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Danish Hussain Thoker
M.Tech. Scholar, SCE, Lovely Professional University, Phagwara, Panjab, India

Sahil Jaggi
Assistant Professor, SCE, Lovely Professional University, Phagwara, Punjab, India

Corresponding Author:
Sahil Jaggi
Assistant Professor, SCE, Lovely Professional University, Phagwara, Punjab, India

Mechanical properties of light weight, fibre reinforced, high strength concrete

Danish Hussain Thoker and Sahil Jaggi

Abstract
Present study intends to explore the effect of fibres and different cement proportions on compressive strength, flexural strength and durability properties of lightweight concrete made with light weight aggregates as coarse aggregate. The effect of fibre on modulus of elasticity and Poisson's ratio of concrete are investigated, and flexural strength, toughness is calculated. Test results show that the effect of volume of fibres and aspect ratio of fibres on flexural strength and fracture toughness is extremely prominent, compressive strength is only slightly improved, and tensile compressive strength ratio is obviously enhanced. Also, deflection of concrete is lowered due to arresting of cracks by fibres. Besides mechanical properties, durability properties also increase.

Keywords: Light weight concrete, mechanical properties, aspect ratio, volume fraction

Introduction
Concrete is one of the most widely used construction material throughout the world. Besides having some good properties, concrete has associated with some undesirable properties too. Heavy self-weight and brittleness are two of them that makes it to some extent uneconomical structural material. Several attempts have been made to reduce the self-weight of concrete and to increase its efficiency in structural material. Due to the fast and rapid construction of high-rise building, special concrete is required like light weight, high strength, high performance etc. Also, in few cases density of concrete is most important than strength.
Self-weight constitutes the major portion of the load coming on the structure. In context to same, there is significant advantage in decreasing in density of concrete. A decreased density of concrete for the same strength level permits a saving in dead-load for structural design and foundation. Therefore, in recent years large research was going on to explore properties of light weight concrete. Zhang and Gjorv (1991) [1] found that the tensile/compressive strength ratio was lower for high-strength, lightweight concrete than that for high-strength, normal weight concrete, and the lightweight concrete becomes more brittle for increasing strength level. Khaloo AR., Sharifian, M. (2005) [2] revealed that the compressive toughness of high-strength, lightweight concrete was lesser as compared to that of normal weight concrete. Thus, the above two researchers made a cohesive inference that for gaining the quality of high-strength, normal weight concrete and the lightweight concrete becomes more brittle for increasing strength level. Wilson H.S., Malhotra, V.M. (1988) [3] reported that the stress-strain curve in uniaxial compressive loading was steeper and more linear to a higher stress-strength ratio for the high-strength, lightweight concrete than for the low strength lightweight concrete. Light-weight, high strength concrete has been widely used construction material, but problems such as low tensile/compressive strength ratio, low flexural strength, low fracture toughness, high brittleness and larger shrinkage, restricts its use in concrete structure. The introduction of different fibres to light weight concrete enhanced various properties, especially for improving tensile/compressive ratio, behaviour of earthquake resistance, resistance to cracking and fracture toughness. Apart from the above mentioned studies, the investigator found large number of the research studies in the same domain. However, results varied interims of intensity of the inferences. Like notable studies conducted by;

Research problem: In the present study an attempt has been made by the investigator to study the research problem which reads as:

"Mechanical properties of light weight, fibre reinforced and high strength concrete"

Literature review: As reported earlier large number of the research studies has been conducted in the relevant domain. The investigator made ample efforts to explore the national and international studies. Accordingly, below mentioned research studies has been surveyed:

Jianming, Gao, Wei Suqa & Keiji Morino (1977) [4] they used expanded clay aggregates to make light weight concrete. They found that steel fibres along with different cement proportion have significant impact on improving mechanical properties of light weight concrete. Compressive strength was not improved significantly, tensile and flexural properties has been enhanced significantly. Besides, Kang, T.H.K., & W. Kim (2010) [5] revealed that the expansion of steel filaments with steel fibre volume portions of 0.5% to 0.75% enhanced the shear strength quality by 25% to 45%. It is likewise discovered that the shear-to-depth ratio influenced the shear quality additionally the shear quality of steel fibre-fortified normal weight concrete is marginally bigger than that of the steel fibre strengthened lightweight solid concrete. Kamran, A. Mohammad, A. Yazdib and Konstantinos, D.T. (2010) [6] He did his experiments on waste steel wires, modified structural lightweight concrete and noticed that while mixing the waste wires with industrial steel fibres up to 0.5% in volume fraction the compressive strength of the structural lightweight concrete increases. However, the addition of more than 0.5% of the waste wires and steel fibres reduces the compressive strength of waste steel fibre reinforced concrete specimens. Dahake, A.G. and Charkha, K.S. (2016) [7] by this paper they found that enhancing the quality of cement depends measuredly on quantity of fibre content used. The optimum fibre content to give most extreme qualities was determined. With expanding fibre content, mode of failure is changed from brittle to flexible when exposed to different loading. With expansion of steel filaments, the mechanical properties of cement are upgraded. Every one of the properties like compressive quality and flexural quality is expanded with decrease in porosity and absorption. With 2.5% expansion of steel fibre, solid show generally improvement. Zhang, L.L. and Paramasivam, (2016) [8] in this paper they used light weight sand instead of normal sand to reduce the density of concrete compared with the lightweight concrete with normal-weight sand. They found that with increase in compressive strength, the maximum bending load taking capacity increases for bath plane as well as reinforced concrete. Under impact loading, the maximum bending loads for the plain lightweight and normal weight concrete with similar compressive strength were also similar. Shunbo, Z., Changyong, L., Mingshuang, Z., Xiaoyan, Z. (2016) [9] This experimental paper says that the impacts of W/B, coarse and fine aggregate are independently qualified on the improvement rate at early age and the later creating condition of autogenous shrinkage the normality of drying shrinkage of SFRLAC can be additionally communicated as a progression of hyperbola fit as a fiddle factors are direct with the volume division of steel fibre, and the affecting components of coarse and fine aggregate are qualified. The slump was influenced by water to binder mix ratio and would in general lessen with expanded of volume fraction of steel fibre. Saul Rico, Roshanak Farshidpour and Fariborz M. Tehrani Hindawi Advances in Civil Engineering Volume 2017: He tried to find the effect of fibres on cement matrix. As per his study the addition of fibres into a brittle cement matrix helps to enlarge the break sturdiness of the composite, by arresting splitting procedure, and helps in empowering the tensile and flexural properties. Mixing fibres improves ductility of lightweight concrete or ordinary weight high-quality solid when joined with regular steel support decreases the brittleness of these materials. Hamid, P. Behbahani, B. and Nematollahi, L (2017) [10] with this research they tried to find the effect of steel fibres on light weight concrete. He concluded that fibres can be incorporated in random, discrete fashion while as steel reinforced is designed and laid properly at different locations. He presents that amongst all varieties of fibres which can be used as concrete reinforcement, steel Fibres are the most famous one. The performance of the metal Fibre reinforced Concrete (SFRC) has shown a significant improvement in flexural power and overall durability in comparison towards traditional reinforced Concrete. Yoo, J. K., Jiong, B. H. (2010) [11] He concluded from his paper that by incorporating air, using surfactants and traditional lightweight aggregate light weight concrete with density 1137kg/m3 can be finished. Also, he determined each compressive properties and elastic modulus are mostly dependent on the quantity of air in the concrete. The increase in surfactant content de-enhances the compressive properties and elastic modulus compared to non-surfactant concrete. Also, they noted that the compressive and elastic properties are lightly dependent on the quantity of fibre in the concrete and the toughness index is highly dependent on the quantity of fibre within the aerated concrete. Chanh, N. V. (2004) [12] He found that using crushed bricks as coarse aggregate and steel fibres together, to produce light weight concrete which has acceptable properties and has optimum density equal to 1812 Kg/m3. Also, the concluded that optimum percentage of steel fibre for compressive properties was (0.75%), however, increasing steel fibres from (0.75%) to (1%) by volume of cement caused reduction in compressive properties. He also noticed that steel fibres, when used in different proportions, improved the static modulus of versatility by about (4%-12%). The maximum percentage of steel fibre was found to be (0.75%) that gives higher static modulus of flexibility superior to (1%) steel fibres There are an expanding in water ingestion for light weight steel strands concrete contrasted and reference mix, and that increments changed (1.31% 9.24%) contingent upon the proportion of steel fibre. Weiler B, Grosse C. (1996) [13] By this paper they found that addition of fibre and replacement of natural aggregates with pumice yields enhancement in strain energy when substituted in various proportions, like at 1.5% of fibre and with 40% replacement of natural aggregate with 40% pumice yields maximum strain energy and at 0.5% of fibre and a 100% replacement of natural aggregate by 100% pumice yields most strain power. Also they noticed that 20% substitution through 20% pumice and with 1.5% fibre is presumed to be best percent. Dhakal R.P., Wang, C., Mander, J.B. (2005) [14] In this paper they noticed that addition of steel fibre to lightweight concrete decrease its workability. They also found that addition of steel fibres to light weight concrete up to 2% volume increase compressive strength but using steel fibre over 2% volume may decrease it. Likewise, the introduction of steel fibre influences the slippage of stress strain bend, even less volume fraction of steel fibres neglects brittle failure. Steel fibre to lightweight cement has no impact on the stress-strain relationship. Flexural properties also increase with the mixing of steel fibre. Sheelan M.H. (2017) [15] with their experimental results they concluded that addition of plastic fibre enhanced the flexural strength parameter of light weight concrete however not so much significant in improving compressive properties. He found that addition of 1% of plastic fibre increases both compressive as well as flexural parameters. He also recognised that different percentage of glass powder as substitute of cement with 1% plastic fibre increased the lightweight properties especially compressive quality and the improvement in properties was clearer with increase in glass powder to 20%. Peng G.F, Yang W.W, Zhao J, (2006) [16] investigated the effect of steel fiber (L = 30 mm and aspect ratio = 60) on the properties of LWAC made of expanded clay (with maximum grain size of 12 mm) in monotonic and cyclic loads. They reported that when this LWAC (of grade 20) was reinforced by steel fiber in volume fractions of 0.5%, 1% and 2%, its compressive strength increased by about 22%, 29% and 38%, respectively in monotonic load and by about 23%, 23% and 41%, respectively, in cyclic load. Domagala (2011) [17] pointed out that the type of test specimen has an effect on the compressive strength of steel fiber reinforced concrete. He showed that a LWAC made with sintered fly ash as coarse aggregate, when reinforced by 0.6% volume fraction of a steel fiber (L = 50 mm and D = 0.75 mm) showed three different increases in the compressive strength of about 3.6% for 150-mm cube, 4.7% for 100-mm cube, and 7.0% for 150 mm _ 300 mm cylinder mould, which reveals that the cylinder specimens have higher compressive strength than the cubic specimens for the same fiber reinforced concrete. Topcu and Canbaz (2018) [18] showed that for normal weight, normal strength concrete containing fly ash, a significant increment in the compressive strength of the steel fiber reinforced concrete was observed (up to 95%) for the cube specimens, while the same concrete showed a slight increase (up to 13%) in the compressive strength when it was tested for the cylinder specimens. Campione G, Miraglia N, Papia M. (2010) [19] showed that the effectiveness of steel fiber on the compressive strength of LWAC strongly depend on the aggregate type. They reported that the incorporation of steel fibers into the matrix of expanded clay LWAC showed an increase in the compressive strength of up to 30%, while in the case of pumice stone LWAC the variation in the strength was negligible. They demonstrated that compared to pumice stone LWA (irregular in shape), the surface of the aggregate in contact with the steel fibers decreases in the case of expanded clay (round and regular in shape). Chen and Liu (2004) [20] also reported that the combination of carbon and steel fibers (each one of 0.5% volume fraction) gave the highest value for toughness index, as compared to 1% volume fraction of a single type of each fiber. Among these fibers, the PP fiber does not affect the compressive strength, while carbon fiber has the highest effect, up to 15% and steel fiber up to 10%. Therefore, a higher strength was observed for expanded clay LWAC. It should be noted that the effectiveness of fibers would be more in composites when they are free from aggregate interference. Which causes better fiber-mortar interfaces. The evidence is reported in the below mentioned table:

Table 1: Showing Properties of three types of fibers

	Carbon	Steel	Polypropylene
Length mm	5	25	15
Diameter (mm)	7	500	100
Shape	Straight	Crimped	Straight round
Density (g/cm^3)	1.6	7.8	0.9
Modules (GPa)	240	200	8
Elongation at break (%)	1.4	3.2	8.1
Tensile strength (MPa)	2500	1500	800

The results of the above reported table indicate that the incorporation of different kinds of fibres and their effects on mechanical properties such as compressive strength, flexural strengths, toughness and bending is significant on light weight concrete.

Conclusion

The inclusion of fibers, particularly steel fibers, into structural lightweight aggregate concrete decreases its workability. For compensating reduction of workability, the use of higher dosage of superplasticizer and fine aggregate and also the use of fly ash in concrete mixture are recommended. Steel fiber increases the density of LWAC. The use of mineral admixtures, air-entraining admixtures and small steel fiber content may compensate for the increase in the density of LWAC. Generally the inclusion of steel fiber to LWAC increases the compressive strength. But, inclusion of steel fiber more than 2% volume fraction may reduce it. However, a fiber reinforced LWAC have significantly higher splitting tensile strength than plain LWAC even at low volume of fibers (especially steel fiber). The use of hooked-end steel fiber and also cementations materials in fiber reinforced LWAC, result in a higher improvement of tensile strength. The positive effect of the addition of fiber on the splitting tensile strength of LWAC is more significant in LWAC with a higher volume of LWA. In addition, the inclusion of fiber to LWAC increases its flexural strength. The increase in flexural strength due to the addition of fiber in LWAC is higher than NWC. The effectiveness of steel fiber in flexural strength seems to be significantly more pronounced than other types of fibers. However, a combination of steel fiber and non-metallic fibers results in higher flexural strength than the usage of individual types of fibers. The inclusion of steel fibers in LWAC significantly affects the descending part of the stress–strain curve. Even very low volume fractions of steel fiber help to prevent brittle failure of LWAC. However, the addition of steel fibers to LWAC has little or no effect on the ascending part of the stress–strain relationship. Therefore, in most cases the modulus of elasticity of fiber reinforced LWAC is not much different than plain LWAC. The effectiveness of fiber for improving the toughness of LWAC is much higher than NWC. A combination of steel fiber and non-metallic fibers results in better toughness.

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