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Improving of Lightweight Concrete Properties Produced with Pumice Aggregate of Nevşehir Region with Fly Ash Substitution

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Abstract

In this study, it was aimed to determine the effects of industrial waste fly ash substitution on physical and mechanical properties of lightweight concrete. In this respect, lightweight concrete samples were produced by the use of fly ash as a cement replacement material in different proportions (1%, 3% and 5%). In lightweight concrete production, the Nevşehir region acidic pumice has been used as aggregate. The physical and mechanical properties of these lightweight concrete samples were investigated and microstructural analysis was carried out.

To determine the physical differences, dry unit volume weight, capillary water absorption, porosity, compactness and freeze-thaw experiments were conducted. For the determination of mechanical properties, tensile splitting strength and compressive strength tests were applied. SEM images have been interpreted to examine the structural differences occurring within the material.

As a result of the study, it was determined that the physical and mechanical properties of the ligtweight concrete were improved with the increase in the amount of fly ash. The best results were obtained from sample with 5% fly ash substitution. The use of industrial waste in a large sector such as construction, which adversely affects the ecological balance, will be an opportunity to dispose of waste.

Keywords: Lightweight concrete, fly ash, pumice, SEM, physical and mechanical properties

1. INTRODUCTION

Mankind need structures to meet the need for shelter. Material is the most important element for obtaining solid and secure structures [1]. Concrete is the most widely used material in the construction industry [2].Concrete is a material that requires attention and diligence in all stages from the production process to the use process. It is preferred more than other building materials due to its features such as easy shape, economy and durability [3].

In parallel with the development of technology in the 21st century, developments have also occurred in the concrete industry. In line with these developments, a wide variety of concrete has been produced according to the purpose of use that can meet different needs. In addition to traditional concrete, as a result of increasing of scientific studies and the development of technology, many types of concrete that meet different needs have been produced [4]. These types of concrete which made their place in the field of concrete technology in a short time, are called special concrete [5].Heavy concrete, shotcrete, self-compacting concrete are a few of these special concrete [6]. One type of the special concrete is called as lightweight concrete [7]. Lightweight concrete has a wide range of use in the construction industry with their unique properties compared to conventional concrete [8,9]. In recent years, composite has become a more popular construction material due to its low density,

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reduction of dead load, and low transport costs [10]. Lightweight concrete is a concrete type with low unit weight, and high insulation [11]. It is widely used in building technology since the unit weight is less than normal and will reduce the building weight given its mechanical resistance [12]. The fact that the unit weight being less than the traditional concrete will decrease the own weight of the structure and therefore will decrease the earthquake load that will affect the structure and minimize the damage that may occur due to earthquake [13]. Lightweight concrete application reduces structural loads and structural element production cost. Therefore, it is widely preferred for structures built in seismic zones [14]. Furthermore, in parallel with the reduction of building weight, the reduction of sections of the bearing elements increases the use rate of lightweight concrete in the construction sector [15].

In lightweight concrete; fly ash, expanded clay, expanded perlite, pumice etc. are partially or completely used instead of traditional aggregates [16-18].

Fly ash, the end product of coal produced by thermal power plants in large quantities, has gained popularity in the construction sector. It has become a sustainable option for the variety of concrete applications [19].Fly ash is one of the inorganic residues resulting from coal burning processes [20].It is a harmful industrial byproduct that pollutes the environment and negatively affects human health [21,22]. It is known that around 600 million tons of fly ash are produced annually around the world. Annual fly ash production in Turkey is averagely 13 million tons, of which only a small fraction is used [23].The disposal of these organic and inorganic wastes is of both environmental and financial importance [24]. With the development of technology, the construction industry has opened a gateway for the transportation of these industrial wastes [25]. Many studies have been done on fly ash. Some studies report that the pressure and bending strengths of fly ash are superior to conventional concrete [26,27]. and suggest that its use would be more appropriate instead of fine aggregate [28,29]. Pumice is a natural aggregate formed by volcanic activities [30].According to TS 3234, pumice is defined as a material with pores, spongy perspective, silicate structure, 1 g/cm^3 unit weight, 6 mohs hardness and glassy texture [31]. Approximately 40% of the 18 billion m3 world pumice reserves are located in Turkey [32].This has increased the availability of pumice material in the construction sector. It has been used as mineral additives in cement sector and as aggregates in lightweight concrete production in many countries of the world [33].Although pumice has many positive advantages such as lightness and insulation, it causes an increase in water absorption of concrete due to its pores [34].

Pumice and fly ash have been reported to be used in lightweight concrete production [35-38].

In this study, it was aimed to investigate the changes in physical and mechanical properties by the substitution of fly ash to light concrete produced with acidic pumice aggregate found in Nevşehir region.

2. MATERIAL AND METHOD

2.1. Material

2.1.1. Pumice

In the study, acidic pumice extracted in Nevşehir region and found in 4 different ranges of 4-2 mm, 2-1 mm, 1-0.5 mm and 0.5-0 mm were used as aggregate. The determination of grain density, water absorption rate and humidity of acidic pumice for each granulometry was determined according to TS EN 1097-6 standard, while the determination of loose and cramped unit volume mass was determined in accordance with 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

Physical Property	Aggregate Size (mm)			
	4-2	**2-1**	**1-0.5**	**<0.5**
Specific Mass (g / cm^3)	1.00	1.08	1.13	1.88
Dry Specific Mass (g/cm^3)	0.77	0.85	0.91	-
Water Absorption (%)	30.11	26.35	23.59	-
Congested BHK (g/cm^3)	0.469	0.475	0.485	-
Loose BHK (g/cm^3)	0.451	0.448	0.422	-
AggregateHumidity Rate (%)	0.40	0.30	0.30	-

Table 2. Physical Properties of Nevşehir Acidic Pumice

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

2.1.2. Fly Ash

Fly ash used in the study, chemical composition of which is given in Table 3, was obtained from Seyitömer Thermal Power Plant. F-Type fly ash with a mass density of 0.88 g/cm^3, a specific gravity of 1.58 g/cm^3, a specific surface area of 0.115 m^2/g and a pH of 8.3 and a lighter structure than other fly ash was used in the experiments.

Table 3. Chemical analysis of Seyitömer fly ash [39]

Component	%
SiO_2	52.34
CaO	7.47
MgO	5.75
Fe_2O_3	9.30
Al_2O_3	18.91
Na_2O	0.88
K_2O	2.17
SO_3	2.25
Na_2O(eş d)	2.31
Free CaO	0.02

2.1.3. Cement

In the experimental study, CEM I 42.5 N type Portland Cement compatible with TS EN 197-1 was used[40]. Cement was obtained from the Medcem cement factory in Mersin. The amount of cement to be used for the whole series of experiments was calculated and obtained at one time in order to make the experiment results healthier. Cement was stored in a place free of moisture and wet. The chemical and some physical properties of the cement used are given in Table 4.

Table 4. Chemical and physical values of cement and limit values of TS EN197-1

Analysis Results	**CEM I 42,5 N**	**TS EN 197-1**
2 Day Compressive Strength (MPa))	22.4	≥20.0
7 Day Compressive Strength (MPa))	39.4	
28 Day Compressive Strength (MPa))	51.0	62.5 ≤ X ≤ 42.5
SO_3 (%)	2.6	≤ 3.5
MgO (%)	2.1	≤ 5.0
Cl (%)	0.007	≤ 0.1
Loss of Ignition (%)	1.7	≤ 5.0
Thawless Relic (%)	0.3	≤ 5.0
Specific Surface (cm^2/g)	3749	
Initial Set (minute)	161	≤ 60.0
Final Set (Hour)	04:20	
Constancy of Volume (mm)	0.4	≤ 10.0
Free Lime (%)	0.5	-
Equivalent Alkali (Na_2O+0,658K_2O) (%)	-	-
Water Demand (Vicat Water) (%)	29.6	-

2.1.4. Sand

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

2.1.5. Mixing Water

During the experimental study, Mersin city drinking water was used in the production of the test samples in accordance with TS EN 1008 standard [41]. The mixing water was taken from the mains without any process and participated in the production.

2.2. Method

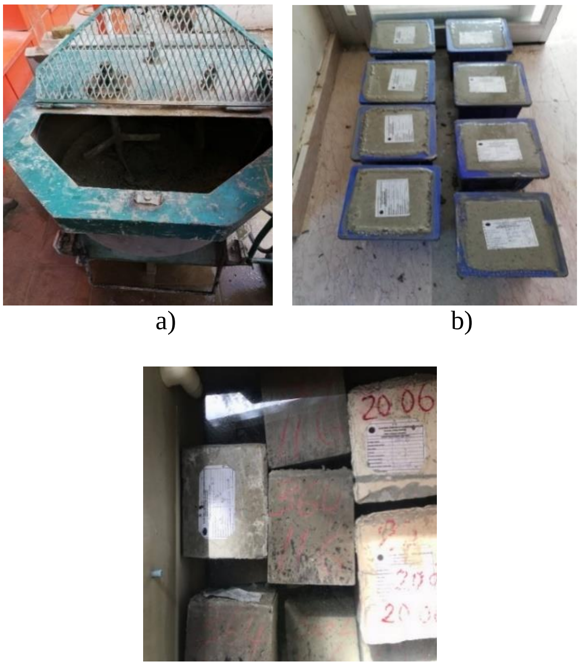
2.2.1. Production of Lightweight Concrete Samples

4 different series of lightweight concrete samples (REF; reference sample, 1% FA; 1% fly ash substituted sample, 3% FA; 3% fly ash substituted sample, 5% FA; 5% fly ash substituted sample) were produced in this study. Since the same amount of water is used in all samples in lightweight concrete production, the water / cement ratio has been kept between 0,25-0,35.
In the study, 90% pumice was used in all samples. 10% sand was added to the mixture to increase the strength. The binding mixture was obtained by substituting fly ash at 1%, 3% and 5% of the amount of cement used and these mixtures were used in production (Table 5). The mixtures were prepared according to TS 2511 standard.

Table 5. Material ratios used in lightweight concrete production

	Pumice (%)	Sand (%)	Cement (%)	Fly Ash (%)
REF	90	10	100	0
1% FA	90	10	99	1
3% FA	90	10	97	3
5% FA	90	10	95	5

First, the light aggregates were placed in the mixer and the water, amount of which was determined for the pre-satiation process was added to allow the mixed aggregates to absorb the water. Then sand was added and mixed until the mixture becomes homogeneous. The mixing process was continued by adding cement and fly ash in determined ratios to the mixture. Finally, a homogeneous mixture was obtained by adding water determined in the mixture calculation and the mixing process was terminated (Figure 1a). The prepared lightweight concrete mixture was placed in 15x15x15 cm^3 cube moulds (Figure 1b). After 1 day, the lightweight concrete samples were removed from the mould and cured in the curing pool at +20°C temperature for 28 days (Figure 1c). After the curing process was finished, the lightweight concrete samples were subjected to experiments to determine the physical and mechanical properties and SEM images were taken for the examination of their microstructure.



a) b) c)

Figure 1. a) Preparation of samples, b) Casting of samples, c) Curing of samples

2.2.2. Experiments Applied to Samples

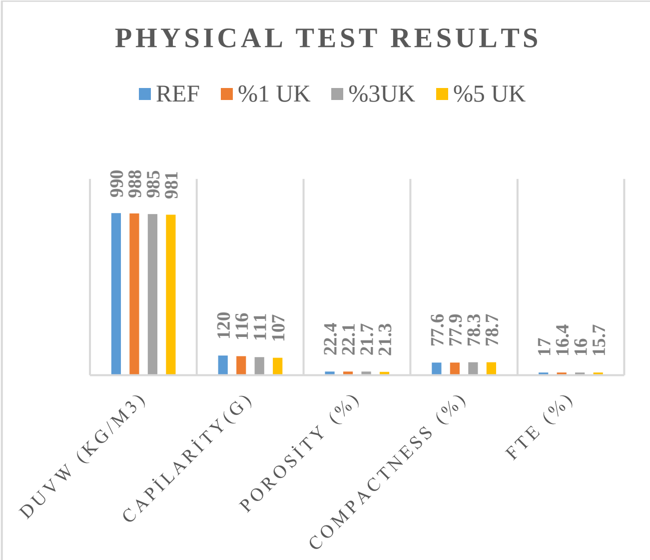
To determine the physical differences, dry unit volume weight, capillary water absorption, porosity, compactness and freeze-thaw experiments were conducted. For the determination of mechanical properties, tensile splitting strength and compressive strength tests were applied. SEM images have been interpreted to examine the structural differences occurring within the material.

3. RESULTS

3.1. Physical Test Results of Samples

In Figure 2, dry unit volume weight, capillary water absorption, porosity, compactness and freeze-thaw effect values of lightweight concrete samples are given.
When dry unit volume weight values are examined, it is observed that the reference sample has the highest value with 990 kg/m^3 and 5% FA has the lowest value with 981 kg/m^3. It has been determined that there is a decrease in DUVW values of the samples produced with the increase of the amount of fly ash. In other words, a lighter concrete material was obtained by using 5% FA.

Capillary water absorption amounts of materials are associated with visible or invisible cavities in their bodies [42]. The more water an object absorbs, the more space it has in its body. When the capillary water absorption values are examined, the reference sample has the highest value with 120 g, while the FA has the lowest value with 107 g of water absorption by 5%. It has been determined that a decrease in capillary water absorption amounts of samples produced with the increase of the amount of fly ash.



**DUVW:Dry Unit Volume Weight; FTE:Freeze-Thaw Effect*

Figure 2. Physical test results of lightweight concrete samples

The findings of capillary water absorption are evaluated together with porosity, as is known, the concrete samples with light aggregates have high porosity and high capillary water absorption amounts. Fly ash substitution reduced porosity and capillary water absorption. This reduction means that the lightweight concrete sample receives less water to its body. This will extend the life of lightweight concrete in the long term and will not adversely affect the built-in comfort conditions.

When the porosity values, which mean the amount of space in the inner structure of the material, were examined, it was observed that the reference sample has the highest porosity with 22.4%. The lowest porosity value of 21,3% was obtained from sample produced by FA substitution of 5%. It was determined that there was a decrease in porosity values of the material with the increase of the amount of fly ash.
When the compactness values which are defined as the ratio of the volume of the full part of the material to the entire volume of the material were examined, it was observed that the reference sample has the lowest compactness with 77.6%. The highest compactness value of 77.8% was obtained from sample produced by FA substitution of 5%. It was determined that an increase in the compactness values of the material occurred with the increase in the amount of fly ash. In other words, fly ash filled the gaps in the material structure to produce a material with a high compactness rate.
When the freeze-thaw effect values given in the chart were examined, the reference sample has the highest value with 17%, while the FA substitution at 5% has the lowest value with 15.7%. It was determined that the freeze-thaw effect of the samples produced decreased with the increase of the amount of fly ash. When the literature is examined; A decrease on the freeze-thaw effect of fly ash substitution with pumice aggregate lightweight concrete samples was observed [44].

3.2. Comparison of Mechanical Test Results of Samples

In Figure 3, compressive strength and tensile splitting strength values of lightweight concrete samples are given.

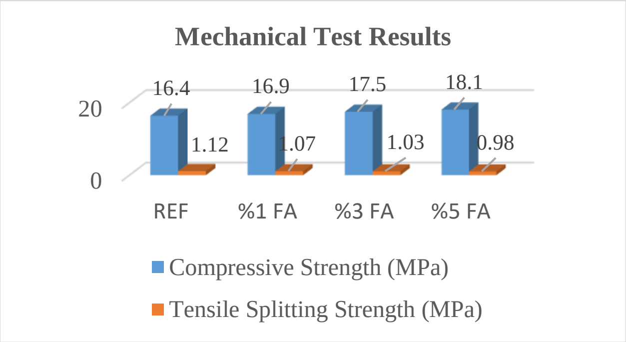


Figure 3. Mechanical test results of lightweight concrete samples

When the Figure 3 was examined, the reference sample has the lowest pressure value with 16.4 MPa, while the lightweight concrete sample produced with 5% FA substitution has the highest compressive strength value with 18.1 MPa. It was determined that the compressive strength of the samples produced was increased with the increase of the amount of fly ash.

The data obtained from the pressure experiment shows that the samples produced using pumice aggregate and 3% and 5% FA have strength values above the determined strength value (17.2 MPa) for structural lightweight concrete in ACI 213R-87. This has shown that lightweight concrete can be produced using the ratios specified in the study.

Although the reference sample and the lightweight concrete sample produced with a FA substitute of 1% cannot be used as a bearing element, it is possible to use as a partitional block element.

When the tensile splitting strength values were examined, it was seen that the reference sample has the highest value with 1,12 MPa. It was determined in the chart drawn from the data that the lowest value was obtained from lightweight concrete sample produced with a FA substitution of 5%. With the increase in the amount of fly ash, it was observed that there was a decrease in the tensile splitting strength values of the samples.

The results found are consistent with those conducted by [43, 44, 45].

3.3. Scanning Electron Microscope (SEM) Images of Samples

The most important feature desired in the material is that its pored structure is regular and crystalline structure. When the SEM image (It was taken from the cement paste-aggregate interface area) of the reference sample given in Figure 4 is examined, it is seen that the material has macro pores and an irregular structure. This cellular structure and the resulting irregular macro pored structure cause the compressive strength of the material to be low.

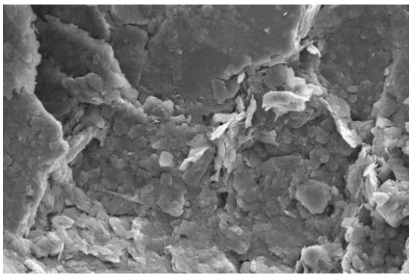
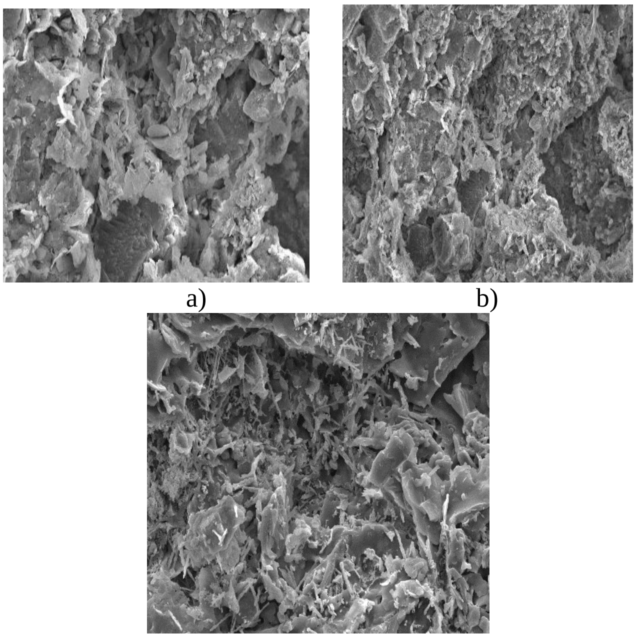


Figure 4. SEM image of reference sample

In Figure 5, SEM images of lightweight concrete samples with fly ash substituted are presented. a) 1% fly ash substituted sample, B) 3% fly ash substituted sample, c) 5% fly ash substituted sample.



a) b)

c)

Figure 5. SEM images of lightweight concretes with a) 1% fly ash substitution, b) 3% fly ash substitution, c) 5% fly ash substitution

When the SEM images were examined, it was seen that the lightweight concrete sample with 1% fly ash substitution has smaller and regular pores than the reference sample. It is seen in the 3% fly ash substituted sample that micro pored structure increases and a more regular structure occurs. It is thought that fly ash fills the voids in light concrete, making the structure more regular. In the sample with 5% fly ash substitution, it is observed that the material is a fibrous regular crystal, micro-pored and grain structure. The grains in the crystal structure appear to be in the form of thin layers. At the SEM images, it is observed that as the amount of fly ash increases in lightweight concrete samples, it becomes a regular and micro-pored structure. This situation provides a positive effect on compressive strength. Furthermore, the material structure has been transformed from macro pore to micro pore by filling the gaps in pumice aggregate with fly ash substitution and by the reactions that took place during production. In addition, the porosity values of the samples were reduced by filling the gaps in the material.

4. CONCLUSION

In the scope of the study, pumice aggregate and fly ash, which is industrial waste, were used as cement substitutes in certain proportions and lightweight concrete samples were produced from the resulting mixture. The experiments and SEM images on the samples are presented below.

- ✓ In the dry unit volume weight experiment, which is one of the physical experiments, a decrease in dry unit volume weight values occurred in parallel with the increased substitution rate with the addition of fly ash.
- ✓ The use of material with low specific gravity such as pumice in the production of lightweight concrete as aggregate will allow the structure's weight to be reduced. This will allow the structure to be subjected to lower levels of earthquake loads.
- ✓ There has been a decrease in the capillary water absorption and porosity values of the lightweight concrete with the increase of fly ash substitution and the best result was obtained from the lightweight concrete sample produced with 5% FA substitution. When the compactness values and looking at the effect on freeze-thaw pressure; It has been observed that these values increase with the increase in the amount of UK.
- ✓ As a result of the experiments performed for the determination of mechanical properties; It was determined that with the increase in the amount of fly ash substitution, compressive strength of lightweight concrete increases, and the tensile splitting strength of it decreases.
- ✓ As a result of the SEM images of the lightweight concrete samples, it was observed that the reference sample has macro pores and an irregular structure irregular structure. With the increase in the amount of fly ash, the internal structure of the material has been transformed into a micro-pored regular crystal structure.
- ✓ 5% of fly ash substituted sample was found to has superior structural character compared to other samples.

According to the findings of the study, it was concluded that fly ash improves the properties of lightweight concrete and there would be no harm in its use if substituted at appropriate rates. The use of fly ash, which is industrial waste, in the production of lightweight concrete, will not only contribute to sustainability but also protect the environment by disposing waste, but also reduce the cost of waste storage.

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