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COMPRESSIVE, FLEXURAL AND SPLITTING TENSILE STRENGTHS OF LIGHTWEIGHT FOAMED CONCRETE WITH INCLUSION OF STEEL FIBRE

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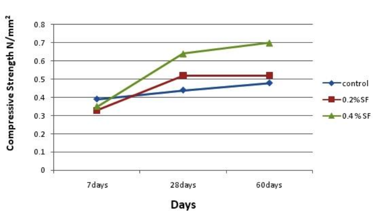
Graphical abstract



Abstract

Lightweight foamed concrete (LFC) application in building construction is rather limited due to its low strength and brittleness. This study has been undertaken to investigate the effects of steel fibers lightweight foamed concrete at a relatively low volume fraction (0.2 % and 0.4 %) on the mechanical properties such as compressive strength, flexural strength and splitting tensile strength. Steel fibres were used as additives. The foamed concrete was designed to achieve the result of effect from volume fraction of steel fibres used with different density of 700 and 1200 kg/m^3 at the age of 7, 28 and 60 days. Detail experiments were setup to study the behavior and reaction of additives which is expected to give different results on mechanical properties of lightweight foamed concrete. The result showed, addition steel fibres have greater contributions in terms of mechanical properties in LFC.

Keywords: Steel fibre, foamed concrete, lightweight concrete, compressive, flexural

Abstrak

Aplikasi konkrit ringan berbusa dalam pembinaan bangunan adalah agak terhad disebabkan kekuatan yang rendah dan sifat rapuh. Kajian ini dijalankan untuk mengkaji kesan penggunaan gentian keluli di dalam konkrit ringan berbusa pada peratusan kecil (0.2% dan 0.4%) ke atas sifat-sifat mekanikal seperti kekuatan mampatan, kekuatan lenturan dan kekuatan tegangan. Gentian keluli telah digunakan sebagai bahan tambahan. Konkrit ringan berbusa telah disediakan untuk mencapai hasil kesan daripada pecahan isipadu gentian keluli yang digunakan dengan ketumpatan yang berbeza iaitu 700 dan 1200 kg / m^3 dan diuji pada usia 7, 28 dan 60 hari. Eksperimen terperinci telah disediakan bagi tujuan mengkaji tindak balas bahan tambahan yang dijangka memberikan hasil yang berbeza pada sifat mekanikal konkrit ringan berbusa. Hasil kajian menunjukkan bahawa gentian keluli memberi kesan kekuatan yang baik ke atas sifat mekanikal konkrit ringan berbusa.

Kata kunci: Gentian keluli, konkrit berbusa, konkrit ringan, mampatan, lenturan

1.0 INTRODUCTION

The construction industry has shown significant interest in the use of lightweight foamed concrete (LFC) as a building material due to its many favorable characteristic such as lighter weight, easy to fabricate, durable and cost effective [1, 2]. The main specialties of lightweight concrete are its low density and thermal conductivity. It's advantages are there is a reduction of dead load, faster building rates in construction and lower haulage and handling costs [3]. LFC is either a cement paste or mortar, relegated as lightweight concrete, in which the air-voids are entrapped in mortar by suitable foaming agent [4, 5]. It therefore has a wide range of application such as material for wall blocks or panels, floor & roof screeds, trench reinstatement, road foundations and also voids filling [6, 7].

However, in itself LFC is a very brittle anisotropic material with high compressive strength and low tensile strength. The inclusion of steel fibres into LFC is one approach to enhance its durability properties. Therefore, in this study special attention is drawn to steel fibres as they are widely used and also the focus of this project to obtain higher concrete strength at considerable porosity of the applied lightweight foamed concrete. According Mustaffa *et al*., hooked-End stainless steel has proven to give the best performance [8]. The shape of hooked-end structure enable it to holds the two parts together and preventing the structure from cracking into two parts [9]. Regarding to the previous research, by adding the steel fiber in concrete matrix, the strength increase and exceeds to 25% [10]. In lightweight fibre reinforced foamed concrete by adding the steel fibres can produces an increase in maximum of compressive strength [11]. This increase can be explicated with the following considerations by the fiber matrix bond mechanisms in concrete.

Besides, the addition of steel fibre in the lightweight foamed concrete can improve the flexural strength. it has been proven from the previous research that the result of friction 0.4% steel fibre has the highest flexural strength for the 28days test [12]. Nevertheless, the specimens also were not cracked into two parts. The usage of steel fibre allows to holds the critical part together giving the alert timing before it cracks into two parts. Inclusion of steel fibres is difficulties connected for concrete but the tensile strength are greater than in ordinary concrete, because the material neither brittle nor isotropic [13]. Basically, lightweight foamed concrete is good in thermal insulating. Additional steel fibre in LFC generates higher thermal properties as compared to normal LFC by accidental causes or by the characteristics of the steel fibre application [14]. This research aims to characterize the mechanical properties of foamed concrete with the inclusion of steel fibre in terms of compressive, flexural and splitting tensile strengths.

2.0 MATERIALS AND MIX PROPORTION

The basic mixed ingredients used were: Cement, fine aggregate, water, foam and steel fibres. No coarse aggregate was used in foamed concrete since it is heavier and will cause segregation [14].

2.1 Cement

The cement used in all concrete mixes was ordinary Portland cement specified by MS 522: Part 1.

2.2 Sand

Fine aggregate used was local natural sand with specific gravity of 2.60 and the maximum size was 3 mm.

2.3 Steel Fibre

The steel fibred used in this study is hooked-end low carbon produces by Hunan Sunshine Steel Fibre Co. Ltd. The properties of the steel fibres used are summarized in Table 1 (tested by supplier) and the geometry of the steel fibres is shown in Figure 1.

Table 1 Steel fibre specifications

Fibre Properties	Quantity
Type of steel Fibre	hooked-end low carbon
Average Fibre Length (mm)	30
Average fibre width, (mm)	0.56
Aspect Ratio (L/d)	54
Shape	hooked
Tensile strength (MPa)	>1100
Ultimate elongation (%)	<2
Specific Gravity	7.85

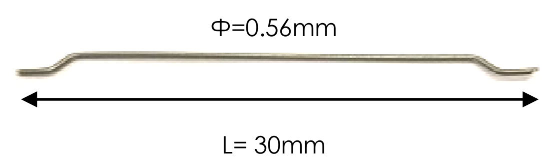


Figure 1 Geometry of steel fibre

2.4 Water

Water shall be clean and free from amount of organic materials.

2.5 Mix Proportion

The main objectives of this research are to determine the mechanical and thermal properties of LFC by addition the steel fibre therefore six types of mixtures was cast with cement-sand ratio of 1:1.5 and water-cement ratio of 0.45 will be used for batches of LFC samples were excogitated with density level 700kg/m^3 and the next mixture was cement-sand ratio of 1:2.3 and water-cement ratio of 0.43 will be used for batches of LFC samples were excogitated with density level 1200kg/m^3.

Table 2 Details of mix design

Mix Design	Control 700	Mix 1	Mix 2	Control 1200	Mix 3	Mix 4
Water-cement Ratio	0.45			0.43		
Cement-sand ratio	1:1.5			1:2.3		
Target Density	700 kg/m^3			1200 kg/m^3		
Steel Fibre	0%	0.2%	0.4%	0%	0.2%	0.4%

Table 2 shows the details of mix design used for foamed concrete in this study with a density of 700 kg/m^3 and 1200 kg/m^3. A total of six types of mixtures were cast with 0%, 0.2% and 0.4% steel fibre volume fraction with difference density. Plain mixture it is used to determine the effectiveness of the percentage of steel fiber for each mixture that has 0.2% and 0.4% steel fiber.

3.0 EXPERIMENTAL SETUP

Laboratory experiments carried out after all the sample reaches the age of 7 days, 28 days and 60 days. Three cube, eighteen cylinders and nine prisms specimens were prepared for each mix were tested for mechanical to determine the effect of addition steel fibres in lightweight foamed concrete.

The compressive strength test (Figure 1) and splitting tensile test (Figure 2) ware performed of a cylinder with a diameter 100mm and high 200mm. The tests have been conducted as specified in the test method MS EN 12390-3: 2012 with the aid of GOTECH GT-7001-BS300 Universal Testing Machine at the HBP Testing Unit in the School of Housing Building & Planning USM For each mixture, 18 specimens were prepared where nine specimens for compressive while nine specimens for splitting tensile test and the tested at 7, 28 and 60 days.

The flexural strength test (Figure 3) was performed on rectangular specimens with dimensions of height (h) 100mm, width (w) 100mm and length (l) 500 mm using the four point loading procedure of MS 26: Part 2.

3.1 Compression Test

Compressive test are required to determine the strength of concrete. Compressive strength was calculated using the following formula:

$$Wf/Ap \quad \text{.........................(Eq. 1)}$$

where;

Wf : Maximum applied load
Ap : Plan area of cylinder mould, (mm2)

Figure 1 Apparatus for compression test

3.2 Splitting Tensile Test

Splitting tensile test is the method to measures the splitting tensile strength of concrete of given mixes proportion by the application of a diametral compressive force on a cylindrical concrete specimen placed with its axis horizontal between the platens of a testing machine. The splitting tensile of the specimen was calculated as follows:

$$T = 2P/\pi ld \quad \text{...................(Eq. 2)}$$

where;

T = splitting tensile strength, kPa
P = maximum applied load indicated by the testing machine, KN
L = length, m
D = diameter, m

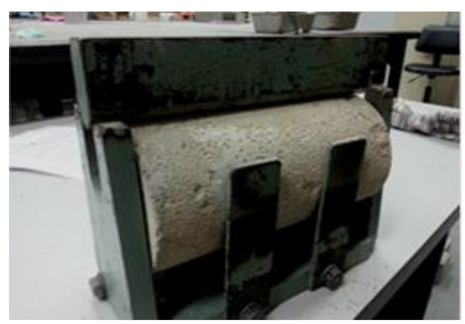


Figure 2 Setup for splitting tensile test

3.3 Bending Test

The objective of this testing is to determine the value of flexural strength. Flexural stress can be calculated on any point on the load deflection curve by using following equation for four point bending test:

$$\delta f = \frac{3FL}{4bd2} \quad \text{.......................(Eq. 3)}$$

where;

δf : flexural stress (MPa)
F : the at a given point on the load-deflection curve (N)
L : the length of the support span (mm)
b : width of the specimen (mm)
d : thickness of the specimen (mm)

Figure 3 Setup for bending test

4.0 RESULTS AND DISCUSSION

4.1 Compressive Strength

Figures 4 and 5 show the data of compressive strength in different density in unit N/mm². Referring to the graph above the lightweight foamed concrete with content 0.2% and 0.4% fraction of steel fibre has higher compressive strength compare to the control lightweight foamed concrete. Moreover, 0.4% fraction of steel fibre in lightweight foamed concrete is the highest compressive strength on both of density. The compressive strength is increasing day by days. Besides, from the data obtained can be seen that the compressive strength will be decreased due to the low fraction of steel fibre and the density of lightweight foamed concrete.

From the data above, it's proven that addition of steel fibre in lightweight foamed concrete can produce an increase the maximum of compressive strength due to the fibre matrix bond mechanism and amount percentage of steel fibre introduced into the lightweight foamed concrete where the steel fibres plays a vital role in compressive strength. Besides, steel fibres is believed to increase the compressive strength because the solidity of its physical structure. It can be finalize the compressive strength will decrease due to the fact that the low density of lightweight foamed concrete encourages an increase the porosity and these result deterioration of compressive strength [15].

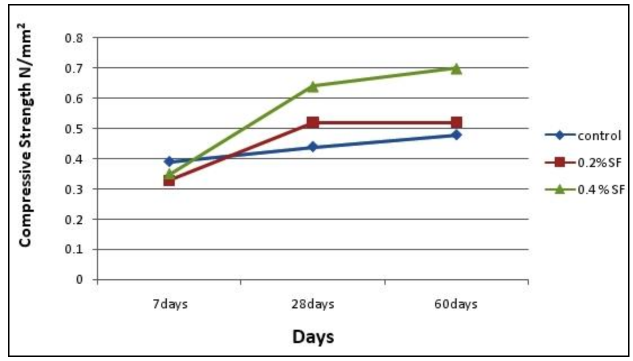


Figure 4 The comparison of compressive strength of control sample with steel fibre reinforced foamed concrete of 700 kg/m³ density

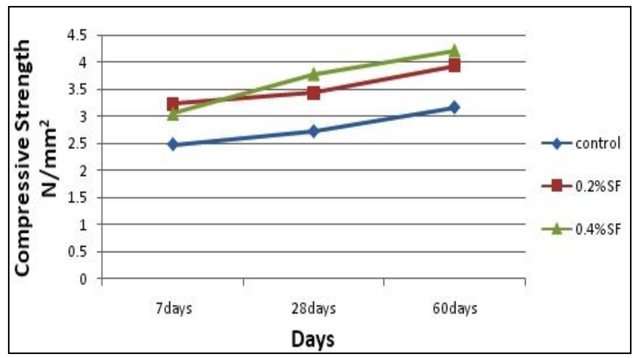


Figure 5 The comparison of compressive strength of control sample with steel fibre reinforced foamed concrete of 1200 kg/m³ density

4.2 Splitting Tensile Strength

Figures 6 and 7 show the data of splitting tensile strength in different density in unit N/mm². From the graph shows the splitting tensile strength increasing day by days on ages of 7days, 28days and 60 days especially in lightweight foamed concrete with additive of steel fibre. The steel fibre those volume fractions of 0.2% have enhancement 17% of tensile strength while, volume fraction 0f 0.4% have enhancement 25% tensile strength in density of 700kg/m³ on age of 60days compared to the control mix. On the other hand, the tensile strength also increases. The steel fibres those volume fractions of 0.2% have enhancement 11% of tensile strength while, volume fraction 0f 0.4% have enhancement 31% tensile strength in density of 1200kg/m³ on age of 60days compared to the control mix. Besides, from both of the graph has been seen that tensile strength on density of 1200 kg/m³ are greater than density of 700 kg/m³.

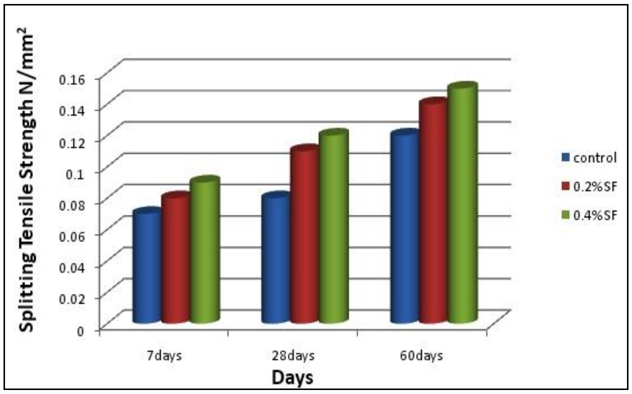


Figure 6 The comparison of splitting tensile strength of control sample with steel fibre reinforced foamed concrete of 700 kg/m^3 density

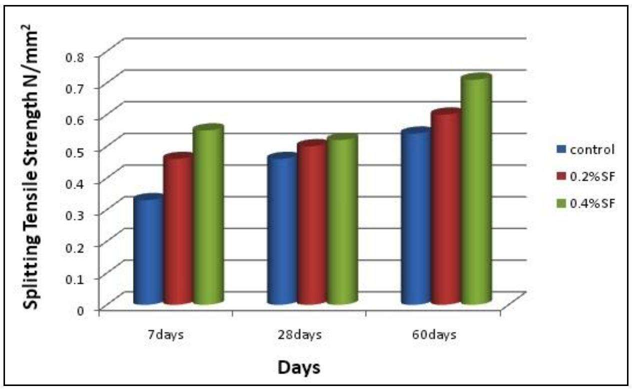


Figure 7 The comparison of splitting tensile strength of control sample with steel fibre reinforced foamed concrete of 1200 kg/m^3 density

Generally lightweight foamed concrete has a low tensile strength and brittle nature [16]. From the data recorded, the tensile strength value slightly increased due steel fibres is difficulties connected for concrete but still the tensile strength are increase than in ordinary concrete. It is because the material used in lightweight foamed concrete neither brittle nor isotropic. Besides, the lengths steel fibre used also taking to develop the tensile strength of it. Moreover, the steel fibre usually crimped and deformed with either a hook at each fibre end in order to improve the bond between fibre and concrete matrix. From all statement above it is proven that the steel fibres are sufficiently strong and bonded to lightweight foamed concrete mix and steel fibre would be able to carry significantly stresses with relatively large strain in the post-cracking stage. Last but not least, from the both of graph it can be concluded that the lower density of lightweight foamed concrete order to high contain of air, higher porosities and lower of strength.

4.3 Flexural Strength

Figures 8 and 9 show the data of flexural strength in different density in unit N/mm^2. From the graph above, it's proved that 0.2% and 0.4% fraction of steel fibre improve the flexural strength compare to the control lightweight foamed concrete at every age. The highest reading of flexural strength is 0.4% fraction of steel fibre at age 60days was recorded, while the lowest flexural strength is in control lightweight foamed concrete with 0% fraction of steel fibre on both of density. Visually as well, the difference strength of flexural in higher and lower density of lightweight foamed concrete can be seen at 7days, 28days and 60 days. Density of 1200kg/m^3 has higher flexural strength than the density of 700kg/m^3 lightweight foamed concrete.

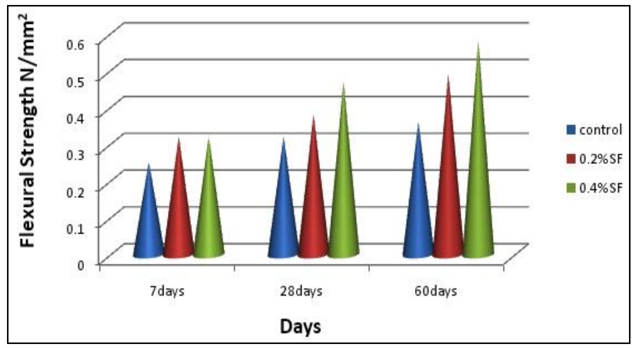


Figure 8 The comparison of flexural strength of control sample with steel fibre reinforced foamed concrete of 700 kg/m^3 density

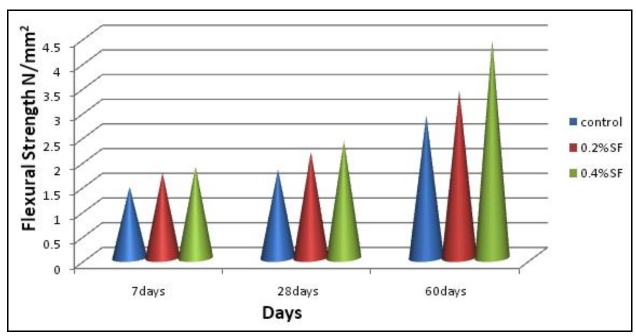


Figure 8 The comparison of flexural strength of control sample with steel fibre reinforced foamed concrete of 1200 kg/m^3 density

Based on the flexural test conducted, the flexural strength increases on the higher addition fraction of steel fibre and higher of density lightweight foamed concrete. This may be caused by several factors which influence the flexural strength. Basically, the behaviors of ratio steel fibres are subjected to some kind of bending load and practical application under flexural. Moreover, the specimen with the addition of steel fibre did not cracks into two parts and holds the partner together because of the used of steel fibre and the type of shape of steel fibre. The shape of hooked-end and used of steel fibre enable to prevent the structure from crack and allows it holding the critical part of specimen together to giving alert timing before the specimen cracks into two parts. Nevertheless, the beginning cracks on the flexural specimen were not visible until the maximum load was reached due to addition of steel fibre consisted of progressive & bonding of steel fibre [17].

5.0 CONCLUSION

The behavior of steel fibre at volume fraction 0.2% and 0.4% on lightweight foamed concrete (LFC) with target density of 700 and 1200 kg/m^3 were investigated experimentally. Then, the effect of mechanical and thermal on the properties of LFC containing steel fibre were investigated. The following conclusions are drawn from this study:

1. The compressive strength of lightweight foamed concrete increase effect by volume fraction of steel fibre due the steel fibre matrix bond mechanism and amount percentage of steel fibre introduce into the lightweight foamed concrete where the steel fibres plays a vital role in compressive strength.
2. The splitting tensile strength was increasing day by days on ages of 7, 28 and 60 days especially in lightweight foamed concrete with additive of steel fibre. It was because, the steel fibre usually crimped and deformed with either a hook at each fibre end in order to improve the bond between fibre and concrete matrix. Then, steel fibre would be able to carry significantly stresses with relatively large strain in the post-cracking stage.
3. The higher flexural strength was on the higher addition fraction of steel fibre due to the behaviors of ratio steel fibres are subjected to some kind of bending load and practical application under flexural. The beginning cracks on the flexural specimen were not visible until the maximum load was reached due to addition of steel fibre consisted of progressive & bonding of steel fibre.

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