DECEMBER 2019 M.Sc. in Civil Engineering YUNUS EMRE TURAN

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COMPARISON OF MECHANICAL AND THERMAL PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETES

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YUNUS EMRE TURAN

COMPARISON OF MECHANICAL AND THERMAL PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETES

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by

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Yunus Emre TURAN

ABSTRACT

COMPARISON OF MECHANICAL AND THERMAL PROPERTIES OF LIGHTWEIGHT AGGREGATE CONCRETES

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M.Sc. in Civil Engineering
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The concept of energy efficiency, which we often hear today, is gaining importance in our country and in the world. In this context, the construction sector has started to work on improving the energy efficiency of concrete and turned to lightweight concrete. Aggregates constitute of 60 - 85% of the concrete by volume and therefore, by using aggregates with low unit volume weight, concrete has been thermally insulated and serious steps have been taken in terms of energy efficiency. Pumice, which is often preferred in the global construction industry in terms of thermal and acoustic insulation, is a lightweight aggregate with abundant reserves in Turkey. It is cheap due to existing reserves in Turkey, has low cost of transportation and labor because of its lightness, and it is an important raw material as it provides insulation 6 times more efficiently than traditional concrete. In this study, lightweight concrete samples were prepared by adding expanded perlite at 3% and 5% ratios to Nevsehir, Isparta, Tomarza pumices. These samples were subjected to compressive strength, flexural strength and thermal conductivity coefficient tests. As a result of the study, the highest compressive and flexural strength was obtained as 19.911 MPa and 3.48 MPa from the samples formed by using Isparta Pumice aggregate. In terms of thermal conductivity coefficient, the best result was obtained from Tomarza Pumice sample as 0.8887 (W / mK). The use of perlite has a negative effect on compressive and flexural strengths and has a positive effect on thermal conductivity coefficient.

Keywords: Pumice, Perlite, Thermal Conductivity, Lightweight Aggregate

ÖZET

HAFİF AGREGALI BETONLARIN MEKANİK VE ISIL ÖZELLİKLERİNİN KARŞILAŞTIRILMASI

TURAN, Yunus Emre
Yüksek Lisans Tezi, İnşaat Mühendisliği
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Günümüzde sıklıkla duyduğumuz enerji verimliliği kavramı, ülkemizde ve dünyada gittikçe önem kazanmaktadır. Bu bağlamda inşaat sektörü, betonun enerji verimliliği açısından iyileştirilmesi için çalışmalara başlamıştır ve hafif betonlara yönelmiştir. Betonun hacimsel olarak % 60 – 85' ini oluşturan agregaların birim hacim ağırlığı düşük olanları kullanarak betona ısı yalıtımı özelliği kazandırılmış, enerji verimliliği konusunda ciddi adımlar atılmıştır. Isı ve ses izolasyonu bakımından dünyada inşaat sektöründe sıklıkla tercih edilen pomza, Türkiye'de bol miktarda rezervi bulunan hafif agregadır. Ülkemizde rezervi bulunmasından dolayı ucuz, hafif olmasından dolayı nakliye ve işçiliği az, geleneksel betona kıyasla 6 kat izolasyon sağlaması sebebiyle önemli bir hammaddedir. Bu çalışmada, Nevşehir, Isparta, Tomarza pomzaları ve Isparta pomzasına ek olarak % 3 ve % 5 oranında genleştirilmiş perlit eklenerek hafif beton numuneleri hazırlanmıştır. Hazırlanan bu numuneler basınç dayanımı, eğilme dayanımı ve ısıl iletkenlik katsayısı deneyine tabii tutulmuştur. Çalışma sonucunda en yüksek basınç ve eğilme dayanımı Isparta Pomzası agregasıkullanılarak oluşturulan numunelerden 19.911 MPa ve 3.48 MPa olarak elde edilmiştir. Isıl iletkenlik katsayısı bakımından en iyi sonuç Tomarza Pomzası numunesinden 0.8887 (W/mK) olarak elde edilmiştir. Perlit kullanımı basınç ve eğilme dayanımlarına olumsuz etki ederken, ısıl iletkenlik katsayısına olumlu etkide bulunmuştur.

Anahtar Kelimeler: Pomza, Perlit, Isıl İletkenlik, Hafif Agrega.

''Dedicated to my wife and daughter''

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$\mathbf{f_c}$	Compressive Strength
$\mathbf{f_{cf}}$	Flexural Strength

LIST OF ABBREVIATIONS

m^3	Cubic Meter
kg	Kilogram
B.C.	Before Christ
MPa	Megapascal
gr	Gram
cm^3	Cubic Centimeter
C	Centigrade
kcal	Kilocalorie
TSI	Turkish Standards Institution
dm^3	Cubic Decimeter
w/c	Water / Cement
mm	Millimeter
N	Newton
mm^2	Square Millimeter

CHAPTER I

INTRODUCTION

Today, with the increase in population density, the needs in the construction sector have increased rapidly. Since its raw materials are found in nature and can be easily produced, the construction material that provides the fastest and economical solution to these needs has been concrete. Consisting of cement, water, aggregate and additives; concrete is a composite material formed by hardening the mixture prepared according to specific needs in the desired molds [1]. Besides providing economic and fast solutions, being resistant to external factors promotes the widespread use of concrete. With the advancement of technology, the emergence of different needs has led to innovations in the concrete industry. To meet different needs, special concretes have begun to be produced for various places of use. Concrete needs to be highly durable and workable, regardless of its purpose [2].

Aggregates, constituting 60-85% of concrete's volume, significantly affect the characteristics of the concrete. Depending on the aggregate used, the unit weight of concrete can be decreased or increased. Concretes with high unit volume weight have high thermal conductivities despite their strength [3]. Lightweight concrete, which is one of the special concrete types, has low thermal conductivity and unit volume weight. Lightweight concretes, which are especially preferred in terms of energy efficiency, reduces the load of the structure in addition to providing heat and sound insulation, thus reducing the incoming earthquake loads. Reducing the load on the carrier elements causes the dimensions of the carrier elements to decrease and thus the earthquake effect is reduced [4]. Thanks to its many advantages, lightweight concrete, which is used for various purposes in the construction sector, has recently been used more [5].

Lightweight concrete, which is of great importance in the construction sector, is provided by forming hollow aggregates or hollow internal structures [6]. Lightweight aggregates, called hollow aggregates, are obtained naturally or artificially. Although artificial aggregate production is not widespread in our country, there are natural aggregate reserves. The use of these existing natural aggregate reserves reduces the cost of concrete.

Natural lightweight aggregates that provide good thermal insulation with hollow and spongy appearance are volcanic rocks, and form the hollow structure with the effect of gas and air upon cooling of lava. These spongy and hollow aggregates are also called volcanic aggregates [7]. In our country, there are pumice, perlite, volcanic tuff and slag.

80% of the pumice aggregate, which is thought to have reserves of 15 billion m3 in total, is used in various fields in the construction sector. Pumice reserves in Turkey are concentrated in and around Kayseri, Nevsehir, Nigde, Van, Bitlis, Isparta and Osmaniye provinces. Pumice, which has a wide usage area in the construction sector with its porous structure and insulation effect, was also used in Ancient Greek and Roman periods. The superior properties of pumice include low unit volume weight, low cost, providing good insulation and reducing dead loads in structures.

Our country has 70% of the total reserve of perlite which has a glassy structure and expands when heated in a controlled manner [8]. Studies on perlite, which is thought to have a reserve of 4.5 billion tons in our country, have increased in order to be used more effectively in the construction sector [9]. America, one of the largest producers in the world, used 417 thousand tons of perlite in the construction sector in 2005 [10, 12]. Used as lightweight aggregate in insulation concretes, perlite is a raw material with high silica content. It contains 70-75% SiO2 and 2-5% water. When heated instantly, perlite’s water content evaporates and expands, transforming into foam aggregate. With this expansion, it can increase to 20 times its initial volume [11, 13].

In this study, lightweight concrete samples were prepared by using Isparta Pumice, Nevşehir Pumice and Tomarza Pumice as light aggregate. In addition to these, perlite was added to mixture, in the amounts of %3 and %5 of the total aggregate mass of

Isparta Pumice. The mechanical properties and thermal conductivity of these prepared lightweight concrete samples were compared and the effect of perlite on thermal conductivity in lightweight concrete was investigated.

1.1 Lightweight Concrete

Concretes with a unit volume weight greater than 800 kg / m^3 and less than 2000 kg / m^3 are called lightweight concrete [14]. While the unit weight of lightweight concrete varies between 300-1800 kg / m^3, those whose unit weight is less than 800 kg / m^3 are called very lightweight concrete.

The history of lightweight concretes dates back to 3000 BC. They can be found in many old structures including Roman temple Pantheon, in the Mughal Palaces in Iraq, in the Hagia Sophia Museum and St. Sofia Cathedral [7-15]. Nowadays, the popularity of lightweight concrete increased due to its good thermal insulation, low unit volume weight and high durability [7].

It is possible to classify lightweight concretes according to their functions and unit volume weights. In terms of their functions, lightweight concretes are divided into three groups: insulation concretes, medium strength concretes and structural lightweight concretes [16-18].

Insulation Concrete: Concrete used for thermal insulation rather than structural purposes, unit volume weights vary between 300-800 kg / m^3.

Medium Strength Concrete: Concrete in the middle class in terms of strength and thermal insulation, with compressive strengths between 7-17 MPa.

Structural Lightweight Concrete: Concrete with a unit volume weight of 1450-1800 kg / m^3 with compressive strength not less than 17,2 MPa

Table 1.1 shows the compressive strengths, heat conduction coefficients and kiln dry unit weights according to the classification made by the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM)

Table 1.1 Classification made by RILEM [12,19]

Class	I	II	III
Lightweight Concrete Type	Structural	Structural and Insulation	Insulation
Kiln Dry Unit Weights (kg/m^3)	1600-2000	<1600	<<1450
Compressive Strength (MPa)	>15,0	>3,5	>0,5
Thermal Conductivity (W/mK)	-	<0,75	<0,30

Lightweight concrete can be used in roofs, floors, building foundations and terraces, where heat insulation is required, decorative panels, water drainage systems, filling insignificant gaps in roads and bridges, floor improvement, reducing dead loads in high-rise buildings, areas with fire risk, etc.

1.2 Pumice

Pumice (Figure 1.1), formed by sudden cooling of molten silica, is a volcanic rock with porous and light structure. Pumice is a light-colored, extremely porous igneous rock that forms during explosive volcanic eruptions. It is used as aggregate in lightweight concrete, as landscaping aggregate, and as an abrasive in a variety of industrial and consumer products. Many specimens have a high enough porosity that they can float on water until they slowly become waterlogged. With the increasing importance given to lightweight construction elements; as a lightweight aggregate pumice has a vast range of use in the construction industry, due to its low unit volume weight, high levels of thermal and acoustic insulation, fluid retention, reducing effect against earthquake loads and low cost [20].

The pores in the structure of the pumice stone (vesicles) give a clue as to the formation of this stone. The structural formation, called vesicular, occurs during rapid cooling of the magma melt containing abundant foam. As a result of sudden temperature drop, gas bubbles are trapped in the rock. The cooling rate of the material is so high that the atoms in the magma harden without crystallization. The structure of the pumice stone is therefore an amorphous volcanic glass known as mineraloid.

Figure 1.1 Pumice aggregate

The most common of pumice which can be divided into acidic and basic pumices, is acidic pumice. Acidic pumice; white or off-white color, has a density of less than 1 g / cm^3 and hardness of 5-6 according to Mohs scale. The basic pumice is brown or black in color with a density of 1-2 g / cm^3 and a hardness of 5-6.

Turkey is thought to have 3 billion m^3 of pumice reseves. Although it is concentrated in Central Anatolia and Eastern Anatolia regions, it is also found in the Mediterranean and Aegean regions [21].

The 24 hours water absorption percentage of pumice that contains %70 air is around 20% in fine aggregate and 30% in coarse aggregate. Water absorption capacity, water absorption rate and the percentage of contained moisture should be taken into account in concrete mixture calculations [22-24].

1.3 Perlite

Perlite, which is a volcanic rock, can expand up to 20 times its raw state upon heating and has a very light and porous structure. The color of its raw form varies from light gray to bright black, while its expanded form is white perlite. Perlite is an amorphous volcanic glass (SiO_2) that has relatively high water content, typically formed by the hydration of obsidian. Perlite has the unusual characteristic of expanding and becoming porous when it is heated. It can expand to as much as twenty times its original volume. Figure 1.2 shows expanded perlite.

Figure 1.2 Expanded perlite

After the raw perlite is preheated to 400 ° C, it is instantly heated to 750-1200 ° C. Thus, the water evaporates and expands into foam aggregate [12]. The physical properties of raw and expanded perlite are shown in Table 1.2.

Table 1.2 Physical properties of raw and expanded perlite [12,25-27]

Properties	**Raw Perlite**	**Expanded Perlite**
Color	Shades of Black and Gray	White
Specific Gravity (kg/m^3)	2200-2400	55-300
Unit Weight (kg/m^3)	950-2700	30-250
Softening Point (C°)	871-1093	-
Melting Point (C°)	1260-1343	1300
Specific Heat (kcal/kg C°)	0,20-0,23	-
Hardness (Mohs)	5-6	-
Thermal Conductivity(W/mK)	-	0,04
Thermal Expansion (m/m K)	-	$4*10^{-6}$-$11*10^{6}$
Fire Resistance	-	Noncombustible
Sound Absorption	-	0,60

Providing high levels of sound and heat insulation, perlite is preferred in construction, agriculture, industry and many other sectors. It has a widespread use in several areas including roof and floor insulation, heat and sound insulation, areas with fire risk, lightweight concretes and plasters.

CHAPTER II

LITERATURE REVIEW

Numerous research and studies have been carried out on lightweight concrete and lightweight aggregates which have been the focus of interest of academicians from past to present.

Dhir et al. [28] aimed to produce structural lightweight concrete with a strength of 50 MPa, using lightweight aggregate and water-reducing additive. It was also observed in this study that water-cured concrete has higher strength [28].

Türkmen and Kantarcı [29] investigated the 28-day compressive strength and permeability coefficients of normal aggregate and expanded perlite aggregate under different curing conditions. The cement and water / binder dosage were kept constant and the concrete samples were cured in 5 different environments. It was observed that the permeability coefficient increased as the expanded perlite aggregate increased, while a decrease in compressive strength of 28 days was observed [29].
Senturk et al. [30] investigated the usability of Isparta region's pumice stone in structures. They concluded that Isparta pumice stone is not suitable as a carrier building element, but it can be preferred as insulation raw material [22].

In his study using expanded perlite aggregate, Azizi [12] observed that thanks to the round and smooth structure of expanded perlite aggregate, the workability increased in fresh lightweight concrete and fresh unit volume weight could change accordingly [12]. For workability to increase, one of the biggest problems encountered in lightweight concrete produced using lightweight aggregate, half of the total aggregate volume should be fine aggregate [30,31].

As a result of his study where he investigated the change in compressive strength of lightweight concrete produced by using pumice from Nevşehir, Kayseri and İzmir regions under different temperature applications; Ceylan [32] observed that the pumice from İzmir region has the highest compressive strength at high temperatures. [32].

Sarıışık [33] investigated the accordance of pumice and expanded polystyrene foam produced blocks to TS EN standards. The heat conductivity and unit volume weight were lower in the produced blocks compared to other building blocks [33].

Temiz and Akçakale [34] investigated the compressive strengths and thermal conductivityies of samples obtained by adding fly ash, wood shavings and ground orange peel to lightweight concretes produced using pumice aggregate. The lowest thermal conductivity value, 0,3417 W / mK, was observed in the sample with fly ash and wood shavings [34].

Blanco et al. [35], obtained lightweight concrete using waste coal produced as a result of burning coal in thermal power plants. The samples were cured in two different ways: Some of the samples were cured with 95% moisture while others were using water. In the study, it is stated that the strength was increased as the curing time increased, and the highest strength obtained was 33 MPa [35].

Gao et al. [36] studied the effect of fibers in lightweight concretes with high strength. They stated that the fibers prevent cracks in the aggregate from reaching the matrix; reported that it does not provide a significant contribution to compressive strength but increases tensile strength up to 90% [36].

Uygunoğlu and Ünal [37] applied autoclave pressure, water and air curing to lightweight concrete mortars produced with pumice aggregate. As a result of the study, it was observed that the mechanical and physical performances of autoclave pressurized steam-cured lightweight concrete mortars yielded better results [37].

Hieronimi et al. [38] used pumice and natural slag as aggregates in their study. Samples were obtained by substituting 10-20-30% and 40%. The sample obtained from Portland cement was used as the control sample. As a result of the study, the optimum substitution level for both aggregates was found to be 10% [38].

Subaşı [39] changed the cement dosages of lightweight concrete samples produced by using expanded clay light aggregate. The physical and mechanical properties of the samples were investigated and lightweight concrete with a compressive strength of 41,27 MPa and a density of 1,7 kg / m3 were obtained [39].

Sadrekarimi [40] investigated the producibility of lightweight reactive powder concrete. The lightweight reactive powder concrete was produced with a total binder amount of 1400 kg / m^3, silica fume and superplasticizer added, and a w / c ratio between 11,8-16,2%. At the end of the study, lightweight reactive powder concrete with a strength of 280 MPa and a density of 1,93 kg/dm^3 was produced [40].

Gökçe [41] investigated the producibility of lightweight concrete by using raw and expanded perlite aggregate. Gökçe produced 16 different samples with 5 different size perlite aggregates. High strength lightweight concrete was produced by substituting with silica fume at the rates of 0%, 5%, 10%, 15%. 28-day compressive strength of hardened lightweight concrete samples remained in the range of 10-86,4 MPa [41].

Taşdemir [42], using styrofoam and pumice aggregates, produced lightweight and semi-lightweight concrete with different unit volume weights. The compressive strength and thermal conductivity of the samples were evaluated. As a result of this study, it was observed that with stropor aggregate, lightweight concrete can be produced in the unit weight range of 300-1600 kg / m3. It was observed that as the unit weight increased, the compressive strength and thermal conductivity values of the lightweight concrete produced with pumice aggregate increased. At the end of the study, Taşdemir recommended the use of lightweight and semi-lightweight concretes for the regions located in cold climates and earthquake belts [42].

CHAPTER III

MATERIALS AND METHODS

3.1 Materials

3.1.1 Cement

Cement, which is one of the most important components affecting the strength and unit price of concrete, should be selected in accordance with the intended use. In this study; CEM I 42,5 R that is produced in Çimsa A.Ş. Kayseri Factory following TS EN 197-1: 2011 standards was used. The physical, mechanical and chemical properties of the cement used in the study were obtained from the company and are given in Table 3.1 and Table 3.2.

Table 3.1 CEM I 42,5 R Physical and mechanical properties

PHYSICAL PROPERTIES		RESULT	METHOD
Density (gr/cm^3)		3,13	EN 196-3.6
Setting Time (Minute) (Vicat)	Start	175	EN 196-3.6
Setting Time (Minute) (Vicat)	Finish	235	EN 196-3.6
Setting Time (Minute) (Vicat)	% Water Requirement	286	EN 196-3.6
Volume Expansion (mm) (Le Chatelier)		0,0	EN 196-3.6
Specific Surface (cm^2/gr) (Blaine)		3685	EN 196-3.6
Compressive Strength	2 days N/mm^2	30,2	EN 196-1
Compressive Strength	7 days N/mm^2	-	EN 196-1
Compressive Strength	28 days N/mm^2	47,9	EN 196-1

Table 3.2 CEM I 42,5 R Chemical properties

CHEMICAL PROPERTIES	RESULT (%)	METHOD
SiO_2	-	XRF
Al_2O_3	-	
Fe_2O_3	-	
CaO	-	
MgO	3,41	
SO_3	3,25	
Na_2O	0,21	
K_2O	0,44	
Ignition Loss	3,86	EN 196-2
Insoluble Matter	0,65	
Cl^-	0,0410	
Equivalent Alkali, Na_2O	0,50	

3.1.2 Aggregate

In this study, Isparta pumice, Nevşehir pumice and Tomarza pumice were used as lightweight aggregate to produce lightweight concrete blocks. Isparta pumice was obtained from Isparta Municipality facility BİLMAŞ Briquette Factory, Nevşehir pumice from Blokbims, and Tomarza pumice was obtained from Doğanlar Bims. Aggregate sizes in the range of 0-3 mm, 3-8 mm, 3-13 mm, 5-13 mm, 7-15 mm, 15-25 mm were preferred. Pumice aggregates of different sizes are shown in Figure 3.1.

Figure 3.1 Pumice aggregates in different sizes.

Specific gravity and water absorption tests of Isparta pumice were carried out in accordance with TS EN 1097-6 standard. The results are presented in Table 3.3. The different sizes of Isparta pumice used are shown in Figure 3.2.

Table 3.3 Physical properties of Isparta Pumice

PHYSICAL PROPERTIES	Aggregate Size (mm)			
	Sand	Fine Gravel	Coarse Gravel (1)	Coarse Gravel (2)
	0-3 mm	0-3mm	3-8 mm	5-13mm
Specific Gravity (kg/m^3)	0	1,75	1,61	1,66
Water Absorption (%)	0	0,2	0,4	0,3

Figure 3.2 Isparta pumice

Water absorbtion test of the material shown in Figure 3.3. The results of the sieve analysis (Table 3.4) of Isparta pumice with lower and upper limits are shown in Figure 3.4 and are made according to TS EN 933-1. Physical properties of the material shown in Table 3.5.

Table 3.4 Isparta Pumice sieve analysis

Isparta Pumice								
0-3 Sieve Analysis			Fine Aggregate			Coarse Aggregate		
4mm	0,002	kg	8mm	0,096	kg	12,5mm	0,234	kg
2mm	0,144	kg	5,6mm	0,2	kg	11,2mm	0,106	kg
1.15mm	0,123	kg	4mm	0,0935	kg	9,6mm	0,3125	kg
1mm	0,063	kg	2mm	0,0985	kg	8mm	0,043	kg
0,600mm	0,052	kg	1.15mm	0,027	kg	5,6mm	0,0055	kg
0,500mm	0,041	kg	1mm	0,035	kg	pan	0,03	kg
0,300mm	0,0655	kg	0,600mm	0,0115	kg			kg
0,250mm	0,003	kg	0,500mm	0,0055	kg			kg
0,125mm	0,023	kg	pan	0,0895	kg			kg
0,063mm	0,115	kg			kg			kg
pan	0,075	kg			kg			kg
Total	0,7065	kg	Total	0,6565	kg	Total	0,731	kg

Table 3.5 Physical properties of Isparta Pumice

Saturated Dry Surface Weight (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,9785 kg	1,3285 kg
Weight in Water (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,3715 kg	0,53 kg
Dried Weight in Oven (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,701 kg	1,0275 kg
Saturated Dry Surface Specific Gravity	
Fine Aggregate	Coarse Aggregate
1,612026 kg	1,663745 kg
Water Absorption Percentage	
Fine Aggregate	Coarse Aggregate
39,58631 (%)	29,2944 (%)

Figure 3.3 Water absorption test

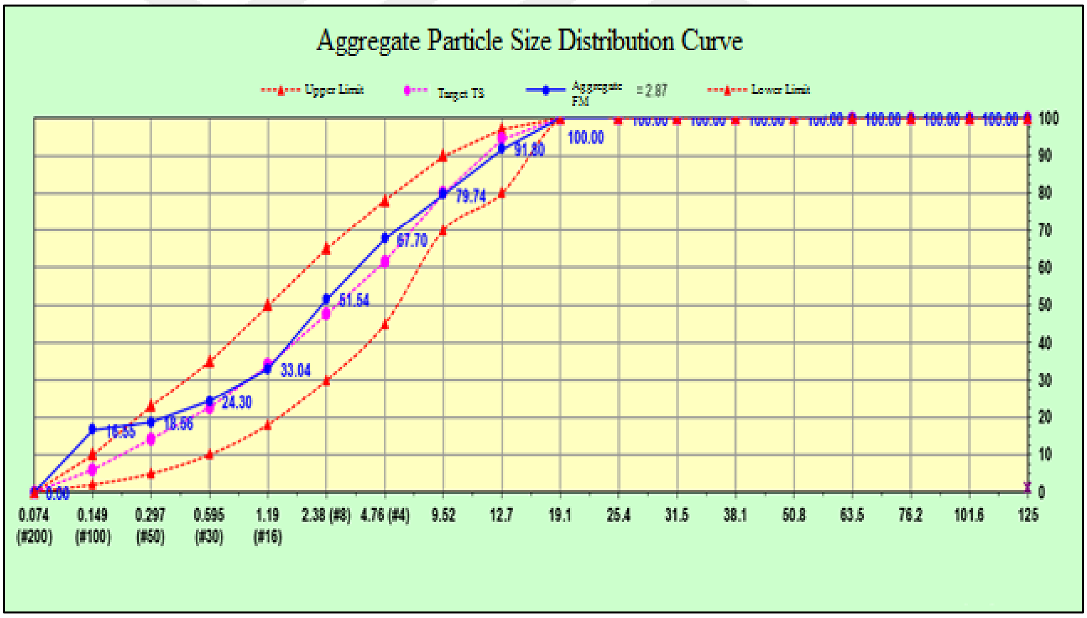

Figure 3.4 Aggregate particle size distribution curve of Isparta pumice

Specific gravity and water absorption tests of Nevşehir pumice were carried out in accordance with TS EN 1097-6 standard. The physical properties of the material is shown in Table 3.6 and Table 3.8. Sieve analysis of the material is shown in table 3.7. Nevşehir pumice of different sizes used can be seen in Figure 3.6.

Table 3.6 Physical properties of Nevşehir Pumice

Physical Properties	Aggregate Size (mm)			
	Sand	Fine Gravel	Coarse Gravel (1)	Coarse Gravel (2)
	0-3 mm	0-3mm	3-8 mm	5-13mm
Specific Gravity (kg/m^3)	0	1,71	1,34	1,28
Water Absorption (%)	0	0,1	0,9	0,9

Figure 3.5 Nevşehir pumice

The results of the sieve analysis of Nevşehir pumice were given in Figure 3.6 with lower and upper limits and were performed according to TS EN 933-1.

Table 3.7 Sieve analysis of Nevşehir Pumice

Nevşehir Pumice								
0-3 Sieve Analysis			Fine Aggregate			Coarse Aggregate		
4mm	0,001	kg	16mm	0,037	kg	16mm	0,5	kg
2mm	0,525	kg	12,5mm	0,365	kg	12,5mm	0,244	kg
1,15mm	0,56	kg	11,2mm	0,1305	kg	pan	0,01	kg
1mm	0,1865	kg	9,6mm	0,2815	kg			kg
0,600mm	0,0935	kg	8mm	0,112	kg			kg
0,500mm	0,0435	kg	5,6mm	0,054	kg			kg
0,300mm	0,033	kg	pan	0,017	kg			kg
0,250mm	0,0005	kg			kg			kg
0,125mm	0	kg			kg			kg
0,063mm	0,0285	kg			kg			kg
pan	0,024	kg			kg			kg
Total	1,4955	kg	Total	0,997	kg	Total	0,754	kg

Table 3.8 Physical properties of Nevşehir Pumice

Saturated Dry Surface Weight (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
1,74 kg	1,826 kg
Weight in Water (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,44 kg	0,3995 kg
Dried Weight in Oven (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,9245 kg	0,9865 kg
Saturated Dry Surface Specific Gravity	
Fine Aggregate	Coarse Aggregate
1,338462 kg	1,280056 kg
Water Absorption Percentage	
Fine Aggregate	Coarse Aggregate
88,20984 (%)	85,09883 (%)

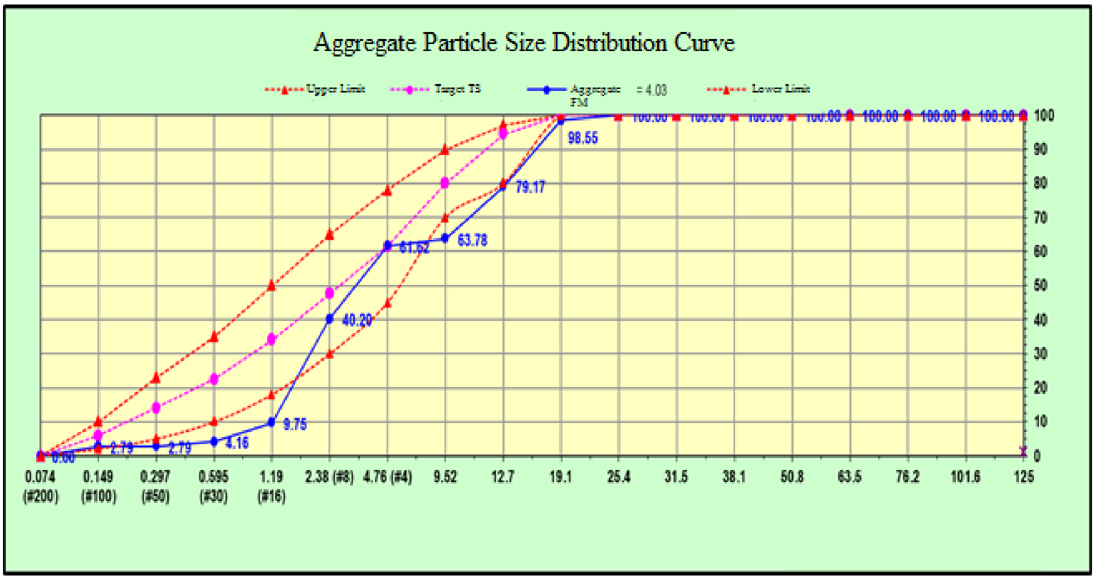

Figure 3.6 Aggregate particle size distribution curve of Nevşehir pumice

When Figure 3.6 is examined, it is seen that the aggregate grain size distribution curve of Nevşehir pumice does not meet the upper and lower limits. Due to the production conditions, it is seen that the fineness modulus is not good and coarse aggregate and sand are more present

The specific gravity and water absorption tests of Tomarza pumice were carried out in accordance with TS EN 1097-6 standard. The sieve analysis result of the material is presented in Table 3.10. Tomarza pumice of different sizes used is shown in Figure 3.7. Physical properties of the material is shown in Table 3.9 and Table 3.11.

Table 3.9 Physical properties of Tomarza pumice

Physical Properties	Aggregate Size (mm)			
	Sand	Fine Gravel	Coarse Gravel (1)	Coarse Gravel (2)
	0-3 mm	3-7mm	7-15mm	15-25mm
Specific Gravity (kg/m^3)	0	1,80	1,64	1,44
Water Absorption (%)	0	0,3	0,4	1,2

Figure 3.7 Tomarza pumice

The results of the sieve analysis of Tomarza pumice were shown in Figure 3.8 with lower and upper limits and were made according to TS EN 933-1.

Table 3.10 Sieve analysis of Tomarza Pumice

Tomarza Pumice								
0-3 Sieve Analysis			Fine Aggregate			Coarse Aggregate		
4mm	0,0005	kg	8mm	0,002	kg	11,2mm	0,1155	kg
2mm	0,095	kg	5,6mm	0,2265	kg	9,6mm	0,129	kg
1,15mm	0,184	kg	4mm	0,0075	kg	8mm	0,1585	kg
1mm	0,183	kg	2mm	0,0015	kg	5,6mm	0,191	kg
0,600mm	0,2085	kg	pan	0,009	kg	pan	0,016	kg
0,500mm	0,157	kg						
0,300mm	0,1585	kg						
0,250mm	0,0015	kg						
0,125mm	0,0095	kg						
0,063mm	0,0875	kg						
pan	0,0365	kg						
Total	1,1215	kg	Total	0,2465	kg	Total	0,61	kg

Table 3.11 Physical properties of Tomarza Pumice

Saturated Dry Surface Weight (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
1,2895 kg	1,5935 kg
Weight in Water (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,505 kg	0,4885 kg
Dried Weight in Oven (for 1kg sample)	
Fine Aggregate	Coarse Aggregate
0,897 kg	0,7135 kg
Saturated Dry Surface Specific Gravity	
Fine Aggregate	Coarse Aggregate
1,643722 kg	1,442081 kg
Water Absorption Percentage	
Fine Aggregate	Coarse Aggregate
43,75697 (%)	123,3357 (%)

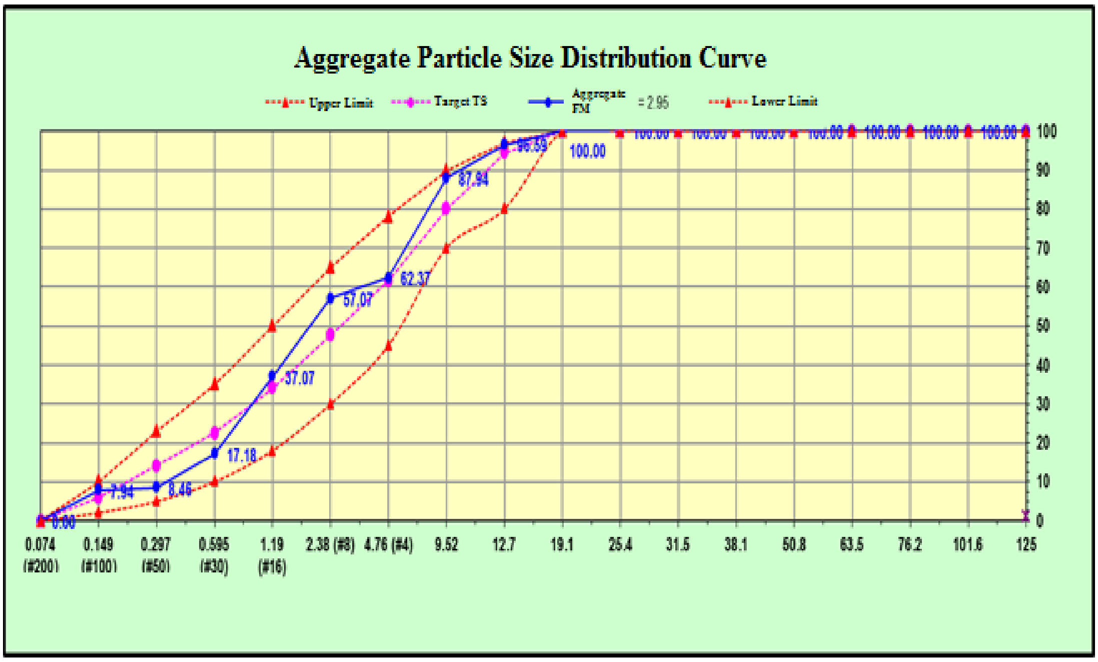

Figure 3.8 Aggregate particle size distribution curve of Tomarza pumice

To compare the lightweight concrete samples prepared with 3 different aggregate types under equal conditions, the methylene blue test was applied to the aggregates. The test was carried out in accordance with TS EN 933-9 + A1 standards, and the results for the pumice used are given in Table 3.12. Figure 3.9 shows the Methylene blue test set up of the material.

Table 3.12 Methylene blue test results

Aggregate	Result
Isparta Pumice	1,25
Nevşehir Pumice	1,25
Tomarza Pumice	1,25

Figure 3.9 Methylene blue test set up

3.1.3 Mixing Water

The water to be used in concrete production must be drinkable, clear, clean and odorless. The water to be used in the mixture should not be acidic or basic. Unsuitable mixing water may adversely affect concrete quality. The mixed water used is “potable.”

3.1.4 Chemical Additive

Water reducer/plasticizer high in BASF was used in the study both to increase machinability and to keep final strength high. Technical specifications of the chemical additive obtained from the company are given in Table 3.13.

Table 3.13 Technical properties of chemical additives

TECHNICAL PROPERTIES	
Material Structure	Modified lignin sulfonate based
Appearance	Light brown - Liquid
Specific Gravity (20 C°- g/cm^3)	1,086
pH value	7,8
Alkali Content (%)	3,64
Chlorine Ion Content (%)	0,0675
Solid Content (%)	17,16

3.1.5 Perlite

Perlite is a light and glassy type of rock which provides high sound and heat insulation in its expanded form. The fact that it can be used in many sectors such as construction, agriculture, food, pharmaceutical and chemical, ceramic and glass, metallurgy increases the importance of perlite. Perlite, which has many advantages including as heat and sound insulation, earthquake mitigation, is an important raw material for the construction sector. There are many applications in the construction sector such as perlite plasters, lightweight concretes with perlite aggregate-perlite added, loose fillers, building elements that require heat-sound insulation. The fact that perlite-doped concrete provides 10 times better heat and sound insulation than normal concrete increases the importance of perlite doped concretes in the sector [45]. Figure 3.10 shows different dimensions of expanded perlite.

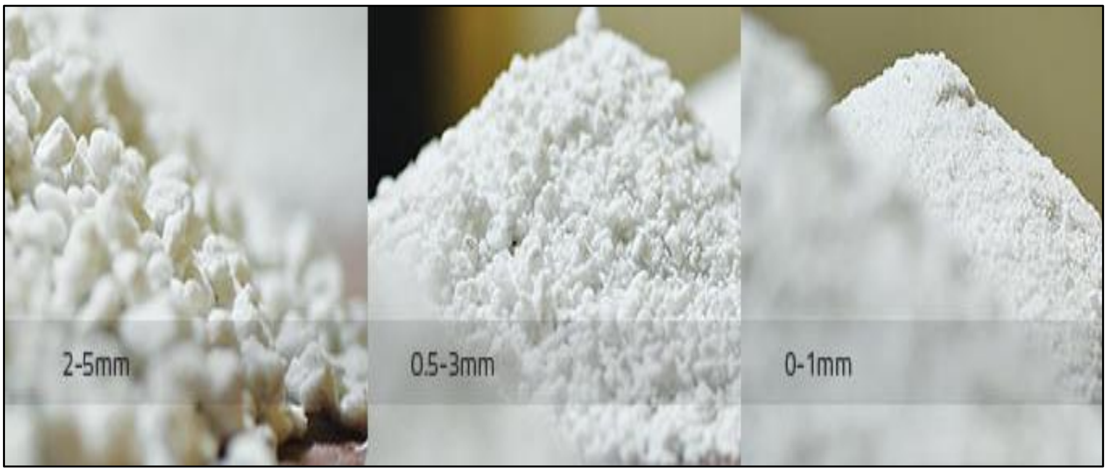

Figure 3.10 Expanded perlite in different sizes [45]

In this study, the expanded perlite was obtained from Gaziantep Europer Perlit. The expanded perlite supplied is shown in Figure 3.11.

Figure 3.11 Expanded perlite

3.2 Test Methods

3.2.1 Lightweight Concrete Mixture Calculations

Concrete production using lightweight aggregates that have high rates of water absorption is a very difficult process. Due to the high rates of water absorption of the aggregates, it is not possible to start the water / cement ratio at minimum rates. The unsuitable water / cement ratio results in the aggregates absorbing water and inadequate hydration of the cement. This result does not provide the desired strength for concrete. In addition to the water required for hydration of the cement, the amount of water absorbed by the aggregates in 24 hours should be added to the mixing water.

In this study; Isparta pumice, Nevsehir pumice and Tomarza pumice were used as aggregates. %61 of the lightweight concrete prepared with Isparta pumice contains aggregates of 0-3 mm, 21% 3-8 mm and 18% 5-13 mm. The lightweight concrete prepared with Nevşehir pumice contains aggregates in the range of 3-13 mm, 61% and 5-13 mm, 39%. The lightweight concrete prepared with Tomarza pumice contains aggregates in the range of 3-7% in 61%, 7-15 mm in 21%, and 15-25 mm in 18%. Water / cement ratio was calculated separately for each mixture. Water quantities were calculated by taking into account the 24-hour water absorption of the aggregates. The cement dosage and the amount of water reducing / superplasticizer were kept constant for each mixture. Mixing calculations for all aggregates were made in accordance with TS 2511: 2017 standard. Table 3.14 shows the mixture calculation for Isparta pumice.

Table 3.14 Isparta pumice lightweight concrete mixture calculations

Isparta Pumice	
Material	Amount
Cement (kg)	360
Water (kg)	195
Water/Cement	0,54
Chemical Admixture (kg)	4,320
0-3mm(kg)	696
3-8 mm(kg)	240
5-13 mm(kg)	205

Table 3.15 shows the mixture calculation for Nevşehir pumice.

Table 3.15 Nevşehir Pumice lightweight concrete mixture calculations

Nevşehir Pumice	
Material	Amount
Cement (kg)	360
Water (kg)	250
Water/Cement	0,69
Chemical Admixture (kg)	4,320
0-3mm(kg)	581
3-13mm(kg)	371

Table 3.16 shows the mixture calculation for Tomarza pumice. Table 3.17 shows the mixture calculation for Isparta pumice lightweight concrete with %3 perlite. Figure 3.12 shows the mixture of the sample of the pumices.

Table 3.16 Tomarza pumice lightweight concrete mixture calculations

Tomarza Pomzası	
Material	Amount
Cement (kg)	360
Water (kg)	255
Water/Cement	0,71
Chemical Admixture (kg)	4,320
3-7 mm(kg)	630
7-15 mm(kg)	217
15-25 mm(kg)	186

Table 3.17 Isparta pumice lightweight concrete with %3 perlite mixture calculations

Isparta Pumice	
Material	Amount
Cement (kg)	360
Water (kg)	215
Water/Cement	0,60
Chemical Admixture (kg)	4,320
Perlite (kg)	18
0-3mm(kg)	353
3-8 mm(kg)	128
5-13 mm(kg)	109

Figure 3.12 Mix design

Table 3.18 shows the mixture calculation for Isparta pumice lightweight concrete with %5 perlite.

Table 3.18 Isparta pumice lightweight concrete with %5 perlite mixture calculations

Isparta Pumice	
Material	Amount
Cement (kg)	360
Water (kg)	225
Water/Cement	0,62
Chemical Admixture (kg)	4,320
Perlite (kg)	23
0-3mm(kg)	258
3-8 mm(kg)	97
5-13 mm(kg)	83

3.2.2 Production and Curing

Lightweight concrete samples were prepared with constant cement dosage, three different aggregates and different rates of perlite additives. Aggregates in quantities that are suitable for gradation were mixed dry. The previously calculated aggregate water absorption amounts are added for the pre-water absorption process. Then, cement and additive are added while the mixing is continued, and fresh lightweight concrete production process is completed. Figure 3.13 shows the production stage of lightweight concrete.

Figure 3.13 Lightweight concrete production stage

Prepared mixtures are filled into molds and compressed by vibration. The concrete must be compressed in such a way as to minimize air gaps to achieve a good performance. After filling the molds, the samples are kept at room temperature for 24 hours. Samples that are kept at room temperature for 24 hours are removed from the molds and cured in the curing pool for 7-14-28 days. Figure 3.14 shows the samples to be kept in the molds for 24 hours.

Figure 3.14 Lightweight concrete samples to be kept in molds for 24 hours

The samples that completed the molding phase are shown in Figure 3.15.

Figure 3.15 Samples that completed the molding phase.

3.2.3 Determination of Hardened Concrete Properties

3.2.3.1 Compressive Strength Test

A total of 15 samples, 3 for each mixture, were prepared in 15 * 15 * 15 cm molds. Samples taken from the cure are placed on the pressure test machine in accordance with TS EN 12390-4 with ± 1% accuracy in the center, perpendicular to the casting direction. The loading speed must be constant between 0,2 MPa / s and 1,0 MPa / s. The test was carried out in accordance with TS EN 12390-3 standard.

Compressive strength test setup is figurated in Figure 3.16. Compressive strength of concrete cube test provides an idea about all the characteristics of concrete. Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, quality control during production of concrete etc. Test for compressive strength is carried out either on cube or cylinder. Various standard codes recommends concrete cylinder or concrete cube as the standard specimen for the test.

Isparta Pumice and Tomarza Pumice have better modulus of fineness because these pumices have cohesive structure. The other pumice and perlite have more porous structure. Thus, they have smaller fineness values. Figure 3.17 shows the samples after compressive strength test.

Figure 3.16 Compressive strength test setup

Figure 3.17 Samples after compressive strength test

The test results were calculated using Equation (3.1).

$$fc = \frac{F}{A} \tag{3.1}$$

fc: Compressive strength (MPa, N / mm^2)

F: Maximum load at breaking moment (N)

A: Cross-sectional area to which the pressure load is applied (mm^2)

3.2.3.2 Flexural Test

Resistance to fracture and deformation caused by tensile forces in concrete is called tensile strength. Tensile strength, which cannot be applied directly to concrete building elements, is usually obtained by approximate methods.

Flexure testing is performed to determine the strength or bending modulus of a material against bending. This test can be done more easily than tensile test and different results can be obtained in this test. The material to be tested is placed on two contact points in the horizontal direction. And then continuous force loading is performed at one or two contact points until the sample breaks. The bending strength of the sample is calculated using the force value at the time the sample is broken.

The samples prepared for the flexural test (Figure 3.18) were cast into 300 * 300 * 20 mm molds. The concrete samples were subjected to the flexural test as plaques. 3 samples for each mixture, a total of 15 flexural tests were performed. The tests were carried out in Kayseri University Materials Laboratory, in accordance with TS EN 213-1 EN 13748-1 and TS EN 213-2 13748-2 standards.

Figure 3.18 Samples prepared for the flexural test

Flexural Test setup is shown in the Figure 3.19. Unlike a compression test or tensile test, a flexure test does not measure fundamental material properties.

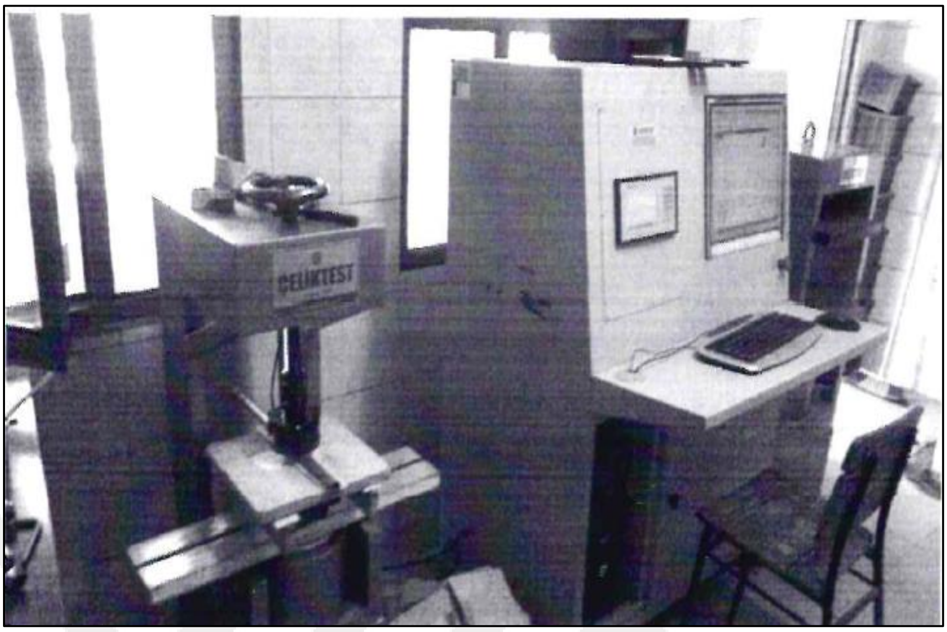

Figure 3.19 Flexural test setup

The test results are obtained using Equation (3.2).

$$f_{cf} = \frac{3*F*L}{2*b*d^2} \tag{3.2}$$

f_{cf} : Flexural strength (N /mm^2)
F: Maximum force (N)
L: Distance between support rollers (mm)
b: Beam width (mm)
d: Beam thickness (mm)

3.2.3.3 Thermal Conductivity Test

This test was carried out using the hot wire method following the ASTM C 1113-90 standard. Required sample sizes should be 100 * 80 * 40 mm and 2 pieces. The measuring range of the device is 0,0116 - 6 W / mK. The measurement time is in the range of 100-120 sec. This method measures the time-varying temperature at specific points [51,52]. This method lasts a maximum of 2 minutes, unlike methods involving other steady-state conditions [53]. The test was carried out in Kahramanmaraş Sütçü

İmam University ÜSKİM laboratory. Thermal conductivity test set up is shown in Figure 3.20

Figure 3. 20 Thermal conductivity test set up

CHAPTER IV

RESULTS AND DISCUSSION

The hardened densities of the concrete samples formed using 5 different contents (Isparta pumice, Nevşehir pumice, Tomarza pumice, Isparta pumice + % 3 Perlite, Isparta pumice + % 5 Perlite) are as follows.

Table 4.1 Densities of hardened concrete samples

Density of Hardened Concrete	
Isparta Pumice (kg/m3)	1,762
Nevşehir Pumice (kg/m3)	1,423
Tomarza Pumice (kg/m3)	1,551
Isparta Pumice + %3 Perlite (kg/m3)	1,680
Isparta Pumice + %5 Perlite (kg/m3)	1,609

4.1 Compressive Strength Test

Three lightweight concrete from each mixture were cast into cubical molds of 15 * 15 * 15 cm. After 28 days of curing, the compressive strength test was conducted. The results of the test are given in Table 4.1.

Table 4.2 Compressive strength test results

	Isparta Pumice	Nevşehir Pumice	Tomarza Pumice	Isparta Pumice + % 3 Perlite	Isparta Pumice + % 5 Perlite
28 days Compressive Strength (MPa)	18,578	16,084	12,076	16,564	15,213
	21,298	13,916	11,982	15,213	16,738
	19,858	14,636	12,173	16,964	16,698
Mean	**19,911**	**14,878**	**12,077**	**16,247**	**16,216**

The test results show that the highest compressive strength of lightweight concrete without perlite added was obtained by Isparta pumice with 19,911 MPa. The lowest compressive strength of 12,077 MPa belongs to the lightweight concrete sample produced with Tomarza pumice.

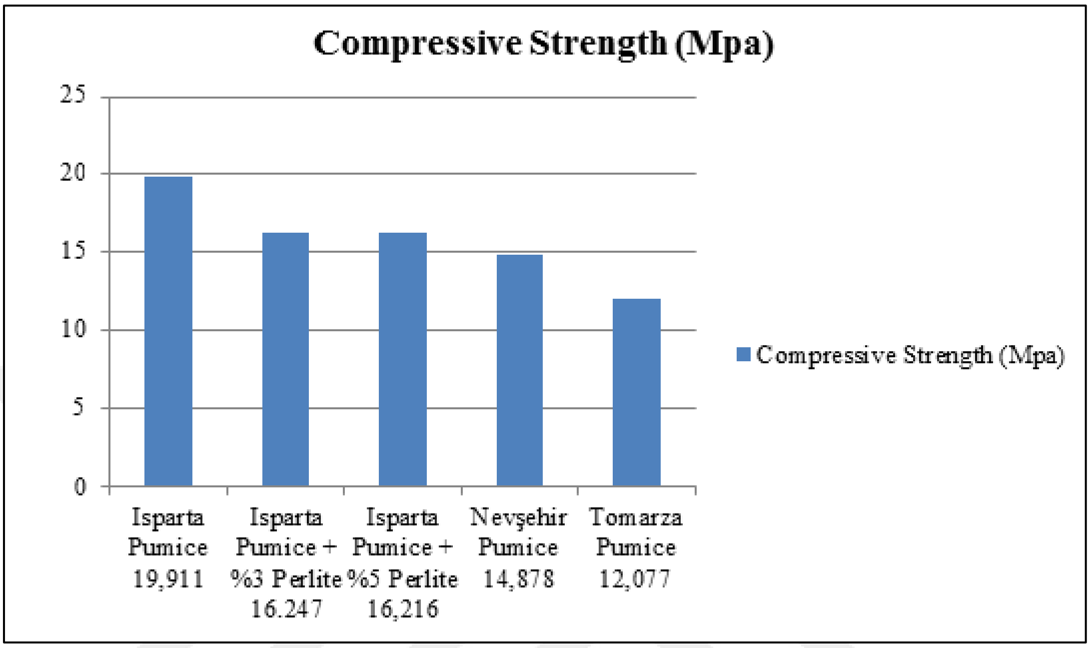

Figure 4.1 Compressive Strength change graph

Figure 4.1 shows that when compared to lightweight concrete with Isparta pumice with no added perlite, the compressive strength of 3% perlite added concrete sample decreased by 19,5%, and 5% perlite added lightweight concrete sample's compressive strength decreased by 19,6 %. Considering that the highest result was obtained from Isparta Pumice concrete sample, it can be said that perlite decreases the strength by causing extra pores.

4.2 Flexural Test

The lightweight concrete mixtures were cast into the molds of 300 * 300 * 20 mm. After being left in the molds for 24 hours, they were subjected to curing for 28 days. The test results are given in Table 4.2.

Table 4.3 Flexural test results

		Isparta pumice	Nevşehir pumice	Tomarza pumice	Isparta pumice + % 3 Perlite	Isparta pumice + % 5 Perlite
Flexural Strength (MPa)		3,55	2,12	1,30	2,98	2,91
		3,47	2,18	1,40	3,06	2,85
		3,41	2,02	1,35	3,05	2,84
Mean		**3,48**	**2,11**	**1,35**	**3,03**	**2,87**

According to the results, the lowest flexural strength value was obtained 1,35 MPa from the lightweight concrete sample with Tomarza Pumice aggregate; while the highest flexural strength value was 3,48 MPa, obtained from the lightweight concrete sample with Isparta pumice aggregate.

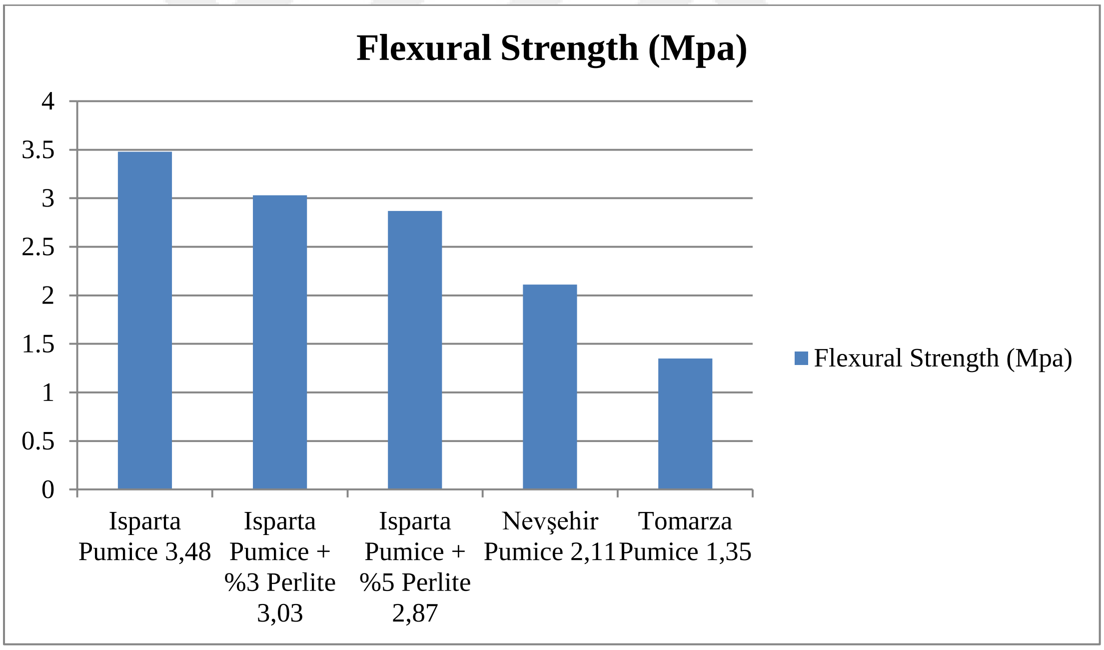

Figure 4.2 Flexural strength change graph

When the flexural strength of lightweight concrete samples of Isparta pumice with and without perlite additions was examined according to Figure 4.2, it was seen that the flexural strength decreased with the increasing amount of perlite. It was seen that the best result was obtained from the lightweight concrete sample with Isparta Pumice without perlite. The lightweight concrete sample with Tomarza Pumice has the lowest flexural strength therefore it shows that the aggregate have more porous structure.

4.3 Thermal Conductivity Test

The thermal conductivity test results of the prepared lightweight concrete samples are given in Table 4.4.

Table 4. 4 Thermal conductivity test results

Sample Name	Test Result (W/mK)
Isparta Pumice	1,1951
Isparta Pumice + % 3 Perlite	0,9781
Isparta pumice + % 5 Perlite	0,8949
Nevşehir Pumice	1,3116
Tomarza Pumice	0,8887

Table 4.3 shows that the lowest thermal conductivity value is with 0,8887 W / mK, obtained from the lightweight concrete sample prepared by using Tomarza Pumice aggregate. The highest thermal conductivity value was obtained from the lightweight concrete sample with Nevşehir Pumice.

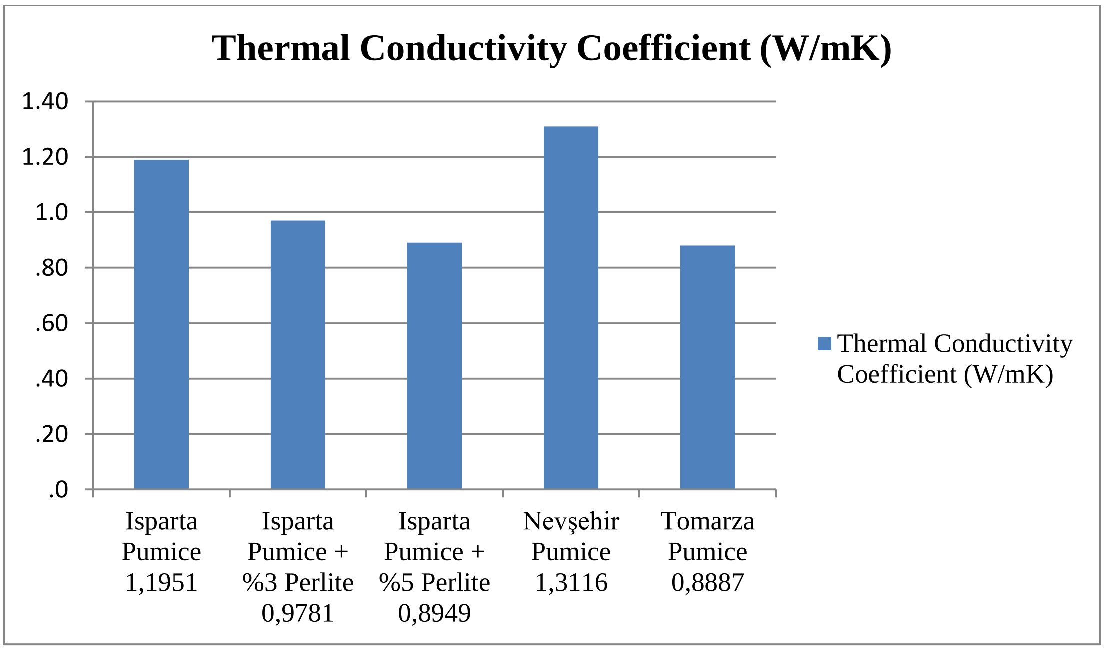

Figure 4. 3 Graph of thermal conductivity coefficient change

Figure 4.3 shows that the graph curve is at the lowest point in the lightweight concrete sample with Tomarza Pumice aggregate. When the lightweight concrete samples with Isparta Pumice aggregate with and without additive are examined, it is observed that the perlite addition decreases the conductivity. The highest thermal conductivity coefficient was observed in Nevşehir Pumice aggregate lightweight concrete. It can be concluded that Tomarza Pumice has a more porous structure.

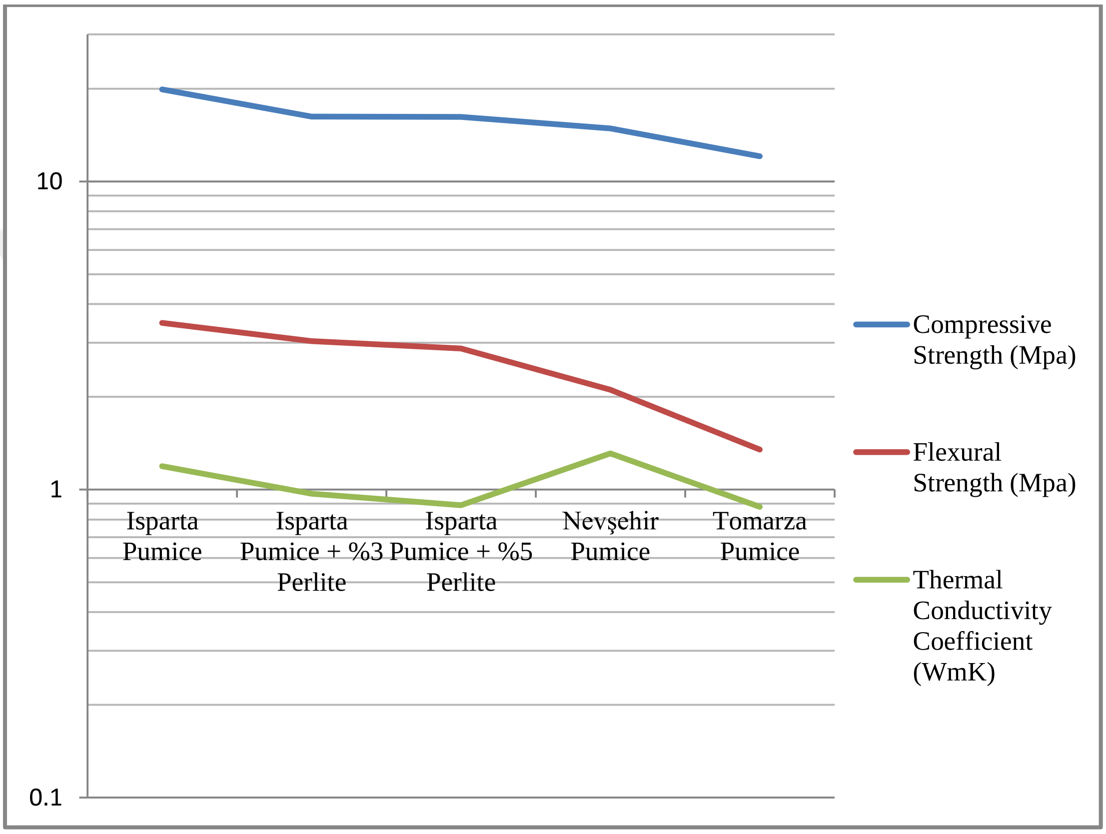

Figure 4. 4 Compressive, flextural and thermal conductivity test result of pumice samples

CONCLUSION AND RECOMMENDATIONS

In this study, the mechanical and thermal conductivity properties of different pumice aggregates were investigated by keeping the amount of cement and additives constant. The test results are summarized below.

When lightweight concrete samples produced by using the same amount of cement are analyzed, the lowest water / cement ratio was 0,54 with Isparta Pumice aggregate and the highest water / cement ratio was 0,71 with Tomarza Pumice aggregate lightweight concrete samples. It was seen that the amount of water increased due to the pore structure and the amount of water absorption of Tomarza Pumice was high.

When the lightweight concrete samples produced with different aggregates and perlite additions were examined, it was observed that the best compressive strength value was 19,911 MPa, obtained from Isparta Pumice aggregate. The lowest compressive strength of 12,077 MPa was observed in Tomarza Pumice aggregate lightweight concrete sample. When Isparta Pumice aggregate lightweight concrete samples with and without perlite additions were examined, the lightweight concrete sample with 5% perlite had the lowest compressive strength as 16,216 MPa. The highest compressive strength was observed in Isparta Pumice lightweight concrete sample. According to result of compressive strength perlite has a negative effect on compressive strength. Also, the best result was obtained from the concretes with Isparta Pumice. Therefore, perlite addition in certain ratios has negative effect in terms of compressive strength. In areas where high strength is not desired, Tomarza pumice can be preferred as aggregate.

When the flexural test results were examined, it was observed that the highest value was obtained from Isparta Pumice aggregate lightweight concrete samples with 3,48

MPa. The lowest value was obtained from Tomarza Pumice aggregate lightweight concrete samples with 1,35 MPa.

When the lightweight concrete samples with Isparta Pumice aggregate with or without additives are examined, it was concluded that perlite has a negative effect on flexural strength. Increasing the percentage of perlite caused a decrease in flexural strength. Isparta pumice aggregate may be preferred in lightweight concrete in the structural elements that will be subjected to flexural strength.

The thermal conductivity test results showed that the lowest result was obtained from Tomarza Pumice aggregate concrete samples with a 0,8887 W / mK. The highest result was obtained from the Nevşehir Pumice lightweight concrete sample with 1,3116 W / mK. When Isparta Pumice aggregate samples were examined with or without additives, it was observed that the perlite addition decreased the thermal conductivity coefficient. It can be concluded that in areas with insulation purposes, the perlite addition will have a positive effect and Tomarza Pumice is suitable as aggregate. It is thought that the pore structure of Tomarza Pumice aggregate is higher than the other aggregates, thus it decreases the thermal conductivity coefficient.

The examination of the results of water absorption, compressive strength, flexural strength and thermal conductivity tests showed that the pore structure affected these values.

As a result of the study, Isparta Pumice should be preferred as lightweight concrete aggregate where high compressive strength is required. It was observed that perlite has a negative effect on both compressive and the flexural strength. For insulation purposes, it was observed that Tomarza Pumice could be preferred as aggregate, due to its porous structure and low thermal conductivity coefficient. It was seen that the use of perlite additive is suitable because it increases the insulation effect. The presence of basalt in Nevşehir pumice increases compressive and bending strength and reduces insulation.

In addition, when the fineness ratio of the aggregates is increased, compressive strength and flexural strength will be improved. If Nevşehir pumice can be purified from the basalt content, the desired thermal conductivity values will be obtained.

As a result, the samples formed using different pumice stones in different parts of Turkey were subjected to various tests. The test results show that more studies can be done on the use of perlite with pumice stone. In addition, it can be investigated that the thermal conductivity of the samples to be formed by keeping perlite rates higher may be better.

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