MATERIALS ENGINEERING | RESEARCH ARTICLE

Investigation of engineering characteristics of mardin stone used in eco-building

A. Sarıışık1 and G. Sarıışık2*

Abstract: The engineering characteristics of samples obtained from Mardin stone were investigated. Natural stones that are produced in the Yalım village quarries, which are close to the Mardin city centre, are popular among the public and commonly used as a building construction component. A series of engineering characterization tests and analyses (mineralogical and petrographic characteristics; chemical, physical, mechanical, and insulation properties) were conducted on the Mardin stone samples. The structure of the Mardin stone was largely composed of micritic and crystallized calcite (>95%). The porosity ratio was 22.16%, the sound speed was 3.270 m/s, the specific mass was 2.680 kg/m³, the Knoop hardness was 120 HK, and the water absorption capacity was 13.72%. Other findings included a compressive strength of 20 MPa, compression strength after frost of 15.58 MPa, Schmidth hardness of 33.1 MPa, SO₄ abrasion resistance in a humid environment of 1.54%, and flexural strength of 3.73 MPa. The stone showed 0.04% resistance to ageing by thermal shock, 0.78% resistance to salt crystallization, and 45.46 mm resistance to abrasion. According to the analysis, the value of thermal conductivity, another important characteristic of the Mardin stone, was 0.72 W/mK. This value was better than those of other natural stones. The highest thermal insulation performance was determined in the stone samples with high porosity and low thermal conductivity values. The results suggest that Mardin stones are suitable for architectural restoration and eco-building.

ABOUT THE AUTHOR

Ali Sarıışık got his bachelors’ degree in the Mining Engineering Department at Anadolu University, Eskişehir/Turkey in 1993, his master and PhD degree in the Mining Engineering Department at Süleyman Demirel University, Isparta/Turkey in 1998. He is still an academic member of the Civil Engineering Department at Harran University. His major areas of interests are: Mining and Mineral System Analysis Methods, Mine Design, Rock Mechanics, Management and Economy, Building Elements, Industrial Raw Materials.

PUBLIC INTEREST STATEMENT

In this study, a laboratory study was carried out on Mardin stone which is a natural building stone. Findings included a porosity ratio of 22.16%, compressive strength of 20 MPa, compression strength after frost of 15.58 MPa, Schmidth hardness of 33.1 MPa, SO₄ abrasion resistance in a humid environment of 1.54%, flexural strength of 3.73 MPa, resistance to ageing by thermal shock of 0.04%, resistance to salt crystallization of 0.78%, and resistance to abrasion of 45.46 mm, and thermal conductivity of 0.72 W/mK. The highest thermal insulation performance was determined in the stone samples with high porosity and low thermal conductivity values. These findings indicate that the Mardin stone could be used in different environmental conditions. Based on climatic conditions, no cracking, powdering on the surface, chipping, or disintegration was found in the Mardin stone. The results suggest that Mardin stones are suitable for architectural restoration and eco-building.
1. Introduction

In Turkey, construction materials that are suitable for different climatic conditions have been used in various regions throughout history. In the eastern and southern regions, the insulation rates of construction materials have been the prominent consideration. Thus, application of the construction materials used in historic periods to current conditions and investigation of the supply of authentic construction materials used in restoration works have gained importance, especially in the area of energy efficiency. Energy efficiency refers to the reduction of energy consumption per unit service or product amount without decreasing comfort, service, and production levels (Manioğlu & Yılmaz, 2008; Sarıışık & Derin, 2015). Studies around the world, particularly those in developed countries, which emphasize energy efficiency, indicate significant energy saving potential in the construction and industrial sectors (Abdelaziz, Saidur, & Mekhilef, 2011; Sarıışık & Derin, 2015). Energy efficiency is as important as the development of new and alternative sources of energy and technologies, because in the last 15 years, the energy consumption of our country has doubled and dependency on foreign sources has increased remarkably (Abdelaziz et al., 2011; Hepbasli & Ozalp, 2003; Oğulata, 2002; Sarıışık & Derin, 2015).

According to Önenç, Kırал, Erkanol, and Tullukçu (2006), Mardin stones are formed inside the lower Eocene, old reef Hoya formation. The average thickness of the formation is between 50 and 600 m. The lithologies that compose the formation are chalky, biomicrite, dolomitic, argillaceous, and fossiliferous limestones. The colours of the stones are yellow, pink, red, white, oyster-white, and grey. The Hoya formation, which is horizontally transitive (with Gaziantep formation), developed on a shallow sea-shelf where reef stones. Products obtained from marble quarries established on the Hoya formation are highly in demand on the global marble markets. Specifically, the Mardin stone is used in works of art and ornaments by cutting the stone into 19 × 20 × 30 cm samples. Other samples with special dimensions are also used. The zone, which is cut by stone cutters vertically a long a straight line in quarries, is also cut by the horizontal blade of the cutter. Highly porous Mardin stones are used in works of art requiring rough workmanship. The stones that undergo fine workmanship are extracted and treated in the shade. Subsequently, the stones are cut according to the desired shape and brought out in the open. The chalky properties and the fine-grained structure, as well as the highly scratchable nature of such limestones, enhance the appeal of Mardin stones for fine workmanship.

Semerci (2008) investigated the properties (physical, chemical, mechanical, and microstructural) of limestone and the literature on Mardin quarries and quarry stones. The resistance of the samples to atmospheric conditions was derived through ageing tests, and their physical, mechanical, and chemical properties were analysed. Stone samples were obtained from historical structures made from Mardin stones, namely Kasmiye Madrasa and Abdullahîf Mansion. These samples were subjected to physical, chemical, and mechanical tests. Further analysis was performed to determine the engineering characteristics. Kaya (2008) identified the physico-mechanical characteristics of the samples from a region that uses Midyat stones as construction materials and examined the physico-mechanical properties of the stones. The usability of the stone for limestone buildings was investigated. The use of Midyat stone as construction material was evaluated. According to Adin (2007), unless an extraordinary development occurs, energy will become more expensive. Therefore, the stone’s suitability for use should be studied by considering the physical life of the building, exterior temperature of the place by month, humidity, hours of sunshine in winter, seismic zone intensity and so on.

Civilizations leave traces because of the treatments applied to objects by people in the environments in which they live. Some civilizations remove these traces, whereas others respect the previous ones and build on them. In the antique graves in Mardin, the Muslim graveyard was established on the Christian (Nisranî) one, but the latter has been preserved until today. The work, which is
2. Experimental studies

2.1. Materials

The Mardin stone samples were obtained from the quarry in Yalım Köy, which is close to Mardin city centre (Figure 1). The spread of the formation is called Hoya formation in the Mardin-Diyarbakır-Siirt-Adıyaman region and Havra Stone in the Kilis and Gaziantep regions.

2.2. Characterization tests

Analysis in accordance with TS EN standards was conducted to identify the engineering properties (physical, mechanical, chemical, mineralogical, and petrographic) of the Mardin stone.

The physical and mechanical properties of the natural stone samples were identified in accordance with the relevant standards of the AKÜ Department of Mining Engineering, Natural Stones Technology Laboratory. Mohs hardness was identified in accordance with TS 6809 (1989), knoop hardness in accordance with TS EN 14205 (2004), specific bulk weight and density in accordance with TS EN 1936 (2013), visible and total porosity in accordance with TS EN 13755 (2014), flexural strength in accordance with TS EN 12372 (2013), flexural strength under constant moment in accordance with TS EN 13161 (2014), resistance to ageing by thermal shock in accordance with TS EN 14066 (2013), compression strength in accordance with TS EN 1926 (2007), and sound propagation speed in accordance with TS EN 14579 (2015).

A mercury porosimetry device (Micromeritics) was used to measure the pore size, evaluate the distribution of pore size and surface area, and determine the mass weight in dust or bulk samples. Samples weighing 2–3 g were used. An ultrasonic testing device was used to determine ultrasound speeds. The receiver and transmitter ends of the device on the samples and sound transit time (T, μs) were measured and the sound transit velocities (V) were calculated using the formula below. The measurements considered the length of the sample as well.

\[ V = \frac{d}{T} \]

The TS EN 14579 (2015) standard was utilized. Firm contact between the sensor (TCİ Thermal Conductivity Analyzer) and the flat surfaces of samples measuring 10 × 10 cm with a thickness of 1 cm was established. Thermal conductivity measurements were performed. For each analysis, four
samples were used. Three measurements were obtained from each sample to give a total of 12 measurements. Thermal conductivity coefficient refers to the quantity of heat that passes through a unit volume of the substance in a given unit of time when the difference in temperature of the two faces is 1°C. After dried in the drying oven at 105 ± 5°C, the samples were put into a thermal conductivity coefficient measurement device. Heat conductivity coefficient was calculated using the following formula:

\[ \lambda = \frac{Q \cdot d}{\Delta t \cdot A} \]  

where \( \lambda \) is heat conductivity coefficient (W/mK), \( Q \) is heat (watts), \( d \) is sample section thickness (m), \( \Delta t \) is sample face temperature difference (°C), \( A \) is face areathrough which heat passes (m²).

Determination of resistance to ageing by thermal shock was performed in accordance with the TS EN 14066 (2013) standard. The procedure covers the testing method for determination of potential variations that may occur due to the effects of sudden temperature changes (thermal shock) in natural stones. The dimensions of the test samples must be 200 × 200 × 20 mm (±2 mm). The TS EN 12371 (2011) standard is utilized for the determination of frost resistance.

Chemical analyses of the Mardin stone were conducted at the Natural Stone Analysis Laboratory (DAL) by the X-ray Fluorescence Spectrometry-XRF (ICP-ES) method and by using an inductive compound plasma-mass spectrometer. A Rigaku RINT 2000 X-ray Diffraction (XRD) device was used for mineralogical analyses of the Mardin stone samples. Fractured surface Scanning Electron Microscope (SEM) images of the raw and fired andesites were obtained via a Leo-1430 VP. Before the analyses, samples were coated with carbon. When the temperatures of the samples were within the range of 0–1,200°C, DTA–TG analysis was conducted by using a LINSEIS L-81 under normal atmospheric conditions in an alumina crucible at a heating rate of 20°C/min. A 20–30 mg sample was used in the analysis.

Mineralogical and petrographical analyses of natural stones were performed using thin sections, which were prepared in conformity with TS EN 12407 (2013). Samples were examined under a polarized microscope, and their characteristics were described and interpreted.

3. Results and discussion

3.1. Mineralogical and petrographical characteristics of the test results

Macroscopic examination indicated that the samples were beige, greyish-beige, and partly fine white mineral-filled rocks. Secondary cracks and their fills were insignificant. Melting voids and pores were observed in the fine-grained and hard massive structures. Colouration and alteration were poorly developed on the rock surface. Further, the rocks showed significant reactions to treatment with 10% diluted HCl acid, and typical reactions to acid treatments were observed. The hardness was found to be approximately 3 Mohs. Microscopic examination revealed that the rocks comprised mostly micritic and crystallized calcite. Micritic calcites measured 0.01 mm and below. Coarser crystallized calcite grains measured 0.1 mm and below. Relatively few opaque minerals were observed apart from these minerals. Small amounts of fossil shells were found to have been completely transformed into secondary calcites. Secondary cracks and secondary minerals were not monitored. Table 1 shows the compounds of the samples identified by using the polarized microscope. An earlier study showed that these rocks consist of micritic limestone (defined as natural mudstone, natural cement) and crystallized calcite, as indicated by mineralogical–petrographical analyses (Sarıışık & Derin, 2015). The analysis of the present study showed that the CaCO₃ content of the Mardin stone was 99%.

| Compound/mineral     | Modal rate (%) |
|----------------------|----------------|
| Micritic calcite     | 54–56          |
| Crystallized calcite | 44–46          |
| Opaque minerals      | <0.5           |
The rocks are semi-micritic semi-crystalline limestone with 99% calcite content. In the TG analysis of the samples, a mass deficit of 144.30 mg occurred (Figure 2). The DTA chart in Figure 3 indicates three endothermic reactions depending on the mass deficit. The initial peak was at 872.2°C, the second at 928.4°C, and the third at 997.0°C. In the endothermic peak at 872.2°C, CaCO$_3$ $\rightarrow$ CaO + CO$_2$ degradation occurred. Disintegration occurred at 928.4°C.

Figures 4–6 present the XRD patterns derived from the mineralogical analysis of the Mardin stone. Almost all of the Mardin stone samples seen in the XRD pattern in Figure 4 are CaCO$_3$ (limestone). Based on the high-temperature XRD patterns, impurities of CaCO$_3$ mineral were vaporized as a result of endothermic reaction. In the XRD pattern shown in Figure 5, the endothermic reaction continued from 800 to 1,050°C. Only CaO element remained at 1,050°C, as seen in Figure 6.

These results were produced by the shape and grain size of the marble, as well as its porosity characteristic, which is the most important factor in coupling. The porosity and water absorption capacity increased, which in turn decreased the strength in parallel with the increase in grain-size.
distribution. In addition, any increase in porosity and water absorption capacity, which are two physical characteristics of the marble, increased the degradation level and weight loss (Sarıışık, Çelik, & Gürçan, 2003; Sarıışık & Sarıışık, 2011).
SEM analysis was performed on the Mardin stone samples. SEM photographs showing the microstructure of the Mardin stone in detail are given in Figures 7 and 8. Although the Mardin stone has a homogeneous microstructure, its porous characteristics stand out. Approximately 100% of the crystal structure has a homogeneous structure consisting of calcite crystals [Photographs (A) and (B)]. The grain sizes of the crystals are very close to each other in many areas, whereas the crystal grain sizes show increases in the areas with porous structures.

In Figure 8, the SEM photograph (C) shows a homogeneous sample, which has grain structures that are very similar. In the images showing porous structure, void sizes are very close to each other and are non-interconnected close pores. Although the void in the SEM photograph (D) seems large, the section is a closed void. SEM photograph (E) shows more apparent porosities around the visible structure. In addition, the grain sizes are very similar, whereas the pores are closed and not interconnected. In SEM photograph (F), the pore structure has the same size as those in the previous photographs. The pore structure is homogeneous in terms of the coarseness of the grains and structure.
3.2. Chemical properties of the test results

Table 2 present the results of the chemical analysis conducted on the Mardin stone sample. No colouration (colour change) or alteration (deformation, cracking, chipping of stone) was found on the surface. These analyses showed that the Mardin stone had a CaCO$_3$ content of 99%. Calcium-based natural stones are more hygienic for human and environmental health during their production and use. The Mardin stone is different from magmatic-based natural stones, which likely contain radiating minerals, because the Mardin stone is calcium based; thus, the danger of radiation is reduced to zero (Sarıışık & Derin, 2015). The chemical properties of building stones need to be considered in conjunction with the physical properties in studying processes of deterioration, and these issues are covered elsewhere in these proceedings (Robertson, 1982). Discoloration not only affects the

| Compound (%)       | Mardin stone |
|--------------------|--------------|
| SiO$_2$            | 0.15         |
| Al$_2$O$_3$        | 0.01         |
| Fe$_2$O$_3$        | 0.06         |
| CaO                | 54.72        |
| MgO                | 0.21         |
| K$_2$O             | 0.18         |
| TiO$_2$            | 0.01         |
| P$_2$O$_5$         | 0.02         |
| SrO                | 0.02         |
| $^*$LoI            | 44.60        |

$^*$Loss on ignition (CO$_2$).

Figure 8. Mardin stone SEM image (pore).
aesthetic appearance of the stone, but can also result in physical damage to the stone (Winkler, 1973). Moreover, the use of the Mardin stone in the restoration and repair makes the structures look new despite usage for long periods of time because the stone provides the colour and pattern. The chemical analyses conducted in compliance with the TS EN 15309 (2008) standard showed that the Fe₂O₃ content is 0.06%, which is the same as the result of the analysis conducted by Sarıışık and Derin (2015). The Mardin stone, similarly to the old city after which it was named, can carry on the work for eternity. Mardin stones are environmentally friendly and do not contain any chemicals apart from their inherent minerals. These characteristics, coupled with the quality and comfort of use, enhance the suitability of the Mardin stone.

3.3. Physico-mechanical properties of the test results

Samples of the Mardin stone with dimensions specified in the standard were prepared. Chemical analyses were conducted. The physical properties, such as unit volume weight, water absorption by weight and volume under atmospheric pressure, specific weight, and porosity, were determined. Further, thermal conductivity measurements were performed. In the preparation of samples and during tests, different testing methods and standards of TS EN were utilized. The physico-mechanical properties of the Mardin stone are given in Table 3.

Most of the studies on the usage areas and classification of natural stones considered the physical and mechanical properties of stones (e.g. density, porosity, water absorption capacity, Knoop hardness, compressive strength, compressive strength after freezing, bending strength, and impact strength). In addition, these studies considered the impact of the environment on natural stones (e.g. chemical corrosion, harmful pollutants, freezing and thawing phases, and crystallization of salt solutions). These studies include Toraman, Kahraman, and Cayirli (2010), Singh, Singh, Mishra, Singh, and Singh (1999), Rodriguez-Navarro, Linares-Fernandez, Doehne, and Sebastian (2002), Benavente, Garcia del Cura, Garcia-Guinea, Sanchez-Moral, and Ordonez (2004), Sharma, Khandelwal, and Singh (2007), Sharma and Singh (2006), Sarıışık and Sarıışık (2011), Sarıışık (2012), Sarıisik, Sarısik, Koch, and Knoblauch (2008), Sarıisik, Sarısik, and Senturk (2010), Sarıışık and Derin, (2015), Sarıışık, Özkan, Kundak and Akdaş (2016), and Vishal, Pradhan, and Singh (2011), Vishal, Das, and Singh (2012). In

| Table 3. Physical-mechanical properties of Mardin stone |
|---------------------------------------------------------|
| **Physical-mechanical properties**                      | SI | Value |
| Color                                                  | -  | Bej   |
| Mohs hardness                                          | -  | 3     |
| Knoop hardness                                         | HK | 120   |
| Specific mass                                           | kg/m³ | 2,680 |
| Unit volume weight                                      | kg/m³ | 1,890 |
| Water absorption                                        | %  | 13.72 |
| Actual porosity                                         | %  | 29.56 |
| Visible porosity                                        | %  | 25.93 |
| Mercury porosimetry                                     | %  | 22.16 |
| Water absorption coefficient by capillarity             | gr/m².s⁰.⁵ | 45.38 |
| Determination of compression strength                   | MPa | 20    |
| Determination of propagation of sound speed             | m/s | 3,270 |
| Frost resistance (loss of weight) and determination of compression strength after frost (25 cycles) | %  | 0.02  |
|                                                      | MPa | 15.58 |
| SO₂ abrasion resistance in humid environment           | %  | 1.54  |
| Flexural strength in constant moment (½ axes)           | MPa | 3.73  |
| Resistance to ageing by thermal shock                   | %  | 0.04  |
| Resistance to salt crystallization (reduction)          | %  | 0.78  |
| Determination of resistance to abrasion                 | mm | 45.46 |
compliance with TS EN 13755 (2014) standards for Mardin stone samples, obtained a value of 11.92% in the water absorption test. Using the same standard, the result of the analysis by was 11.60% (Sanışık & Derin, 2015).

Fine workmanship is rendered in areas such as caves. Stones are extracted by fine workmanship according to their dimensions. Moreover, abandoned quarry pits exist in Mardin Province. Fine and rough workmanship on works of artis found in graves, balcony parapets, and capstones. Rough work is particularly carried out on porous, oyster-white limestones, which are harder than chalky limestone. The hardness of the Mardin stone is mohs 2.5 to 3, the compression strength is ≤50 MPa, and its impact and abrasion resistances increase in the process of dehydration. Dehydrated Mardin stone lightens easily. The fill rate of this highly porous stone is 85–90%, and its CaCO₃ content is 99%.

The test results demonstrated that the Mardin stone was capable of SO₂ abrasion resistance of 1.54% in a humid environment. In a study on the effect of water on the physico-mechanical behaviour of rocks, the results revealed that acidic water changes their behaviour and strength (Sharma et al., 2007; Singh et al., 1999).

The test results further indicated that the Mardin stone had a resistance to ageing by thermal shock of 0.04% and resistance to salt crystallization of 0.78%. Sulfated water dissolves calcium carbonate, and as a result, cracks and fissures develop with the expansion of salt crystals (increase in volume). Structural deformations, which result from anisotropic thermal expansion and shrinkage, proceed toward the inner structure of the natural stone. Deformation and disintegration are the final phases of this process. The physical and mechanical characteristics of the natural stones can deteriorate (Amoroso & Fassina, 1983; Benavente, García del Cura, Bernabéu, & Ordóñez, 2001; Benavente, García del Cura, Fort, & Ordóñez, 1999; Fookes, Gourley, & Ohikere, 1988; Siegesmund, Ullemeyer, & Weiss, 2000; Winkler, 1987).

Successful application of mardine stone in hot climate has been established. The Mardin stone sample was frozen (to −40°C) and dissolved each time for 25 cycles. This treatment was repeated 25 times (Sanışık & Derin, 2015). When the same test was conducted by Sanışık and Derin (2015), the results showed that the Mardin stone’s weight loss after frost remained at 0.02%. A highly porous structure is a significant advantage of the Mardin stone. Porosity and pore size distribution are key factors in controlling the uptake and transport of fluids within a stone (Rodríguez-Navarro & Doehne, 1999). Stones such as calcarenite, which have a high proportion of mesopores connected to large pores, are very susceptible to salt weathering (Benavente et al., 2004; Sarıisık et al., 2010; Schaffer, 1932).

### 3.4. Insulation properties of the test results

The value of thermal conductivity, which was determined to be 72 W/mK by the analysis, is another important characteristic of the Mardin stone. Table 4 presents the results of the thermal conductivity analysis of the Mardin stone.

Limestones, which are generally known as Mardin stones in the region, have been used in many architectural and historical structures. The use of the Mardin stone together with other construction materials, such as gas concrete and pumice concrete, is increasing because of its lightness and qualities that provide sound and heat insulation.

| Table 4. Thermal conductivity analysis of Mardin stone |
|------------------------------------------------------|
| Mardin stone | SI unit | Value  |
| Temperature  | °C      | 26.32  |
| Thermal conductivity | W/mK | 0.72   |
The thermal conductivity of the Mardin stone was investigated. The utilization of these stones as decorative, insulating, and coating material was evaluated. The stone has a strong relationship that is not available in all natural stones. Further, the Mardin stones are easy to treat, resistant, and soft when brought to the surface and also exhibit insulation properties. These properties allow for mechanical application. The insulation feature of the stone is at a high level because the pores in the stone structure do not come into contact with each other.

Thermal insulation is a significant method of saving energy. The systems of thermal insulation can be characterized by thermal conductivity. Thermal conductivity is primarily controlled by the mineral composition and texture of the rock (Popov, Pribnow, Sass, Williams, & Burkhardt, 1999). Relevant studies on the utilization of thermal conductivity in material characterization include Gündüz, Ugur, and Demirdag (2001), Demirdag and Gündüz (2003), Vosteen and Schellschmidt (2003), Meola, Carlomagno, and Giorleo (2004), Niática and Harmuth (2005), Meola (2007), and Shi, Wu, and Wu (2007). In addition, the insulating performance of various rocks or insulating materials has been investigated thoroughly by many scientists (Al-Kassir, Fernandez, Tinaut, & Castro, 2005; Barreira & de Freitas, 2007; Durmus & Görhan, 2009; Synnefa, Santamouris, & Livada, 2006).

The mechanism of heat transfer and thermal insulation should be defined in terms of the porosity, thermal conductivity, and texture of stone samples. A porous structure should decrease the thermal conductivity because of the presence of air in the pores, which enhances the insulation property of the samples (Tufan & Kun, 2014).

Under the same experimental conditions, the thermal performance of the Mardin stone samples with respect to utilization as an insulation material in eco-building has been proven to be the best.

4. Conclusions
In this study, a laboratory work was conducted to identify the engineering characteristics of the Mardin stone, a natural building stone. A water absorption test was conducted on the Mardin stone in accordance with the TS EN 13755 (2014) standard, and the result showed an absorption capacity of 13.72%. The water absorption rate of the Mardin stone is lower than 30%, which indicates that the stone could be used in humid environments. In addition, when a uniaxial compression strength of 20 MPa and a tensile strength of 3.73 MPa were considered, the strength of the Mardin stone was close to those of construction materials, such as concrete and brick. However, the stone showed low resistance compared to high-strength natural stones. In addition to its successful use in hot climates, the Mardin stone is capable of frost resistance (down to −40°C). Loss of weight of the Mardin stone after frost remained at 0.02% and the compression strength value after frost was 15.58 MPa. These findings indicate that the Mardin stone could be used in different environmental conditions. Based on climatic conditions, no cracking, powdering on the surface, chipping, or disintegration was found in the Mardin stone. The reason for the absence of colour changes under various climatic conditions is the low percentage of Fe₂O₃.

The high-level insulation feature, as seen in the SEM image (pore), is caused by the absence of contact between the pores in the structure of the Mardin stone. This quality is enhanced by the porous characteristics of the stone. In addition, the mercury porosimetry analysis of the sample showed a porosity value of 22.16%. Similarly, the thermal conductivity of the Mardin stone was 0.72 W/mK. The heat insulation values of the materials were directly proportional to the number of pores. Thermal insulation materials have low density and a considerable amount of pores that retain stable air. Insulation material that is 3 cm thinner can be used on facades coated with Mardin stone.
Acknowledgments
This study was supported by Afyon Kocatepe University Scientific Research Committee (Project No. 14.HIZ.DES.62). We would like to thank for their contributions.

Funding
This study was supported by Afyon Kocatepe University Scientific Research Committee (Project No. 14.HIZ.DES.62).

Author details
A. Sarıışık
E-mail: sariiskali@yahoo.com
G. Sarıışık
1 Faculty of Engineering, Department of Civil Engineering, Harran University, Şanlıurfa, Turkey.
2 Faculty of Engineering, Department of Industrial Engineering, Harran University, Şanlıurfa, Turkey.

Citation information
Cite this article as: Investigation of engineering characteristics of mardin stone used in eco-building, A. Sarıışık & G. Sarıışık, Cogent Engineering (2016), 3: 1275412.

References
Abdelaziz, A. E., Saidur, R., & Mekhilef, S. (2011). A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews, 15, 150–168. doi:10.1016/j.rser.2010.09.003

Adin, H. (2007). "Mardin ve Midyat'ta kullanılan bina yapılışında bazı fiziksel özellikleri [Some physical properties of building stones used in Mardin and Midyat]," Mühendis Makina [Engineer Machine], 48, 13–17.

Al-Kassir, A. R., Fernandez, J., Tinaut, F. V., & Castro, F. (2005). "Adin, H. (2007). Mardin ve Midyat’ta kullanilan bina yapısı fiziksel özellikleri [Some physical properties of building stones used in Mardin and Midyat], Mühendis Makina [Engineer Machine], 48, 13–17."

Amoroso, G. G., & Fassina, V. (1983). Stone decay and conservation: Atmospheric pollution, cleaning, consolidation and protection. Materials Science Monographs, 11, 54–110.

Barreira, E., & de Freitas, V. P. (2007). Evaluation of building materials using infrared thermography. Construction and Building Materials, 21, 218–224. doi:10.1016/j.conbuildmat.2005.06.049

Benavente, D., Garcia, M. A., Garcia, J., & Ordoñez, S. (2009). Thermodynamic modelling of changes induced by salt pressure crystallisation in porous media of stone. Journal of Crystal Growth, 296, 164–178. doi:10.1016/j.jcrysgro.2009.01.163-3

Benavente, D., García, M. A., Bernabéu, A., Ordoñez, S., & del Cura, M. A. (2001). Quantification of salt weathering in porous stones using an experimental continuous partial immersion method. Engineering Geology, 59, 313–325. doi:10.1016/S0012-825X(00)00020-5

Benavente, D., García, M. A., García, J., Sánchez-Moral, S., & Ordoñez, S. (2005). Role of pore structure in salt crystallisation in unsaturated porous stone. Journal of Crystal Growth, 260, 532–544. doi:10.1016/j.jcrysgro.2003.09.004

Demirdağ, S., & Gündüz, L. (2003). The characteristics of pumice and analysis of thermal insulation (In Turkish) (pp. 10–13). 18th International Mining Congress and Exhibition, Turkey.

Durmus, G., & Görhan, G. (2009). Evaluation of textural images with respect to thermal conductivity (In Turkish). Journal of Technical-Online, 8, 48–57.

Fookes, P. G., Gourley, C. S., & Ohlke, C. (1988). Rock weathering in engineering time. Quarterly Journal of Engineering Geology and Hydrogeology, 21, 33–57. doi:10.1144/QJEG1988.021.01.03

Gündüz, L., Uğur, L., & Demirdağ, S. (2001). A technical analysis on the specific heat capacity values for the marble types (pp. 181–196). 3. Marble Symposium, Proceedings Book, Afyon.

Hehparsli, A., & Ozap, N. (2003). Development of energy efficiency and management implementation in the Turkish industrial sector. Energy Conversion and Management, 44, 231–249. doi:10.1016/S0360-1285(02)00051-1

Kaya, A. C. (2008). "Midyat taşının kaplama ve yapıda kullanılabilirliğini artırılması [The usage of Midyat stone as a covering and building material researching]" (Masters Thesis). Ç.Ü. Fen Bilimleri, Institute of Sciences, Adana.

Manoğlu, G., & Yılmaz, Z. (2008). Energy efficient design strategies in the hot dry area of Turkey. Building and Environment, 43, 1301–1309. doi:10.1016/j.buildenv.2007.03.014

Meola, C. (2007). Infrared thermography of masonry structures. Infrared Physics & Technology, 49, 228–233. doi:10.1016/j.infrared.2006.06.010

Meola, C., Carlonagno, G. M., & Giorleo, L. (2004). The use of infrared thermography for materials characterization. Journal of Materials Processing Technology, 155–156, 1132–1137. doi:10.1016/j.jmatprotec.2004.04.268

Nilco, R., & Harmuth, H. (2005). Mechanical and fracture mechanical characterization of building materials used for external thermal insulation composite systems. Cement and Concrete Research, 35, 1641–1645. doi:10.1016/j.cemconres.2005.04.001

Oğuloto, R. T. (2002). Sectoral energy consumption in Turkey. Renewable and Sustainable Energy Reviews, 6, 471–480. doi:10.1016/S1364-0321(02)00012-6

Önçel, D. İ., Kiral, N., Erkan, D., & Tulluğ, A. (2006). "Mardin Taşı" ve özellikleri, Türkiye Jeoloji Kurultayı Bildiri Özetleri Kitabı ["Mardin Stone" the characteristics of mardin stone]. Ankara: TMMOB Jeoloji Mühendisleri Odası/TMMOB Chamber of Geological Engineers.

Popov, Y. A., Pribnow, D. F., Sass, J. H., Williams, C. F., & Burkhardt, H. (1999). Characterization of rock thermal conductivity by high-resolution optical scanning. Photogeotechnics, 28, 253–276. doi:10.1016/S0375-6505(99)00007-3

Robertson, E. C. (1982). Physical properties of building stone (pp. 62–86). Washington, DC: National Academy Press.

Rodríguez-Navarro, C., & Doehne, E. (1999). Salt weathering: Influence of evaporation rate, supersaturation and crystallization pattern. Earth Surface Processes and Landforms, 24, 191–209. doi:10.1002/(SICI)1096-9837

Rodríguez-Navarro, C., Linares-Fernandez, L., Doehne, E., & Sebastian, E. (2002). Effects of ferrocyanide ions on NaCl crystallization in porous stone. Journal of Crystal Growth, 243, 503–516. doi:10.1016/S0022-0248(02)01499-9

Sarışık, A., Çelik, M.Y., & Gürcan, S. (2003). Mermerlerin mineralojik-petrografik özelliklerinin jeomekanik parametreleri olan etkileri [The effects of mineralogical-petrographic properties of marbles on mechanical parameters]. Suleyman Demirel University 20th Geological Symposium, Isparta.

Sarışık, A., & Derin, P. (2015). "Urfa taşı ve Mardin taşının, binalarda yapı elemanı olarak kullanılmasına ekolojik özelliklerini karşılaştırmalar [Comparison of ecological characteristics of Mardin and Urfa stone used as structural elements in the building]." S. Modencilik ve Çevre Sempozyumu Bildiri Kitabı [Mining and Environment Symposium Proceeding Book], Antalya.

Sarışık, A., & Sarıışık, G. (2011). Environmental interaction properties of marble used in the restoration of historical monuments (Dolay-Kaunos), Ekojol, 19, 12–20. doi:10.5053/ekojol.2011.792.
Sarıışık, G., Sariisik, A. (2010). Characterization of physical and mechanical properties of natural stones affected by ground water under different ambient conditions. Ekoloji, 19, 88–96. doi:10.5053/ekoloji.2010.7713
Sarıışık, G. (2012). Determining perforance of marble finished products on their usage areas by a new impact resistance test method. Journal of Testing and Evaluation, 40, 945–951. doi:10.1520/JTE104352
Sarıüşık, G., Özkam, E., Kundak, E., & Akdaş, H. (2016). Classification of parameters affecting impact resistance of natural stones. Journal of Testing and Evaluation, 44, 1650–1660. doi:10.1520/JTE20140276
Sarıışık, G., Sarıışık, A., Koch, R., Knoblauch, U. (2008). The weathering of natural building stones (DSM, Building Research Special Report No. 18). London: Stationary Office.
Semerci, F. (2008). Mardin kırıkçının yapı taşı olarak artırılması [A study on Mardin limestone as a construction component] (Yüksek Lisans Tezi). I.U. Fen Bilimleri, Institute of Sciences, Istanbul.
Sharma, P. K., Khandelwal, M., & Singh, T. N. (2007). Variation on physico-mechanical properties of Kota stone under different waterey environments. Building and Environment, 42, 4117–4123. doi:10.1016/j.buildenv.2006.11.032
Sharma, P. K., & Singh, T. N. (2006). Effect of saline water on strength and durability of granite rock—a case study. Mining & Engineering Journal, 4, 20–26.
Shi, W., Wu, Y., & Wu, L. (2007). Quantitative analysis of the projectile impact on rock using infrared thermography. International Journal of Impact Engineering, 34, 990–1002. doi:10.1016/j.ijimpeng.2006.03.002
Siegesmund, S., Ullemeyer, K., & Weiss, T. (2000). Physical weathering of marbles caused by anisotropic thermal expansion. International Journal of Earth Sciences, 89, 170–182. doi:10.1007/s100040100032
Singh, T. N., Singh, S. K., Mishra, A., Singh, P. K., & Singh, V. K. (1999). Effect of acidic water on physico-mechanical behaviour of rocks. Indian Journal of Engineering and Materials Sciences, 6, 66–72.
Synnefa, A., Santamouris, M., & Livada, J. (2006). A study of the thermal performance of reflective coatings for the urban environment. Solar Energy, 80, 968–981. doi:10.1016/j.solener.2005.08.005
Toraman, O. Y., Kahraman, S., & Cayirli, S. (2010). Predicting the crushability of rocks from the impact strength index. Minerals Engineering, 23, 752–754. doi:10.1016/j.mineng.2010.04.004
TS 6809. (1989). Determination of scratch hardness according to mohs scale (p. 6). Ankara: Turkish Standards Institute.
TS EN 12371. (2011). Natural stone test methods-determination of frost resistance (p. 8). Ankara: Turkish Standards Institute.
TS EN 12372. (2013). Natural stone test methods - determination of flexural strength under concentrated load (p. 15). Ankara: Turkish Standards Institute.
TS EN 12407. (2013). Natural stone test methods - petrographic examination (p. 17). Ankara: Turkish Standards Institute.
TS EN 13161. (2014). Natural stone test methods-determination of flexural strength under constant moment (p. 17). Ankara: Turkish Standards Institute.
TS EN 13755. (2014). Natural stone test methods—determination of water absorption at atmospheric pressure (p. 3). Ankara: Turkish Standards Institute.
TS EN 14066. (2013). Natural stone test methods - determination of resistance to ageing by thermal shock (p. 7). Ankara: Turkish Standards Institute.
TS EN 14205. (2004). Natural stone test methods—determination of knoop hardness (p. 11). Ankara: Turkish Standards Institute.
TS EN 14579. (2015). Natural stone test methods—determination of sound speed propagation (p. 13). Ankara: Turkish Standards Institute.
TS EN 15309. (2008) Characterization of waste and soil - Determination of elemental composition by X-ray fluorescence (p. 43). Ankara: Turkish Standards Institute.
TS EN 1926. (2004). Natural stone test methods—determination of compressive strength (p. 10). Ankara: Turkish Standards Institute.
TS EN 1936. (2010). Natural stone test methods: determination of real density and apparent density, and of total and open porosity (p. 13). Ankara, Turkish Standards Institute.
Tufan, B., & Kun, M. (2014). Thermal insulation performance and thermal conductivity evaluation of natural stones by infrared thermography. Proceedings of the International Conference on Mining, Material and Metallurgical Engineering Prague, Czech Republic, 62, 1–9.
Vishal, V., Das, R., & Singh, T. N. (2012). Investigating the frictional response of granitic rock surface: An experimental approach. Journal of the Geological Society of India, 80, 493–498. doi:10.1007/s12594-012-0168-y
Vishal, V., Pradhan, S. P., & Singh, T. N. (2011). Tensile strength of rock under elevated temperatures. Geotechnical and Geological Engineering, 29, 1127–1133. doi:10.1007/s10706-011-9440-y
Vosteen, H. D., & Schellschmidt, R. (2003). Influence of temperature on thermal conductivity, thermal capacity and thermal diffusivity for different types of rock. Physics and Chemistry of the Earth, Parts A/B/C, 28, 499–509. doi:10.1016/S1474-7065(03)00069-X
Winkler, E. M. (1973). Stone: Properties durability in man’s environment (p. 230). New York, NY: Springer Verlag. http://dx.doi.org/10.1007/978-3-7091-4120-5
Winkler, E. M. (1987). Weathering and weathering rates of natural stone. Environmental Geology and Water Sciences, 9, 85–92. doi:10.1007/BF02449939