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Araştırma Makalesi/Research Article

Experimental Study on Engineering Properties of Basalt Fiber Reinforced Lightweight Mortar

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Abstract

Basalt fiber is a new inorganic fiber type that has recently taken attention in cementitious materials reinforcing applications. In this study, the effect of the chopped basalt fiber inclusion and volume fractions on workability, mechanical properties, and capillarity of mortars were investigated. Lightweight mortars (LWM) were prepared by partial replacement of river sand with pumice aggregate as 0%, 25%, and 50% by volume. The chopped basalt fibers with a volume fraction of 0%, 0.25%, and 0.5% were utilized in LWM mixes. According to the applied tests, it was concluded that the increase of pumice aggregate content is significantly effective on obtained values, whereas, the influence of adding basalt fiber is changeable for the performed test results. Additionally, the statistical analysis of experimental results was implemented by general linear model ANOVA.

Keywords: Basalt Fiber, Lightweight Mortar, Engineering Properties

Bazalt Elyaf Takviyeli Hafif Harcın Mühendislik Özellikleri Üzerine Deneysel Çalışma

Özet

Bazalt elyaf, takviyeli çimentolu malzeme uygulamalarında son zamanlarda dikkat çeken bir inorganik elyaf türüdür. Bu çalışmada, kırpılmış bazalt lif katkısının ve hacim oranlarının harçların işlenebilirliği, mekanik özellikleri ve kapilaritesi üzerindeki etkisi araştırılmıştır. Hafif harçlar (HH), nehir kumunun hacimce %0, %25 ve %50 oranlarında pomza agregası ile kısmi olarak değiştirilmesi ile hazırlanmıştır. HH karışımlarında hacim oranı %0, %0,25 ve %0,5 olan kırpılmış bazalt lifleri kullanılmıştır. Uygulanan testlere göre, pomza agregası içeriğindeki artışın elde edilen değerler üzerinde önemli ölçüde etkili olduğu, bazalt lif ilavesinin etkisinin ise gerçekleştirilen test sonuçları için değişebilir olduğu sonucuna varılmıştır. Ayrıca, deneysel sonuçların istatistiksel analizi genel doğrusal model ANOVA ile gerçekleştirilmiştir.

Anahtar kelimeler: Bazalt Elyaf, Hafif Harç, Mühendislik Özellikleri

1. INTRODUCTION

Lightweight concrete (LWC) has some superiorities such as the lower dead load of structure [1], better thermal insulation [2-4], durability properties [5-6], and fire resistance [7-9] when compared to normal weight concrete (NWC). Therefore, LWC has been an interesting subject to be investigated with various experimental and real cases [10, 14-17]. Bouguerra et al. [18] studied the impact of microstructure on the mechanical and thermal properties of LWC that consists of cement, clay, and wood aggregates. It was found that the pore structure is substantially effective in the thermal properties of LWC. Şengül et al. [19] focused on the influence of expanded perlite replacement with natural aggregate on unit weight, compressive strength, modulus of elasticity, and thermal conductivity of LWC. The increase of expanded perlite content provided a reduction in the values obtained for all properties mentioned above. Chen and Liu [20] prepared lightweight concrete, using polystyrene beads as artificial aggregate, and various amounts of foam. Yildizel and Toktaş [21] studied on ultra high foam concrete. The results indicated that the workability, thermal and strength features of polystyrene beads foamed concrete can be enhanced with suitable foam content.

It is well known that the conventional concrete that commonly used as a structural material in the construction industry has some disadvantages such as brittleness, lower tensile strength and insufficient resistance to crack formation in the structure industry [22]. To achieve the deficiencies and improve the engineering properties of plain concrete the first application appeared in the early 1960s [23]. Fibers have been incorporated in the cementitious matrices. Adding fiber to the cementitious materials by considering the various types, different amounts and volume ratio of fibers is an efficient way to improve the undesirable characteristics of the conventional concrete [24-26]. The usage of fiber in concrete production provides higher toughness, energy absorption, flexural strength, compressive strength, and durability while prohibiting crack width propagation [27-33]. It has also been found that the fiber usage in concrete may cause some negative effects, such as higher dead load, prolonged mixing/placing time and reduction of workability of fresh concrete [34-36].

Basalt fiber (BF), is a new reliable, eco-friendly fiber type attained by extracting melted rock without adding any additive material [37]. Due to its high mechanical performance and more economical manufacturing process compared with other fiber types, BF has recently attracted manufacturers' and researchers' interest to be used as reinforcing material in many areas [38-43]. Jiang et al. [44] carried out a study on the mechanical and microstructure of basalt fiber reinforced concrete. While using BF had a positive effect on flexural strength, tensile strength, and toughness index of LWC, a slight increase in compressive strength of concrete was sighted. Results demonstrated that the BF length influenced the mechanical characteristics of LWC and the addition of BF changed pore structure. High et al. [45] confirmed that the BF usage fiber showed a slight impact on the compressive strength of LWC, whereas, it considerably improved flexural rupture modulus. Ayub et al. [46] searched the combined effects of additive and BF on high-performance fiber reinforced concrete. The results showed that, though, adding BF up to 2% volume increased compressive strength, the higher volume of BF decreased the strength values due to the occurrence of voids. It was also concluded that there was no important impact of BF on Young's modulus.

The target of the study is to reach the impact of BF content and pumice aggregate amount on the flowability, mechanical of lightweight mortars (LWM). The fundamental features of BF reinforced LWM such as sorptivity, water absorption, workability, compressive strength and flexural strength were experimentally examined and the correlations between these parameters were demonstrated in this study. Besides, the experimental results were assessed by statistical analysis and determined the effects of variables on each other.

2. EXPERIMENTAL STUDY

2.1. Materials Properties

Portland cement (CEM I 52.5 N) according to TS EN 197-1 is preferred as a basic binding material for all mixtures in this study. The table provided in Table 1 contains the chemical components of the cement that has been utilized.

Table 1. The chemical properties of the cement

Oxides(%)	K_2O	MgO	Na_2O	SO_3	CaO	Fe_2O_3	Al_2O_3	SiO_2
CEM I 52.5 N	0.68	1.60	0.14	2.42	63.28	3.12	5.02	18.91

River sand, having 0.5 and 2.63 values for water absorption value and specific gravity, respectively, and Nevşehir (in Turkey) pumice aggregate, having 25.6% and 1.37 values for water absorption value and specific gravity, respectively, were used as fine aggregate in the experimental study. The chemical properties of pumice aggregate were also given in Table 2.

Table 2. The chemical properties of lightweight aggregate

Oxides(%)	K_2O	TiO_2	Na_2O	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
LWA	4.32	0.15	3.17	70.14	16.44	1.01	0.74	0.2

The maximum particle sizes of both river sand and pumice aggregate were 4 mm in the study. Figure 1 illustrates the particle size distributions of fine aggregates.

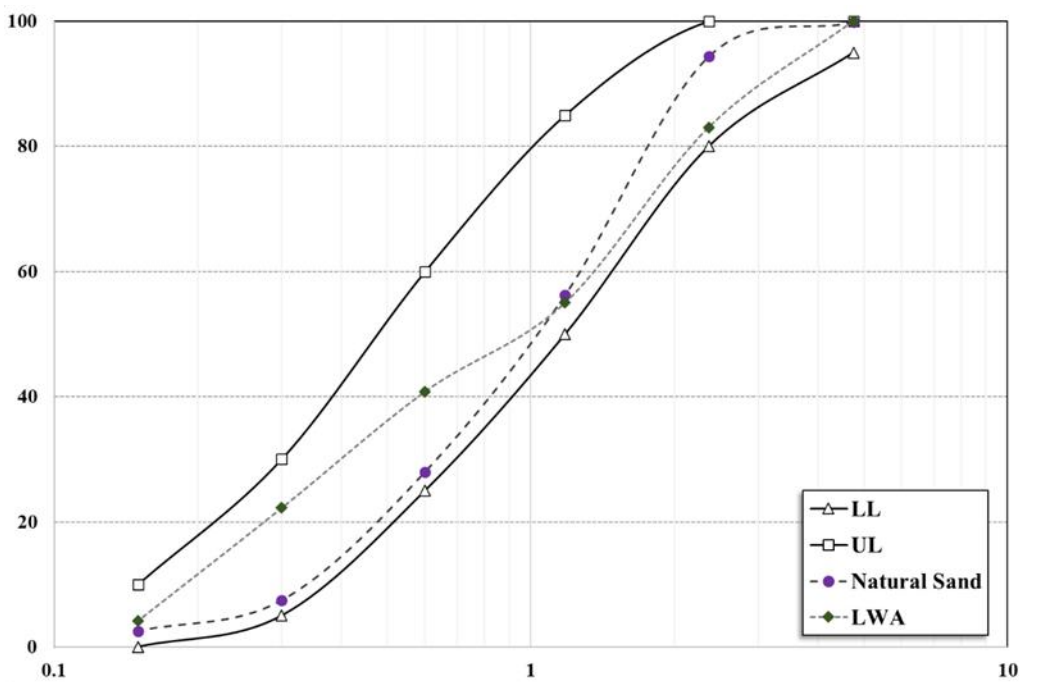

Figure 1. Particle size distributions of the fine aggregates

Basalt fiber with a length of 3 mm was utilized in this research. Specific gravity and aspect ratio of the BF are 2.78 and 214, respectively. Polycarboxylate ether-based superplasticizer was preferred to obtain proper viscosity and workability in fresh fiber-reinforced lightweight mixtures.

2.2. Mixtures and Testing Methods

Laboratory tests were carried out before pumice aggregate substitution rates and basalt fiber amounts were determined, and the engineering properties of the mortars produced were aimed to remain within certain limits, taking into account the effects of these two materials on each other. When the literature studies were examined, it was seen that there were studies using basalt fiber at a maximum rate of 0.2% [48] as well as studies using a maximum rate of 2% [49]. In this study, fiber was added at a maximum rate of 0.5% by volume, taking into account the decrease in strength values when used with aggregate. All mixtures have a constant aggregate-cement ratio of 2.75 and a water-cement ratio of 0.49. Aggregate combinations were prepared by partially replacing river sand with pumice aggregate at 0%, 25%, and 50% of the volume of the river sand. BF contents of the mixtures were determined as 0%, 0.25%, and 0.5% of the total volume of mortar. In the laboratory, nine distinct LWM mixtures were created under normal room temperature conditions. The table labeled "Table 3" contains this experimental study's relevant mixing details. The description of each mix varies according to the amount of the lightweight aggregate (LWA) and basalt fibers added during mixing. For instance, LW50-F0.25 demonstrates that for this LWM mixture the content of LWA and volume fraction of BF were 50% and 0.25%, respectively.

Table 3. Mix proportions of mixtures for 1 m^3

					Lightweight aggregate		
Mix description	**Cement**	**Sand**	**Water**	**BF**	**2-4 mm**	**1-2 mm**	**0-2 mm**
LW0-F0	500	1375	242.5	0	0	0	0
LW25-F0	500	1031.25	242.5	0	27.71	29.27	121.55
LW50-F0	500	687.5	242.5	0	55.42	58.55	243.11
LW0-F0.25	500	1375	242.5	18.9	0	0	0
LW25-F0.25	500	1031.25	242.5	18.9	27.71	29.27	121.55
LW50-F0.25	500	687.5	242.5	18.9	55.42	58.55	243.11
LW0-F0.5	500	1375	242.5	37.8	0	0	0
LW25-F0.5	500	1031.25	242.5	37.8	27.71	29.27	121.55
LW50-F0.5	500	687.5	242.5	37.8	55.42	58.55	243.11

After mixing the combined aggregate with basalt fiber for about 3 minutes, the other materials were added to the pan mixer and it took another 5 minutes to mix them all. All specimens were unmoulded after 24 h and stored in water curing tanks until testing at the age of 28 days.

A flow table test was conducted to determine the consistency of the fresh fiber-reinforced LWMs. The compressive strengths of hardened LWMs with 50 × 50 × 50 mm dimensions at 28 days were tested using a 3000 kN capacity universal testing machine. Flexural strengths of the LWMs were measured on prismatic samples of 40x40x160 mm at the age of 28 days through three-point bending test apparatus having a span of 100 mm. The loading rate of the compressive strength and flexural strength tests were determined as 0.5 kN/s and 0.1 kN/s, respectively.

Water absorption and capillary water absorption values were reached through experiments on cubic samples with dimensions of 50x50x50 mm. The LWM specimens were dried in an oven at 105 ± 5 °C for 24 h and recorded the dry weights of the samples. After being submerged in water for 24 hours, the weight of the specimens was measured at their saturated surface dryness. Three samples were tested at 90 and 28 days. Figure 2 illustrates flowchart of mixing procedure and experiments conducted.

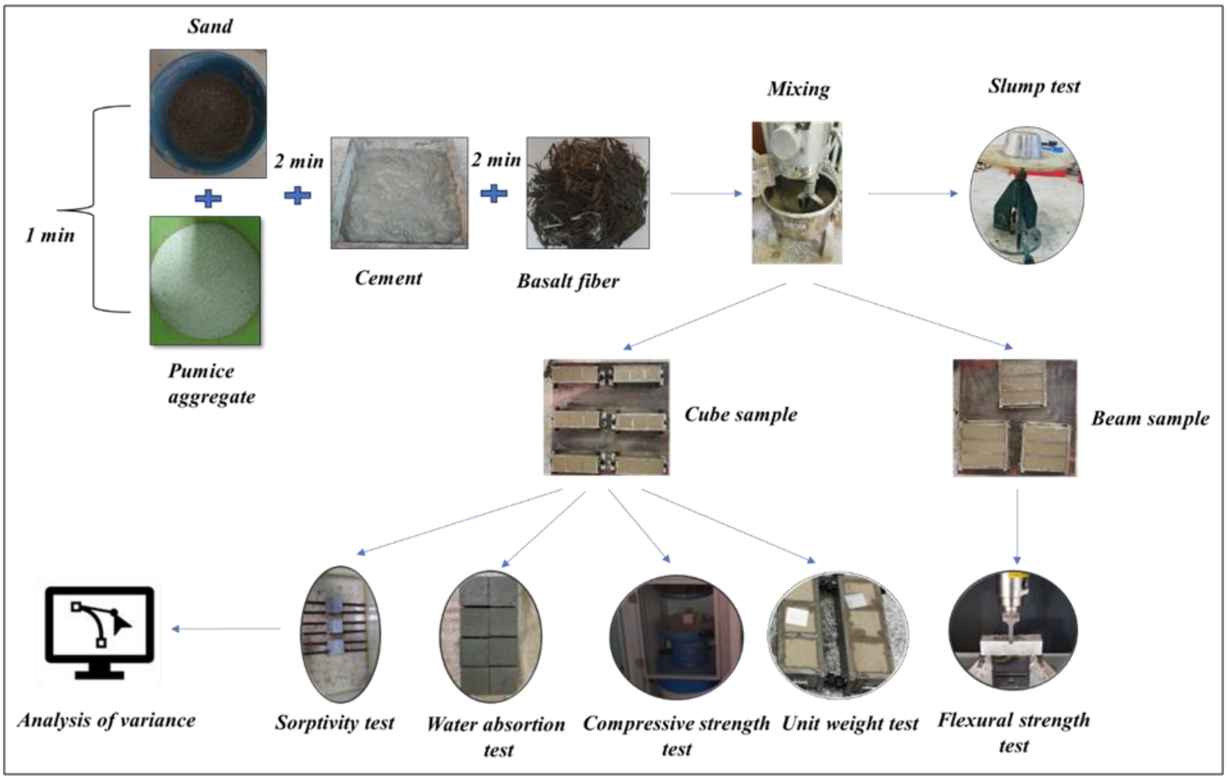

Figure 2. Flowchart of mixing procedure and experiments

3. RESULTS and DISCUSSION

3.1. Flow Table Test Results

The results of slump flow measurements demonstrate the free deformation ability of the fresh mixtures and flowability is a significant parameter due to representing compactness, porosity, and density of samples in the hardened state. The fibers usage in cementitious matrices has a negative effect on the workability performance of fresh mixtures [25, 34].

The determination of fresh mortar spread was performed by the average of two perpendicular measurements. Flow properties of fresh mortars considering BF content and LWA amount were indicated in Figure 3. The highest flow value of 55.5% and the lowest flow value of 15% were measured in the BF free LW0 mix and LWM50 mix that contains BF volume of 0.5%, respectively. As expected, the increase in BF volume negatively affected the fluidity of all the mixtures. LWM25 and LWM50 mixtures had almost the same flow values with decreasing trends. It means that adding LWA also decreased the fluidity of mortars. This can be attributed to the angular shape of the LWA particles and pore structure [47].

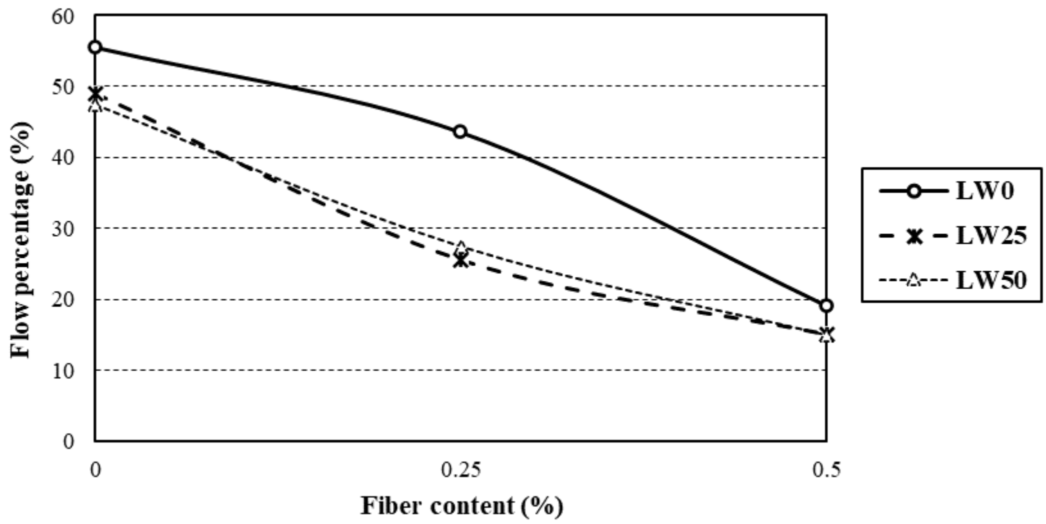

Figure 3. Slump flow results of fresh mixtures

3.2. Dry Unit Weight

The dry unit weight values of specimens were given in Figure 4. Results showed that the dry unit weight of mortars decreased with increasing LWA content. The BF content had no substantial effect on decreasing dry unit weight values. Unit weight results ranged between 1520-2070 kg/m3. The maximum dry unit weight value was obtained with BF-free specimens in the LWM0 mix. The minimum dry unit weight value was achieved with a BF volume of 0.5% in the LWM50 mix.

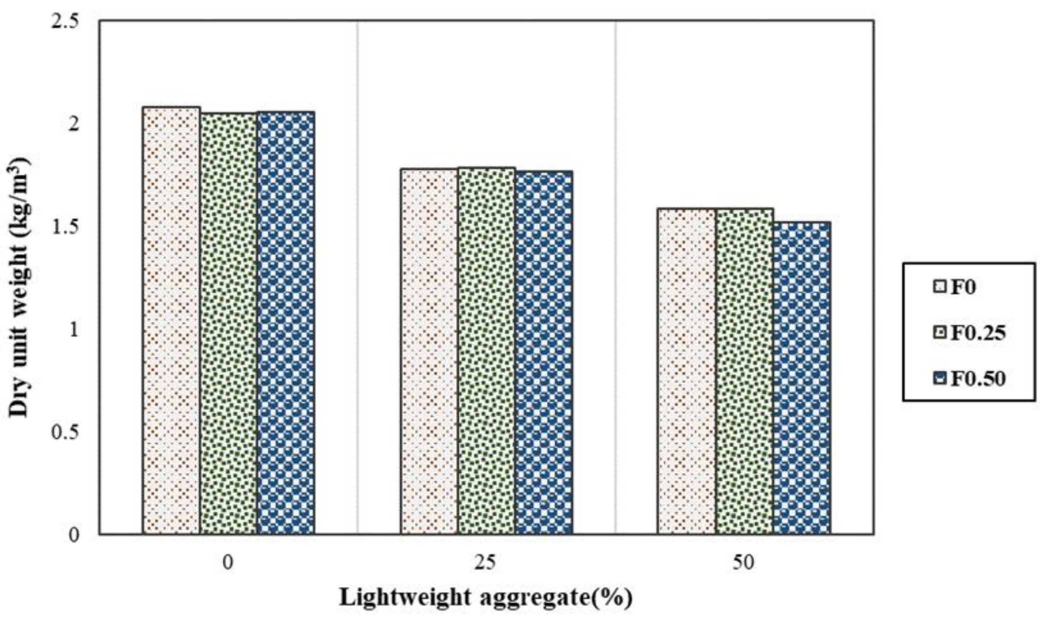

Figure 4. Dry unit weight results of cubic samples

3.3. Compressive and Flexural Strength

The compressive strength values of mortar specimens at 28 days were presented in Figure 5. As the LWA content increased, the strength of all mixes declined independently of the amount of BF. In the LWA0 mix, the addition of BF with the volume fractions of 0.25% and 0.50% increased the compressive strength of the mortars by 0.21% and 13.55% respectively. The effect of BF amount change on the compressive strength of LWM for LWA25 mix was fluctuant, whereas, adding BF with 0.25% and 0.50% volume fractions resulted in a decrease of the compressive strength of LWM in the LWA50 mix by 10.16% and 13.21%, respectively.

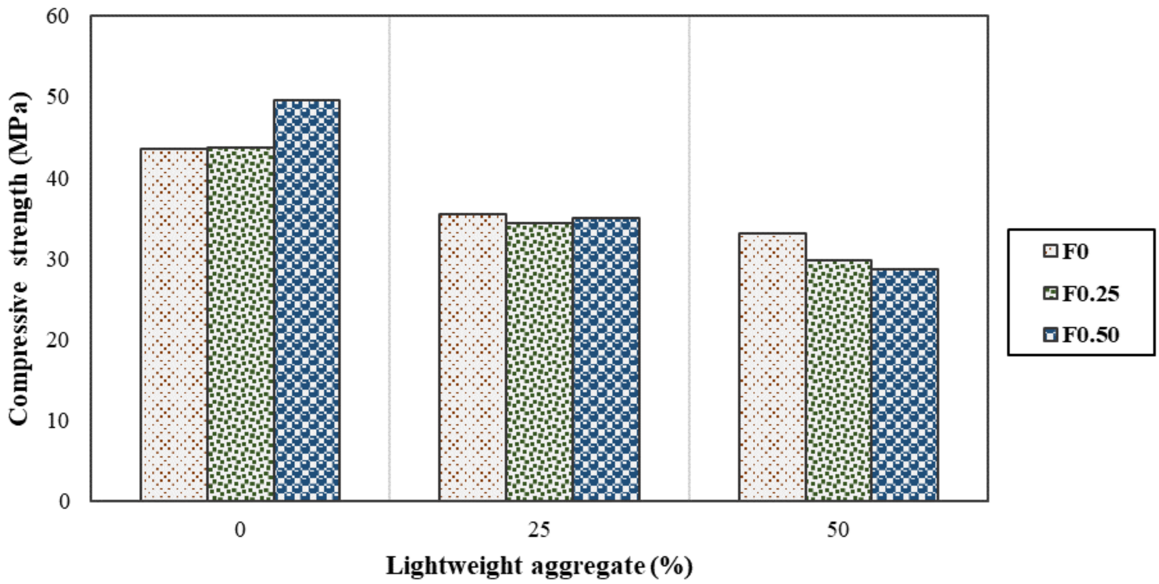

Figure 5. Compressive strength (MPa) values of hardened samples

Considering all specimens, the highest compressive strength value of 49.5 MPa was attained with BF content of 0.5% and LWA amount of 0% in the LWA0 mix. The minimum compressive strength result of 28.75 MPa was obtained with a BF volume of 0.5% and LWA amount of 50% in the LWA50 mix. Deterioration of the strength with the incorporation of both BF and LWA can be attributed to void occurrence due to fiber addition and weaker bond of LWA and fiber-reinforced matrix.

Figure 6 shows the flexural strength results of mortar specimens. The LWA content increment caused a decline in flexural strength values of specimens reinforced with BF volume fractions of 0.25% and 0.50%. In the mixes without BF, the flexural strength of samples with the LWA content of 25% slightly improved by 2.24%, but the increase of LWA content up to 50%, caused a decrease of flexural strength value by 19.66%. It is also seen that the increase of BF content had a positive effect on flexural strength characteristics of specimens without LWA addition. According to the results, the maximum flexural strength value of 11.74 MPa, and the minimum flexural strength value of 7.73 MPa were reached at the same BF volume fraction of 0.5% with an LWA amount of 0% and LWA amount of 50%, respectively.

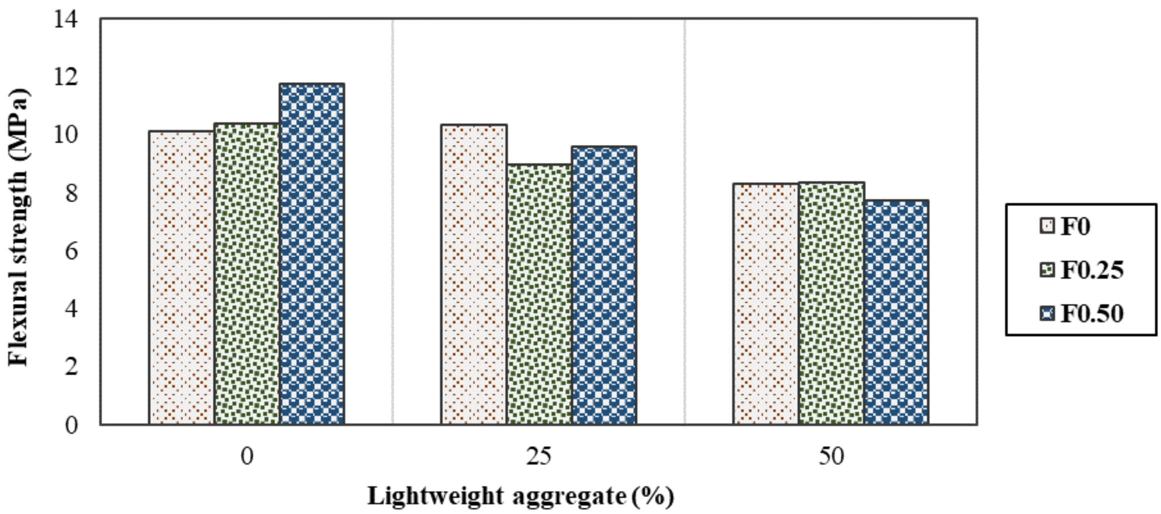

Figure 6. Flexural strength (MPa) values of hardened samples

The correlation between compressive strength and flexural values of all LWMs obtained from experimental test results was illustrated in Figure 7. The obtained best fit curve can be expressed by a simple exponential function. The coefficient of correlation (R) between the flexural and compressive strengths of LWMs at 28 days was obtained as 0.91. It is obvious that there is a strong link between these two critical parameters. Wang et al. [48] reached a similar conclusion in their study investigating the effect of basalt fiber.

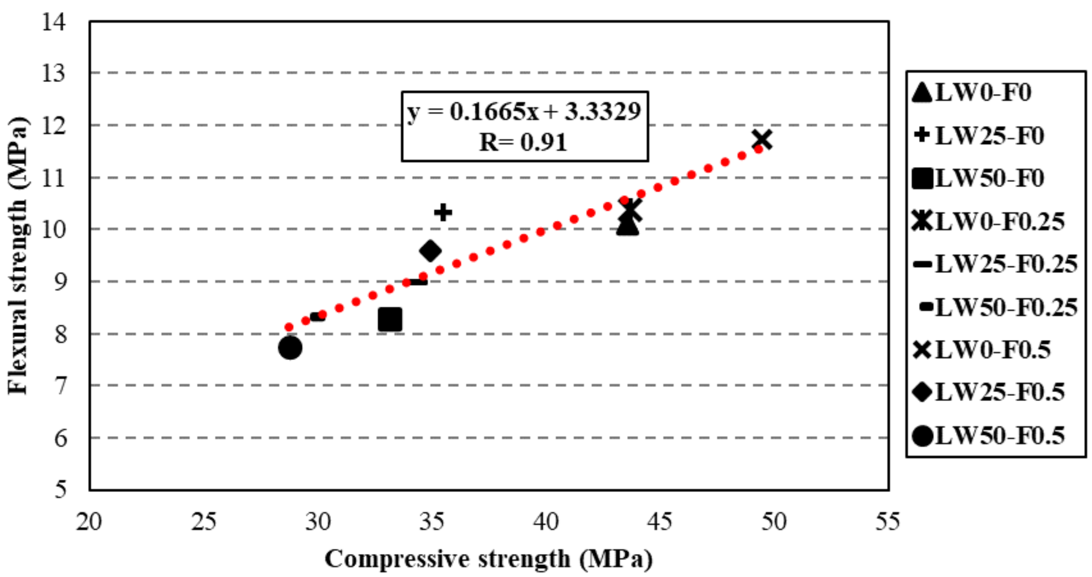

Figure 7. The correlation between flexural strength and compressive strength values

3.4. Water Absorption and Sorptivity

Variations of water absorption values of specimens at 28 days were presented in Figure 8. Water absorption percentage of mortars increased with increasing LWA content in mixes. For both LWA25 and LWA50 mixes, the lowest water absorption percentages were obtained with specimens without containing BF. Whereas, the minimum water absorption value of 8.33% in the LWA0 mix was reached with a BF volume of 0.5%.

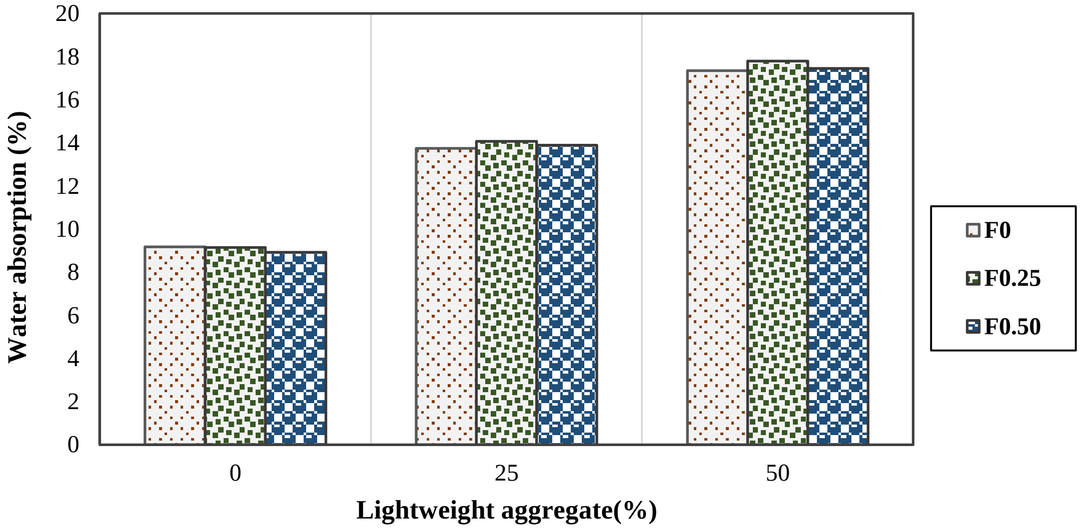

Figure 8. Water absorption (%) values of hardened samples

Figure 9 shows the correlation between compressive strength and water absorption. As seen, there is an inverse relationship between the two important parameters that affect the mechanical and durability performance of cementitious materials. The coefficient of correlation (R) between the water absorption (%) and compressive strengths of LWMs at 28 days was obtained as 0.95.

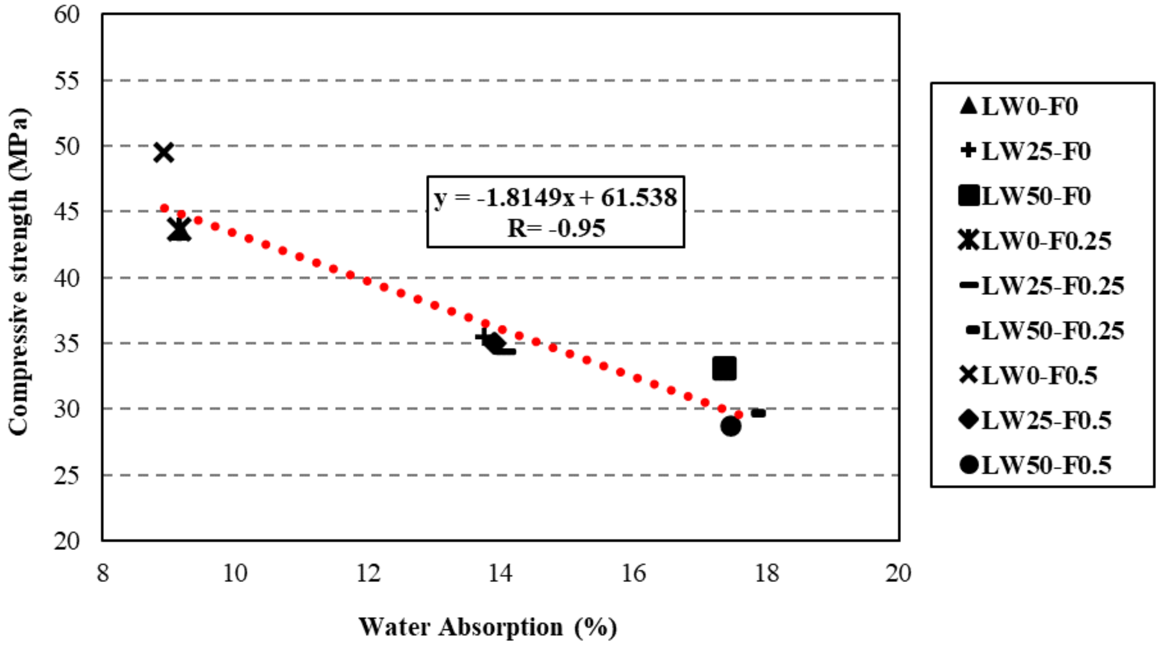

Figure 9. The correlation between compressive strength (MPa) and water absorption (%) results

Sorptivity results of specimens can be seen in Figure 10. The increase of LWA percentage in mixes resulted in a decrease in sorptivity values. Generally, reduction of sorptivity is presented as improvement of pore structure. However, sometimes, when a large open porous structure occurs in the mortar or concrete, the rise of water by capillary action can reduce.

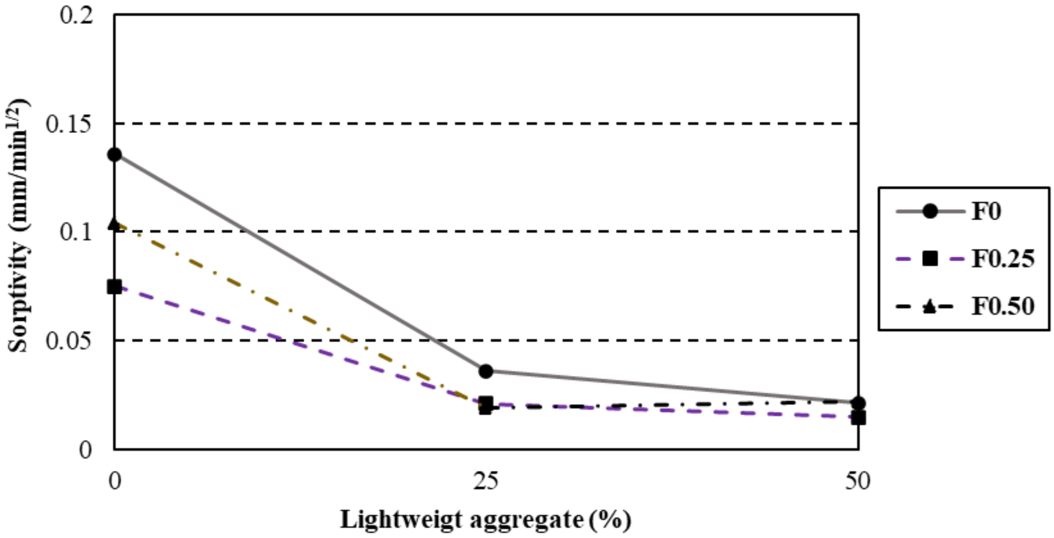

Figure 10. Water sorptivity (mm/min$^{1/2}$) values of hardened samples

The maximum sorptivity value of 0.13 was obtained in the LWM0 mix with specimens without BF addition. It was also seen that while BF content was considerably effective on sorptivity values of LWM0 mix, it slightly changed the sorptivity results of LWM25 and LWM50 mixes. The lowest sorptivity value was attained with the LWM0 mix that has a BF volume fraction of 0.5%.

The correlation between sorptivity and water absorption values of specimens were shown in Figure 11. The correlation coefficient (R) between the sorptivity and water absorption results of all specimens at 28 days were found as 0.94. It is clear that there is a nonlinear inverse relation between the two characteristics.

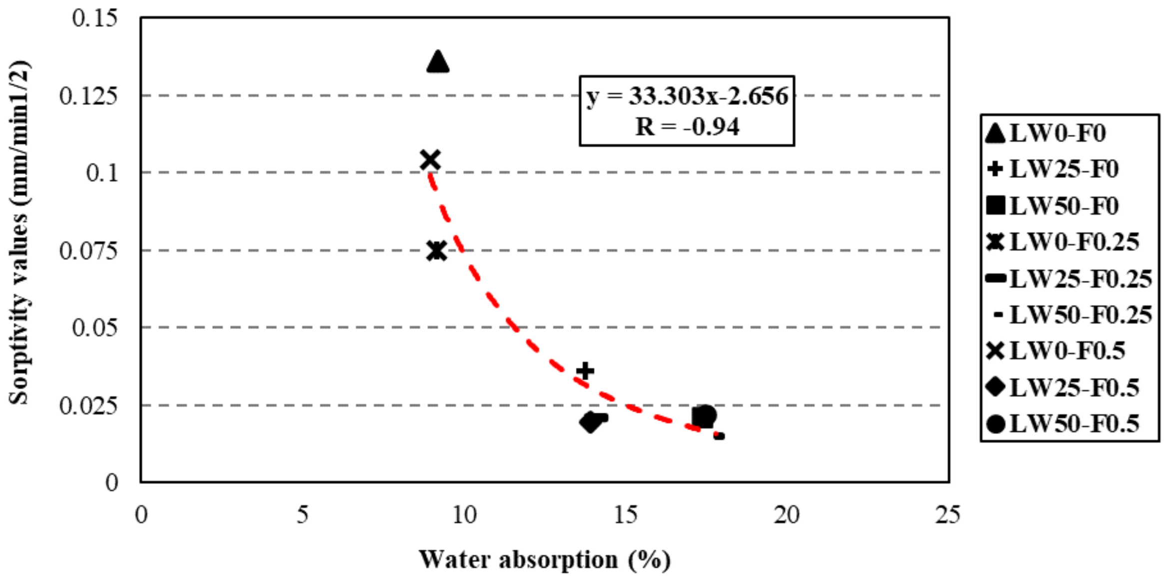

Figure 11. The correlation between water absorption (%) and water sorptivity (mm/min$^{1/2}$) results

3.5. Statistical Evaluation

It was aimed to reach the statistical analysis results considering the experimental data in this section. ANOVA (analysis of variance) is used to analyze how the independent variables interact with each other and the effects of these interactions on the dependent variable. The obtained test results were assessed by the useful GLM-ANOVA (general linear model analysis of variance) tool in this study. The software of Minitab was performed for the statistical evaluation. Table 5 submits the analysis results in detail. In this study, slump, unit weight, compressive strength, flexural strength, water absorption, and sorptivity results were determined as dependent variables whereas aggregate content (%) and fiber content (%) were chosen as independent variables. The p-value indicates whether the independent variables have a significant effect on the dependent variables. The p-values lower than 0.05 represent the meaningful influence of independent variables. When Table 5 is examined, it can be stated that the effectiveness level of aggregate content and fiber content varies according to the conducted different tests. Aggregate content has a meaningful impact on the unit weight, compressive strength, flexural strength, water absorption, and sorptivity results, whereas, fiber content is the independent variable that affects the slump results.

Table 5. Statistical analysis results for this experimental study variables

Dependent variable	independent variable	SumSq[a]	DF[b]	MeanSq[c]	F	p-value	Contribution (%)	Case
Slump	Aggregate (%)	177.388	2	88.694	5.534	0.070	8.811	nonsignificant
	Fiber (%)	1771.722	2	885.861	55.270	0.001	88.004	significant
	Error	64.111	4	16.028			3.185	
Unit Weight (Dry)	Aggregate (%)	0.373	2	0.187	419.647	0.000	99.054	significant
	Fiber (%)	0.002	2	0.001	2.008	0.249	0.474	nonsignificant
	Error	0.002	4	0.000			0.472	
Compressive Strength	Aggregate (%)	359.205	2	179.603	25.207	0.005	91.335	significant
	Fiber (%)	5.579	2	2.789	0.391	0.699	1.419	nonsignificant
	Error	28.5	4	7.125			7.247	
Flexural Strength	Aggregate (%)	10.352	2	5.176	8.813	0.034	79.381	significant
	Fiber (%)	0.34	2	0.170	0.289	0.763	2.604	nonsignificant
	Error	2.349	4	0.587			18.015	
Water Absorption	Aggregate (%)	107.826	2	53.913	2819.562	0.000	99.819	significant
	Fiber (%)	0.119	2	0.060	3.113	0.153	0.110	nonsignificant
	Error	0.076	4	0.019			0.071	
Sorptivity	Aggregate (%)	0.014	2	0.007	29.776	0.004	86.917	significant
	Fiber (%)	0.001	2	0.001	2.482	0.199	7.245	nonsignificant
	Error	0.001	4	0.000			5.838	

a:Sum of squares b:Degree of freedom c:Mean of squares

4. CONCLUSION

The obtained results according to the experimental and statistical study are as following:

The increase in volume fraction of BF and LWA content negatively affected the fluidity of all the mixtures.

The dry unit weight of mortars decreased with increasing LWA content, whereas, the variation of BF content had no significant impact on the results.

While the increment of LWA amount resulted in reduction of compressive strength values, there is no a stable trend for strength results according to BF content.

The increase of LWA content has a negative effect on the flexural strength values. The same BF volume fraction of 0.5% resulted in the maximum flexural strength of 11.74 MPa for 0% LWA amount and minimum flexural strength of 7.73 MPa for 50% LWA amount.

The tests' results have proven that a robust correlation exists between flexural strength and compressive strength.

Sorptivity and water absorption values were negatively affected from LWA increase. The results vary with the BF volume fraction. There is an inverse relationship betwen the two parameters with 0.95 R coefficient value.

According to statistical results, aggregate content is effective for the all test results, whereas fiber content has an influence on the slump values.

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