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Research Article

Thermal and Mechanical Properties of Building Stones Used in Some provinces in the Marmara Region

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ABSTRACT

In this study, some physical properties of Lefke (Bilecik), Keşan (Edirne), Çan (Çanakkale) and Küfeki (Istanbul) stones, which are used as building materials in their regions, were investigated. Samples were taken from two separate quarries for each stone, and after chemical analysis, thermal conductivity, compressive strength, water absorption, respiration ability and abrasion tests were performed. As a result of the tests, it has been revealed that *i*) Çan, Tüfekî and Lefke stones, among the ones examined, with low thermal conductivity coefficient values (0.342 W/mK, 0.564, 0.860 W/mK), can be used as briquettes, bricks or wall covering materials for thermal insulation and decoration purposes, *ii*) Keşan stone can be used in load-bearing wall material and wear-resistant flooring with 81.3 MPa compressive stress and 4.83% wear rate values and *iii*) four stones have rich reserves and low costs. The results were compared with other building materials especially in terms of energy saving, strength and comfort conditions.

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Introduction

Stones that are prepared in certain shapes and sizes by being removed from the earth's crust and used for various purposes in construction works in different shapes and thicknesses are called building stones. Building stones have been used by humans from the beginning of civilization to the present day. Natural stones, BC. It was used in the construction of buildings and monuments around 600 BC, and in ancient Greece, it was first used in columns that replaced wooden columns, and then their use became widespread. While the Turkish-Seljuk-Ottoman culture was dominant in Anatolia, natural stone was used differently from Europe, but at least as intensely and skillfully as the ones there [1].

Natural stones show different characteristics from each other due to their different internal structures resulting from their formation. For this reason, the properties sought in natural stones vary according to the place and purpose of use of the stone [2]. Not every stone in nature can be used as a building material. The stone to be used in the building should be homogeneous [3]. The largest historical buildings standing today are made of stone. Egyptian Pyramids, Greek Acropolises, Ottoman fountains and mosques, Artemis Temple and Halicarnassus Mausoleum are typical examples. The structures in question were built with stones brought from hundreds of kilometers away, as a result of years of efforts. Today, natural building stones are widely used for coating, carrier and decorative purposes in buildings, as well as in a wide area such as building exterior surfaces, flooring, border and edge decoration or building stone dam construction and aggregate production. [4].

The use of natural stones as building and decoration materials has led to an increase in world natural stone production. Turkey is one of the countries rich in natural stone assets and has a great potential in terms of both reserves and diversity. Today, both the price increases in construction materials and the increase in the demand for housing bring the use of natural stones as carrier and filling elements, depending on the geological structure of each region.

In the literature, many studies have been done on building stones. Some of these studies are summarized below in two groups. The first group studies are the studies on the determination of natural stones used as building materials, their geological formation, determination of their properties and their geographical distribution, and Taşlıgil and Şahin [4], Pivko [5], Gevrek & Kazanci [6], Kazanci & Gürbüz [7], Dinçer et al. [8], Duran, [9], Kaygısız [10], Türkdönmez and Bozcu [11], Devecioglu [12] can be cited as an example to these studies.

The second group of studies is about the use of stones in the construction industry, which can be counted as an example of Bakış et al [13],

Bicer [14, 15, 16], Demir [17], Çavumirza et al [18]. Daloğlu & Emir [19], Kılıç [20], Kılıç & Gültekin [21].

In order to evaluate natural stones as building materials in the best way, their physico-mechanical properties should be well known. In this study, Lefke stone (Bilecik), Kesan stone (Edirne), Çan stone (Çanakkale) and Küfeki stone (Istanbul), which are used extensively in their regions, were examined and some of their properties were investigated. 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.

Materials and Methods

Materials

Lefke Stone:

Lefke stone is a type of sandstone and is extracted in yellow color from the quarries located in the south of Osmaneli district of Bilecik province. While it is used as coating, ground stone and curbstone in public and private buildings in the construction sector, it is used in historical buildings and buildings to replace the worn, aging and worn parts of the natural building stones applied on the surface. The Lefke stone used for the restoration of Haydarpaşa train station is a good example (Fig 1-a). This sandstone has been widely used for centuries in the historical Eskişehir Government Office (Fig 1-b), Bebek and Bostancı mosques, and mosques, madrasas, churches and houses in and around Osmaneli town center (Fig 1-c). The hardness of the stone is 4.5-5 Mohs grade [22].

a) b) c)

Fig 1. Lefke stone a) Haydarpaşa station building [21], b) historical Eskişehir government building [23], c) Rüstempaşa mosque (Osmaneli), [22].

Kesan Stone:

These are light gray, dirty green, sandstone type stones found in the Keşan district of Edirne province. Stones are generally used as building and covering materials. It is seen that it is frequently used in columns as blocks, in load-bearing walls as masonry, and as facade and floor covering material in historical buildings (Fig. 2 -a, b, c). The hardness of Keşan sandstone is between 5-6 Mohs.

a) b) c)

Fig 2. Keşan stone applications, a) Trakya Uni. historical rectorate building [20], b) Keşan municipality, c) Kunduracılar bazaar [24],

Çan Stone

Çan stones are rhyolitic tuffs, the pyroclastic product of the Biga Peninsula Oligocene volcanism, with widespread outcrops around the Çan district of Çanakkale. Its history goes back to the settlement history of the villages around the Çan district. Since people living in this region are close to this stone and can easily obtain it, they used it as a coincidence in their structures in the past.

a) b)

Fig 3. Application areas of Çan stone a) Patterned structure, b) Exterior cladding [11]

Çan stone is a stone with a high appeal with its patterned appearance (Fig 3-a). The production of the stone is made from the quarries around the villages of Söğütalan, Haliağa, Uzunalan, Göle, Bilaller and Dereoba in the district of Çan [11]. Due to their lightness, easy processing, and good thermal and sound insulation, they are used as capstone and decorative light building stone for building exterior covering (Fig 3-b). Stones have also been used on the walls of mosques, on the covering of historical artifacts and art structures since ancient times. The Çan stone has different motifs of light yellowish, cream, reddish, brown.

Küfeki Stone:

Küfeki stone is an organic sedimentary stone composed of limestone, silica and fossil (like oyster and mussel) sediments**.** It is a compact stone with fine-grained and sandy appearance, fossiliferous, void and crystalline, in light beige, light yellow, gray tones. It is soft before it comes off the stove. So it is very easy to process. Then it hardens by taking carbon dioxide gas from the air. This hardening continues for a long time. Over the years, its strength increases relative to concrete and its lifespan reaches up to 2,500 years. Küfeki stone, which has been used in many works throughout history, was used in many important structures such as city walls, aqueducts, Topkapı Palace, Süleymaniye Mosque during the Roman, Byzantine and Ottoman periods (Fig 4 a and b). Stone found a very rich usage area in the works of Mimar Sinan during the Ottoman period. In important structures that affect the silhouette of Istanbul, such as Edirne Selimiye Mosque, Şehzade Mosque, Süleymaniye Mosque and Mihrimah Sultan complexes. Küfeki stone blocks, which were prepared from dense and homogeneous layers extracted from the vicinity of Bakırköy, were used. Mimar Sinan used a wide range of limestone in his buildings, such as in the outer walls, bodywork and outer covering, in the interior as interior wall material and floor covering, in the carrier legs, arches, portals, altars and railings [25].

a) b) c)

Fig 4. Küfeki stone applications a) Topkapi palace [26], b) Süleymaniye mosque [27], c) exterior covering [28].

Methods

Samples with dimensions of 150x60x20 mm for thermal tests and 100x100x100 mm for pressure and abrasion tests were prepared from the stones obtained from the quarries. Chemical analyzes of the stones were determined and shown in Table 1. The following tests were applied to the stones.

The measurement procedures have been performed with "*Shotherm-QTM*", conducting measurement in the temporary regime and running in the hot-wire method (Fig. 5). This device was used to perform measurements in accordance with the DIN 510406 norm from 3 different spots on each sample under the room temperature of between 22 ºC and 25 ºC, taking the calculations of the arithmetic mean of these 3 values. The device's thermal conductivity coefficient has a tolerance of 5% between 0.02 and 6 W/mK [29, 30]. The outcome of the measurements is provided in Table 2.

Fig 5**.** Thermal conductivity meter unit

Endurance tests have been conducted on the samples as per TS 699 standard [31]. Compressive strength tests have been conducted on the samples with the device of the brand Ele International, offering the following features: 3000 kN loading capacity; digital control panel; adjustable loading rate; applying uniaxial force. Volume loss abrasion outcome for 88 rpm within the scope of the frictional abrasion tests are provided in the Table 2.

The aim of water absorption test (WAR) is to identify the dry volume, in where the ice crystals within can expand, as the building materials freeze in direct contact with the water [32]. This feature provides an assurance for the material against freezing. Each sample's dry weight (W_k) has been identified. Then level of water is increased gradually within the water tank hosting the samples, water is added into the tank in a manner to ensure the samples to be submerged. The change of the weight of samples based on time is provided in Figure 3. Upon maintaining the samples within the water for 48 hours, they have been removed out of the water and wiped accordingly, revealing the water-absorbed weight (W_d), while on the other hand, calculating the water absorption ratio with the Eq. 1.

$$WAR = \{[W_d - W_k] / W_k\}.100 \quad (1)$$

Dry weights of the samples have been taken with the weighing machine with a tolerance of 1%, while the levels of density levels have been calculated by determining the volumes of the samples.

Results and Discussions

In this study, which was conducted to investigate the thermal and mechanical properties of some stones with large reserves and used in the provinces and districts of Bilecik, Edirne, Çanakkale and Istanbul in the Marmara Region, the following findings were determined.

Lefke stone:

It is a sandstone type building material used as coating, ground stone and curbstone in buildings in Bilecik and its surrounding provinces. The average density of the stone is 2.18 g/cm^3, its porosity is 10.38 %. The water absorption rate is 5.93 %. Compressive strength was determined as 74.4 MPa and wear rate as 10.34 %. Lefke stone seems to have a thermal conductivity coefficient of 0.860 W/mK, which can be considered low in its class. Also, when compared to some of the building materials given in Table 3, granite looks better than marble and limestone, but has about the same value as concrete. For this reason, if it is used as a wall covering material in buildings, it will provide heat and sound insulation. In addition to these, the compressive strength value of Lefke stone seems to be approximately the same as its class materials. Lefke stone seems to be suitable for both the carrier (limit value

68.7 MPa) and coating (limit value 39.2 MPa) in the building with a pressure value of 74.4 MPa (according to TS 11145 [33]. It is also used as a floor covering material with a wear loss value of 10.34 %.

Keşan Stone:

Keşan stone is from the sandstone class like Lefke stone and is generally used as a building and covering material. However, since it has a hardness between 5-6 Mohs, 4.83 % volume abrasion and 81.3 MPa compressive stress, in addition to its usage area, it is widely used in bearing walls and flooring as floor covering material and for decorative purposes. As seen in Table 2, the compressive stress of Keşan stone appears to be better than materials other than granite. Although the thermal conductivity value (1.204 W/mK) is higher among the examined stones, it is smaller than granite and marble, and about the same as limestone (Table 3). With its porosity rate of 7.7 %, it is smaller than the stones of its class (sandstones).

Çan Stone:

Among the stones examined, this stone has the smallest thermal conductivity coefficient (0.342 W/mK). For this reason, it is very advantageous in terms of energy saving to be used as a facing stone in building exterior cladding, as it is very good for heat insulation and sound insulation. Due to the light weight (1.45 kg/m^3), patterned structure and easy processing of the Çan stone, it is also used extensively for decorative purposes. For this reason, the stones do not disperse at temperatures of 1.175 °C. Commonly used in fireplaces. With 9.65 % water absorption value indicates that it can be used in humid environments. Move thermal conductivity coefficient (0.342 W/mK) and compressive strength (13.2 MPa) values. They

are smaller than the materials shown in Table 3, For this reason, it does not seem appropriate to be used on load-bearing walls. Çan stone is not suitable for flooring with a volume abrasion value of 15.55 %.

Küfeki Stone:

Küfeki stone is an organic sedimentary stone and is very soft and easy to work when extracted from the quarry. It hardens over time and gains strength, so it is used for many years. The use of stone in many buildings during the Roman, Byzantine and Ottoman periods is an indication of this. This is why Mimar Sinan uses it as a material for exterior walls and exterior cladding, as interior wall material and floor covering for interiors, for carrier legs, as arch and altar material. The stone is important in terms of thermal insulation and sound insulation due to its 0.564 W/mK thermal conductivity coefficient. The Çan stone has a better appearance than the similar materials given in Table 3. Compressive strength value (13.2 MPa) is the value of the stone after 28 days of drying and this value will increase in the long run. Historical buildings are indicators of this fact.

In Figure 6, the thermal and mechanical properties of the examined stones are shown collectively to evaluate them together. The change in weights with respect to time in the water absorption test is shown in Figure 7, and the drying rates are shown in Figure 8. In the case of examining the drying rates, it can be said that the four local stones examined have breathing ability, albeit slightly.

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

Component / Material	SiO2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Loss of ignition	Undefined
Lefke stone:	58.12	16.31	9.62	-	1.21	0.45	8.52	5.86
Kesan stone	69.65	14.70	6.65	-	-	0.13	6.23	1.74
Çan stone	69.56	13.21	0.93	0.43	0.20	5.17	7.18	3.42
Küfeki stone	22.61	16.31	1.41	52.31	1.18	0.28	7.70	6.21

Table 2. Thermal and mechanical properties of stones

Materials	**Density (kg/m^3)**	**Thermal conductivity (W/mK)**	**Compressive strength (MPa)**	**Water absorption (%)**	**Volume abrasion (%)**
Lefke stone	2.18	0.860	74.4	5.93	10.34
Kesan stone	2.42	1,204	81.3	18.63	4.83
Çan stone	1.45	0.342	13.2	9.65	15.55
Küfeki stone	1.68	0.564	10.4	5.7	18.13

Table 3. The physical properties of some building materials [34].

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

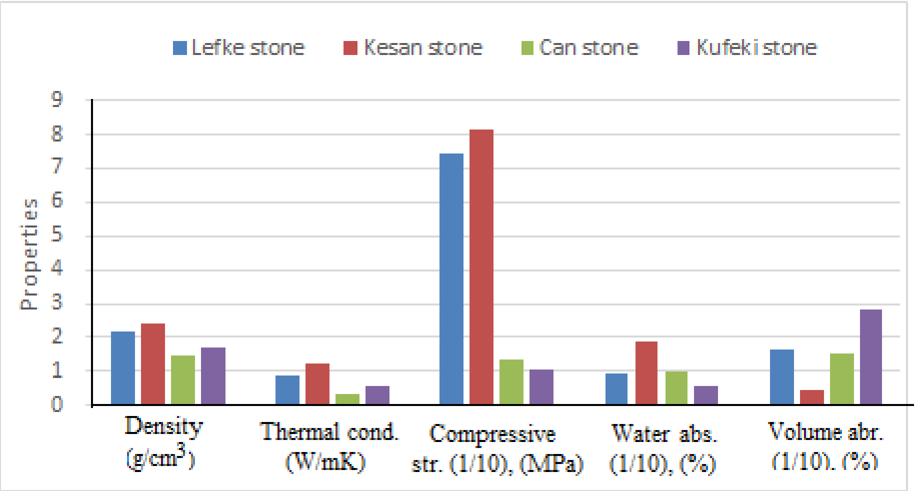

Fig.6. View of the physical properties of the stones together

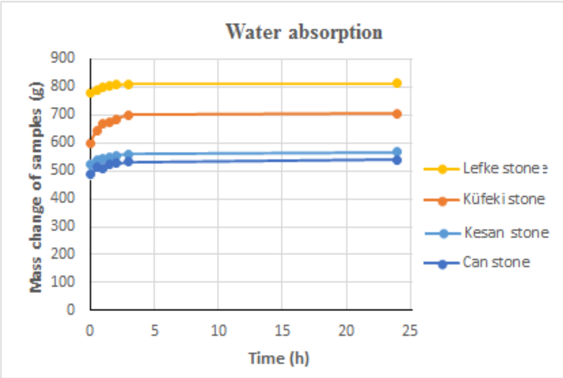

Fig 7. Mass change of stones based on time in water absorption test.

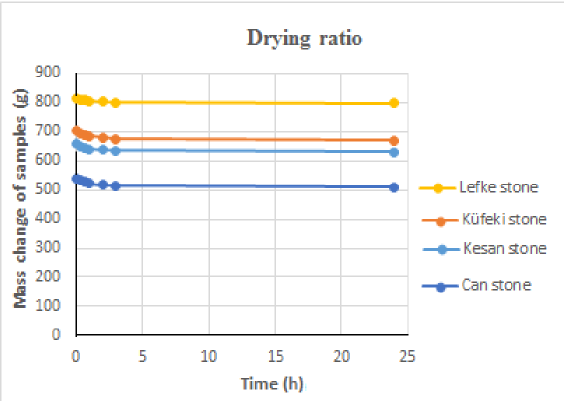

Fig 8. Mass change of stones based on time in drying test

Conclusions

The thermal and mechanical properties of the local stones used as building structural elements in the centers and districts of Bilecik, Edirne, Çanakkale and Istanbul were experimentally examined and the results are given below.

✓ Lefke stone, with its 0.860 W/mK thermal conductivity coefficient and 74.4 MPa compressive strength values, will provide heat and sound insulation and reduce building heating costs if it is used in the construction of load-bearing walls or as wall covering material in buildings. In addition, the low water absorption rate is an advantage in this respect.

✓ Keşan stone, like Lefke stone, is advantageous in terms of energy economy, with its compressive strength of 81.3 MPa and thermal conductivity of 1.2014 W/mK, being used instead of bricks in building load-bearing walls or as wall covering material. In addition, with a wear rate of 4.83 %, it is preferred because it is used as a wear-resistant floor covering.

✓ Çan stone is the stone with the smallest thermal conductivity (0.342 W/mK) among the stones studied, and it is important in terms of thermal comfort. In addition to this feature, it is highly preferred to be used as briquettes or bricks in the wall construction of multi-storey buildings with its light weight (1.45 kg/m^3) and 13.2 MPa compressive strength, as it will reduce the dynamic loads on the structure. The patterned structure of the stone and its ease of processing are the reasons why it is preferred for decorative purposes.

✓ When the küfeki stone is taken out of the quarry, it is very soft and easy to work, and the stone hardens over time. Because of this feature, it has been heavily preferred in historical works in the past. In addition, having a thermal conductivity value of 0.564 W/mK is an important reason for the preference of the stone in terms of energy economy.

✓ In addition to the characteristics of the stones examined, the fact that the quarry reserves are rich, easy to obtain, can be used directly by cutting and the cost is low are also accepted as an important reason for preference.

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