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Thermal and Mechanical Properties of Certain Building Stones Located at Mediterranean Region

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Abstract

In this study, certain physical properties of Limra (Antalya), Geyran and Köfke (Isparta) and Toprakkale (Iskenderun-Hatay) stones have been investigated. For each stone, samples have been taken from two separate quarries and subjected to thermal conductivity, compressive strength, water absorption, impermeability and abrasion tests following the chemical analysis. As a result of the tests, it has been identified that i) Isparta Köfke stone as having the smallest thermal conductivity value of 0.265 W/mK, ii) Hatay Toprakkale stone as having the highest compressive strength 93 MPa, iii) the water absorption rate of the four stones is below the critical 30% value. The results have been benchmarked with other building materials particularly in terms of energy saving, strength and comfort conditions.

Keywords: Limra stone, Geyran stone, Köfke stone, Toprakkale stone, Natural stones, Building stones.

Akdeniz Bölgesi'nde Yer Alan Bazı Yapı Taşlarının Isıl ve Mekanik Özellikleri

Özet

Bu çalışmada, Limra (Antalya), Geyran ve Köfke (Isparta) ve Toprakkale (İskenderun-Hatay) taşlarının, bazı fiziksel özellikleri araştırılmıştır. Her taş için iki ayrı taş ocağından numuneler alınarak kimyasal analizlerden sonra ısıl iletkenlik, basma gerilmesi, su emme, teneffüs kabiliyeti ve aşınma deneylerine tabi tutulmuştur. Yapılan testler sonucu, i) incelenen taşlardan en küçük ısı iletim katsayısı 0.655 W/mK değeri ile Isparta Köfke taşı, ii) en yüksek basma gerilmesi değeri Hatay Toprakkale taşı 93 MPa, iii) dört taşın su emme oranları kritik %30'nin altında olduğu, belirlenmiştir. Sonuçlar özellikle enerji tasarrufu, mukavemet ve konfor şartları açısından diğer yapı malzemeleri ile karşılaştırılmıştır.

Anahtar Kelimeler: *Limra taşı, Geyran taşı, Köfke taşı, Toprakkale taşı, Doğal taşlar, Yapı taşları.*

1. Introduction

The commencement of use of natural stones as construction and decoration materials has led to increase in the world's natural stone production. Turkey has a great potential with its natural stone resources in terms of both reserves and the diversity. Today, both the price increases in construction materials and the increase in the demand for residential buildings introduce the use of natural stones as carrier and filling elements, depending on the geological structure of each region. Recognition of the fact that the natural stones have a substantial place in terms of people's health, ensures that the natural stones are preferred in human life (Kılıç, 2011).

Many studies are available in the literature regarding the building stones. Some of these studies are summarized below.

Taşlıgil and Sahin (2016) examined the properties of natural stones used as building materials in Turkey by identifying them in accordance with the geographical regions. Gevrek & Kazanci (1991) have studied the ignimbrite formation; Kazanci & Gurbuz (2014) have studied the geological formation of the natural stone of Turkey. Pivko (2003) conducted research on the formation of stones. Bakış et al. (2014) investigated the usability of Ahlat Stone in the construction industry. Bicer has made several studies on the mechanical and thermal properties on the building stones. On these studies, it has been advised that building stones of East Anatolia Region Malazgirt (Mus) and Ahlat (Bitlis) stones (0.288 W/mK, 0.342 W/mK), Southeastern Anatolia Region Mardin (Mardin) and Midyat (Batman) stones (0.58 W/mK, 0.60 W/mK), Central Anatolia Region Urgup (Nevsehir) and Derbent (Eskisehir) stones (0.53 W/mK, 0.355 W/mK) have smaller thermal conductivity coefficient and insulation property. On the same studies and regions, it has been shown that East Anatolia Region Korpe (Elazig) stone (52.6 MPa), Southeastern Anatolia Region Karacadag (Diyarbakir), Hasankeyf (Batman) stones (105 MPa, 42.47 MPa) and Central Anatolia Region Mucur (Kirsehir) stone (88.46 MPa) have more compressive strength values (Bicer, 2019-a, b, c, 2021).

For natural stones to be used as building materials in the best manner, their entire physico-mechanical properties should be well known. In this study, Limra stone (Antalya), Geyran and Köfke stone (Isparta), Toprakkale stone (Hatay-Iskenderun), used extensively in such regions, were examined and some of their properties were investigated. The stones have been preferred by the local people until today and have been used in many buildings. This study reveals the reasons for preference with the features determined as a result of the tests applied to the stones.

2. Material and Methods

2.1. Material

Limra Stone: Limra stone is extracted from the quarries in the Limra region, 5 km away from the district of Finike of Antalya province. It is a light cream-colored homogeneous limestone. It has been used as a natural building material by civilizations in the region for years. This stone has a soft structure and is easy to process which extracted from the quarry. In the past, the Egyptians used Limra stone in the construction of the pyramids in blocks (Fig. 1-a), while the Romans used the concrete-like materials obtained by mixing the Limra stone with volcanic ash in construction [Avsaroglu, 2020]. During the Ottoman period, the constructions of Süleymaniye Mosque and Hagia Sophia Mosque, Beyazit II Mosque, and Çelebi Sultan Mehmet Mosque set examples to the areas of the usage (Fig. 1-b).

Limre stone has been used for both insulation and decorative purposes in the exterior facade coating of buildings in recent years due to its light and insulating properties. In addition, Limra stones of low quality are used as filling material on highways as well as in the production of mortar and cement. The stones are used as marble board with a thickness of 25-30 mm and a length and width of 300-900 mm. The hardness of the stone is 3 Mohs.

a) b)

Fig. 1. a) Egyptian Pyramids (URL-1), b) Çelebi Sultan Mehmet Mosque (Kepez, Antalya) (URL-2)

Geyran Stone: Geyran stones produced in Isparta region and from Geyran Mountain are tuffs called Rose stone (Fig 2-a). The stone is the product of Gölcük volcanism, and it has been observed that many churches and ancient buildings built with this stone have remained intact despite a period of 1,500 years. Geyran stone was frequently used in pavement and flooring and in Ottoman architecture [13]. The high pore ratio (40%) of andesite stone, which is generally used in construction foundations in Isparta and its surroundings, is preferred in terms of thermal insulation (Fig 2-b). As a result of high porosity, surface hardness and strength are lower. These tuffs, used as trusses in the cement industry, are also used as cement additives. The hardness of the stone is 4 Mohs.

a) b)

Fig. 2. Some applications of Geyran stone a) decoration (URL-3), b) building cladding practice (URL 4)

Köfke Stone: Köfke stone is one of the local stones of Isparta province and is extracted near the town of Sav at the 11th km of the Isparta-Antalya highway. The welded tuffs, referred to as “Köfke” by the local people, are the product of Gölcük volcanism and are generally gray colored trachy-andesites. This rock is also locally referred to as topknotted stone, castle stone, slap stone. Since they contain cracks in various directions like other igneous stones, they are also used by being removed from the quarries as blocks of certain sizes (Taşlıgil and Şahin, 2016). There are areas of material that has been widely used in the city, especially in monumental architecture, since ancient times. It is a building stone that has been used for a long time in the Aegean and Region of Lakes, especially in Isparta and Burdur (Fig 3). Köfke stone can only be used up to the basement level, and there are also examples applied up to the first-floor level. Its hardness is 2 Mohs. The heat transmission coefficient of Köfke tuffs varies between 0.2 and 0.4 W/m.K. The determined chemical components of the stone are shown in Table 1, and its physico-mechanical properties are shown in Table 2.

a) b)

Fig. 3. Kofke stone application in Isparta province
a) Garrison building (URL-5), b) Government building (URL-6)

Toprakkale Stone: Toprakkale stone is a basalt type stone and is extracted in the Eastern Mediterranean Region as well as in the region between the district of Toprakkale and Erzin and Iskenderun Bay. It is a sought-after rock especially for laying pedestrians and roads (Fig 4-a) and as a building construction material (Fig 4-b), as it paves smooth fracture surfaces due to its homogeneous structure. Although there is little or no quartz, it is a very hard rock. Toprakkale basalts can be observed in the field as massive, black-gray colored, large-small and angular blocks. Basalts, in the class of hard stones and the colors of which are usually black, have an intense and homogeneous color. The order in which minerals are formed depends primarily on the initial composition and temperature of the magma. The hardness of the stone is 6-7 Mohs.

a) b)

Fig. 4. Toprakkale stone applications a) floor covering (URL 7), b) use in construction (URL-8)

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

Compo. / Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Loss of ignition	Undefined
Limra stone	0.15	0.24	0.13	53.64	0.58	0.79	19.33	1.67
Geyran stone	59.80	-	4.25	4.58	7.81	4.26	9.6	10.5
Köfke stone	56.51	17.12	2.65	5.11	2.28	4.6	6.56	5.28
Toprakkale stone	55.20	13.86	11.63	5.70	7.58	1.85	3.25	1.12

2.2. Methods

The stones taken from the quarries were shaped in 150x60x20 mm and 100x100x100 mm dimensions for thermal and mechanical tests (Fig. 5). The stone samples were subjected to the following tests.

a) b) c) d)

Fig. 5. Pictures of the stones a) Limra stone, b) Geyran stone, c) Köfke stone, d) Toprakkale stone

The "Shotherm-QTM "unit which operates according to the hot wire method of DIN 51046 is used to measure the thermal conductivities of the specimens (Fig. 6-a), (Denko, 1990, Vysnıauskas & Zıkas, 1988). The measurements on three locations of each sample block are repeated to reflect the average of three values. Measurement results are given in Table 2.

Compressive strength and abrasion tests were performed on the sample according to TS 699 standard (TS 699, 2009), (Fig 6-b, c), the results are shown in Table 2.

Due to the risk of cracking, fragmentation, or dispersion of the building materials in contact with water because of freezing under 0 ^{o}C temperatures, the calculated water absorption rates should be below the critical value of 30% (BS 812-109, 1990). Water absorption values were calculated by Equation (1). The change of the samples' weight based on time can be seen in Fig 7.

$$\text{Water absorption percent}=\{[\, W_d - W_k]/ W_k \}x100 \qquad (1)$$

Here, W_k and W_d are dry weight and the water absorbed weight.

a) b) c)

Fig. 6. Test units, a) Shotherm-QTM, b) compressive strength, c) volume abrasion

3. Results and Discussion

In this study, conducted to research the thermal and mechanical properties of some building stones with large reserves and used as building construction materials in Antalya, Isparta and Hatay (Iskenderun) and neighboring provinces in the Mediterranean Region, the following findings were determined.

Limra Stone:

Limra stone is produced as limestone. With its 1.91 g/cm^3 density and 0.813 W/mK thermal conductivity values, the stone was preferred to be used for insulation and decorative purposes in the exterior facade coating of buildings (Table 2). Because the stone is light and easy to process, it is easy to manufacture. Limra stones of low quality are used as filling material on highways and used in the production of mortar and cement.

Limra stone, with its thermal conductivity coefficient value, looks better than granite, marble, limestone, and sandstone. Therefore, it will provide heat and sound insulation if it is used as an exterior coating material in buildings. In addition to these, considering the 22 MPa compressive strength value, although it is lower than high-strength natural building stones, it has approximately equivalent strength to the concrete material. The low water absorption value (4.8 %) indicates that there will be no risk of stone disintegration because of freezing at temperatures below 0 ^{o}C.

Geyran Stone:

Geyran is a type of andesite class stone, and its surface has a hard structure. Therefore, it has been used as a construction material in very old historical buildings, ensuring that the buildings remain intact until today. Today, the stone is used extensively in paving, floor coverings and building foundations. With its highly porous structure and 0.345 W/mK thermal conductivity coefficient values, it is preferred by the local people for insulation purposes. Therefore, it is preferred intensely as a building coating material today. On the other hand, with a pressure value of 28 MPa, it seems weaker than similar andesite class building stones. Geyran stone seems suitable to be used as pavement, floor covering and wall coating material with 1.6 % wear loss.

Kofke Stone:

The thermal conductivity coefficient of Köfke tuffs is 0.265 W/mK, and it is considered better than granite, limestone, sandstone, common brick, and marble. With its 88 MPa compressive strength, it seems more durable than Limra and Geyran stones. The fact that the water absorption rate is less than 30 % indicates that the stones can be used in humid environments. With both its thermal and mechanical properties, Köfke stone shows that it can be used as bridge construction, flooring of parks, building wall coating, briquette, or brick. Köfke stone, which is easily available in the region, has been preferred because it is a material with a high insulation level, easy to process and low cost.

Toprakkale Stone:

With a compressive strength of 93 MPa, it is in better condition than other thinned stones and materials other than granite shown in Table 3. In addition, it is a rock that is sought after for paving roads and pedestrians with its 0.7 % volume abrasion value and 0.8% water absorption values. It can be argued that it does not have an insulating property with a thermal conductivity coefficient of 1.761 W/mK, therefore it is not appealing in terms of energy saving.

If the drying rates of the stones seen in Figure 8 are examined, it can be acknowledged that the four local stones examined have little breathing ability.

Table 2. Thermal and mechanical properties of stones

Materials	Density (kg/m³)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Water absorption (%)	Volume abrasion (%)
Limra stone	1.91	0.813	22	4.8	9.2
Geyran stone	1.65	0.345	28	1.98	1.6
Köfke stone	1.38	0.265	88	18	15.7
Toprakkale stone	2.75	1.761	93	0.80	0.7

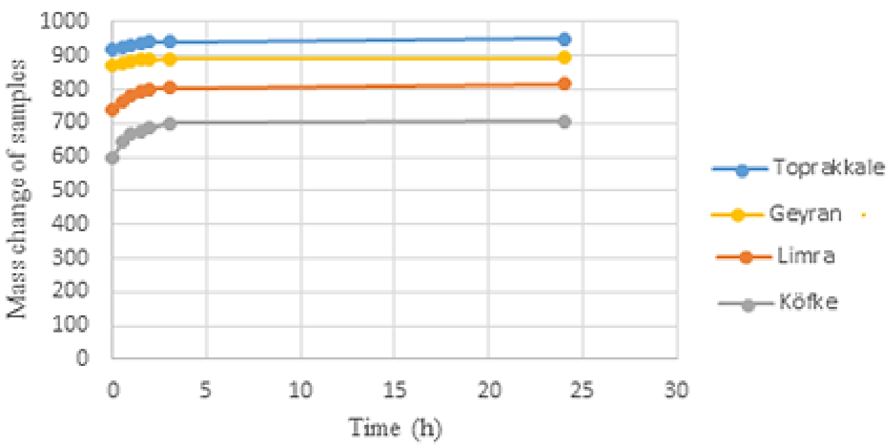

Fig. 7. Mass change of stones according to time in water absorption test

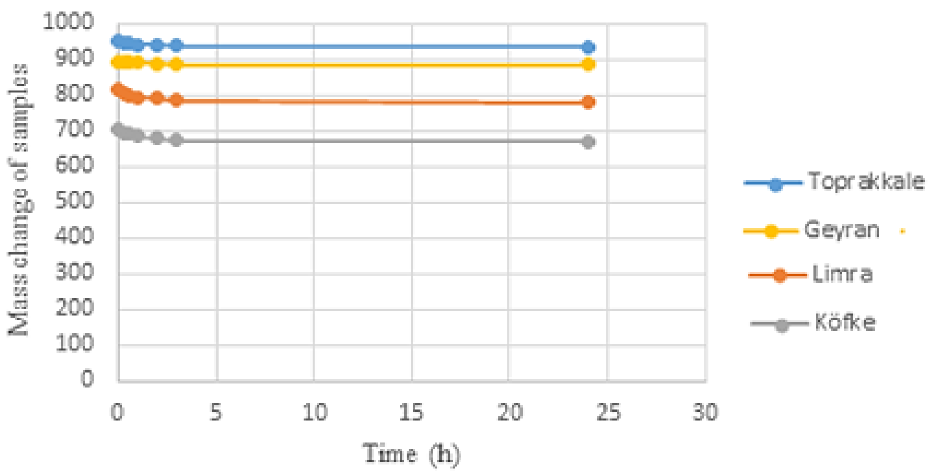

Fig. 8. Mass change of stones according to time in drying test

Table 3. The physical properties of some building materials (Toksoy, 1988).

Materials	Density (kg/m³)	Thermal conductivity (W/mK)	Compressive strength (MPa)
Concrete	1906	0.814	20
Granite	2643	1.73	120
Limestone	2483	1.16	35
Sandstone	2235	1.85	80
Marble	2603	2.77	50
Common brick	1602	0.692	16

4. Conclusions

The thermal and mechanical properties of Limra stone (Antalya), Geyran and Köfke stones (Isparta) and Toprakkale (Hatay) local stones, which are used as building construction elements, are experimentally examined and the results are presented below.

- ✓ Limra stone is preferred to be used for both insulation and decorative purposes in exterior coating of buildings, with its easy processability and aesthetic appearance and thermal conductivity coefficient of 0.813 W/mK..
- ✓ Geyran stone's surface is hard and can be used as road pavement material with a wear rate of 1.6 %. With its porous structure and 0.345 W/mK thermal conductivity coefficient, it is preferred by the local people for heat and sound insulation
- ✓ Köfke is the stone with the lowest thermal conductivity (0.265 W/mK) among the stones examined and is preferred for heat and sound insulation. On the other hand, its compressive strength of 88 MPa shows that it can be used as a load-bearing wall material and as a coating material for the walls of the buildings.
- ✓ The high thermal conductivity coefficient of 1.761 W/mK of Toprakkale basalt samples indicates that the insulating property of the stone is not appealing. On the other hand, the compressive strength value of 93 MPa shows that it can be used comfortably in the load-bearing wall material, coating industry, and lightweight concrete production

The richness of the quarry reserves, the easy supply and the low cost can be considered as an important reason for preference in addition to the properties of the stones examined.

Author Contibution

I hereby declare that the planning, execution and writing of the article was done by me as the sole author of the article.

Conflict of Interest

I declare that there is no conflict of interest during the planning, execution and writing of the article.

Statement of Research and Publication Ethic

In the study, research and publication ethics were complied with.

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