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Research Article

The Thermal and Mechanical Properties of Building Stones from the Afyon, İzmir, Muğla and Denizli Region

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ABSTRACT: This study investigated the thermal and mechanical properties of Iscehisar stone, Alacati stone, Milas marble, and Denizli schist. Samples were taken from quarries for each stone. Chemical analyses were carried out. Afterward, thermal conductivity, compressive stress, water absorption, water vapor permeability, and wear experiments were conducted. Alacati stone had the highest thermal conductivity (0.381 W/mK). Denizli schist had the highest compressive strength (95 MPa). All samples had water absorption rates lower than 30%. The results were compared with energy-saving, strength, and comfort with other building materials.

Keywords: Iscehisar stone, Alacati stone, Milas marble, Denizli schist, Building material.

1. INTRODUCTION

Natural stones are prevalent in all parts of the world. Most historic buildings are made of natural stones, such as Pyramids, Greek Acropolises, Roman Amphitheaters, and Ottoman fountains and mosques. Natural Stones are commonly used because they are stronger and more durable than other traditional building materials. Stones were brought from hundreds of miles away to build those structures. However, sometimes natural stones are used because there are rich stone reserves around the construction area.

We need to know some physico mechanical properties to determine where to use natural stones. For example, while density and porosity negatively affect some physical and mechanical properties, they positively affect heat and sound insulation. Those properties are even more critical when it comes to the construction of outdoor spaces and large structures under different climatic conditions.

Having a considerable and quite diverse mineral base, Turkey has one of the world's largest natural stone reserves. Natural stones build roads, patios, walkways, walls, and dams. Natural stone production has become an important sector with developments in the construction sector in recent years [1]. Natural stones have become more popular because the prices of construction materials have risen, and the demand for housing has exceeded its supply.

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There is a large body of research on building stones. Some of those studies focus on natural stones' geological formation, properties, and geographical distribution [1- 9]. Other studies address building stones in the construction industry [10 - 18].

We need to know the physicomechanical properties of natural stones to use them as building materials in the best way. This study focused on the thermal and mechanical properties of Iscehisar stone (Afyon), Alacati stone (İzmir), Milas White Marble (Muğla), and Denizli schist. Local people have used those stones throughout history. This study investigated why they were preferred.

2. MATERIALS AND METHODS

2.1. Materials

Iscehisar Stone (Afyon)
Samples were obtained from the andesite quarries of Ağın Mountain, north of the Iscehisar sub-district of Afyonkarahisar to determine the technical characteristics of the Iscehisar stone. The quarries in question are up and running, and andesites produced by them are used as building blocks in the region. Those andesites are grayish, pinkish, or red-purple. Iscehisar andesites are volcanic rocks used as parquet, flooring, and covering stones in buildings, walkways, parks, and gardens in different regions of Turkey (Fig 1). In addition, Iscehisar stone is also used to restore historical buildings and as sitting groups and flower beds [19]. In recent years, Iscehisar andesite has become popular among domestic and foreign natural stone users because it is homogeneous and unfading with unpolished, wiped, hammered, or rough-hewn surface forms. It has a hardness of 3-4 Mohs.

a) b)

Figure 1. Iscehisar stone examples a) Iscehisar (Koca) bridge, [20], b) Building surfacing [21]

Alacati stone (Izmir)
Alacati stone (Izmir) is called so because of the stone quarries in the Alacati region of the Cesme district of Izmir province [22]. It is also known as “Alapietra.” It is a light-colored, slightly porous type of sedimentary stone composed of volcanic ash, sand, and lava particles. It is white, off-white, or cream. It is easy to chip and shape because it is soft when quarried. It hardens over time and turns into a natural building material. There is no need for plastering, whitewashing, or similar applications on the interior and exterior facades of buildings made of Alacati stone. It is also a natural thermal insulator. It is used as a decoration element in indoor and outdoor spaces, providing a visual richness in walls, arches, columns, and gardens (Fig 2). It has been used to build stone houses in the region throughout history. It has a hardness of 3 Mohs.

a) b)

Figure 2. Alacati stone examples a) Pazaryeri mosque [23], b) Stone houses [24]

Milas White Marble

Samples were obtained from the marble quarries located in the Milas district of Muğla province. The Milas White Marble has homogeneous lines with very light gray tones in white color. It has a hardness of 3-4 Mohs. It is used in all applications in interior and exterior areas and special projects (baths, fireplaces, etc.) and home decorations. It is also widely used in buildings, floors, counters, stairs, steps, exteriors, tombs, and sculptures [25] (Fig 3).

a) b)

Figure 3. Milas White Marble a) floor and stair covering [26], b) processed state [27]

Denizli schist

There are rich schist reserves around Çal and Bekilli districts in the northeast of Denizli. Denizli schist, also called a slate stone, is used as decorative and accessory coating stones in domestic and foreign markets [28]. Slate stone is introduced to domestic markets, especially in Istanbul, Izmir, Bursa, and Antalya [29]. Slate stone is used in walkways, park and garden arrangements, wall covering, and pool edges (Fig 4). It has a hardness of 5-6 Mohs.

a) b)

Figure 4. Denizli schist applications a) Wall covering [30], b) Flooring [31]

2.2. Methods

Thermal experiments were performed on 150x60x20 mm samples, while compressive strength and wear experiments were performed on 100x100x100 mm samples.

A Shotherm-QTM unit based on DIN 51046 hot wire method was used to measure the thermal conductivity values of the samples [32**,** 33]. Measurements were made from three different points of each sample, and the average of the three values was taken.

The compressive strength and wear tests were carried out according to TS 699 standard [34]. Table 2 shows the results.

Water absorption rates should be below the critical value of 30 % because of the risk of cracking, fragmentation or dispersion in case building stones come into contact with water below 0 °C [35]. Water absorption rates were calculated using Equation (1). Fig 5 shows the variation of the weights of the samples with time. Fig 6 shows the drying rates.

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

where,

W_k and W_d are the dry and water absorbed weights, respectively.

Table 2 shows the measurement and calculation results collectively.

3. RESULTS AND DISCUSSIONS

This study investigated some stones' thermal and mechanical properties from Afyon, İzmir, Muğla, and Denizli in the Aegean Region, Turkey. Below are the results.

Table 1 shows the components determined as a result of chemical analysis collectively.

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

component / Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Loss of ignition	Undefined
İşcehisar stone:	58.40	14.7	4.88	4.71	2.83	2.92	8.25	3.85
Alacatı Stone	57.88	8.34	0.83	10.54	0.76	4.01	10.22	7.45
Milas Matble (white)	0.231	0.085	0.09	53.7	0.62	0.06	43.7	1.53
Denizli schist	70.18	4.81	0.06	0.21	0.64	3.25	16.11	4.75

Iscehisar andesites are volcanic rocks with a volume abrasion and water absorption of 7.43 % and 5.39 %, respectively. They are used in many regions in buildings, walkways, and paving stones. Iscehisar andesites have a thermal conductivity coefficient of 0.531 W/mK, which is better than concrete, granite, marble, limestone, and sandstone in Table 3. This result indicates that Iscehisar andesites can provide heat and sound insulation if used as a filling material on bricks, briquettes, and walls. Iscehisar andesites have a compressive strength of 70 MPa, close to sandstone and better than limestone, marble, and common brick. In addition to these features, Iscehisar andesites are commonly used due to abundant stone reserves and low costs.

Alacati stone is a lightweight building material that is easy to sculpt and shape because it is soft when first quarried. Therefore, it is widely used in buildings. There is an increased demand for Alacati stone because it is used on interior and exterior facades without the need for plaster, whitewash, and similar applications. It is also used as an ornamental element. This is indicated by the fact that it has been widely used to build stone houses in the region for a very long time. It has a thermal conductivity of 0.381 W/mK, suggesting that it is better than the other construction materials (Table 3) and can provide heat and sound insulation in buildings. It has a water absorption rate of smaller than 30 %, indicating that it can be used in humid environments. It has a compressive strength of 16.29 MPa, which is smaller than artificial materials such as concrete, briquette, brick, and aerated concrete (Table 3). Therefore, it should not be used as a bearing element. However, it has a density value of 1.370 kg/m^3, suggesting that it can reduce building loads if used as aggregate in concrete. It has a volume abrasion rate of 25.48 %, indicating that it should not be used as a flooring material.

Milas Marble has a thermal conductivity of 2.720 W/mK, which is not very promising. However, it has a compressive strength of 64.7 MPa and a volume abrasion of 1.10 %, indicating that it can be used as a flooring material. It has a water absorption of 0.18 %, suggesting that it can be used to make kitchen counters as it is suitable for wet floors.

Denizli Schist has compressive strength, volume abrasion, and water absorption of 95 MPa, 0.12 %, and 0.33 %, respectively. These values show that it can be used to construct walkways, park and garden arrangements, wall coverings, and poolsides. It has a heat transfer coefficient of 1.163 W/mK, suggesting that it can be used as a wallcovering. There is an increased demand for Denizli schist because it looks nice and provides insulation. It has a higher thermal conductivity than granite, sandstone, and marble. Its thermal conductivity is similar to that of limestone. However, it looks better than all materials, except for granite (Table 3).

For five reasons, there has been an increased demand for Iscehisar stone, Alacati stone, Milas marble, and Denizli schist. First, they have good thermal and mechanical properties. Second, Turkey is rich in reserves. Third, they are easy to access. Fourth, they are low cost. Fifth, they are easy to process.

Table 2. Thermal and mechanical properties of stones

Materials	Density (kg/m^3)	Thermal conductivity (W/mK)	Compressive strength (MPa)	Water absorption (%)	Volume abrasion (%)
İşcehisar stone	2.335	0.531	70	5.39	7.43
Alacatı stone	1.370	0.381	16.29	24.9	25.48
Milas matble	2.720	2.461	64.7	0.18	1.10
Denizli schist	2.150	1.163	95	0.33	0.12

The change in weights concerning time in the water absorption test is shown in Figure 5, and the drying rates are shown in Figure 6. In the case of examining the drying rates, it can be said that the four local stones examined have breathing ability, albeit slightly. In Figure 7, the thermal and mechanical properties of the examined stones are shown collectively to evaluate them together.

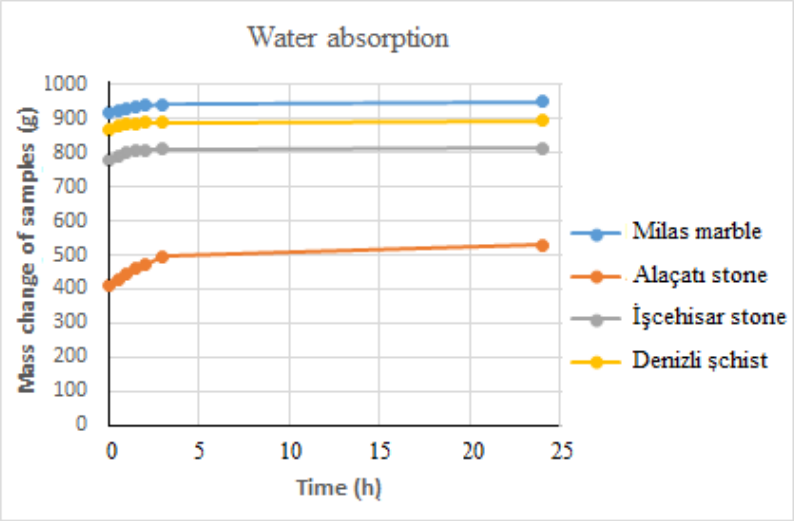

Figure 5. Mass change of stones according to time in water absorption test

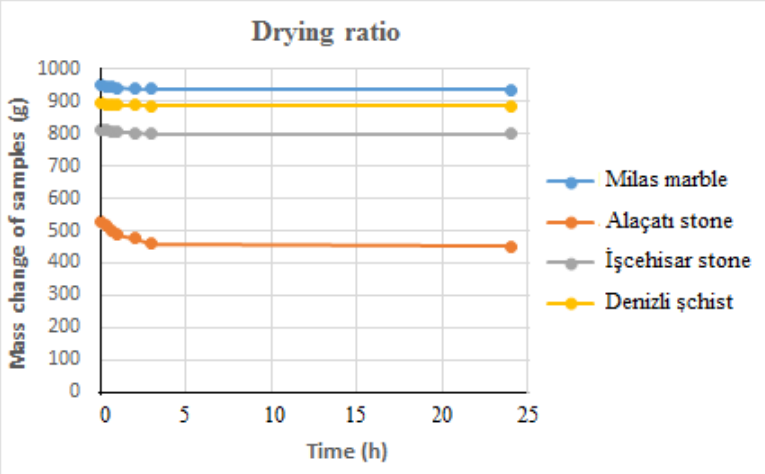

Figure 6. Mass change of stones according to time in drying test

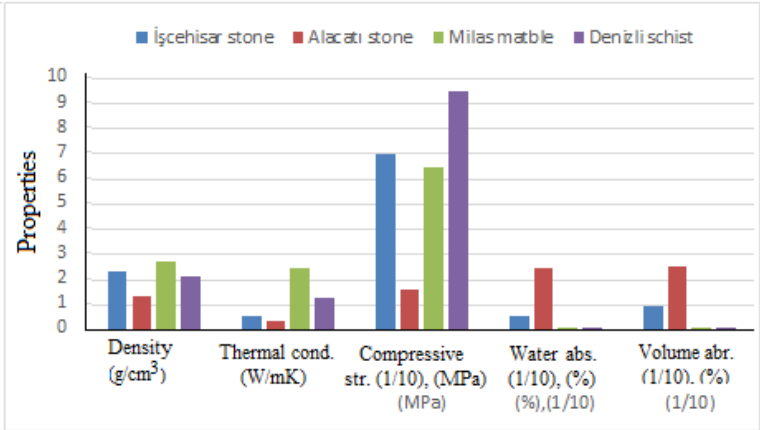

Figure 7. View of the physical properties of the stones together

Table 3. The physical properties of some building materials [36].

Materials	Density (kg/m^3)	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

This study investigated some stones' thermal and mechanical properties from Afyon, İzmir, Muğla, and Denizli in the Aegean Region, Turkey. The results are as follows:

✓ Iscehisar stone has a low thermal conductivity (0.531 W/mK) and compressive strength (70 MPa) value. Therefore, it can provide an energy economy advantage if used on load-bearing walls or as a coating material.

✓ İzmir Alacati stone can be used as an aggregate and wall covering material in low-density concretes, briquettes, and bricks because it is a lightweight material (1370 kg/m^3) with a low heat transfer coefficient (0.381 W/mK). If it is used for that purpose, it can reduce heating costs. It has a high volume abrasion (25.48 %), which cannot be used as a floor covering material.

✓ Milas Marble has a thermal conductivity of 2.461 W/mK, which is not promising. However, it can be used as a floor covering for wet floors.

✓ Denizli schist has compressive strength, volume abrasion, and water absorption of 95 MPa, 0.12 %, and 0.33 %. Therefore, it can be used in applications, such as floors, wall cladding, and poolsides.

✓ Iscehisar, Alacati, Milas marble, and Denizli schist have good thermal and mechanical properties. Moreover, those stones are easy to access and process at low costs. In addition, Turkey is rich in reserves.

✓ While the rocks with small density have lower thermal conductivity values, stones with bigger density have higher compressive strength values.

Declaration of Competing Interest

The author declares that they have no known competing financial interests or personal relationships that could influence the work reported in this paper.

Author Contribution

Ayşe Biçer contributed 100% at every stage of the article.

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