peak load on the load-deflection curve as the basis for the calculation. In most cases, the adding of SFs led to a rise in flexural strength. When SF was added at a volume fraction of 0.4%, the flexural strength of SFRELC increased by 5.9%, on average, and 11.2% per percentage point. This is because the bridging effect of the SFs before the cracking reduced the fracture of the coarse lightweight aggregate. This can be clarified by the fact that. Steel fiber is able to endure the expansion and elongation of cracks even after flexural cracking has occurred since it is made of steel [140].

At a constant value of $V_f = 0.8\%$, the flexural strengths of SFRELC made with (42.5 and 52.5 cements) were 3.64 MPa and 3.60 MPa, respectively, with standard deviations of 10.2% and 4.7%. In addition, the flexural strength of SFRELC was not any lower at $w/b = 0.35$ than it was at $w/b = 0.30$ even though the ratio of the two was different. This would imply that the strength of the cement and the water-to-cement ratio had little to no impact on the flexural strength of the SFRELC. Because a higher flow ability is frequently advantageous for the dispersion of SFs in the concrete matrix, this phenomenon can be attributed to a more uniformly distributed of steel fiber discovered in the tensile zone of the cross-section where the fracture took place [129,141].

Flexural strength reportedly rises as SF content does, agreeing to Iqbal, et al. [1]. The strain softening behavior of the concrete containing 0.5% SF is demonstrated by the initial fracture load and peak load being equal. However, as the fiber concentration is raised further, the concrete begins to exhibit strain hardening behavior as the ultimate load increases after the initial crack. The maximum peak load is for the concrete blend with 1.25% SF content, and it rises along with the increase in fiber concentration [142,143].

Regarding to the effects of steel fibers on the flexural strength of SFRELC (steel fiber-reinforced lightweight aggregate). The authors found that when the volume fraction of steel fibers was increased, the flexural strength of the SFRELC increased as well. They also found that the steel fibers had a bridging effect before the cracking of the lightweight aggregate which improved the flexural strength. Lastly, they found that the strength of the cement and the water-to-cement ratio had little to no impact on the flexural strength of the SFRELC.

When the fiber percentage was increased (0% – 1%), the 28-day flexural strength increased (5.42–7.09 MPa), which is equivalent to a rise from 13.8% to 15.8% of the 28-day compressive strength. According to the findings of past investigations for LWAC

Table 11
Summary of previous studies about the flexural strength of SF lightweight concrete.

Reference	Field of Use	Mix Proportion	Steel Fiber %	Flexural strength (MPa at 28 day)
Iqbal, et al. [120]	Lightweight Self-Compacting High Strength Steel Fiber Concrete	1: 0.65: 1.12: 0.58	0.5	4.42
			0.75	6.13
			1	6.36
			1.25	7.62
Yap, et al. [121]	The torsional behavior of SF lightweight concrete	1: 2.5: 0.62	0.55	5.74
			0.65	5.79
			0.80	6.04
			0	5.42
Shafigh, et al. [130]	Steel fiber on oil palm shell lightweight concrete	–	0.25	6.35
			0.5	6.26
			0.75	6.4
			1	7.09
Li, et al. [77]	self-compacting lightweight concrete	1: 1.70: 1.83: 0.49	0	6.63
			0.25	5.95
			0.5	7.03
			0.75	10.46
Hosen, et al. [139]	Fibrous-Reinforced High-Strength Lightweight Concrete	1: 1.29: 1.82: 0.45	1	11.7
			0	5.5
			0.5	7.69
			1	10.83
			1.5	15.17

manufactured with OPS [144,145] and expanded clay LWA [146] are higher than this range value.

Flexural strength increases at rates of 17%, 15%, 18%, and 31%, respectively, from 0% to 0.25%, 0.5%, 0.75%, and 1% of steel fiber blends. These figures demonstrate that an increase in the volume of steel fibers up to 0.75% has a nearly same impact on the growth in flexural strength. However, the flexural strength significantly increases when a higher fiber volume of (%) is used. Yew, et al. [147] demonstrated that a tiny amount of fiber improves ductility while having no effect on the flexural strength of LWC. The LWC used in this investigation had dry densities of 800–1400 kg/m³ and compressive strengths ranging (8–50 MPa) [130]. (Fig. 7 and Fig. 8).

For both 50% and 100% LECA mixes, according to Nahhab and Ketab [76], despite the fact that the influence of fibers was more noticeable in mixtures composed entirely of 100% LECA. Specifically, for aggregates no larger than 10 millimeters in size, the flexural strength was directly related to the amount of micro-SF that were contained in the material. Concrete became more capable of supporting flexural loads and resistant to crack propagation as steel fiber content increased. The following factor was likely responsible for the micro steel fiber's more pronounced influence at 100% mixes matched to 50% LECA blends. When the amount of steel fiber was increased, the blends became more ductile and less susceptible to first crack propagation, in contrast to the 50% LECA mixtures, which had brittle aggregate particles and weak strengths that resulted in low flexural strengths. Furthermore, Iqbal, et al. [120] found that increasing the volume fraction of micro steel fibers from 0.5% to 1.25% resulted in an 18% enhancement in the indirect tensile strength of high strength steel fiber self-compacting concrete.

According to Li, et al. [111] the flexural strength initially decreased but subsequently greater than before as the concentration of SFs grew in the material. Long steel fiber samples with a content of 0.25% and 1.0% yielded a minimum flexural strength of 5.15 MPa, which is 22.32% less than self-compacting lightweight aggregate concrete (SLC), and a maximum flexural strength of 10.95 MPa, which is 65.16% more than SLC. These results are presented in the table below. When the content of micro-steel fiber was 0.25 vol% and 1.0 vol%, respectively, the samples achieved minimum flexural strengths of 5.95 MPa (10.26% lower than SLC) and maximum flexural strengths of 11.70 MPa (76.47% higher than SLC), respectively. These results were obtained when the micro-steel fiber content was.

According to Simões, et al. [148], Çavdar [149], the geometry, kind, size, volume, and dispersion of the fibers as well as the bond strength between them all had a significant impact on the behavior of fiber reinforced concrete. Although adding steel fiber could reduce crack initiation and spread and increase the strength of SLC, it should also be taken into account that doing so would reduce the compactness of the concrete matrix and negatively impact flexural strength [69,150].

Therefore, Li, et al. [111] observed that the beneficial and negative impacts of the fiber on strength were comprehensively embodied in the rise or decrease of flexural strength when compared to plain concrete. Therefore, it was easy to assume that when the fiber concentration was less than 0.5 vol%, the reduction in flexural strength brought on by the fiber's negative impact on the matrix's compactness was larger than the gain in flexural strength brought on by the fiber's crack-bridging effect. MSF was able to greatly growth the flexural strength of SLC in comparison to LSF. This was in line with the explanation for why MSF had a better improvement effect on SLC's compressive strength than LSF. Additionally, Li, et al. [111] noted that the peak deflection and flexural of fiber self compacting lightweight concrete (FSLCs) exhibited a non-linear trend with an increase in fiber content. Overall, the deflection corresponding to the specimen's maximal load may rise as a result of the addition of steel fiber to SLC. It suggested that adding steel fiber to SLC would boost its toughness and increase its brittleness.

To conclude, adding up to 0.75% steel fibers had a positive impact on flexural strength, resulting in a 17–31% increase in flexural strength. Increasing the steel fiber content beyond 0.75% had a significantly greater impact on the flexural strength, with an increase of 65.16% being observed when 1.0% fibers were added. It was also found that the geometry, type, size, volume, and dispersion of the fibers, as well as the bond strength between them all had a significant impact on the behavior of fiber reinforced concrete. Additionally, it was found that adding steel fibers could reduce crack initiation and spread and increase the strength of SLC, however, it should also be taken into account that it can reduce the compactness of the concrete matrix and negatively impact flexural strength.

The correlation among compressive and flexural strength in respect to the amount of SF into Lightweight Concrete is depicted in

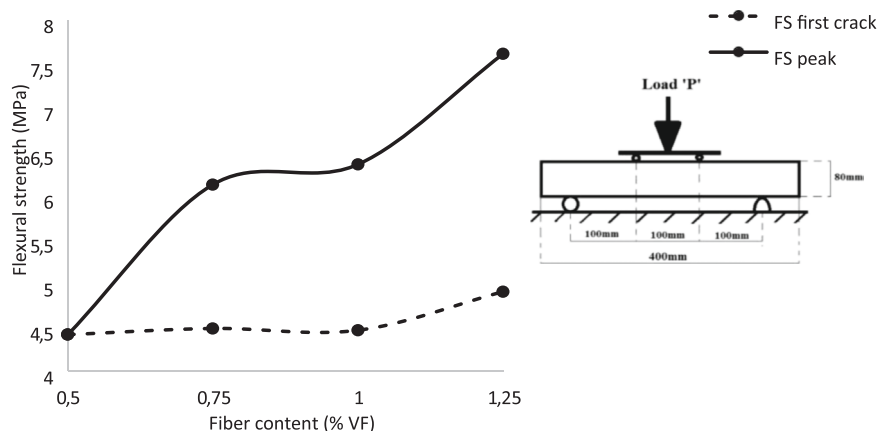


Fig. 7. The flexural strength of concrete can vary significantly, [1].

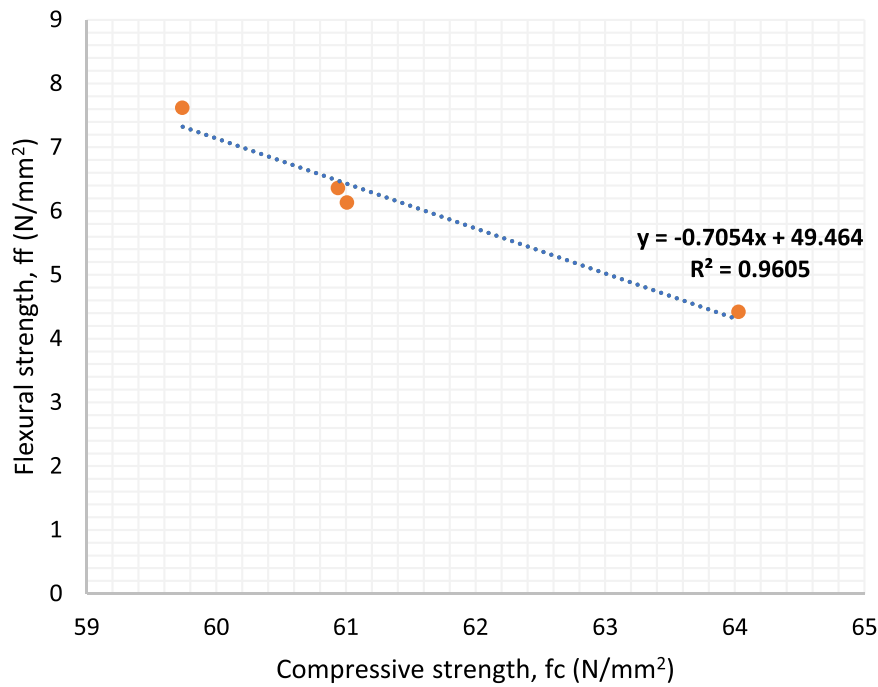


Fig. 8. The relationship between the flexural and compressive strengths in respect to the amount of SF.

Fig. 9. The figure depicts the relationship equation.

5. Durability properties

5.1. Failure mode of steel fiber lightweight concrete

When the loading was first initiated, the specimens were in the elasticity deformation stage, and there were no surface phenomena that were immediately apparent, according to Xiang, et al. [80]. As the weight was raised, the micro-cracks that were slanted and located in the middle of the specimen enlarged. The specimens immediately failed with a harsh sound as soon as the load reached its maximum bearing capacity. The failure mode was a typical splitting one, and the inclined cracks ran through the whole length of the material. The concrete on the surface of a specimen that did not include steel fiber was severely ripped off after the specimen was damaged, and the specimen no longer retained its novel shape. The concrete has fractured into many prisms on both sides of the crack, indicating that the specimen's integrity is fragile after failure and exhibiting an obviously brittle failure.

On other hand, Xiang, et al. [80] mentioned that SF specimens had a binding influence on the concrete on both sides of the crack, bore the shear stress that was created by the crack, and released some of the energy that had been accumulated during the loading process. As a direct consequence of this, the pace of fracture formation slowed down, the width of the crack shrunk, and the integrity of the concrete on both sides was preserved to some degree. Because SF was unable to withstand the shear force required to generate the crack, the specimen's crack breadth became somewhat different when the fiber concentration was 0.5%. This is because the magnified figures of the specimens make it possible to notice this variation. When there was 1% of steel fiber present, there was an improvement in the fiber bridging effect between fractures, and there was a decrease in the crack width.

For specimens with low reinforcement ratios, steel fibers were helpful in reducing the fracture width at service load, according to

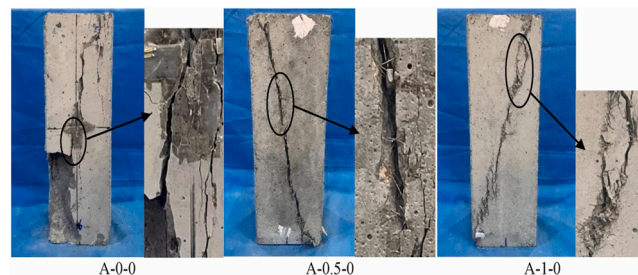


Fig. 9. The failure mode of SFLW concrete specimens, [80].

Liu, et al. [67], but they also marginally increased it for beams in height reinforcement ratios. Additionally, although no obvious association was seen, the reinforcement ratio had an impact on the fracture width at service load. These outcomes could be related to the fact that growing the reinforcing ratio and adding SFs at the same time increased the service load and prevented fracture widening (at low load levels).

5.2. Stress-strain behavior

Badogiannis, et al. [108] reported that the steel fiber mixes had compressive strengths that were 16–76% higher than those of the reference mixture LWC. In view of the fact that the relationship between (regular) aggregates and paste is weaker than the link between fibers and paste, the observed strength increase does not conform with the literature [69]. Therefore, it is not anticipated that the SF addition will have a particularly good impact on compressive strength, especially at increasing content, per the literature [69].

Also, Badogiannis, et al. [108] noted that the greatest growth ratio of 76% in steel fiber mixes is comparable to the one (60%) reported by [135]. According to Xiang, et al. [80], Since the steel fibers began to agglomerate as a result of an uneven dispersion of the fibers, the maximum tensile of some instances dropped as the proportion of steel fibers in the material increased from 0.5% to 1%. However, the behavior and attitude of the downward section, which contains the slope, drop height, and position of the ultimate strain, reveals that the positive effect of steel fiber on the ductility of the samples was bigger than the detrimental impact of fiber aggregation. This was the case due to the fact that the ultimate strain was located in the descending section. As the number of carbon fiber-reinforced polymer (CFRP) layers grew, the SFSLC specimens showed improvements in all four of the following areas: peak stress, peak strain, deformation capacity, and ultimate axial strain. These improvements were seen to varied degrees. The greatest reduction in peak stress was achieved. The improvement in peak strain was the second most noticeable. The least amount of improvement was made to the deformation capacity. When there was a low estimate of CFRP layers, the effects of the transformation in content of steel fibers on the slope of the descending section of the SFSLC specimens was much greater than when there was a massive amount of CFRP layers. This was the case because the slope of the downwards segment of the SFSLC specimens was more sensitive to the change in steel fiber content. In contrast to specimens that comprised a significant number of CFRP layers, this was the case with all of the layers. Whenever there were several CFRP layers, the specimen's stress levels were noticeably increased while it was in the load-holding stage. The research reveals that when the number of CFRP layers increases, the interior core concrete's plasticity increases as well. This results in sufficient lateral deformation in the specimens to totally damage the CFRP in the center of the structure.

5.3. Ductility

The ductility criterion is a vital indicator of a capability since it measures the capacity of structures or pieces to flex plastically upon attaining their maximum weight. This capacity is an important signal of the capability. The ductility of the CFRP-confined SFCLC with a content of steel fibers of 0.5% varied between 3.3 and 9.06 based on the size of the fiber volume fraction. This was determined by measuring the diameter of the steel fibers. According to Xiang, et al. [80], due to the fact that the ductility of the CFRP-confined SFSLC instances having 1% steel fiber varied between 3.75 and 9.6, it is deduced that the incorporation of steel fiber can significantly improve the ductility of the CFRP-confined SLC specimens. So when specimen's steel fiber content goes from 0.5% to 1%, there is a possibility that the fiber will combine, which will slow the rate at which the ductility increases. The fact that the fiber has a positive effect on ductility that overcomes the influence of its agglomeration is perhaps the most important thing to note about this phenomenon. The behavior of the descending portion of the stress-strain curve indicates that this discovery is consistent with previous findings based on the characteristics of the curve. When both the number of CFRP layers and the steel fiber content were at the same level, the specimens' capacity to resist damage improved, but their ductility was significantly reduced. This was the case even if the specimens' strength grade improved. This was the case because equally important contributions were made by both components to the total level of strength. This ultimately causes a decrease in the ductility of CFRP-confined SFSLC specimens because it leads to a weakening of the strengthening effect of CFRP and steel fiber, which in turn leads to a weakening of the strengthening effect of CFRP and steel fiber. When the grade of a specimen's durability goes up, the amount of energy that is accumulated at the site of maximum stress goes up as well, and the specimen's brittle qualities become more obvious. According to the findings of this study, a gain in the toughness coefficient is not always accompanied by an increase in ductility, despite the fact that there was such a growth.

Additionally, Altun and Aktaş [117] noted that in lightweight concrete containing 350 kg/m³ cement, the ductility values increased by 18% and 9%, respectively, when reinforced with steel fibers at 30 kg/m³ and 60 kg/m³, respectively. When lightweight concrete made with 400 kg/m³ cement was used, the ductility values improved by 21% for steel fiber weighing 30 kg/m³, and by 69% for steel fiber weighing 60 kg/m³. In conclusion, the use of 450 kg/m³ cement in lightweight concrete that contained either 30 kg/m³ or 60 kg/m³ SF greater than before ductility by 64% and 98%, respectively. According to Caratelli, et al. [151] adding around 30 kg/m³ of hooked SFs to the monotonic test increases the ultimate load by about 20% while increasing ductility (measured as the difference among the ultimate and yielding displacements) by about 65%.

5.4. Modulus of elasticity

Table 12 provides a summary of the consequences for the modulus of elasticity for each of the four types of concrete mixtures. As seen in the table, the modulus of elasticity of concrete slightly decreases as the amount of steel fibers rises, but this change is negligible and the values essentially stay the same [120].

Hosen, et al. [139] mentioned that the modulus of elasticity (MOE) has a significant impact on the strength of concrete used in

structural applications. Additionally, Committee [152] stipulated that The modulus of elasticity of the concrete relies heavily on both its density and its compressive strength. In the case of POC-comprising, fibrous, reinforced, high-strength, lightweight concrete, it was found that the volume percentage of steel fibers appeared to have a substantial influence on the rise in the modulus of elasticity (which reached up to 40%).

Steel fiber concrete's static MOE values with (0%, 0.50%, 1.0%, and 1.5%) were (24.83, 27.06, 33.20 and 34.78 GPa, respectively). According to the results of these assessments, the incorporation of SFs significantly improved the MOE of the environmentally friendly, low-carbon footprint, high-strength, lightweight concrete. 1.68–2.47 was the range of numbers that constituted the standard deviation. Steel fibers improved the stiffness and decreased displacement of the POC-containing, high-strength, lightweight concrete during the pre-peak period.

6. Conclusions

The literature review showed that steel fibres used in lightweight concrete (SF-LWC) had a length range of 30–36 mm and a diameter range of 0.5–0.92 mm, with a smooth surface and high tensile strength of 1100–3000 MPa. The addition of steel fibres improved the compressive and flexural strengths, and increased the ductility of LWC. The study found that the addition of 0.50% steel fibres to freshly mixed concrete decreased the slump values by 40–70%, and the formation of a fibre-cement matrix network resulted from the dispersion of steel fibres throughout the concrete. The porosity between fibres and paste increased with the amount of SF added, and the new density of LWC increased modestly.

The results indicated that the best compressive and flexural strength values were achieved with a percentage of steel fibres in LWC ranging between 0.75% and 1%. Steel fibres had a binding effect on the concrete, absorbing shear stress and slowing the growth of cracks, which improved the durability and service load of the structure. The ductility of the material increased with the addition of steel fibres, although there was a slowdown in the pace of increase as the percentage of fibres increased. This study contributes to the advancement of sustainable and environmentally friendly construction methods by providing valuable insights into the properties and performance of SF-LWC. It evaluates prior research and presents a comprehensive analysis of the use of steel fibres in LWC, offering suggestions for future research and advancements in the field.

While this study provides a comprehensive analysis of prior research on SF-LWC, it is based solely on a literature review and does not include experimental testing. Future research should include practical testing to validate the findings of this study. The study only evaluates the use of steel fibres in LWC, and further research could explore the potential of incorporating other types of fibres in concrete production. The study only focuses on the effects of steel fibres on the compressive and flexural strengths, ductility, and durability of LWC, and future research could explore other properties such as fire resistance and thermal conductivity.

The use of steel fibres in LWC improved the compressive and flexural strengths and increased the ductility of the material. The addition of steel fibres slowed the growth of cracks, improving the durability and service load of the structure. The study provides valuable insights into the properties and performance of SF-LWC and offers suggestions for future research and advancements in sustainable construction methods. This study advances the field of sustainable construction by providing a comprehensive analysis of the use of steel fibres in LWC. The findings offer valuable insights into the properties and performance of SF-LWC and contribute to the advancement of environmentally friendly and energy-efficient construction methods. The study lays a solid foundation for further research in this area and has the potential to inform the design and production of sustainable and durable concrete structures.

7. Recommendations

The possibility of incorporating steel fibres into lightweight concrete has been demonstrated in the research that has been published. The following are among the suggestions and opportunities for additional research:

1. Conduct in-depth research and analysis on the effects of using steel fibre reinforced lightweight concrete in various settings, including its impact on the environment and its economic implications.
2. Expand the current research to include a more comprehensive evaluation of the material's properties, such as fresh properties, splitting tensile strength, shrinkage, ultrasonic pulse velocity, water absorption, sulphate resistance, chloride resistance, and acid resistance.
3. Investigate the long-term performance of steel fibre reinforced lightweight concrete to determine its durability and longevity.
4. Explore the potential benefits and drawbacks of combining steel fibres with other types of materials in the concrete mixture.
5. Conduct a thorough cost-benefit analysis of using steel fibres in lightweight concrete, including an evaluation of the potential costs and profits associated with its implementation.

Table 12

The elasticity modulus of each of the four distinct types of concrete mixes, [120].

SF %	Modulus of elasticity (MPa)
0.5	15,782
0.75	15,595
1	15,672
1.25	15,349

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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