

The Properties of Glass Fiber Reinforced Lightweight Concrete under the Effect of High Temperature

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Abstract
This study aimed to produce lightweight concrete by using 50% pumice as coarse aggregate and 0.1% and 0.3% glass fiber. It is aimed to investigate the changes that will occur in the compressive strength and splitting tensile strength properties of the samples when this lightweight concrete produced is exposed to temperatures of 150 °C, 300 °C, 450 °C and 600 °C. The study was carried out in six stages. In the first stage, reference samples were produced. In the second stage, 0.1% and 0.3% glass fiber reinforced lightweight concrete samples were produced. In the third stage, unit weight, porosity, compressive strength and splitting tensile strength tests were applied to the produced samples. In the fourth step, the samples were gradually exposed to different temperatures (150 °C, 300 °C, 450 °C and 600 °C). In the fifth stage, compressive strength and splitting tensile strength tests were applied to the samples exposed to high temperature. In the sixth and final stage, SEM images of 0.1% glass fiber reinforced lightweight concrete samples were analysed. As a result, it was observed that the unit weight value decreased and the porosity values increased with glass fiber reinforcement. There was also an increase in compressive and splitting tensile strengths. In addition, it was observed that the samples exposed to 150 oC temperature had the highest compressive strength and splitting tensile strength. In the analysis of SEM images, with the increase in temperature, it was determined that the samples in microstructure changed into macrostructure as well as the cracks occurred in the sample structure. The importance of this study stem from increasing tensile strength of lightweight concrete with glass fiber reinforcement so as to prevent loss of life and property in an earthquake.This study is important because it increases the tensile strength of lightweight concrete with low tensile strength with glass fiber reinforcement. This will result in less loss of life and property in an earthquake.
Keywords: Glass fiber, pumice, lightweight concrete, high temperature
DOI: 10.7176/CER/14-4-07
Publication date: June 30th 2022

1. Introduction

Concrete is a widely used building material but is subject to many limitations in engineering applications due to poor ductility, high brittleness, low tensile strength, low tensile stress and poor impact toughness. (Yin *et al.* 2015; Kizilkanat *et al.* 2015; Tassew & Lubell 2014; Shaikh 2013). Its practicality and relatively low cost are the most important reasons for choosing concrete (Pakravan & Ozbakkaloglu 2019).

Due to reasons such as the development of technology and the differentiation of user demands, there have been improvements in some properties of concrete (Kale *et al.* 2021; Aldakshe et. al. 2020; Tezel et al. 2020; Palta et al. 2020;). In line with these demands, special types of concrete such as self-compacting concrete, shotcrete, powder concrete, lightweight concrete etc. were produced. Lightweight concrete, a special type of concrete, is one of the right solutions for overcoming structural problems with high bulk density. The bulk density of the produced concrete is less than 2200 kg/m^3. At the present time, lightweight concrete applications are carried out for both structural and non-structural components such as lightweight concrete blocks (Sutrisno *et al.* 2017; Sari & Sani, 2017; Suttaphakdee *et al.* 2016), precast slab (Suizi *et al.* 2019; Yardim *et al.* 2013; Rochman *et al.* 2021) and precast lightweight concrete beam (Vimonsatit *et al.* 2012; Yip *et al.* 2015; Gulec *et al.* 2020).

The most common material used as coarse aggregate in the production of lightweight concrete is pumice (Karaburc *et al.* 2020). Based on the literature review, pumice stone was chosen instead of coarse aggregate in this study (Muralitharan *et al.* 2015; Devi *et al.* 2017). Pumice stones are rocks of volcanic origin formed in many parts of the world. Pumice stone is a natural lightweight aggregate that is light enough to be used in lightweight concrete and strong enough despite its lightness (Chandan *et al.* 2017; Mohan *et al.* 2020). Replacing the pumice aggregate with coarse aggregate reduces the concrete's self-weight and causes a decrease in the self-weight of the structure (Saini *et al.* 2018; Karthika *et al.* 2021).

In order to improve the mechanical properties of lightweight concrete material, both fresh and hardened, the use of lightweight aggregates with fiber has been developed. This has led to the development of Fiber Reinforced Lightweight Concrete. Various types of Fiber Reinforced Lightweight Concrete have been developed, studied and used in many experimental and real case studies (Fantilli *et al.* 2015; Caratelli *et al.* 2016a; Caratelli *et al.* 2016b; Alhassan *et al.* 2017). Glass fiber was used in the samples produced within the scope of the study. Concrete has significant brittleness leading to poor toughness, fracture and splitting tensile strength. Therefore, glass fibers are used to limit brittleness and improve the properties and durability of lightweight concrete. Glass fibers are also used to modify toughness, effective strength and fracture energy (Dawood & Ramli 2011; Ahmad *et al.* 2010; Badogiannis *et al.* 2019).

The inclusion of glass fibers is effective in improving the flexural and tensile strengths of lightweight concrete (Wang *et al.* 2019; Yew *et al.* 2015; Aslani *et al.* 2019). Glass fibers improve shrinkage and early tensile strength and reduce or stop the growth of initial cracks through mechanical bridging (Li *et al.* 2016). Alex & Arunachalam (2019) investigated the flexural behavior of lightweight aggregate (LWA) concrete with steel and glass fiber reinforcements in their study. In order to obtain lightweight concrete, pumice aggregate was used instead of normal weight aggregate to reduce the concrete density. Steel and glass fibers were added separately as 0.5%, 1.0% and 1.5% according to the concrete weight. As a result of the study, it has been reported that the bearing capacity of the 20% LWA and 0.5% steel fiber beam sample increased by 28% compared to the control beam, and the ductility ratio of the same beam was 85% higher than the control sample. Falliano *et al.* (2019) investigated the mechanical strength of fiber reinforced lightweight foam concrete. It has been revealed that the additional glass fiber reinforced polymer mesh in the tensile zone together with the short fibers significantly improves the flexural capacity and is the best strategy to achieve the high mechanical strengths associated with the low densities typical of ultralight concrete elements. Bideci *et al.* (2018) aimed to ensure the recycling of glass fiber reinforced concrete (GRC) wastes as cement replacement material. Ahmad et al. (2021) produced lightweight concrete using peach bark. Various percentages (2%, 4%, 6% and 8%) of glass and nylon fibers were used to improve mechanical performance. As a result, they found that as glass and nylon fibers were added, the density of lightweight concrete decreased by 6.6%, and the compressive, splitting tensile and bending strengths increased by 10.20%, 60.1% and 63.49% respectively. Mastali et al. (2016) revealed that the addition of glass fiber provides a significant improvement in the impact resistance, compressive and tensile strength of glass fiber reinforced lightweight concrete. In this context, besides fresh mortar tests, compressive strength, flexural strength, heating-rain and freeze-thaw tests were performed on cement mortar samples produced with 0% (Reference), 5%, 10% and 15% crushed GRC wastes by weight. As a result of their experimental studies, they reported that the reuse of 5% crushed GRC wastes in the mortar would make a positive contribution to the environment. Ali *et al.* (2019) produced a new material by adding glass fiber into fresh concrete in their study. They found that while glass fiber did not contribute to the compressive strength in the samples that were not exposed to fire, it contributed significantly to the tensile strength.

This study aimed to produce lightweight concrete by using 50% pumice as coarse aggregate and 0.1% and 0.3% glass fiber. It is aimed to investigate the changes that will occur in the compressive strength and splitting tensile strength properties of the samples when this lightweight concrete produced is exposed to temperatures of 150 °C, 300 °C, 450 °C and 600 °C.

2. Material and Method

2.1 Material

2.1.1 Pumice

In the study, the pumice to be used for sample production was supplied from Nevşehir region and acidic pumice in four different ranges as 4-2 mm, 2-1 mm, 1-0.5 mm and 0.5-0 mm was used. Grain density, water absorption rate and moisture determination of each granulometry of acidic pumice were made according to the TS EN 1097-6 standard, and loose and compacted bulk unit density (BUD) determination was made according to the TS 3529 standard. The physical properties of the aggregate used are presented in Table 1, and the chemical properties are presented in Table 2.

Table 1. Physical Properties of Nevşehir Acidic Pumice

	Aggregate Size (mm)			
Physical property	**4-2**	**2-1**	**1-0.5**	**<0.5**
Specific Gravity (g/cm^3)	1.00	1.08	1.13	1.88
Dry Specific Gravity (g/cm^3)	0.77	0.85	0.91	-
Water Absorption (%)	30.11	26.35	23.59	-
Compacted BUD (g/cm^3)	0.469	0.475	0.485	-
Loose BUD (g/cm^3)	0.451	0.448	0.422	-
Aggregate Moisture (%)	0.40	0.30	0.30	-

Table 2. Chemical Components of Nevşehir Acidic Pumice

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	TiO_2	SO_3	L.O.I
%	73.22	12.33	1.13	0.74	0.09	3.64	4.19	0.04	0.08	0.02	4.50

2.1.2 Cement

CEM I 42.5 R type cement produced by Nuh Cement Factory was used in the study. The properties of cement are presented in Table 3.

Table 3. Properties of Cement Used in Experiments

Chemical Composition %		
Component	**Cement**	
	Nuh CEM I 42,5R	
CaO, total	63,41	
CaO, free	1,2	
SiO_2, total	20,22	
Al_2O_3	5,67	
Fe_2O_3	2,91	
MgO	0,96	
SO_3	2,92	
Loss on ignition	3,32	
Insoluble residue	0,93	
Physical and Mechanical Property		
Specific Weight	3,19	
Blaine (cm^2/gr)	3654	
Compressive Strength (MPa)	2- Days	29,8
	7- Days	49,6
	28- Days	61,1

2.1.3 Glass Fiber

The glass fiber used in the study was obtained from the Fiber Elyaf Kompozit company. The glass fiber used is given in Figure 1 and its properties are given in Table 4.

Figure 1. Glass Fiber

Table 4. Glass Fiber Properties

Property	Value
Tensile strength (MPa)	2000
Softening point (°C)	860
Density (t/m^3)	2,68
Length (mm)	1,2
Diameter (mm)	0,55
Aspect ratio (Length/Diameter)	2,18

2.1.4 Sand

The stream sand used in the study and obtained from within the provincial borders of Kırşehir was washed and sieved. The grain diameter of the sand used varies between 0-4 mm.

2.1.5 Mixing Water

During the experimental study carried out within the scope of the study, city water of Kırşehir province was used in the production of the test samples in accordance with the TS EN 1008 standard. Mixing water was added to the production as it was taken from the city water supply without any treatment.

2.2 Method

2.2.1 Production of Glass Fiber Reinforced Lightweight Concrete Samples

In the study, three different series of lightweight concrete were produced. The first series is the reference sample (REF), the second series is the 0.1% glass fiber reinforced lightweight concrete sample (0.1% CEH), and the third series is the 0.3% glass fiber reinforced lightweight concrete sample (0.3% CEH). The water/cement ratio was determined as 0.30. Mixture recipe of glass fiber reinforced lightweight concrete samples is presented in Table 5.

Table 5. Mixture Recipe

	Cement (kg/m^3)	Water (kg/m^3)	Aggregates (kg/m^3)			Glass Fiber (kg/m^3)
			Fine Aggregate	Normal Aggregate	Pumice	
REF	450	150	682	305	305	---
%0,1 CEH	450	150	682	305	305	5,1
%0,3 CEH	450	150	682	305	305	10,2

Glass fiber reinforced lightweight concrete was produced according to the TS 2511 standard. According to Chart 2.8, the cement dosage is 450 kg, the fine aggregate is between 0-40 mm and 40%, the coarse aggregate is between 4-16 mm and 60%. All aggregates were used as a saturated-surface-dry in the production of lightweight concrete samples.

First, the dry materials to be used in production were taken into the mixing bowl. Cement, fine aggregate and coarse aggregate were mixed in dry form. Then the mixing water was added and the mixing process was continued. The mixing process was terminated when a homogeneous paste was obtained. Then, the prepared mixture was moulded into cube sample moulds measuring 15x15x15 cm (Figure 2).

Figure 2. Pouring the Lightweight Concrete Mix Into the Molds

After the moulding process was completed, the compression process was started and the samples were left to set for 24 hours. At the end of the period, the samples were removed from the moulds and placed in the curing pool at ±20 °C. The curing time of the samples is 28 days. At the end of 28 days, the samples were removed from the curing pool. Finally, the samples were subjected to dry unit volume weight, porosity, compressive strength, splitting tensile strength tests.

2.2.2.Tests Applied to Samples

Saturated unit weight and porosity tests were applied to determine the physical differences, and compressive strength and splitting tensile strength tests were applied to determine the mechanical properties of the glass fiber reinforced lightweight concrete samples. Scanning Electron Microscope (SEM) images were taken for microstructure analysis. Finally, compressive and splitting tensile strength tests were applied by exposing them to high temperatures (150-300-450-600 °C).

3. Research Results and Evaluation

3.1 Unit Weight

The unit weights of all mixtures were measured in fresh form. The values obtained are given in Figure 3 When the figure is examined, it is seen that the unit weight varies between 1841-1855 kg/m^3. The highest value was obtained in the reference sample, and the lowest value was obtained in the samples with 0.1% glass fiber. It is observed that the use of the glass fiber reinforcement at the rate of 0.1% causes a decrease in the unit weight value. It is thought that this decrease may be due to the increased void volume in the concrete. When 0.3% glass fiber was used, there was a decrease compared to the reference sample and an increase compared to the 0.1% CEH sample.

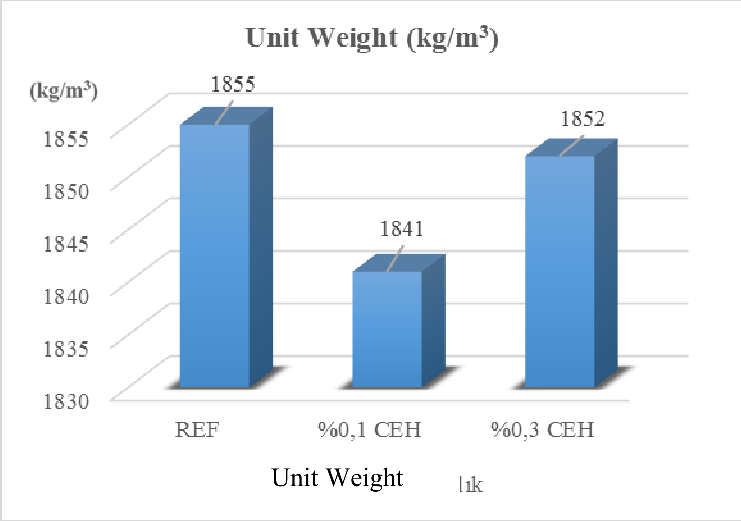


Figure 3. Unit Weight Graph of Samples

It has been observed that the unit weights of the mixtures are in accordance with the ACI213R-03 standard. It is seen that the thesis study is in line with different studies in the literature (Mydin *et al.* 2012; Amin *et al.* 2020).

3.2 Porosity

The porosity values of the material are given in Figure 4 When the figure is examined, it has been determined that an increase in porosity values occurs when glass fiber is used in the production of lightweight concrete samples. It is seen that the reference sample has the lowest value with 21.8%, and the CEH sample with 0.3% has the highest value with 23.5%.

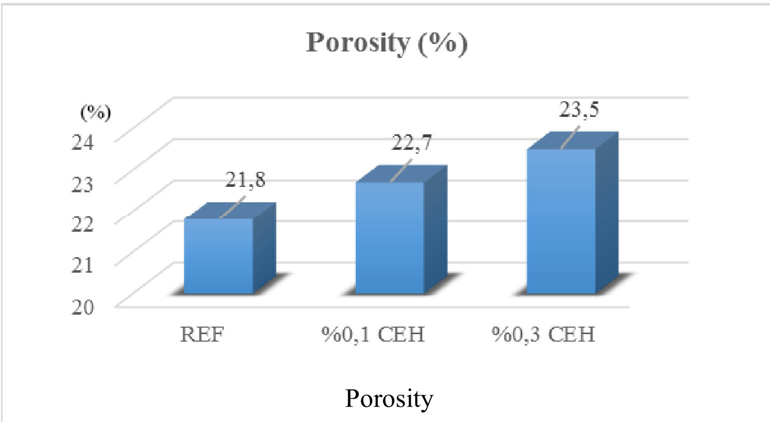


Figure 4. Porosity Graph of Samples

The literature review supports the results obtained within the scope of the experiment. According to Demirel & Gonen (2008), as the amount of fiber used in concrete increases, the amount of pores in the concrete increases, and this causes an increase in the porosity value of the concrete. Also, Demirel & Kelestemur (2010) reported that an excessive amount of pumice in lightweight concrete production will cause an increase in the porosity value. The SEM images taken from the samples prove the porosity that occurs with the increase of the fiber amount.

3.3 Compressive Strength

The data obtained as a result of the compressive strength test applied to the reference and glass fiber reinforced samples are presented in Figure 5 When the graph was examined, it was determined that the glass fiber reinforcement slightly increased the compressive strength of the lightweight concrete samples. While the reference sample had the lowest compressive strength with 37.4 MPa, it was observed that the 0.3% CEH sample had the highest compressive strength with 38.9 MPa.

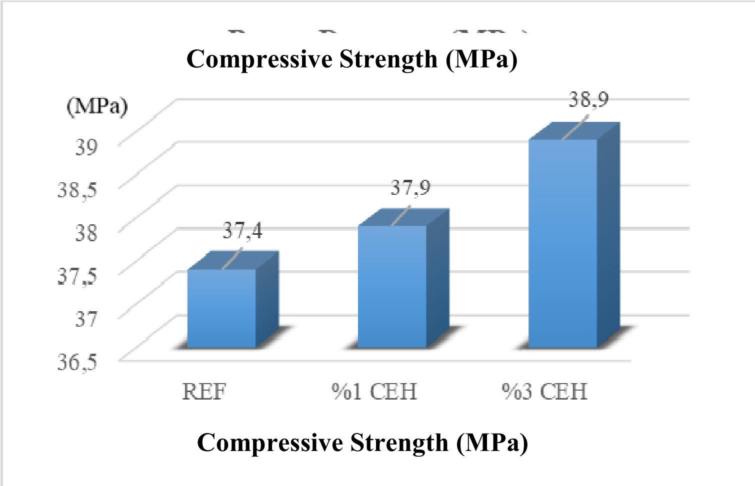


Figure 5. Compressive Strength Graph of Samples

Studies in the literature support this thesis (Sawant *et al.* 2013; Chandramouli *et al.* 2010; Harle 2014; Yuan & Jia 2021). The increase in compressive strength can be expressed as that the fibers prevent crack development in concrete (Wang H & Wang L 2013). In addition, it is thought that an increase in compressive strength occurs due to the formation of a strong bond between cement paste and glass fibers by adding glass fiber to the concrete (George *et al.* 2019). This can be also explained by the coating of the glass fiber surface with cement hydration products and the strong adhesion between the glass fiber and the matrix (Wu *et al.* 2018).

3.4 Splitting Tensile Strength

The splitting tensile strength test results of the samples are shown in Figure 6. When the figure was examined, it was seen that the splitting tensile strength of the samples varied between 3.70-5.09 MPa. The highest splitting tensile strength value belongs to the CEH samples of 0.3%, and the lowest splitting tensile strength value belongs to the reference sample. With the increase in the use of glass fiber in lightweight concrete, the splitting tensile strength has also increased.

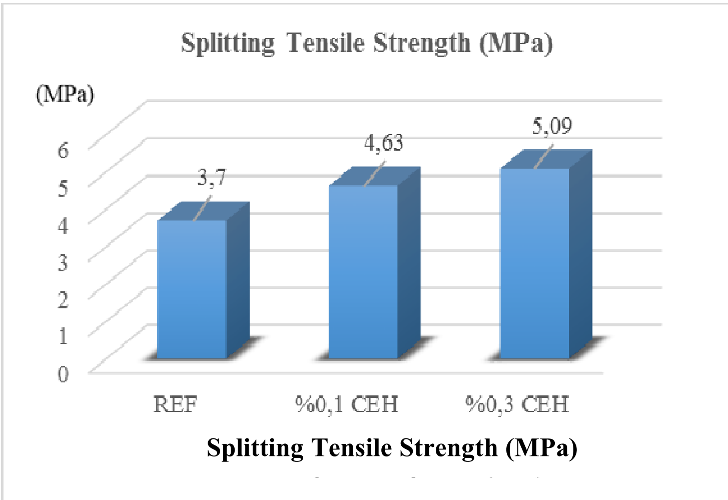


Figure 6. Splitting Tensile Strength Graph of Samples

The splitting tensile strength values of the samples improved with the increase of glass fiber reinforcement (Paktiawal & Alam 2021). The reason for this can be considered as the glass fiber combined with the materials that make up the lightweight concrete provides a great improvement in the bonding force surrounding the fiber and withstands the great deflection (i.e. crack-arrest effect). Glass fiber bundles added to concrete are divided into millions of bundles due to the abrasive effect of aggregates. Glass fibers are distributed throughout the entire matrix and provide support to the concrete in all possible directions. It also explains the mechanism of how the interface between the glass fibers and the cement matrix is formed after the glass fibers are incorporated into the concrete (Tao *et al.* 2019; Hossain *et al.* 2019).

3.5 The Effect of High Temperature on Compressive Strength

In order to determine the effect of high temperature on the compressive strength of the samples, the samples were exposed to 24 °C (assumed room temperature), 150, 300, 450, 600 °C. The values found are given in

Figure 7 According to the figure, it is seen that the compressive strength decreases with the increase in temperature. The highest value was obtained from the samples exposed to 150 °C temperature, and the lowest value was obtained from the samples exposed to 600 °C.

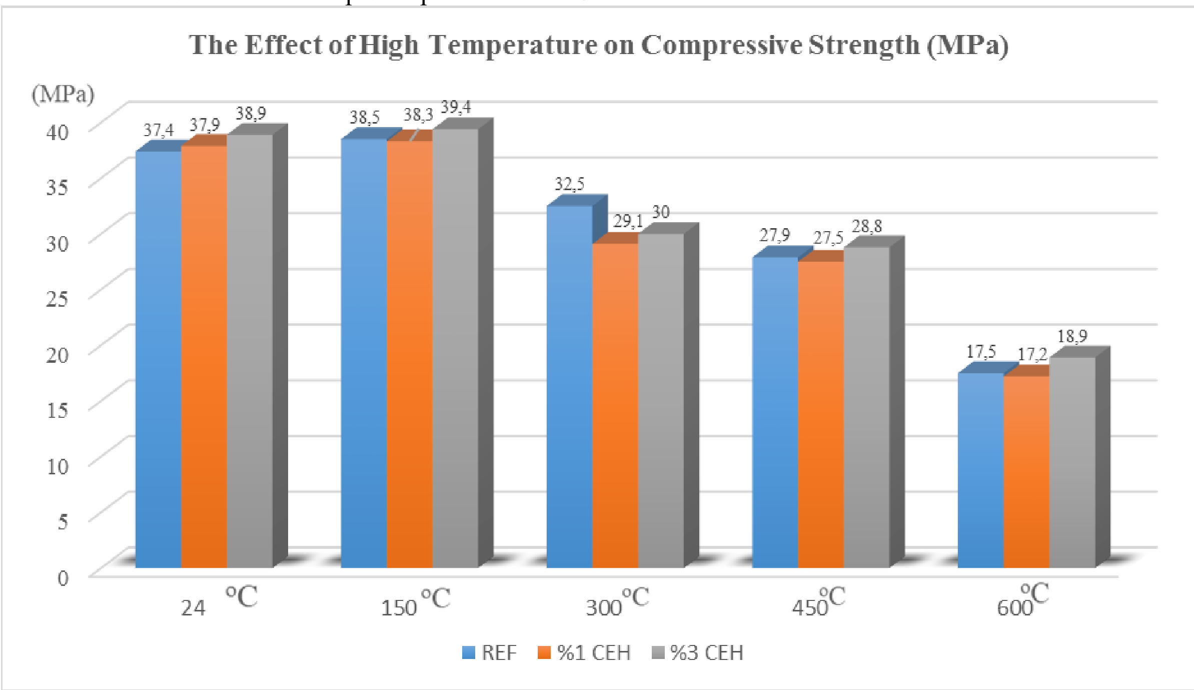


Figure 7. The Effect of High Temperature on Compressive Strength

The compressive strength of lightweight concrete samples increased up to 150 °C and then showed a tendency to decrease. It is thought that this increase may be due to the hydrothermal interaction of the free lime released during the hydration reaction and the silica contained in the pumice as a result of the temperature increase. It has been determined that these values are compatible with the studies (Saad *et al.* 2020; Choe *et al.* 2019; Alfahdawi *et al.* 2019; Eidan *et al.* 2019).

The compressive strength increased by 2.9% in the reference samples, by 1% in the samples reinforced with 0.1% glass fiber, and by 1.3% in the samples reinforced with 0.3% glass fiber at 150 °C. At 300 °C, the compressive strength decreased by 13% in the reference samples, by 23.2% in the samples reinforced with 0.1% glass fiber, and by 22.8% in the samples reinforced with 0.3% glass fiber. At 450 °C, the compressive strength decreased by 25% in the reference samples, by 27.4% in the samples reinforced with 0.1% glass fiber, and by 26% in the samples reinforced with 0.3% glass fiber. At 600 °C, the compressive strength decreased by 53% in the reference samples, by 54.6% in the samples reinforced with 0.1% glass fiber, and by 51.4% in the samples reinforced with 0.3% glass fiber.

3.6 The Effect of High Temperature on Splitting Tensile Strength

The data obtained as a result of the effect of high temperature applied on the reference and glass fiber reinforced samples on the splitting tensile strength are presented in Figure 8 When the graph is examined, the splitting tensile strength values decreased with the increase in temperature. The highest splitting tensile strength values were obtained at 24 °C, and the lowest at 600 °C. When all temperatures and mixing ratios are taken into account, it has been observed that the splitting tensile strength values of the samples vary between 1.3 and 5.09.

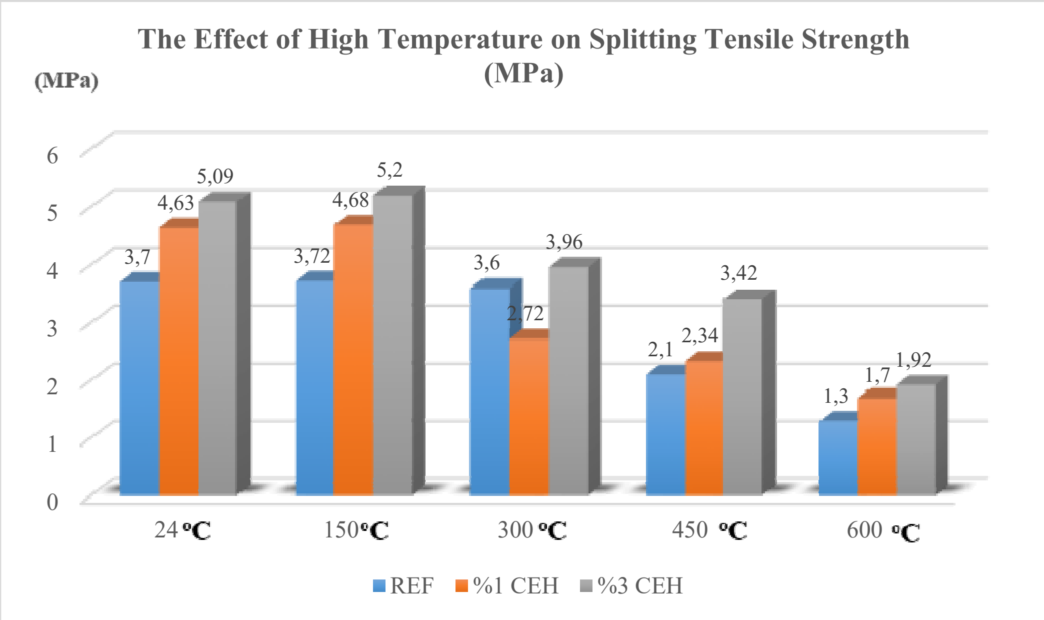


Figure 8. The Effect of High Temperature on Splitting Tensile Strength

At 150 °C, the splitting tensile strength increased by 0.5% in the reference samples, by 1.07% in the 0.1% glass fiber reinforced samples and by 2.0% in the 0.3% glass fiber reinforced samples. At 300 °C, the splitting tensile strength decreased by 27% in the reference samples, by 41.2% in the samples reinforced with 0.1% glass fiber and by 22.2% in the samples reinforced with 0.3% glass fiber. At 450 °C, the splitting tensile strength decreased by 43.2% in the reference samples, by 49.4% in the samples reinforced with 0.1% glass fiber, and by 32.8% in the samples reinforced with 0.3% glass fiber. At 600 °C, the splitting tensile strength decreased by 64.8% in the reference samples, by 63.2% in the samples reinforced with 0.1% glass fiber and by 62.2% in the samples reinforced with 0.3% glass fiber.

3.7 The Effect of High Temperature on Microstructure

The structure of the concrete composite can be divided into three stages as cement paste, coarse aggregate, and between aggregate and cement paste (ITZ). The mechanical and physical properties of lightweight concrete are significantly affected by the strength of light coarse aggregates and the interfacial transition zone between cement paste and aggregates (Mydin *et al.* 2012). A microstructural analysis based on SEM observation was performed for ITZ between glass fiber and cement paste.

Among the produced glass fiber reinforced lightweight concrete samples, 0.1% glass fiber reinforced lightweight concrete samples with high compressive strength were used. SEM images of the samples are given in Figure 9 When the images are examined, it is seen that the internal structure of the sample is porous, regular-shaped and micro-structured at 24 °C. At 150 °C, the cement paste began to shrink and micro-cracks began to form. The reason for the formation of these cracks can be explained by the evaporation of the water contained in it. This situation continues up to 600 °C. In addition, an increase in the pore structure and serious deterioration of the cement paste occurred. At 300 °C, since the CSH gel deteriorates and completely loses its water, the pores increase. The regular-shaped microstructure turns into an irregular-shaped macrostructure. A significant increase in micro-cracks occurred at 450 °C. The regular-shaped structure is almost gone, it has turned into a macro-porous irregular-shaped structure. At this temperature, calcium hydroxide decomposes into water and lime. At 600 °C, the regular-shaped microstructure was completely finished and turned into an irregular-shaped macrostructure. The pore structure has increased significantly. Cracked and porous structure also increased with the effect of temperature.

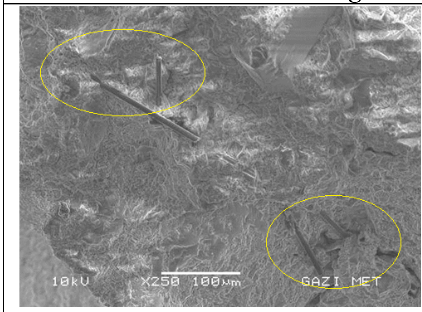
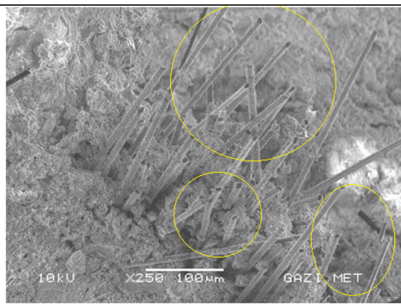
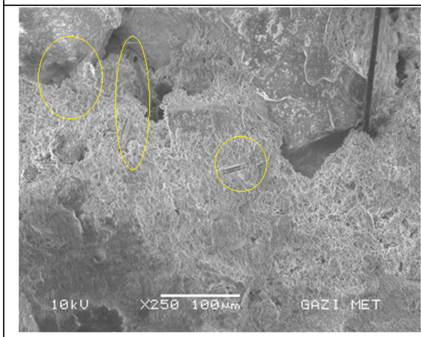
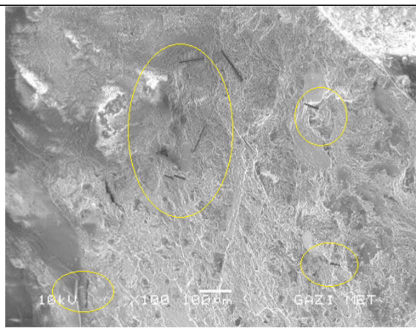
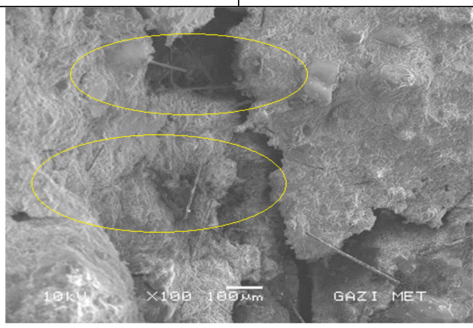
The Effect of High Temperature on Microstructure	
 SEM image of 0.1% CEH sample at 24 °C	 SEM image of 0.1% CEH sample at 150 °C
 SEM image of 0.1% CEH sample at 300 °C	 SEM image of 0.1% CEH sample at 450 °C
 SEM image of 0.1% CEH sample at 600 °C	

Figure 9. SEM Images of Samples Exposed to High Temperature

In general, when the glass fiber in lightweight concrete is heated from 24 °C to 300 °C, there appears to be a good bonding between the glass fiber and cement paste. The high compressive strength value of the samples at these temperatures supports the SEM images. Cracks formed at 600 °C indicate that the lightweight concrete sample is weak. Also, considering the compressive strength values, the lowest value is observed in the samples at 600 °C.

4. Conclusions

In this study, lightweight concrete was produced by using 50% pumice, 0.1% and 0.3% glass fiber as lightweight aggregate and dry unit volume weight, porosity, compressive strength, splitting tensile strength tests were applied to the produced samples, and the effects of high temperature on compressive strength and splitting tensile strength were investigated. The results obtained from the study are given below.

- With the use of glass fiber in the lightweight concrete samples, a decrease in unit weight and an increase in porosity values occurred. The lowest unit weight value was obtained from the glass fiber reinforced samples at the rate of 0.1%, and the lowest value was obtained from the reference sample.
- Glass fiber has no obvious effect on the compressive strength of lightweight concrete, but glass fiber changed the fracture behavior of lightweight concrete from brittle to ductile fracture. After 28 days, the compressive strength of all mixtures ranged from 37.4 MPa to 38.9 MPa. The splitting tensile strength has improved significantly. Glass fibers dispersed in the concrete prevented the formation of early period cracks. This increased the toughness of the material. The splitting tensile strength values of the 28-day glass fiber reinforced lightweight concrete samples increased by 25.1% and 37.5%, respectively.
- The compressive strength values of glass fiber reinforced samples at all temperatures vary between 1%

and 54.6%. In addition, cracks were observed in the samples, and it was seen that lightweight concrete was produced with weak glass fiber-paste interface.

- The splitting tensile strength values at all temperatures vary between 0.5% and 23.2%. When the SEM images were examined, it was observed that the internal regular-shaped microstructure of the sample turned into an irregular-shaped macrostructure. With the increase in temperature, the cracks and porosity of the material also increased.
- It was observed that the samples lost their water at temperatures of 300 °C and above.
- Taking this study as a reference, lightweight concrete properties can be further investigated by using glass fiber in different ratios.
- In addition, physical mechanics and microstructure can be examined by trying different temperatures.

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