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Mechanical and fresh properties of fiber reinforced self-compacting lightweight concrete

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Abstract. In this study, the workability and mechanical properties of Fiber Reinforced Self-Compacting Lightweight Concrete (FRSCLC) were investigated. Concrete samples were produced with steel fiber to which low and high carbon were added. The fluidity of FRSCLC was conducted with two categories of flow ability; the property and viscosity of fresh concrete. The mechanical performance of the concrete mixes was determined with short and long-term tests, which include compressive and flexural strength at 3, 7, 28 and 365 days. The test results showed that adding fibers to self-compacting lightweight concrete mixtures decreases workability. On the other hand, compressive strength was less enhanced, compared to the results of flexural strength. As a result, the compressive and flexure strength of SCLWC's increased up to 30% and 43%, by adding fiber at 28 days, respectively.

1. Introduction

Concrete is the most abundant composite material used in the construction industry. Plenty of research is available regarding the properties of concrete. Self-Compacting Concrete (SCC), first developed in Japan in 1990, is a significant development in the concrete industry. SCC should supply two objectives. One is filling its formwork by its own weight and another is compaction without any device. SCC needs excess cure, due to a low water/binder ratio, high amounts of powder and high material costs. In general, these concretes have high strength and high impermeability. Penetration of cure water to the inner part of the concrete becomes difficult, due to high impermeability. Although these concretes have high performance levels, there are many disadvantages such as: It is difficult to infiltrate cure water to the inner part of the specimen due to high impermeability; it always gives more strength than target strength; and it is brittle. Self-compacting lightweight concrete or using lightweight aggregate in self-compacting concrete eliminates these disadvantages [1].

Earthquake forces acting on the building is proportional to a structure's dead weight. If Lightweight Concrete (LWC) is used in the building, a certain decrease in earthquake force is seen compared to the prior weight of the building. The seismic period of a weighted building has a long seismic frequency. Considering the disadvantages of either LWC in buildings or LW aggregate used in concrete, it certainly decreases the total weight of the building. As a result, less load transfers to the foundation. During the earthquake, the building made of lightweight material is less damaged, due to lesser inertial force [2,3]. The basic rule in producing LWC is to create porosity by different methods. One method is to use porous aggregate in the mix design. Usually, the production of concrete is named according to its aggregate type [4,5]. As a result, the concrete produced when the unit weight is below

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2000 kg/m^3 is called LWC, according to TS EN 206-1 [6].

Using fibers is one of the most effective methods to enhance the performance of concrete, such as bending, tension, ductility, energy absorption, cavitation resistivity and crack propagation. Corinaldesi [7] mentioned that fiber addition proved to be very effective in counteracting the drying shrinkage of self-compacting concrete; usually a great problem for this material, which is rich in powders and poor in the fraction of coarse aggregate. Different types of fiber can be used for this purpose, such as glass, polypropylene, carbon and steel. The process of enhancing tensile strength and toughness, while using short and long fibers together in a concrete mix can be explained as follows: As micro fibers prevent micro crack propagation, tensile strength increases, and when the cracks reach macro levels, long fibers help the fiber reinforced concrete to behave with more ductility [8]. An experimental study showed that there is no effect on compressive strength and Young's modulus by adding fiber to LWC [9]. On the other hand, it develops the toughness of the concrete. Kayali [10] showed that polypropylene fiber additive has no effect on the mechanical properties of fiber reinforced high performance lightweight concrete. However, steel fibers enhance flexural strength by 118%. Daneti [11] studied macro and micro fibers as mono and hybrid. This study underlines a small decrease in compressive strength, but, on the other hand, these fibers enhance the segregation resistivity and tensile strength. On the basis of their experiments, Gao [12] alleges that fiber reinforcing enhances compressive strength. Bozkurt [13] claimed that macro fibers decreased compressive strength when used in self-compacting concrete, while micro fibers enhanced compressive strength [13].

There are many studies related to fiber reinforced concrete, but few studies are available regarding fiber reinforced self-compacting lightweight concrete. In this article, mono and hybrid fibers were used in the mix design and many mechanical characteristics were examined, like compressive strength and bending capacity.

2. Materials and method

2.1. Materials

Portland cement, CEM I 42.5, according to EN197/1 [14], was used for all concrete mixtures. The chemical composition of the cement used is given in Table 1. The specific gravity of the cement used was 3.10 g/cm^3, and the Blaine-specific surface area of the cement was 3370 cm^2/g.

In this study, Fly Ash (FA) was used as powder. The Fly Ash (FA) used was obtained from the electricity-generating Kangal Thermal Power Station in the Center of Turkey, and its chemical composition is given in Table 1. Its specific gravity was 2.30 g/cm^3 and the Blaine-specific surface area was 2340 cm^2/g. The remaining FA on the 45μ sieve was 14%. It is a class C fly ash, since it is obtained by burning lignite coal.

Table 1. Chemical composition of cement and fly ash used in mixture.

Chemical composition (%)	Portland cement	Fly ash
SiO_2	21.12	38.34
Al_2O_3	5.62	16.69
Fe_2O_3	3.24	5.11
CaO	62.94	27.62
MgO	2.73	1.60
SO_3	2.30	4.44
Na_2O	-	-
K_2O	-	-
Cl	-	-
LOI*	1.78	0.79
Insoluble residue	0.27	5.41
Physical properties		
Specific gravity (g/cm^3)	3.10	2.3
Blaine fineness (cm^2/g)	3370	2343

* Loss of ignition.

Basaltic pumice crushed stone was used as an aggregate to produce the lightweight concrete. Aggregates were obtained from Elazig province, Yenikoy local. The loose unit weight of the coarse and fine aggregates is 789 kg/m^3 and 836 kg/m^3, respectively, and the specific gravity of the pumice aggregate is 2.07 g/cm^3. The water absorption capacity is 17.7% for coarse aggregate, and 8.3% for fine aggregate. Aggregates were classified into two groups: 0-4 mm and 4-16 mm. Furthermore, two types of fiber were used in the mix, which has both high and low carbon content (see Figure 1). The properties of the fibers are tabulated in Table 2.

Table 2. Properties of fibers.

	OL6/0.16 (High carbon content)	RC 65/35 BN (Low carbon content)
Length (mm)	6	35
Diameter (mm)	0.15	0.55
Density (kg/dm^3)	7.17	7.85
Tensile strength (MPa)	2000	1150

Figure 1. Fibers: (a) High carbon fiber; and (b) low carbon steel fiber.

Table 3. Mixture proportions.

Mixture	M1	M2	M3	M4	M5	M6	M7	M8
Cement (kg/m^3)	440	440	440	440	440	440	440	440
Water (kg/m^3)	170	170	170	170	170	170	170	170
Fly ash (kg/m^3)	110	110	110	110	110	110	110	110
Fine pumice (kg/m^3)	557	550	554	550	554	550	550	550
Coarse pumice (kg/m^3)	528	521	523	521	523	521	521	521
SP (kg/m^3)	6	6	6	6	6	6	6	6
OL6/0.16 (kg/m^3)	-	-	-	50	25	25	37.5	12.5
RC 65/35 BN (kg/m^3)	-	50	25	-	-	25	12.5	37.5

2.2. Mix proportions
A forced pan mixer capacity of up to 56 dm^3 was used throughout the mixing process. The mixing procedure was as follows: Cement, fly ash and aggregate was added first and mixed for 1 minute; nine-tenths of the mix water was added and mixed for 10 minutes, then, the rest of the water and super plasticizers were mixed. The mixtures without fibers were mixed for a further 30 s. In cases of fiber addition, the further mixing time at this stage was 90 s. This extended mixing time was required to dissolve the glue of the fiber bundles. Details of the tests and dimensions of the specimens are given in Table 3. All specimens were demoulded after 24 h, and the samples were cured in a water tank saturated with lime at 20 ± 2°C. The mixture design is made according to the absolute volume method. Cement, fly ash, water and super plasticizer were kept constant as 440, 110, 170 and 6 kg/m^3, respectively. A novel poly carboxylic ether type Super Plasticizer (SP), produced by a local manufacturer, was used in all concrete mixtures.

2.3. Test on fresh concrete
The testing apparatus for slump flow is consisted of a standard slump cone and a steel plate, with dimensions of 900-900 mm. Slump flow time, spreading up to 500 mm in diameter (T500), for FRSCLWC and SCLWC, were measured by this apparatus, according to the European Federation of National Associations Representing producers and applicators of specialist building products for Concrete (EFNARC) [15]. A V-funnel flow test evaluated the viscosity of FRSCLWC and SCLWC, and V-funnel measurements were carried out according to EFNARC [15].

2.4. Test on hardened concrete
Ultrasonic pulse velocity and compressive and flexural strength were carried out to harden the concrete specimens at the end of the typical cure process. For each mixture, cubic specimens were loaded under compressive load to failure (ultimate load) at 3, 7, 28 and 365 days. Compressive and flexural strength was computed from the average of three cubes of 150 mm and three prismatic $10 \times 10 \times 150$ mm specimens. The Ultrasonic Pulse Velocities (UPV) of all six cube specimens were measured on the two smooth sides of the specimen at 3, 7 and 28 days. The UPV test was conducted with a direct transducer arrangement, using a pair of narrow band 54 kHz transducers with a commercially available PUNDIT system.

3. Results and discussion

3.1. Properties of fresh concrete
Limit values proposed by EFNARC [15] and many of the tests carried out on fresh concrete were tabulated in Tables 4 and 5. In this study, the slump test proved that fresh concrete has the ability to expand by self-weight. Test results showed that the expanded fresh concrete diameter varied between 610-705 mm after the slump test. T500 varied between 1.2 and 2.7 sec, while the V funnel was between 9 and 22 sec.

Table 4. Test results of fresh concrete.

	M1	M2	M3	M4	M5	M6	M7	M8
Slump flow (mm)	700	610	640	640	650	705	680	630
V funnel (s)	9	22	10	11	11	13	15	16
T500 (s)	1.5	2.7	2.0	2.0	1.9	1.3	1.2	1.5
Fresh unit weight (kg/dm^3)	1.90	1.90	1.90	1.90	1.91	1.92	1.93	1.92

Table 5. Limit values proposed by EFNARC [10] for fresh concrete.

Method	Class	Limit values
Slump-expansion (mm)	SF1	550 - 650
	SF2	660 - 750
	SF3	760 - 850
V-funnel time (s)	VF1	≤ 8
	VF2	9 to 25
T500 (s)	VS1	≤ 2
	VS2	> 2

It was seen that T500 and V funnel time were stable around limited values, although the RC 65/35 type fiber amount increased. On the other hand, no effect was recognized when adding excess OL 6/16 type fiber, as demonstrated in Table 4. This result could be explained by the geometry of the fiber. Similar results were obtained by Sahmaran and Yaman [16].

By measurement, it was shown that the unit weight of fresh FRSCLC changes between 1900 kg/m^3 to 1930 kg/m^3. According to results obtained from the weighing, there was no considerable increase in the unit weight of FRSCLC while adding fibers.

3.2. Properties of hardened concrete

Compressive strength test results of the whole concrete specimen are illustrated in Figure 2 at the ages of 3, 7, 28 and 365 days. The compressive strength of the concrete was varied between 30.4 MPa and 39.3 MPa at the age of 28 days. It was seen that minimum compressive strength results were obtained for the control specimens, whereas maximum values

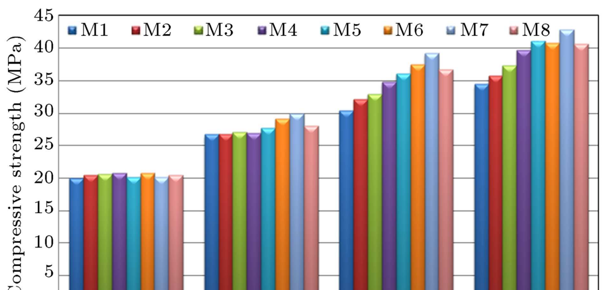

Figure 2. Compressive strength test results of self-compacting light weight concrete reinforced with fiber (SCLWCF).

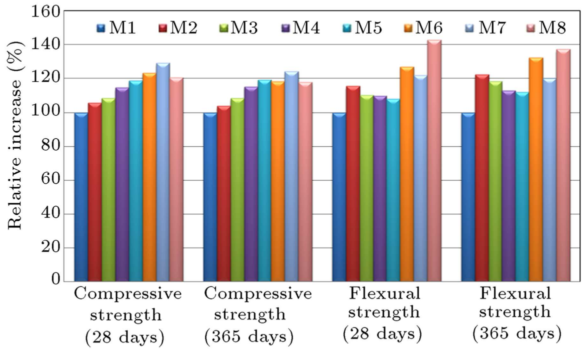

Figure 3. Compressive and flexural strength change of SCLWCF.

were obtained from the hybrid specimens. Compressive strength differences of specimens increased gradually parallel to further ages. The fiber effect on compressive strength test results at 28 days and 365 days can be seen clearly in Figure 3. In general, the fiber reinforcement of concrete developed the compressive strength property. It showed that the compressive strength increase of FRSCLC reached 29%, as seen in Figure 3. Compressive strength test results indicated that 50 kg of fiber in the mix (M2 and M4) decreased the compressive strength, compared with 25 kg of fiber (M3 and M5) in the mix design. Lightweight concrete with various types of fiber has been researched in previous studies. The highest increase in compressive strength for lightweight concrete with steel fiber was reported by Libre [17]. He reported that adding 0.5% volume of steel fiber ($L = 35$ mm and $D = 0.55$ mm) to natural pumice increased compressive strength up to 47%, while, with the addition of 1%, the compressive strength only increased up to 44%. For a steel fiber volume fraction more than 0.5%, the effect of steel fiber on compressive strength seems insignificant and rather inconsistent. Furthermore, there are increases up to 30%, 22%, 21%, 20% and 14% for the compressive strength of steel fiber reinforced lightweight concrete in different studies [18-22].

Hybrid specimens, M6, M7 and M8, that contain 50 kg/m^3 fiber showed higher strength, compared with single fiber reinforced concrete specimens and concrete control specimens at the age of 28 days. Akçay and Taşdemir [23] emphasized that hybrid mixes show higher compressive strength compared with others. The length of steel fiber was another parameter affecting compressive strength. This study also showed

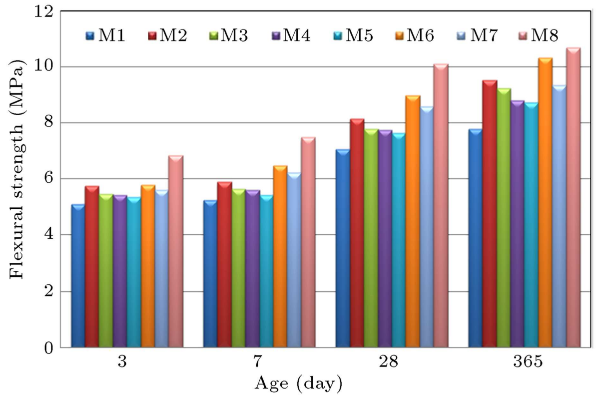

Figure 4. Flexural strength test results of FRSCLC.

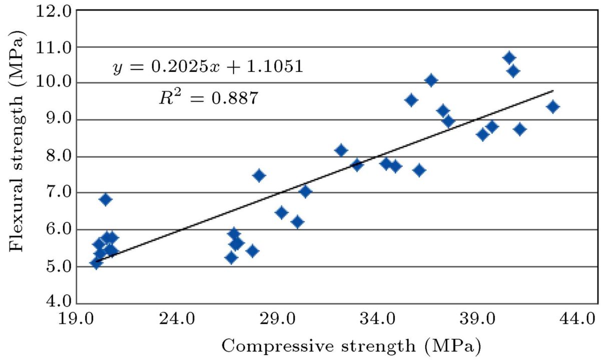

Figure 5. Relation between flexural strength and compressive strength.

that long fibers supplied more flexural strength than short fibers. Sahmaran and Yaman [16] preferred steel micro fiber to steel macro fiber for obtaining higher compressive strength, as did Nehdi and Ladanchuk [24]. Qian and Stroeven [25] emphasized that using micro fiber in the mix created considerable strength compared with macro fiber.

Flexural strength test results of specimens at the ages of 3, 7, 28 and 365 days are shown in Figure 4. Generally, the hybrid mix of concrete showed higher flexural strength. It is interesting that the M7 numbered mix contained 12.5 kg/m^3 macro fiber, but this mix showed the lowest flexural strength between the other hybrid mixes on the basis of flexural strength. The flexural strength of specimens containing 50 kg of fiber in the 1 m^3 mix was higher than specimens containing 25 kg of fiber. Test results showed that macro fibers have better flexural strength than micro fibers, in terms of fiber type. The test results showed that optimum amounts were 37.5 kg for macro fiber in a 1 m^3 mix and 12.5 kg for micro fiber in a 1 m^3 mix, to obtain the best flexural strength. These mix designs were numbered with M8 in this study. The flexural strength of the M8 group is about 43% higher than that of the control concrete, and the compressive strength of the M8 group is 21% higher than the control concrete. These values are shown in Figure 3. The flexural strength of M7 is 22% higher than the control concrete and the compressive strength of M7 is 29% higher than the control concrete.

Experiments were carried out using four types of specimen age and two types of fiber. Variance analysis and Duncan's multiple range tests were applied to the test results. The age factors on concrete compressive strength at 3, 7, 28 and 365 days showed 1% difference between each other after analyzing the data.

The Duncan tests results were given in Table 6. There is no considerable difference between the 3 and 7 day age levels of the flexural strength of the concrete, considering statistical results. However, there is 1% difference between the other ages of the specimens.

The relation between compressive strength and flexural strength is shown graphically in Figure 5, and there is a very good linear relationship between them. The correlation coefficient between compressive strength and flexural strength was determined to be 0.887 at 1% importance level, as seen in Figure 5.

4. Conclusion

In this study, self-compacting lightweight concrete was produced with basaltic pumice aggregate. Then, fiber was added to the mix to produce self-compacting lightweight concrete reinforced with fiber (FRSCLWC). Next, the workability and mechanical properties of the specimens were examined. Two types of fiber were used at different amounts, as 25 kg/m^3 and 50 kg/m^3. Both the mono and hybrid series of the specimens were produced and all specimens were provided with the criteria of self-compacting. Increasing the amount of long fibers affected the workability of the fresh concrete negatively. On the other hand, there is no effect on workability when increasing the amount of short fibers. The compressive and flexural strength of self-compacting lightweight concrete is developed by hybrid fiber reinforcement. It was possible to enhance the compressive strength of the self-compacting lightweight concrete up to 10% by adding long fibers, 20% by

Table 6. Means of compressive and flexural strength.

	3 days	7 days	28 days	365 days
Compressive strength MPa	20.44^a	27.71^b	35.01^c	39.81^d
Flexural strength	5.67^a	6.00^a	8.26^b	9.31^c

^{a,b,c,d}: Duncan's ranking. The results with the same latter are means of an insignificant statical difference.

adding short fibers and 30% by hybrid addition. The flexural strength of the self-compacting lightweight concrete was raised up to 15%, 10% and 43% with long, short and hybrid. There was not a considerable difference between the mechanical properties at early ages, but, these differences increased gradually at further ages. Moreover, there is no distinct influence of curing age on the flexural strength of concrete specimens between the ages of 3 and 7 days, considering statistical evaluation.

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Biography

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