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THERMAL AND MECHANICAL PROPERTIES OF CONCRETES WITH POROUS AGGREGATES

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Abstract

Original scientific paper

The results of an experimental study on the thermal and mechanical properties of concretes using porous aggregates instead of conventional aggregates are presented in this study. Oriented at this purpose, eleven concrete samples containing organic sediment stones, volcanic stones and artificial porous aggregates were prepared as porous aggregates. The concrete samples were subjected to certain tests at the end of 28 days of drying period and their thermal and mechanical properties were determined accordingly. With this study, the following values were obtained: i) The lowest heat transfer coefficient for concrete with expanded polystyrene aggregates from the group of artificial porous aggregates: 0.175 W/mK, ii) The highest compressive strength value is basalt-type stone (Karaca dag) from the group of volcanic stones: 117 MPa.

Keywords: *Porous aggregates, concrete, building stones, artificial porous aggregates*

GÖZENEKLİ AGREGALI BETONLARIN ISIL VE MEKANİK ÖZELLİKLERİ

Özet

Orijinal bilimsel makale

Bu çalışmada, geleneksel agrega yerine gözenekli agrega kullanılan betonların ısıl ve mekanik özellikleri üzerine yapılan deneysel bir çalışmanın sonuçlan sunulmuştur. Bu amaçla gözenekli agrega olarak organik sediment taşlar, volkanik taşlar ve yapay gözenekli agregalar ihtiva eden on bir adet beton numuneler hazırlanmıştır. Beton numuneler, 28 günlük kuruma sureci sonunda bazı testlere tabi tutularak ısıl ve mekanik özellikleri belirlenmiştir. Bu çalışma ile i) en düşük ısı iletim katsayısı, yapay gözenekli agregalar gurubundan genleşmiş polistiren agregalı beton 0.175 W/mK olarak, ii) en yüksek basma gerilmesi değeri volkanik taşlar gurubundan basalt-type stone (Karaca dag) 117 MPa olarak belirlenmiştir

Anahtar Kelimeler: *Gözenekli agregalar, beton, yapı taşları, yapay gözenekli agregalar*

1 Introduction

The unit volume weight of conventional concrete used in reinforced concrete constructions is not ideal due to the fact that it increases the self-weight of the building. Based on this reason, the lightweight concrete production efforts have recently been increased in order to solve such problems as reducing the unit weight of concrete and providing its reliability against earthquake and fire, as well as heat and sound insulation [1]. Today, as one of the most important construction material in residential construction, lightweight concrete is produced through a number of methods, but most of these methods cannot ensure to achieve the intended economic conditions. This type of concrete can be produced using porous and low density aggregates. Instead of normal concrete aggregate, it can be quite desirable to produce lightweight concrete by means of utilizing the natural lightweight aggregate that is present in the regions. Since the production of natural light adhesives does not require any technology or fabrication, the costs are low, while on the other hand the concrete to be produced with these materials is cheaper [2].

Porous aggregates can be divided into two groups as natural and artificial aggregates. Examples of natural aggregates include the following; organic sediment stones, volcanic stones (andesite tuff, ignimbrite, pumice ect). For artificial ones, the following units can be shown as examples: expanded polystyrene (EPS), expanded clay (EC), expanded perlite (EP). Studies on the subject can be summarized in two groups. The first group, certain studies on the evaluation of porous stone organic sediment stones and volcanic stones as building materials were carried out. The example studies carried out in this context can be shown as follows:

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Bicer [3 and 4] experimentally determined the thermal and mechanical properties of local porous stones. Also, Gevrek and Kazanci, [5], ignimbrite formation, Kazanci and Gurbuz, [6], the geological formation of the natural stone of Turkey; Pivko, the historical formation of stones in the world [7]. In addition, Akıllı, [8], carried out studies on the factors that cause the destruction of stone artifacts. Gurdal, [9], carried out researches on the deterioration and protection of natural stones used in monuments and buildings. The studies conducted by Akin et al., [10], within the scope of "the sensitivity of Ahlat Stone under atmospheric effects" can be shown as an example in this context. Bicer and Celik [11], Akpinar and Kocyigit [12], also studied the thermal and mechanical properties of pumice aggregate low density concrete on an experimental basis.

In the second group, certain studies on the evaluation of artificial porous aggregates as building materials were carried out. To give an example on these studies, Kaya and Kar [13] tried to reduce the thermal conductivity coefficients by creating artificial pores in the cemented parts of the concrete structure by adding resin to EPS aggregate concretes. Xue et al [14], Gnip et al [15], Demirboga and Kan [16] can be cited as examples of studies on the reuse of waste EPS for thermal recycling in a modified form and its physical properties. Devecioglu and Bicer [17], Bouvard et al [18] and Chen and Liu [19] studied on thermal and mechanical properties of concrete with expanded clay aggregate Bartolini et al [20] mixed the expanded clays and epoxy resin which was used as a binder. Rossignolo et al [21] studied production of sturdy prefabricated constructional components by means of using the expanded clay aggregates, Vasina et al [22] mixed expanded clays of various diameters with cement, fuel ash and plasticizer additive, while also carrying out a research on the acoustics performance of the samples. Onuralp et al [23] Topcu and Isıkdag [24] carried out studies on the properties of expanded perlite aggregate concretes.

In this study, organic sediment stones (Şanlıurfa, Midyat, Mardin, and Nemrut stones), volcanic stones (Basalt-type stone, (Karacadag), andesite tuff (Malazgirt stone, Ahlat stone and pumice)) and the thermal and mechanical properties of eleven different low density concrete produced by using EPS, EC, EP from artificial porous aggregates have been subjected to analysis. The results of this study will assist in the selection of aggregates for iso-concrete type production in buildings.

2 Materials and Methods

2.1 Materials

Three groups of aggregates were used as porous aggregates, organic sediment stones, volcanic stones and artificial porous aggregates in the study.

2.1.1 Organic Sediment Stone

The common characteristics of such stones can be summarized as follows: having whitish or yellowish colors, having large reserves in their regions, being easy to process and shape due to the moisture in the body when they are removed from the furnace, getting hardened at a level of 3-4 mohs due to the removal of moisture in the internal structure within a few days. Şanlıurfa stone, Midyat stone, Mardin stone and Nemrut stone can be shown as the examples for this type of rock.

Şanlıurfa stone has been used for construction of masonries in particular within the region for many years. Having large amounts of reserves, these stones after being taken out of the query, it can be easily formed and processed compared to other stone structures (Fig. 1-a).

Midyat stone: A great deal of stones are present in the rich seams near Keferhuvvar village of Estel region in Midyat town of Mardin. The seams are 10 km far from Midyat and 6 km from Estel. Travvelling between region in Midyat and Estel is very easy. But the road between Estel and the seam is not surfaced. The stones are being used in the region extensively as building material. Their withdrawing are easy and water contentshigh [3].

Mardin stone is obtained from Kabala region of Mardin province. The seam is 2 km far from city center and near the road. It can be shaped easily without damage. It has a yellowish and whitish color and with a hardness level of 3-4 mohs [3].

Nemrut stone, is located in Kahta Country of Adıyaman. Categorized under organic sedimentary stone, it has a yellowish and whitish color. With a hardness level of 3-4 mohs, it can be processed in terms of its physical properties. Unless it loses the moisture within after being removed from the quarry and it is exposed to chemical impact of the outer environment for a long this, this stone can be conveniently shaped and processed [4].

2.1.2 Volcanic Stones

The common feature of these stones is that they are colored. In basalt type, black pores are larger and very hard (6-7 mohs). Karacadag Mountain can be given as an example for this group (obtained in the Karaca Mountain from the southeast of Turkey) (Fig. 1-b).

Another group is the andesite tuffs. The common features of these stones are that they are in red, black and gray colors, they are easy to work with, while having the same the degree of shaliness is 1-2 mohs, and their structure is in layers. This group can be given as examples of Ahlat and Malazgirt stones (These stones were obtained in the foothills of Mount Nemrut and Suphan in the east of Turkey) (Fig. 1-b) [2].

Pumice is a glassy volcanic rock with a high porosity. Construction industries consume the highest on the pumice production. Insulation of heat and sound, fire resistance and ease of cutting, shaping and nailing can be stated as the advantages of this [11, 12] (Fig 1-c)

2.1.3 Artificial Porous Aggregates

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Expanded polystyrene (EPS): It is a 98 per cent air-consisting material, and the rest is polystyrene [13-16]. The block EPS obtained from the EPS manufacturing facility is used for the production of samples at the same factory's disintegration unit according to particle diameters of 2–4 mm (Fig 1-d).

The expanded clays (EC) are artificial materials, and in no expanded form can they be found in nature. Not every clay that can be found in nature expands. Early sintering clay, sand clay and clay schist are the raw materials used for producing growing clays [17-23]. Expanded clays are immediately processed in rotary furnaces heated to over 1000 °C at high temperatures. Following the process, their volumes increase and a sintered hard crust develops on the outside surface and a porous layer develops within (Fig 1-e).

Expanded perlite (EP) is a porous, low-density, pearly-luster acidic, volcanic rock, generally obtained by means of expanding raw perlite, while also being instantaneously heated up to temperatures between 750-1100 °C. Once the raw perlite particle is expanded, it increases approximately 10-30 times in volume and the thermal conductivity coefficient becomes 0.04-0.055 W/mK. The perlite is used as aggregate in plaster for thermal insulation in the construction industry, as an insulation blanket in packs or in the form of plates. (Fig 1-f) [24]. The aggregates components are given in Table 1.

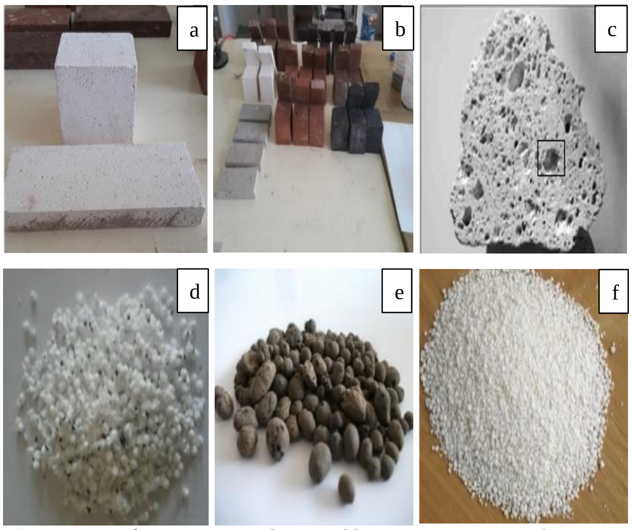


Fig. 1. View of porous materials; a) and b) stones, c) pumice, d) EPS, e) EC f) EP

2.1.4 Concretes Containing Porous Aggregates

The aggregate size of the concretes produced by means of mixing the examined aggregates with cement binder was used as 2-4 mm, where the mixing ratios 60% aggregate and 40% cement, while the use of water/cement=0.5 of was kept constant. The density, thermal conductivity and compressive strength values of the prepared concrete samples were determined accordingly after 28 days of drying period.

2.2 Testing Methods

In order to measure the thermal conductivities of the specimens, a Shotherm-QTM unit (Showa Denko), operating based on the DIN 51046 hot wire methodology. Its range and sensitivity were 0.02-6.00 W/mK with ± 5 % precision respectively [25]. The measurements on three locations of each sample block were repeated three times to reflect the average of nine values. The temperature was between 22°C and 25°C during measurement (Fig.2).

Fig. 2. Shotherm-QTM unit

Compressive strength tests were carried out on the samples in accordance with TS 699 standard [26, 27]. Compressive strength tests for the samples were carried out with Ele International branded device, bearing the following features: 3000 kN loading capacity; digital control panel; adjustable loading rate; applying uniaxial force (Fig.3).

Fig. 3. Compressive strength tests unit

Eq.1 was applied to the aggregates, and the calculated porosity values are given in Table 2 as a whole.

$$\Phi = 1 - \frac{\rho_{\text{porous aggregate}}}{\rho_{\text{porous aggregate matrix}}} \quad (1)$$

The aim of water absorption ratio (WAR) is to investigate the maximum amount of water absorption of samples. This property is important in determining the suitability of this material against freezing hazards. The critical amount of moisture is 30 percent of the total dry volume, below which the material doesn't deform on freezing [13]. The experiments were performed according to the BS 812. Part 2 standard [28]. Specimen's dry (Wd), and wet weights (Wk) are necessary to calculate water absorption ratios. Water absorption rates (WAR) were calculated by using Eq. 2 and are shown in Table 3.

$$WAR = \{[W_d - W_k]/W_k\}.100 \quad (2)$$

The thermal and mechanical properties determined following the tests and calculations made on porous aggregates and concrete samples produced with these aggregates can be seen in Table 2 and Table 3.

3 Results and Discussions

3.1 Organic Sediment Stones

Among the aggregates of this group, Mardin stone has the lowest value as density (1.35 g/cm^3) and thermal conductivity coefficient, which is 0.58 W/mK). However, the values of Midyat and Nemrut stones are close to Mardin stone. Within this group, Şanliurfa stone density (2.19 g/cm^3) and thermal conductivity (1.28 W/mK) have the highest values. The porosity (19.02% and 18.52%) and compressive strength values (10.2 MPa and 24 MPa) of Nemrut and Şanlıurfa stones are higher than those of Midyat and Mardin stones (Table 2), (Fig. 4). Sanlıurfa stone was determined to have the highest compressive strength value, while Mardin stone has the smallest one.

The water absorption rates were found to be below 30% in all the stones subjected to analysis. Therefore, there is no risk of decomposition and dispersion at temperatures below 0°C.

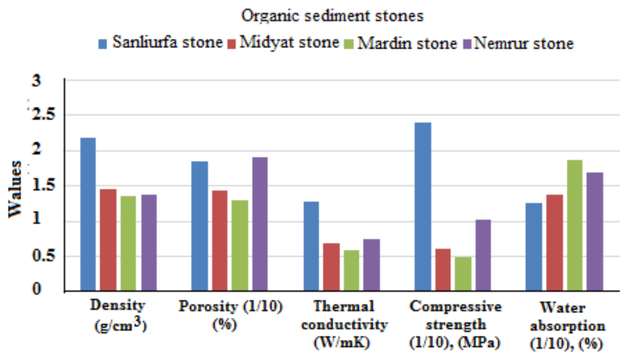


Fig. 4. Some physical properties of organic sediment stones

3.2 Volcanic Stones

From this group of aggregates, Pumice, Malazgirt and Ahlat stones' density values (0.82 g/cm^3, 0.88 g/cm^3 and 1.18 g/cm^3, respectively) and thermal conductivity values (0.255 W/mK, 0.288 W/mK and 0.312 W/mK) are considerably lower than the organic sediment stones (Table 2), (Fig. 5). In this group, the highest density and thermal conductivity coefficient (2.89 g / cm^3 and 1.51 W/mK) belong to Karacadag stone. In the compressive strength values, Karacadag stone has the highest value (105 MPa), while pumice has the lowest (5.23 MPa). The porosity of this aggregate group is higher than organic sediment stones. Volcanic stones water absorption rates are below 30% of the critical value.

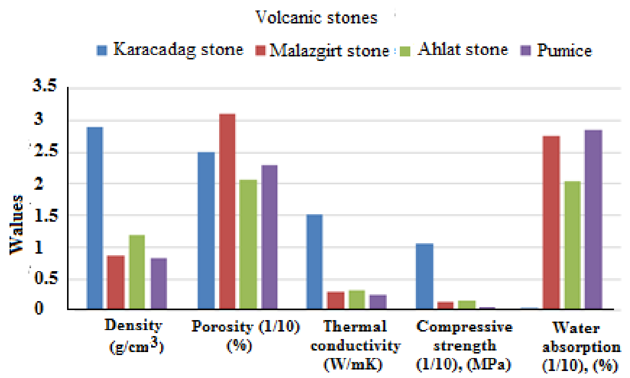


Fig. 5. Some physical properties of volcanic stones

Midyat stone, Mardin stone, Nemrut stone, Malazgirt stone and Ahlat stone can be used as concrete aggregate, as well as a partition element in the form of brick or briquette. Sanliurfa stone seems to be able to be used as both brick and concrete aggregate as well as load-bearing concrete aggregate along with Karacadag stone.

3.3 Artificial Porous Aggregates

From this group of aggregates, EPS, EC and EP density values (0.013 g/cm^3, 0.511 g/cm^3 and 0.236 g/cm^3, respectively) and thermal conductivity values (0.038 W/mK, 0.133 W/mK and 0.050 W/mK) are considerably lower than organic sediment stones volcanic stone (Table 2), (Fig. 5). In this group, the lowest density and thermal conductivity coefficient belong to EPS, while the highest value belongs to EC. This aggregate group has higher porosity than other aggregates.

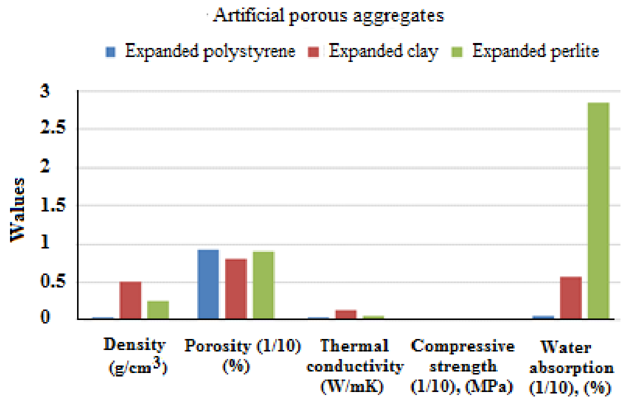


Fig. 6. Some physical properties of artificial porous aggregates

3.4 Concretes Containing Porous Aggregates

The following findings were obtained following the tests carried out on concrete samples produced using the examined aggregates.

3.4.1 Density

Among the concretes produced with 11 different aggregates, the highest density values were determined to belong to Şanlıurfa stone (2.514 g/cm^3) from the organic sediment stones group, Karacadag stone (2.934 g/cm^3) from the volcanic stones group and EC (1.506 g/cm3) from the artificial porous aggregate group. On the other hand, the one with the lowest values was Mardin Stone (1.208 g/cm3), pumice (1.411 g/cm3), EPS (1.117 g/cm3), respectively. (Table 3). The reason for this matter is based on the density of the aggregates.

3.4.2 Thermal Conductivity

Among the concretes subjected to analysis, Nemrut stone (0.81 W/mK) and Mardin stone (0.87 W/mK) from the organic sediment stones group, pumice (0.336 W/mK) from the volcanic stone group and EPC from the artificial porous aggregates group (0.175 W/mK) are determined to be aggregate concretes. The artificial porous aggregates group has the lowest thermal conductivity values among the analyzed aggregate groups as can be seen in Table 3 and Figure 7, Figure 8, Figure 9. If Table 3 can be examined, it can be seen that concretes with organic sediment and volcanic stones, EC and EP have the properities to be used for isolation and carrier concrete. Concretes with EPS aggregates can be used as insulation concrete.

3.4.3 Compressive Strength

Karacadag stone (117 MPa) is a aggregate concrete from the volcanic stones group, with the highest compressive strength value among concretes. Moreover, the compressive strength values of Ahlat stone aggregated concrete (20.42 MPa) from the same group and Sanliurfa stone aggregate concrete (29.72 MPa) from the organic sediment stones group are higher than other concretes.

If Table 4, which is prepared for lightweight concrete classification by Mindess, can be examined, it can be seen that light weight concretes with organic, volcanic stones or artificial porous aggregate can be classified as medium strength concrete. But the light weight concretes with Şanliurfa or Karacadag aggregate can be classified as carrier light concretes

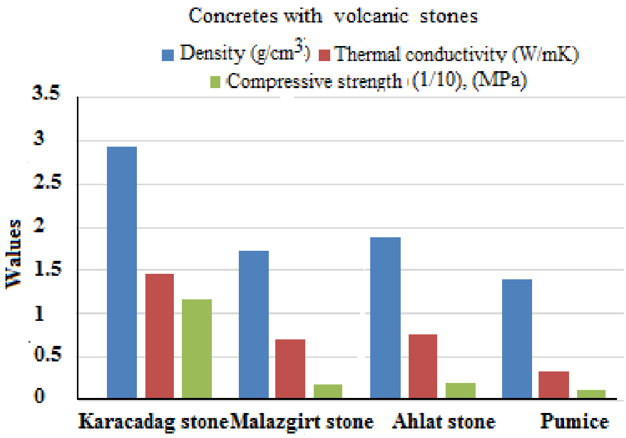


Fig.8. Some properties of volcanic stones aggregate concrete

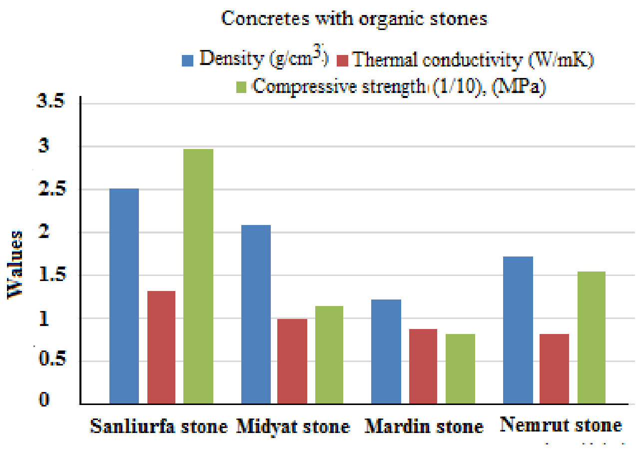


Fig.7. Some properties of organic sediment stones aggregate concrete

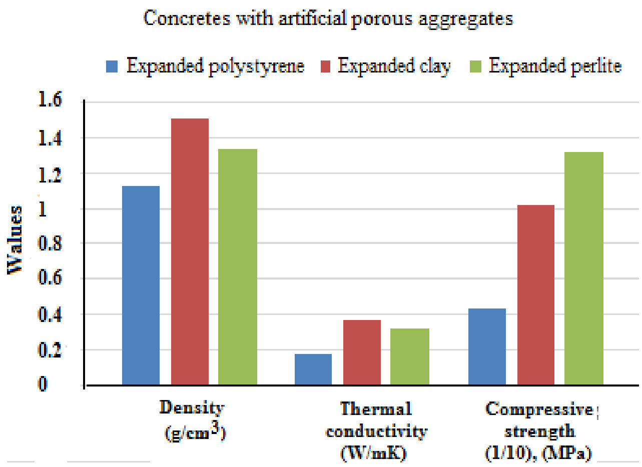


Fig.9. Properties of concretes with artificial porous aggregates

Table 1. The chemical composition of the aggregates, (%)

Component Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss of ignition	Undefined
Şanlıurfa stone	1.00	0.15	0.10	53.48	1.02	43.63	1.52
Midyat stone	0.30	-	-	34.10	18.65	46.63	0.32
Mardin stone	0.18	-	-	30.00	22.58	47.09	0.15
Nemrut stone	46.80	14.45	16.20	12.23	4.88	-	1.44
Karacadag stone	47.24	15.30	4.70	13.04	3.74	13.58	2.40
Malazgirt stone	63.73	14.97	4.45	3.66	-	3.40	9.79
Ahlat stone	63.80	16.50	4.50	3.23	-	2.53	8.97
Pumice	53.83	14.81	4.61	4.64	2.75	3.49	8.18
Expanded polystyrene	23.51	6.15	4.00	58.51	2.27	3.04	1.42
Expanded clay	18.08	6.15	3.25	3.46	4.10	7.97	9.85
Expanded perlite	74.18	17.61	1.20	0.51	0.5	2.58	3.55

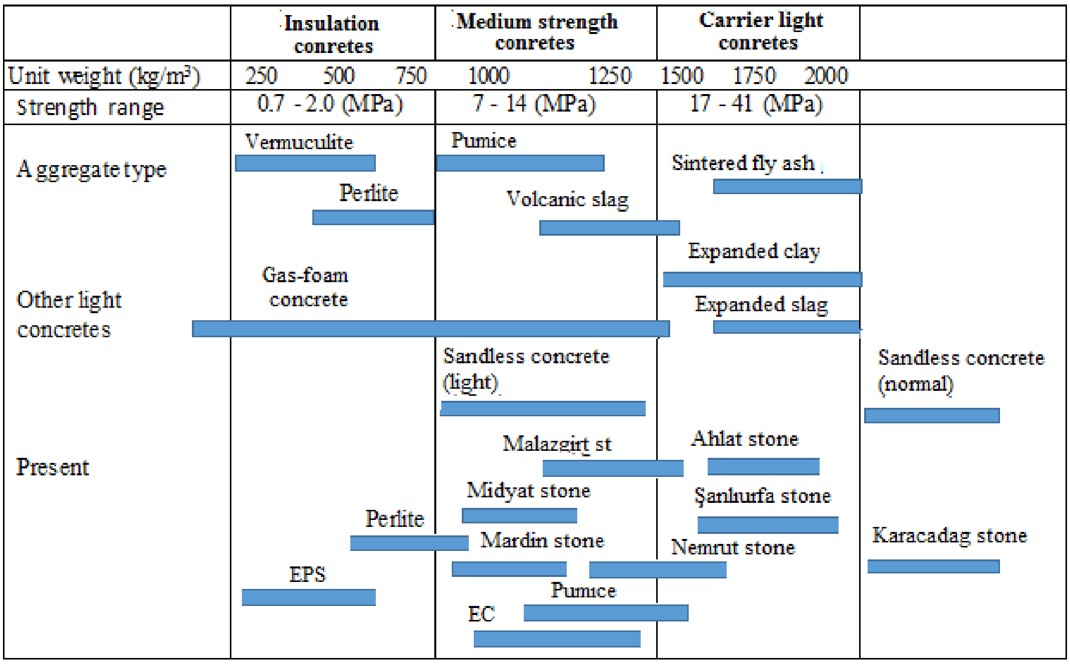
Table 2. Some properties of aggregates which were determined by experiments

Materials	**Density (g/cm^3)**	**Porosity (%)**	**Thermal conductivity (W/mK)**	**Compressive strength (MPa)**	**Water absorption (%)**
			Organic sediment stones		
Sanlıurfa stone	2.190	18.52	1.28	24	12.50
Midyat stone	1.460	14.41	0.69	6.13	13.70
Mardin stone	1.350	13.03	0.58	4.91	18.64
Nemrut stone	1.385	19.02	0.75	10.2	17
			Volcanic stones		
Basalt-type stone (Karaca dag)	2.890	25	1.410	105	0.31
Andesite tuff (Malazgirt stone)	0.880	31.01	0.288	12.5	27.6
Andesite tuff (Ahlat stone)	1.181	20.58	0.312	16.4	20.5
Pumice	0.820	22.94	0.255	5.23	28.4
			Artificial porous aggregates		
Expanded polystyrene (2-4) mm	0.013	92.96	0.038	-	0.45
Expanded clay (2-4) mm	0.511	81.10	0.133	-	5.70
Expanded perlite (2-4) mm	0.236	90.38	0.050	-	28.5

Table 3. Some properties of concretes which were containing porous aggregate and place of use according to Ref. 29

Materials	Density (g/cm^3)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Carrier	Carrier + insulation	İnsulation
	Thermal conductivity coefficient			→	<0.75	<0.30
Organic sediment stones						
Sanlıurfa stone	2.514	1.31	29.72	+		
Midyat stone	2.076	0.98	11.31	+		
Mardin stone	1.208	0.87	8.18	+		
Nemrut stone	1.708	0.81	15.36	+		
Volcanic stones						
Basalt-type stone (Karaca dag)	2.934	1.450	117	+		
Andesite tuff (Malazgirt stone)	1.728	0.706	16.85	+		
Andesite tuff (Ahlat stone)	1.908	0.758	20.42	+		
Pumice	1.411	0.336	11.23		+	
Artificial porous aggregates						
Expanded polystyrene (2-4) mm	1.117	0.175	4.34			+
Expanded clay (2-4) mm	1.506	0.366	10.17		+	
Expanded perlite (2-4) mm	1.241	0.317	13.18		+	

Table 4. Strength classification of lightweight concrete in line with the aggregate used according to Mindess [30]



4 Conclusion

The use of aggregate concrete to be utilized within the production of low density concrete should be designated according to its purpose of use. The following results were obtained in the study conducted on the examined porous aggregates and concretes produced with these aggregates.

- The thermal conductivity values of the concretes produced with the aggregates of Midyat stone, Mardin stone, Nemrut stone, Malazgirt stone and Ahlat stone were determined to be as 0.98 W/mK, 0.87 W/mK, 0.81 W/mK, 0.706 W/mK and 0.758 W/mK, respectively. These aggregates can be used in low density concrete production, as well as in the form of bricks or briquettes.
- Where Sanliurfa stone is used as concrete aggregate, it can be used as concrete aggregate due to the thermal conductivity and compressive strength of the concrete (1.31 W/mK and 29.72 MPa). Also, Karacadag stone can be used both as a brick and as a load-bearing concrete aggregate with its values: "1.45 W/mK and 117 MPa".
- It is a great advantage that the aggregates in organic sediment stones and volcanic stones groups have rich reserves, while the costs of the same are low. This advantage needs to be utilized accordingly.
- Since concretes produced with EPS, EC and EP artificial aggregates are the group with the lowest thermal conductivity values (0.175 W/mK, 0.366 W/mK and 0.317 W/mK, respectively) and pumice from the volcanic stone groups have following values (0.336 W/mK and 11.23 MPa), it will assist saving energy and reduce the building load where they are used as aggregate in the production of concrete shear walls, floors and ceiling slab concrete

In conclusion, it is recommended to choose aggregate in the production of low density concrete for buildings according to the use of purpose of the concrete within the scope of the study.

Declaration

Ethics committee approval is not required for this study.

References

[1] Bicer, A. (2020). Make Use of Volcanic Slag as Aggregate in the Production of Concrete. *Uluslararası Doğu Anadolu Fen Mühendislik ve Tasarım Dergisi*, 2(2), 337-347.

[2] Bicer, A. (2019). Ahlat ve Malazgirt yapı taşlarının bazı fiziksel özellikleri, Fırat Üniversitesi Müh. *Bil. Dergisi*, 31(2), 301-307.

[3] Bicer, A. (2019). Some physical properties of the building Stones from southeastern Anatolia region. *Bartın University International Journal of Natural and Applied Sciences*, 2(1), 9-15.

[4] Bicer, A. (2019). Some physical properties of the building stones from Elazıg-Nevsehir region. *Nevşehir Bilim ve Teknoloji Dergisi*, 8(2), 96-102.

[5] Gevrek, A. İ., & Kazancı, N. (1991). İgnimbrit: oluşumu ve özellikleri. *Jeoloji Mühendisliği Dergisi*, 38, 39-42.

[6] Kazancı, N., & Gürbüz, A. (2014). Jeolojik miras nitelikli Türkiye doğal taşları. *Türkiye Jeoloji Bülteni,* 57(1), 19-44.

[7] Pivko, D. (2003). Natural stones in earth's history. *Acta Geologica*, 58, 73-86..

[8] Akıllı, H. (1987). Taş eserlerin tahribatına neden olan etkenler. *Rölöve ve Rastorasyon Dergisi*, (6), 129-134.

[9] Gürdal, E. (1982). Anıtlarda ve yapılarda kullanılmış doğal taşların bozulmaları ve korunmaları. *Rölöve ve Restorasyon Dergisi*, 1(1), 27-30.

[10] Akın, M., Özvan, A., Dinçer, İ., Oyan, V., & Tapan, M. (2014). Ahlat Taşı'nın atmosferik etkiler altındaki duyarlılığı, *III. Uluslararası Ahlat-Avrasya Bilim, Kültür ve Sanat Sempozyumu Bildiriler Kitabı (Editörler Doğru M. ve Aksoy E.),* 60-69

[11] Bicer, A., & Celik, N. (2020). Influence of pine resin on thermo-mechanical properties of pumice-cement composites. *Cement and Concrete Composites, 112,* 103668.

[12] Akpinar, E. K., & Koçyigit, F. (2016). Thermal and mechanical properties of lightweight concretes produced with pumice and tragacanth. *Journal of adhesion science and Technology,* 30(5), 534-553.

[13] Ayse, K., & Filiz, K. A. R. (2016). Properties of concrete containing waste expanded polystyrene and natural resin. *Construction and building materials*, 105, 572-578..

[14] Xu, Y., Jiang, L., Xu, J., & Li, Y. (2012). Mechanical properties of expanded polystyrene lightweight aggregate concrete and brick. *Construction and Building Materials*, 27(1), 32-38..

[15] Gnip, I., Vėjelis, S., & Vaitkus, S. (2012). Thermal conductivity of expanded polystyrene (EPS) at 10 C and its conversion to temperatures within interval from 0 to 50 C. *Energy and Buildings,* 52, 107-111.

[16] Demirboga, R., & Kan, A. (2012). Thermal conductivity and shrinkage properties of modified waste polystyrene aggregate concretes. Construction and Building Materials, 35, 730-734.

[17] Devecioğlu, A. G., & Biçer, Y. (2016). The effects of tragacanth addition on the thermal and mechanical properties of lightweight concretes mixed with expanded clay. *Periodica Polytechnica Civil Engineering, 60*(1), 45-50.

[18] Bouvard, D., Chaix, J. M., Dendievel, R., Fazekas, A., Létang, J. M., Peix, G., & Quenard, D. (2007). Characterization and simulation of microstructure and properties of EPS lightweight concrete. *Cement and concrete research,* 37(12), 1666-1673.

[19] Chen B., & Liu J., (2004). Properties of lightweight expanded clay concrete reinforced with steel fiber, *Cement and Concrete Research,* 34, 1259 —1263.

[20] Bartolini, R., Filippozzi, S., Princi, E., Schenone, C., & Vicini, S. (2010). Acoustic and mechanical properties of expanded clay granulates consolidated by epoxy resin. *Applied Clay Science,* 48(3), 460-465.

[21] Rossignolo, J. A., Agnesini, M. V., & Morais, J. A. (2003). Properties of high-performance LWAC for precast structures with Brazilian lightweight aggregates. *Cement and Concrete Composites,* 25(1), 77-82..

[22] Vasina, M., Hughes D.C., Horoshenkov K.V., & Lapcik J., (2006). The acoustical properties of consolidated expanded clay granulates, *Applied Acoustics*, 67, 787-796.

[23] Uluer, O., Karaağaç, İ., Aktaş, M., Durmuş, G., Agbulut, U., Khanlari, A., & ÇELİK, D. (2018). An investigation of usability of expanded perlite in heat insulation technologies.

[24] Topçu, İ. B., & Işıkdağ, B. (2008). Effect of expanded perlite aggregate on the properties of lightweight concrete. *Journal of materials processing technology,* 204(1-3), 34-38.

[25] Denko, S. (1981). Shotherm operation manuel No, 125-2 KK Instrument Products Department 13-9 Shiba Daimon.

[26] American Society for Testing and Materials Standards. (1983). *Standard test method for compressive strength of hydraulic cement mortars* (ASTM C 109-80).

[27] Turkish Standards Institution. (2016).*The test and experiment methods of natural building stones* (TS 699/T1).

[28] British Standards Institution. (1990). *Testing aggregates-part 109: methods for determination of moisture content* (BS 812-109).

[29] Taşdemir, C. (2003). Hafif betonların ısı yalıtım ve taşıyıcılık özellikleri. *TMMOB İnşaat Mühendisleri Odası Türkiye Mühendislik Haberleri Dergisi*, (427), 57-61.

[30] Mindess, S., Young, J.F., Darwin, D. (2003). Concrete. 2nd Edition, Prentice Hall, New Jersey. U.S.A