

# The effects of volume fraction and aspect ratio of steel fiber on fracture parameters of steel fiber reinforced lightweight concretes

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**Abstract.** This study involves the experimental investigation of the effects of steel fiber volume fraction and aspect ratio on the fracture parameters of steel fiber reinforced lightweight concrete (SFLWC). Specimens were produced by adding steel fibers with aspect ratios (steel fiber length/steel fiber diameter) of 55, 65 and 80 at fiber contents of 0, 15 kg/m<sup>3</sup>, 30 kg/m<sup>3</sup>, 45 kg/m<sup>3</sup> and 60 kg/m<sup>3</sup> to lightweight concrete produced using pumice aggregate. The reference lightweight concrete strength class was taken as LC25/28. Compressive, splitting tensile and flexural tensile tests were performed on specimens. Load-crack mouth opening displacement (CMOD) curves, fracture energies, characteristic lengths and fracture toughness were also determined by flexural tests. The stresses transferred to the steel fibers after the first crack were carried by the steel fibers, preventing sudden failure and this behavior continued until the steel fibers were pulled out from the matrix. Accordingly, the steel fibers improved the behavior of the concrete after the peak load and continued to deform under decreasing load. With increasing amount of strain, the toughness or energy absorption capacity of the semi-brittle concrete increased. Based on the test results obtained, significant increases in fracture energy, splitting and flexural tensile strengths were obtained by increasing the amount of steel fiber.

**Keywords:** concrete fracture; concrete technology, construction materials, lightweight aggregate (LWA) concrete, steel fiber reinforced concrete (SFRC)

## 1. Introduction

Lightweight concretes allow for a significant reduction in structural dead loads (Kim *et al.* 2022, Pekgöz and Tekin 2021, Lu 2023, Rustamov *et al.* 2021, Pordesari *et al.* 2021). By reducing the unit volume weight of concrete, the structure becomes lighter and the dimensions of the bearing members of foundation, slab, column and beams can be reduced. Lightweight concretes can be produced by expanding the cement paste, by using only coarse aggregates in concrete or by adding lightweight aggregates to concrete instead of normal aggregates used in concrete. The most commonly used method in the production of load-bearing lightweight concrete is the substitution of lightweight aggregates for the conventional concrete aggregates present in the concrete. The main lightweight aggregates used are natural aggregates such as pumice, volcanic tuff, volcanic slag or artificial aggregates such as expanded clay, shale, perlite, fly ash and blast furnace slag.

Especially in recent years, lightweight concrete, which is a privileged type of concrete, has been used for structural purposes. Bearing lightweight concretes can also be preferred in order to reduce the cross-sections of reinforced concrete structural elements and accordingly to reduce the dead load of the structure. In addition, lightweight concretes

play an active role in increasing the usage areas and spans of high-rise buildings. In order to show that lightweight concretes can be used instead of conventional concretes, there are a large number of studies in the literature investigating the mechanical properties of lightweight concretes (Papanicolaou and Kaffetzakis 2011, Yang *et al.* 2022, Chi *et al.* 2003, Hossain 2009, Sancak *et al.* 2005, Majhi *et al.* 2021, Chien *et al.* 2014). The most obvious disadvantage of lightweight concretes is that they have lower compressive strength compared to normal concretes.

Steel fibers are used to improve the mechanical and fracture properties of concrete and reinforced concrete elements and to increase their performance. Many researchers have investigated the effects of fiber type and fiber content on the properties of concrete (Kaffetzakis and Papanicolaou 2016, Bao *et al.* 2024, Köksal 2004, Zhou *et al.* 2024, Bankir and Bikce 2024, Sahin and Koksak 2011, Eisa *et al.* 2020, Murali and Meena 2021, Su *et al.* 2023). It has been reported that the use of steel fibers in concrete significantly reduces crack formation, significantly increases the deformation capacity of concrete, especially after peak load, and causes significant increases in toughness, impact strength, fatigue and tensile strength of concrete. In addition, it is stated that it significantly improves the ductility and crack resistance of concrete, provides load carrying ability to concrete after crack formation, significantly reduces the formation and development of shrinkage cracks with bridging effect against voids and cracks in concrete. (Banthia and Trottier 1995, Koksak *et al.* 2002, Shah and Rangan 1971, Chang

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and Chai 1995, Ahmad and Zhou 2023, Zhang *et al.* 2023, Dadmand *et al.* 2020, Kontoni *et al.* 2023).

It can be said that the two most important properties of steel fibers in improving concrete properties are aspect ratio (steel fiber length/steel fiber diameter) and fiber content (the dosage of steel fiber added to concrete mix as  $\text{kg/m}^3$ ) used (Bayramov *et al.* 2004, Arslan and Aydın 1999, Taşdemir 2000, Ünal 1999). It is important that the aspect ratio should be within certain ranges because decreasing the aspect ratio decreases the strength of the steel fiber-matrix bond, and increasing the aspect ratio causes agglomeration, which causes mixing and homogeneity not to be achieved (Hartman 1999). Similarly, it was determined that when the amount of steel fiber added to the concrete increases more than necessary, the steel fiber agglomerates in the concrete and its distribution becomes less homogeneous, and even the compressive strength values are lower than normal concrete (Swamy and Mangat 1974, Swamy 1971). The use of steel fibers in excessive amounts leads to the agglomeration of steel fibers in fresh concrete, resulting in weak areas in the concrete and the formation of air voids that can adversely affect concrete properties. For this reason, the effects of steel fibers on concrete properties may remain at much lower levels than expected. In order to prevent agglomeration in the concrete mix and to obtain the desired workability value, it is useful to set an upper limit on the aspect ratio and volume of steel fibers in concrete.

The factors affecting the properties of steel fiber reinforced concrete, in addition to the factors affecting normal concrete, can be expressed as the type, shape, length, aspect ratio, amount in concrete, orientation in the matrix, tensile strength of steel fiber and its pull-out resistance from matrix (Banthia and Trottier 1995, Köksal *et al.* 2002, Balaguru *et al.* 1992, Ramakrishnan *et al.* 1989, Gao *et al.* 1997, Shah 1991, Banthia *et al.* 1994). It has been reported that steel fiber aspect ratio, steel fiber volume and orientation of steel fibers in the matrix are important in predicting the initial crack load (Balaguru *et al.* 1992, Gao *et al.* 1997). The improvements in flexural strength and ductility of steel fiber reinforced concrete (SFRC) are determined by the crack bridging effect of steel fibers and their pull-out resistance from matrix. On the other hand, previous studies have shown that the best performance of SFRC on flexural strength, flexural toughness and initial crack load is exhibited by steel fibers with hooked ends. (Balaguru *et al.* 1992, Banthia and Trottier 1995, Ramakrishnan *et al.* 1989, Banthia *et al.* 1994).

The fracture energy of concrete is one of the most important parameters used to understand the failure of concrete and to determine the design criteria for large concrete structures. Fracture energy ( $G_F$ ) is defined as the energy per unit fracture surface area and is expressed as the area under the load-displacement curve. The most widely used fracture mechanics models for analyzing concrete structures are the fictitious crack model (FCM) proposed by Hillerborg *et al.* (Hillerborg *et al.* 1976, Hillerborg 1983, 1985). RILEM (RILEM 1985, 1990) and Petersson (1980) proposed a method for the determination of  $G_F$  by simple three-point bending tests.

In order to interpret stress-strain and load-deflection curves of concrete correctly, concepts such as ductility and energy absorption capacity should be known. It is desirable for a concrete member to exhibit a ductile behavior and consume high energy under the load to which it is subjected, because the damping of earthquake loads by the member is vital for surviving the earthquake without loss of life (Zahn *et al.* 1989).

In this study, compressive, splitting and flexural strengths as well as fracture parameters such as characteristic length and fracture toughness of concretes produced by using three different steel fibers with aspect ratios of 55, 65 and 80 at ratios of 0, 15  $\text{kg/m}^3$ , 30  $\text{kg/m}^3$ , 45  $\text{kg/m}^3$  and 60  $\text{kg/m}^3$  were investigated.

## 2. Experimental study

### 2.1 Materials

CEM I 42.5 R type Portland Cement was used in the study. The density of the cement used is  $3.15 \text{ g/cm}^3$ . Drinkable water was used as mixing water. Limestone based crushed sand with a diameter of 0-4 mm and pumice aggregates with diameters of 0-4 mm, 4-8 mm and 8-16 mm were used as aggregates. Locally available limestone and pumice aggregates were chosen in the experiment. Both limestone and pumice aggregates are mostly used in production of normal and lightweight concrete in Turkey. The physical properties of the aggregates used are given in Table 1.

In addition, silica fume with a density of  $2.38 \text{ g/cm}^3$  was used in the mixtures. A high range water reducer chemical admixture was used to keep the workability of the concretes constant. Three types of steel fibers with both ends hooked were used in the study. The properties of the steel fibers used are given in Table 2 and their photos are given in Fig. 1.

Steel fibers with aspect ratios of 55, 65 and 80 were added to the lightweight concrete mixtures in the amounts ( $V_f$ ) of 0, 15  $\text{kg/m}^3$ , 30  $\text{kg/m}^3$ , 45  $\text{kg/m}^3$  and 60  $\text{kg/m}^3$ . Water/binder ratio was kept constant as 0.38 in all steel

Table 1 Properties of aggregates

Aggregate type	Size (mm)	Specific gravity ( $\text{g/cm}^3$ )	Water absorption (%)
Pumice	0-4	1.35	29
	4-8	1.25	35
	8-16	1.15	43
Crushed sand	0-4	2.62	1.63

Table 2 Properties of the steel fibers

Steel fiber	Length, l (mm)	Diameter, d (mm)	Aspect ratio (l/d)	Density ( $\text{g/cm}^3$ )
55/30	30	0.55	55	7.85
65/60	60	0.90	65	7.85
80/60	60	0.75	80	7.85

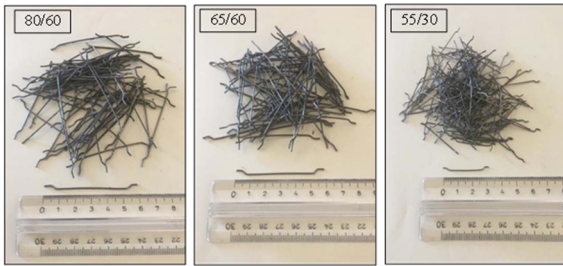


Fig. 1 Steel fibers used



Fig. 2 Flexural test setup

Table 3 Mix proportions of concretes (kg/m<sup>3</sup>)

Steel fiber content	Cement	Water	Silica fume	Crushed sand	0-4 mm pumice	4-8 mm pumice	8-16 mm pumice	Chemical admixture
0	427	181	47.5	693	218	176	160	7.1
15	426	181	47.4	691	217	176	160	7.1
30	426	180	47.3	690	217	176	160	7.1
45	425	180	47.2	688	217	175	159	7.1
60	424	179	47.1	687	216	175	159	7.1

fiber reinforced lightweight concrete mixtures. The mix proportions of the produced concretes are given in Table 3.

## 2.2 Production of Specimens

For the tests, 13 series of concrete specimens were produced together with reference. Six standard cylinder specimens (diameter = 150 mm, height = 300 mm) were produced for the compressive and splitting tensile strength tests of each series. Three prismatic beams with dimensions of 150 × 150 × 600 mm<sup>3</sup> for each series were produced for flexural tensile test. The coding of the concrete series was based on the steel fiber aspect ratio and the amount used. For example, a concrete with the coding S80V15 represents the sample obtained by adding 15 kg/m<sup>3</sup> of steel fiber with an aspect ratio of 80.

## 2.3 Tests

Slump test to determine the workability of fresh concrete in accordance with EN 12350-2 (2019) standard and unit weight test in accordance with EN 12390-7 (2019) standard were performed. Compressive strength and splitting tensile strength tests was made according to EN 12390-3 (2009) and EN 12390-6 (2009) respectively. Flexural tests on notched beam specimens were carried out in accordance with EN 14651 (2005) standard in a servo-controlled loading frame with a capacity of 20 tones with a loading rate of 0.1 mm/min. The flexural test was continued until the midpoint deflection and crack opening displacement (CMOD) of the notch reached 4 mm and load-CMOD curves were simultaneously obtained during test.

The flexural test setup is given in Fig. 2. In all experiments, the results were determined by averaging the test results obtained from 3 specimens. The flexural strengths ( $f_{fl}$ ) of the concretes were calculated according to Eq. (1) using the maximum load obtained from the 3-point

(centrally loaded beam) flexural test on notched beam specimens.

$$f_{fl} = \frac{3PS}{2B(D-a)^2} \quad (1)$$

where P, S, B, D and a are the maximum load, distance between supports, width of the specimen, height of the specimen and notch length, respectively.

Load-CMOD curves obtained from the flexural test were used to determine the fracture energies of the specimens. Fracture energy ( $G_F$ ) was calculated using the following equation proposed by RILEM TC 50-FMC (1985)

$$G_F = \frac{w_0 + m(1-k^2)g\delta}{B(D-a)} \quad (2)$$

where,  $w_0$  is the area under the load-CMOD (taken as the area under the load-CMOD curve up to 4 mm in this study), m is the mass of the specimen, g is the acceleration of gravity (9.81 m/s<sup>2</sup>),  $\delta$  is the CMOD (4 mm), B is the specimen width, D is the specimen depth, a is the notch depth, k is a coefficient depending on the specimen dimensions  $k = (\square/S)-1$ ,  $\square$  is the length of the specimen and S is the distance between the supports.

The nominal strength of the characteristic length ( $l_{ch}$ ) is taken into account in concrete mix design as it controls the fracture mode and crack growth (crack modelling) (Lange-Kornbag and Karihaloo 1998).  $l_{ch}$  is included in the concrete mix design criteria and calculated as in Eq. (3) using parameters such as fracture energy ( $G_F$ ), modulus of elasticity (E) and uniaxial tensile strength  $f_t'$ . In this study  $f_{st}$  (splitting tensile strength) was used instead of uniaxial tensile strength.

$$l_{ch} = \frac{G_F \cdot E}{f_t'^2} \quad (3)$$

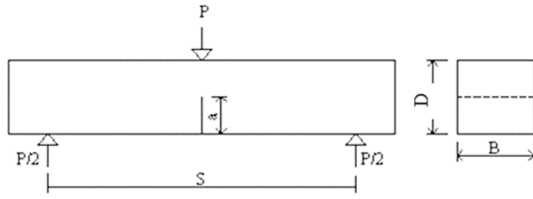


Fig. 3 Three-point bending test for the calculation of fracture toughness

Linear elastic fracture mechanics (LEFM) can be applied to brittle materials such as hardened cement paste. Only one material parameter, fracture toughness ( $K_{IC}$ ), is sufficient to describe crack propagation and fracture in brittle materials (Akkaya *et al.* 2003).

In LEFM, fracture toughness for brittle materials can be successfully calculated with specimens of various geometries. The most commonly used method for determining fracture toughness is three-point or four-point bending tests applied to pre-notched beam specimens. The advantage of using notched beam specimens in three-point bending tests is that the production is economical and the test process is easier than other methods. In the three-point bending test (Fig. 3), the specimen is gradually loaded until the notch begins to open and the maximum load ( $P_{max}$ ) is calculated to find the bending moment at the center of the span.

The fracture toughness  $K_{IC}$  was calculated as in Eq. (4) as suggested by RILEM TC89- FMT (1990) and Srawley (1976)

$$K_{IC} = 3(P_{max} + 0.5mg) \frac{S\sqrt{\pi} \cdot a \cdot f(\alpha)}{2d^2b} \quad (4)$$

where,  $P_{max}$  is the maximum load,  $S$  is the span length,  $mg$  is the notched beam specimen weight,  $a$ ,  $d$  and  $b$  are the notch depth, thickness and width of the prism specimen, respectively. Given  $\alpha = a/d$ ,  $f(\alpha)$  is obtained from the following equation (Mindess *et al.* 1977)

$$f(\alpha) = \frac{1.99 - \alpha \cdot (1 - \alpha)(2.15 - 3.92 \cdot \alpha + 2.7\alpha^2)}{\sqrt{\pi} \cdot (1 + 2\alpha)(1 - \alpha)^{\frac{3}{2}}} \quad (5)$$

### 3. Test results

Slump and dry unit weight test results are given in Table 4. Steel fibers negatively affected the workability because they limited the mobility of the concrete. As the amount of steel fiber increased, slump values decreased. It was observed that steel aspect ratio had no effect on workability. Due to the higher unit weight of steel fibers compared to other concrete components, it was observed that the dry unit weight values slightly increased as the amount of steel fiber increased and the dry unit weight values of all samples were below  $2000 \text{ kg/m}^3$ . The lowest dry unit weight value was obtained as  $1914 \text{ kg/m}^3$  in reference specimens (without steel fiber), while the highest dry unit weight value was obtained as  $1992 \text{ kg/m}^3$  in concretes with 80 aspect ratio and  $60 \text{ kg/m}^3$  fiber content. It can be stated that steel fiber

Table 4 Slump and dry unit weight test results

Aspect ratio, $l/d$	Mixture code	Fiber content $V_f$ , $\text{kg/m}^3$	Slump, cm	Dry unit weight, $\text{kg/m}^3$
-	REF	0	10.0	1914
55	S55V15	15	9.5	1924
	S55V30	30	9.0	1948
	S55V45	45	8.5	1967
	S55V60	60	7.5	1978
65	S65V15	15	9.5	1920
	S65V30	30	8.5	1942
	S65V45	45	7.5	1962
	S65V60	60	7.0	1974
80	S80V15	15	9.5	1936
	S80V30	30	8.5	1972
	S80V45	45	7.5	1984
	S80V60	60	6.5	1992

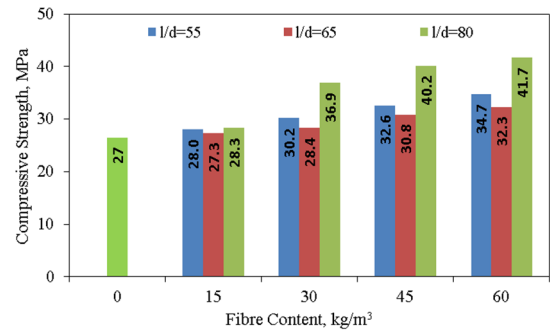


Fig. 4 The relations of compressive strengths with fiber content and aspect ratio

aspect ratio has no significant effect on dry unit weight.

The changes of the compressive strength test results depending on the steel fiber content are given in Fig. 4. With the increase in the amount of steel fiber, compressive strength values increased in all aspect ratios. In previous studies, it is stated that the addition of steel fiber causes increases in compressive strength (Azmat and Khan 2018, Balaguru and Shah 1992, Dawood and Ramli 2010). Although the addition of steel fiber was small compared to the increases in flexural and tensile strengths, it was determined that the addition of steel fiber had an improving effect on the compressive strength of the concretes and the largest increases were observed in the specimens with  $60 \text{ kg/m}^3$  fiber content at 80 aspect ratio in terms of its contribution to the compressive strength. The highest increase in compressive strength compared to the reference specimen was obtained as  $41.7 \text{ MPa}$  with  $57.4\%$  in concretes with 80 aspect ratio and  $60 \text{ kg/m}^3$  fiber content.

The variations of the modulus of elasticity results depending on the steel fiber content for each aspect ratio are given in Fig. 5. Modulus of elasticity increased slightly with the increase in steel fiber content. The highest increase in the modulus of elasticity compared to the reference

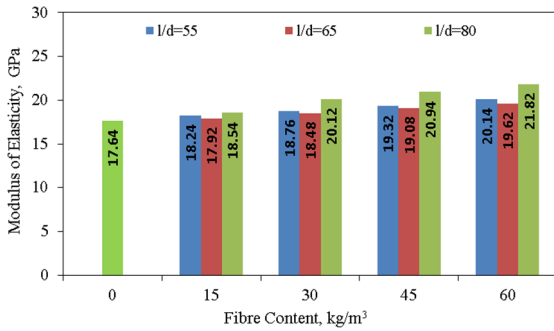


Fig. 5 Variation of modulus of elasticity with fiber content and aspect ratio

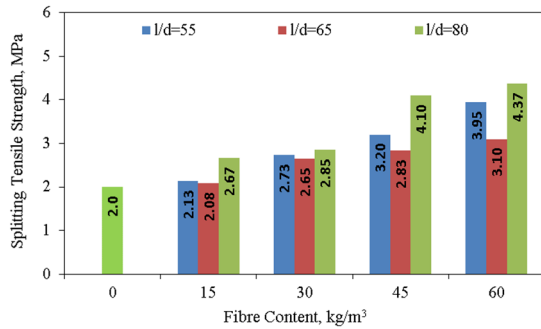


Fig. 6 Relations of splitting tensile strengths with fiber content and aspect ratio

specimen was 23.7% for specimens with aspect ratio of 80 and 60 kg/m<sup>3</sup> fiber content. In previous studies, it has been reported that the addition of steel fiber to concrete increases the modulus of elasticity of concretes very slightly (Yıldırım 1994, Taylor *et al.* 1997).

The addition of steel fiber is known to increase the splitting tensile strength of concrete, although to a lesser extent compared to the direct tensile and flexural strengths. The most important factors affecting the splitting tensile strength of SFRCs are steel fiber content, aspect ratio and steel fiber-matrix properties (Köksal *et al.* 2002, Gao *et al.* 1997, Yıldırım 1994, Taylor *et al.* 1997, Lim and Oh 1999). The variations of the splitting tensile strengths depending on the steel fiber content and aspect ratio are given in Fig. 6. As a result, it was observed that the addition of steel fiber has an improving effect on the splitting tensile strength of concretes and increases in splitting tensile strength were obtained with the increase in the amount of steel fiber used. In terms of contribution to the splitting tensile strength, the specimens with 60 kg/m<sup>3</sup> fiber content at 80 aspect ratio showed the largest increases. The highest increase in splitting tensile strength compared to the reference specimen was obtained as 4.37 MPa with 118.5% in concretes with 80 aspect ratio and 60 kg/m<sup>3</sup> fiber content.

Toughness or energy absorption capacity is the most distinctive property that distinguishes steel fiber reinforced concrete from concrete without steel fiber. The energy absorption capacities of steel fiber reinforced concretes, under bending, can be obtained from load-deflection curves and load-CMOD curves. The load-CMOD curves of the specimens are given in Figs. 7-9 for 55, 65 and 80 aspect

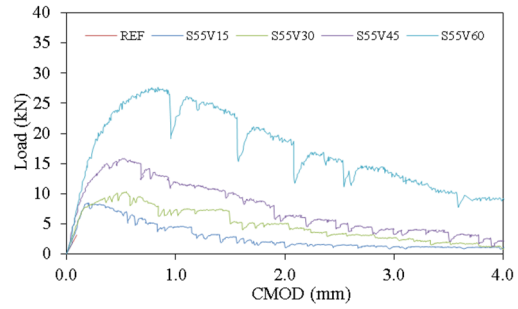


Fig. 7 Load-CMOD curves for the steel fiber aspect ratio of 55

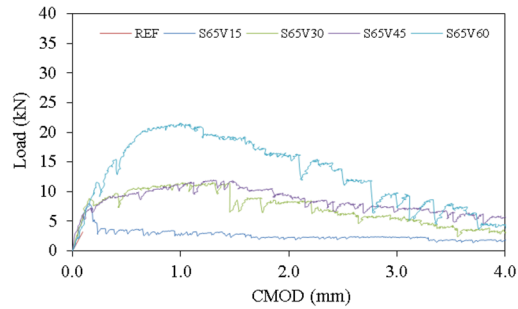


Fig. 8 Load-CMOD curves for the steel fiber aspect ratio of 65

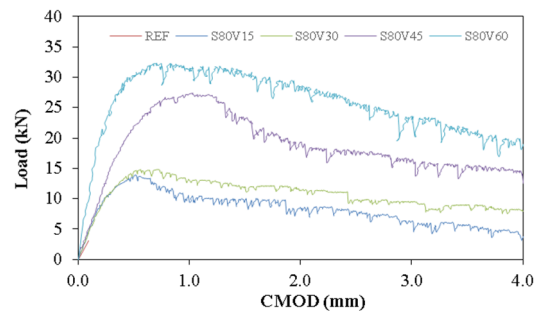


Fig. 9 Load-CMOD curves for the steel fiber aspect ratio of 80

ratios, respectively.

The energy absorption capacities of steel fiber reinforced concretes are largely dependent on the position of the crack, the type and volume of steel fiber, its orientation in the matrix and the resistance of the fiber to pull out from the matrix (Taylor *et al.* 1997, Moyson *et al.* 1994, Balendran and Zhou 2002). The flexural tensile strength, fracture energy, characteristic length and fracture toughness of the tested SFLWCs are given in Table 5.

Steel fibers randomly distributed in the concrete exhibit a behavior that delays crack formation and prevents crack propagation with a bridging effect by carrying the stresses transferred by the matrix after the first crack formation. In this way, steel fibers ensure that the concrete continues to carry the load after the peak load and increases the deformation, causing the concrete to exhibit a more ductile behavior. The variations of flexural strength ( $f_f$ ) depending on the steel fiber content and aspect ratio are given in Fig. 10.

Table 5 The results of flexural tensile strength, fracture energy, characteristic lengths and fracture toughness

Aspect ratio, l/d	Mixture code	Fiber content, kg/m <sup>3</sup>	Flexural tensile strength, MPa	Fracture energy, Joule	Characteristic length, mm	Fracture toughness, MPa. m <sup>1/2</sup>
-	REF	0	1.01	65	287	0.20
55	S55V15	15	2.70	721	2888	0.54
	S55V30	30	3.23	1217	3055	0.71
	S55V45	45	4.11	1652	3116	0.90
	S55V60	60	4.36	2549	3290	1.20
65	S65V15	15	2.73	1003	4141	0.53
	S65V30	30	2.92	1775	4671	0.70
	S65V45	45	3.06	2089	4964	0.86
	S65V60	60	3.24	2653	5417	1.12
80	S80V15	15	3.24	1732	4505	0.77
	S80V30	30	3.34	2081	5154	0.86
	S80V45	45	5.70	4368	5441	1.70
	S80V60	60	6.24	4849	5549	1.73

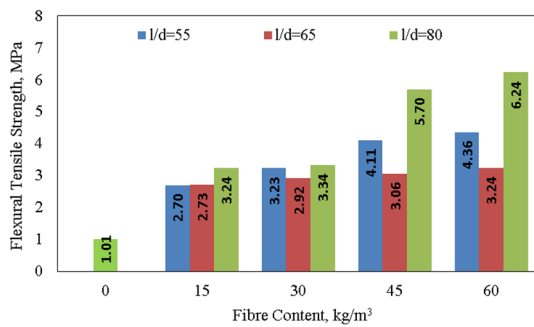


Fig. 10 Flexural tensile strength test results

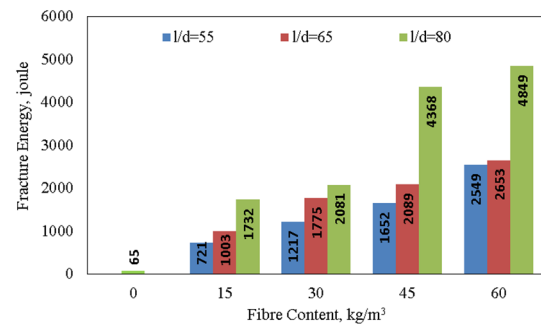


Fig. 11 Changes of fracture energy depending on aspect ratio and fiber content

It was observed that the flexural strength increased with increasing steel fiber content. The highest increases in flexural strength were observed for concrete specimens with 80 aspect ratios for each fiber content. The highest increase in flexural strength compared to the reference specimen was obtained as 6.24 MPa for concrete with 80 aspect ratio and 60 kg/m<sup>3</sup> fiber content with a 518% increase.

The changes on the fracture energy, calculated from the load-CMOD curves, depending on the steel fiber content are given in Fig. 11. It was observed that the fracture energies increased significantly with increasing steel fiber content. The highest increases in fracture energies were observed for specimens with steel fibers aspect ratio of 80. The highest increase in fracture energy compared to the reference specimen was observed in concretes with an aspect ratio of 80 and a fiber content of 60 kg/m<sup>3</sup>. The maximum fracture energy value was 4849 joules, 73.6 times that of the reference specimen.

Characteristic length is given as a measure of ductility (Bayramov *et al.* 2005). A larger characteristic length indicates a more ductile behavior. The variation of the characteristic lengths of the SFLWCs calculated based on the experimentally obtained fracture energy, modulus of

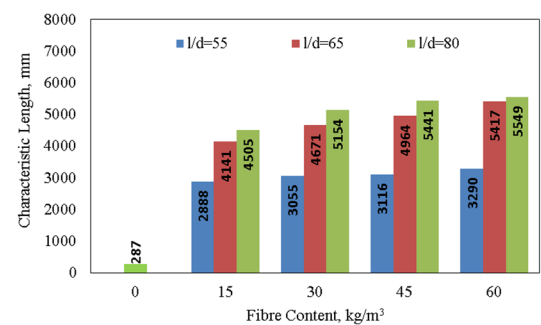


Fig. 12 Characteristic length results

elasticity and tensile strength at splitting with the steel fiber aspect ratio and steel fiber content is shown in Fig. 12. Significant increases in characteristic lengths were observed with increasing steel fiber content and aspect ratio. For all aspect ratios, increases in characteristic lengths were obtained with increasing steel fiber content. The maximum characteristic lengths value was 5549 mm, 19.3 times that of the reference specimen.

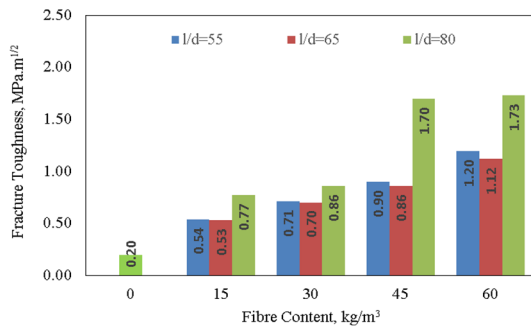


Fig. 13 Fracture toughness

The variations of fracture toughness ( $K_{IC}$ ) of SFLWCs depending on the steel fiber content and aspect ratio are given in Fig. 13. It was observed that fracture toughness increased with increasing steel fiber content for each aspect ratio. The highest fracture toughness was obtained as 1.73 MPa.m<sup>1/2</sup>, which was 8.65 times that of the reference specimen.

#### 4. Conclusions

The general results experimentally obtained are given as follows:

- Steel fibers had a positive effect on the compressive strength of concretes. Increases in compressive strengths were obtained depending on the steel fiber content. Compared to the reference specimens without steel fibers, the highest increase in the compressive strength of concrete was determined as 57.4% in concretes with 80 aspect ratio and 60 kg/m<sup>3</sup> fiber content.
- Significant increases in the splitting tensile strength of the concretes were obtained with increasing steel fiber content. The steel fibers prevented the lateral deformations of the SFLWCs under tensile load in splitting, resulting in an increase in the splitting tensile strengths. The maximum increase in splitting tensile strength was 118.5% in concretes with 80 aspect ratio and 60 kg/m<sup>3</sup> fiber content compared to the reference specimens.
- Flexural strengths, fracture energies, characteristic length values and fracture toughness of the SFLWCs were increased by increasing steel fiber content for each fiber aspect ratio. For all those parameters, the highest enhancements in SFLWCs were determined with an aspect ratio of 80 and containing 60 kg/m<sup>3</sup> fiber. The increase percentages in flexural strengths compared to the reference specimens varied between 167%-518%. Compared to the reference specimens, the fracture energies increased between 10-73.6 times. Similarly, the increases in characteristic length values compared to the reference samples ranged from 9.1 to 18.3 times. The increase rates in fracture toughness compared to the reference specimens ranged between 165%-765%.

In general, steel fibers greatly improved the energy absorption capacity and ductility of SFLWCs by preventing the opening of matrix cracks with bridging effect after the initial crack load. Steel fiber content was more effective in these improvements compared to steel fiber aspect ratio. The best performance on the mechanical strength and fracture parameters of the specimens was shown by the specimens containing steel fibers with an aspect ratio of 80 for each fiber content.

In this study, it was observed that the use of steel fiber had a positive effect on all investigated mechanical properties of lightweight concrete. Considering that the addition of steel fiber content in the amounts of 15 kg/m<sup>3</sup> and 30 kg/m<sup>3</sup> significantly improved the mechanical properties of lightweight concrete, it can be said that the addition of steel fiber in the range of 15 kg/m<sup>3</sup>-30 kg/m<sup>3</sup> to lightweight concrete is appropriate in terms of usability and economy.

It is concluded that the design of structural lightweight concrete mix with steel fiber reinforcement should be optimized to determine the most suitable fiber content and aspect ratio in terms of performance and economics by considering the fracture parameters. However, it can be stated that the use of steel fiber is of great importance in terms of increasing the ductility and energy absorption capacity of the structural members of earthquake resistant lightweight reinforced concrete structures.

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