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Research Article

Investigation of physical and chemical properties of Batman's stone

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ABSTRACT

The widespread use of special stones in the construction industry in recent years makes it necessary to know the properties of these stones well. The stones extracted in Batman region can be used in many areas in the construction sector. It is very important to characterize the physical and chemical properties of these stones and use them under optimum conditions for their successful commercialization. Stone samples were taken from the mine in Batman region; many properties such as porosity, capillary coefficient, thermal conduction coefficient, sound velocity propagation, Shore D hardness test, compressive strength, bending strength, bulk, and grain density were determined. The chemical composition and ratios of Batman stone were determined by XRF analysis. It is seen that this stone is preferred especially in buildings due to its mechanical, thermal, and economic properties. According to the measurement results obtained, as the bulk density of the stone increased, its porosity and thermal conductivity coefficient decreased. It has been observed that as the density increases, the porosity decreases, and Shore D hardness values also tend to increase. The results obtained in the experimental studies and the values found in the theoretical models were compared with statistical analysis.

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INTRODUCTION

In the studies in the literature, the effect of porous structures on the thermal conductivity coefficient has been investigated. Sol-gel and nanoparticle-based porous structures were prepared and the thermal conductivity coefficient was measured at room temperature and vacuum. It has been determined that the films have a pore ratio varying between 10% and 70%, thickness between 150 nm and 800 nm, pore diameters between 3 nm and 19 nm, and thermal conductivity coefficients between 0.07 W/m.K and 0.66 W/m.K. It has been observed that as the porosity increases, the thermal conductivity coefficient decreases. The structure, density, and distribution of the pore in nanostructured materials affect the heat conduction coefficient [1].

In recent years, the use of underground geothermal energy to provide heat in buildings has gained great importance. Many parameters such as heat transfer between thermal pipes and the environment, ground conductivity, and system performance will affect the geothermal energy

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efficiency. To determine the thermal conductivity of the underground, it is necessary to analyze many parameters such as water content of the ground, material structure, and porosity, rock or soil type. In this study, basic assumptions were made, effective parameters were examined in detail, and models for natural conditions were developed. For some rock and soil types, the real values have been approached in the model results by considering the experimental measurements [2].

The effective thermal conductivity of dry, gas, oil and water-saturated rocks of various porosities was measured in the temperature range 273 K to 523 K at atmospheric pressure at the steady-state. Thermal conductivity measurements were made according to systematic and random errors at 95% confidence level and 2-4% sensitivity. Various theoretical models have been used to check the accuracy, predictive ability, and applicability of thermal conductivity measurements of liquid saturated rocks. The size, density, shape, and distribution of the pores of the liquid-saturated rocks and the effect of the mineralogical structure of the rock on the thermal conductivity measurements were examined and discussed. A new simple equation has been proposed for liquid-saturated rocks that take into account the structure of the porous medium. Using the models in the literature, the thermal conductivity, thermodynamic properties, density, thermal expansion coefficient, enthalpy, and heat capacity of dry rock materials were calculated with various assumptions [3].

Determining the effective thermal conductivity of porous rocks and similar structures, their microstructure was examined. The homogenization process has been developed based on the microstructure observations of composite rocks consisting of many solid components. This process, which was developed by examining solid matrix and pores, was compared with existing homogenization. In the developed method, the physical parameters were taken into consideration by examining the mineralogical and morphological effects of the structures. Inhomogeneous distributions were determined for each matrix, taking into account the material properties and pore interaction. The phases that appear homogeneous on a macroscopic scale differ from effective heat conduction due to their physical properties (microscopic non-homogenizations). In addition, the inhomogeneity of microscopic geometry has been evaluated in the results that it has significant effects on thermal conductivity [4].

In this article conducted on isotropic and anisotropic rocks, many thermal conductivity measurements were made by optical scanning methods. Thermal conductivity measurements and characterization processes of the rock were made and compared with different methods. Research has been made on the principle of scanning the surface with a temperature sensor using Optical Scanning Method. Despite the inhomogeneity of the rocks and minor inconsistencies, this method was found to give consistent results [5].

The effective thermal conductivity coefficient of porous rocks was investigated by developing a formula with a statistical approach. It has been observed that theoretical models developed with a statistical method give results compatible with experimental data. Thermal conductivity data were obtained by making correlations at a high confidence level with statistical analysis [6].

Among the most important physical properties of porous media (sand), the thermal conductivity model was developed in a numerical simulation study. Here, the comparison of the effective heat conduction coefficient of dry sandstones with the help of statistical parameters has been made. The validity of the presented model with the application of new methods and algorithms to improve existing models was evaluated. Experimental data for determining the heat conduction coefficient of dry sandstones and R^2 values of the results in the theoretical model were found to be high and the mean absolute relative deviation low. The results obtained from the current studies and the proposed models have shown that sandstones were compatible, reliable, and efficient in calculating the effective thermal conductivity coefficient [7].

A theoretical model is presented for the estimation of the thermal conductivity of rocks that are assumed to be fully saturated with a single-phase liquid. Flat spherical pores solid (mineral) phase and homogeneously dispersed liquid phase were simulated. The thermal conductivity, pore distribution, and shape of the solid and liquid phases were theoretically optimized. The experimental data of the samples taken in various sediments and crystals were evaluated and the thermal conductivity values were compared in models. In the rock structure formed by the phases saturated with liquid or gas, if the shape and distribution of the pores are evaluated well, it has been observed that theoretical models give compatible results [8].

The isotropic damage and effect of brittle rocks and their effect on thermal conductivity were investigated by micro-mechanical analysis. The micromechanical damage mechanism can be modeled by examining closed micro-cracks modeled by an experimental hyperbolic relationship. The shear behavior of the cracks was simulated by this technique of homogenization of micro-pores. Porosity, micro-crack shape, and degree of saturation refer to the microstructure and hence the accumulation of macro damage. The effect of these damages on thermal conductivity has been observed in experimental and theoretical studies. For good modeling, thermo-mechanical and thermo-hydro-mechanical processes should be examined and micro-cracks and deformations should be evaluated. The contributions of this research were to simulate the effective thermal conduction model with the help of laboratory tests by evaluating microstructure behavior, macroscopic observations, and damage accumulation. The damage caused by the micro-fracture of rocks has been verified with recommended models and laboratory tests [9].

Figure 1. The location of the mining site.

MATERIAL AND METHODS

The location of the mining site belonging to Gündoğdu Company, located in the North 37° 33′ 20″ latitude and East 41° 11′ 10″ longitude coordinates in the town of Gercüş in Batman province is shown in Figure 1.

Experimental samples shown in Figure 2 were prepared to examine the physical and chemical properties of Batman's stone. These samples prepared for the experiments were ground between 0.149-0.074 mm in size and the grain density was found. The bulk densities, thermal conductivity coefficients, and porosities of the cubic samples (10·10·10 cm^3) were calculated.

In Table 1, the chemical composition of Batman's stone sample at 23.5 °C temperature and 37% humidity was determined by XRF analysis. Table 2 shows the test results of the Batman's stone sample at 20.8 °C temperature and 36.7% humidity.

MODELING OF THE EXPERIMENTAL RESULTS

Some expressions are given below; effective thermal conductivity coefficient (k), solid-phase thermal conductivity coefficient (k_s), gas-phase thermal conductivity coefficient (k_g), porosity (ε), and correlation coefficients (a, b, c) are expressed [10]. In other equations, the porosity correlation coefficients (m, n, and z), bulk density (ρ_b), grain density (ρ_g), and capillarity coefficient (C) are shown by the amount of water per unit time (M), the area of the sample in contact with water (A) and the residence time in water (t).

$$k = a\varepsilon k_g + b(1-\varepsilon)k_s + c \quad \text{Modified parallel model (1)}$$

$$k = \frac{1}{[\frac{a\varepsilon}{k_g} + \frac{b(1-\varepsilon)}{k_s}]} + c \quad \text{Modified serial model (2)}$$

$$k = ak_g^{\ \varepsilon} + bk_s^{\ (1-\varepsilon)} + c \quad \text{Modified geometric model (3)}$$

Figure 2. Batman's stone was extracted and processed in Batman region.

Table 1. Chemical analysis by XRF for Batman's stone

Chemical composition	%
SiO_2	0.15
Al_2O_3	0.01
Fe_2O_3	0.06
CaO	54.72
MgO	0.21
K_2O	0.18
TiO_2	0.01
P_2O_5	0.02
SrO	0.02
Volatile Components	44.60

$$k = \frac{k_s[k_g + 2k_s + 2a\varepsilon(k_g - k_s)]}{[k_g + 2k_s - \varepsilon b(k_g - k_s)]} + c \quad \text{Modified Maxwell-Eucken (4)}$$

$$k = \frac{ak_g\varepsilon}{bk_s(1-\varepsilon)} + c \quad \text{New thermal conductivity model (5)}$$

$$\varepsilon = m(1 - \frac{\rho_b}{\rho_g})^n + z \quad \text{Fractional porosity (6)}$$

$$\varepsilon = m[1 - (\frac{\rho_b}{\rho_g})^n] + z \quad \text{Modified porosity model (7)}$$

$$C = \frac{M}{A\sqrt{t}} \quad \text{Capillary coefficient (8)}$$

STATISTICAL TESTS

Root mean square error (*RMSE*) refers to the standard deviation of the estimated errors. Predictive errors indicate how far the data points are from the regression line. How far these errors are spread can be found with the help of *RMSE*. That is, it shows how dense the data is in optimum results. Chi-square statistic is commonly used to evaluate independence tests using a two-variable table, a cross-values table. Cross tabulation shows the intersections of bivariate distributions simultaneously. The independence test evaluates if the variables are independent of each other according to the observed results, that is,

Table 2. Chemical analysis by XRF Batman's stone

Test/Analysis	Results	Method
Sound speed propagation	2.78 km/s	TS EN 14579
Water absorption coefficient by capillarity	53.21 $g/m^2s^{0.5}$	TS EN 1925
Compressive strength	20.70 MPa	TS EN 1926
Specific Gravity of soil solid by gas pycnometer	2790 kg/m^3	ASTM D-5550-06
Water absorption at atmospheric pressure	11.92 %	TS EN 13755
Flexural strength under the constant moment	3.73 MPa	TS EN 13161
Resistance to ageing by SO_2 action in the presence of humidity	1.54 %	TS EN 13919
Resistance to ageing by thermal shock	0.04 %	TS EN 14066
Abrasion resistance	45.46 mm	TS EN 1341

Table 3. Correlation coefficients for thermal conductivity models

Exp.	Models	*a*	*b*	*c*	R^2	*RMSE*	*SSE*	*SSR*	χ^2
	1	-264.45	0.62999	0.30972	0.98679	0.00480	0.00023	0.01711	0.00168
	2	0.83932	0.87211	0.03731	0.99721	0.00461	0.00005	0.01604	0.00166
1	3	1.80985	0.17828	-1.3272	0.98431	0.00573	0.00027	0.01699	0.00178
	4	7.04325	16.7087	0.09210	0.98692	0.00474	0.00023	0.01704	0.00167
	5	-144.15	1.51494	0.54329	0.97475	0.00810	0.00046	0.01783	0.00208
	1	-100.25	0.65968	0.16358	0.98729	0.00408	0.00014	0.01112	0.00159
	2	0.50925	1.18746	0.05921	0.98779	0.00388	0.00014	0.01107	0.00157
2	3	1.81266	-0.0172	-1.2553	0.99988	0.00244	0.00001	0.01059	0.00143
	4	-47.031	163.752	0.06040	0.98693	0.00422	0.00015	0.01123	0.00161
	5	-399.20	5.15884	0.50042	0.98349	0.00523	0.00020	0.01219	0.00173

Table 4. Correlation coefficients for the porosity models

Models	*m*	*n*	*z*	R^2	*RMSE*	*SSE*	*SSR*	χ^2
6	27329.6	15.5140	0.26960	0.97756	0.00923	0.00060	0.02696	0.00020
7	522.214	0.00179	-0.1677	0.88089	0.02112	0.00312	0.02385	0.00104

whether there is a relationship between the two variables. Residual sum of squares (*SSR*) is used to evaluate probabilities in a data distribution not explained by a regression model. Now the sum of squares represents how well the data in a regression model describes [11]. That is, it shows the discrepancy between the data and its prediction model (shows how much the results obtained in the theoretical models deviate from the experimental data). It is used as an optimal criterion in parameter selection and model selection. Statistical tests such as *RMSE* and Chi-square are used to determine the most appropriate models by comparing the results obtained from model equations with experimental data [12, 13]. In Table 3, mean square root error (*RMSE*), Chi-square (χ^2), residual sum of squares (*SSR*), error sum of squares (SSE), total sum of squares (*SST*), and R^2 statistical parameters were calculated.

In Table 4, correlation coefficients were calculated for the porosity models (6) and (7), taking into account the bulk and grain density. The most suitable model was determined by calculating the statistical values R^2, RMSE, SSE, SSR, and χ^2.

RESULTS AND DISCUSSION

The solid phase, gas phase, pore shape, and distribution of the sample whose effective thermal conduction coefficient has been measured were modeled in two dimensions and the temperature distribution is shown in Figure 3. Here, the ambient temperature was taken as 20 °C and 60 °C was applied to the center of the surface of 10·10 cm^2. TLS-100 device was used to measure the thermal conduction coefficients of samples in experimental studies. According to the working principle of this device, the simulation model is designed in ANSYS program.

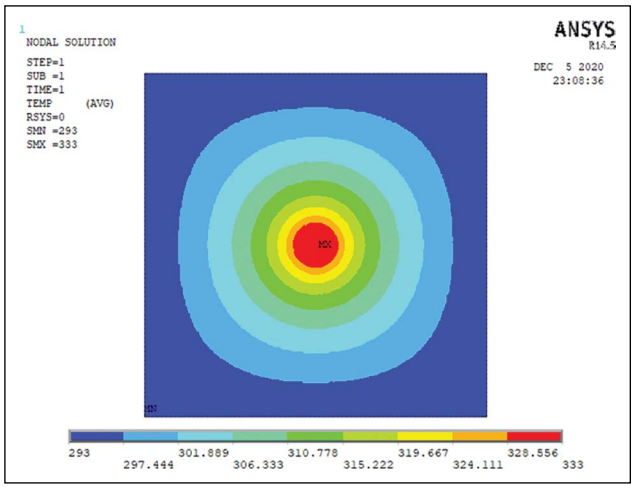

Figure 3. Effective thermal conductivity model for Batman's stone.

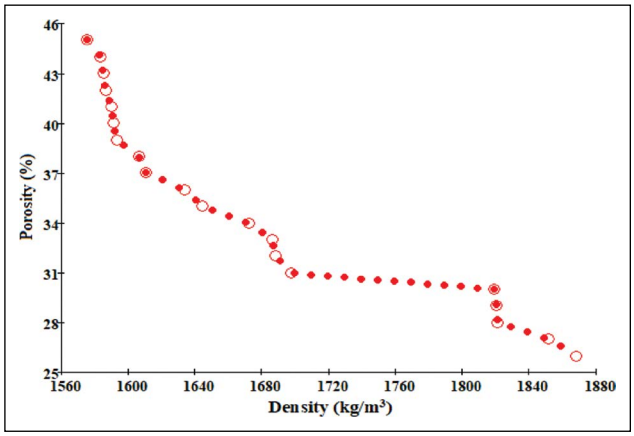

Figure 4. Variation of the porosity of the stone in Batman region with density.

As seen in Figure 4, as the density of the stone extracted from the mine in Batman region increased, its porosity decreased. The density and size of the pores in the mineral stone and the mineral structure of the stone directly affect the density. As the number of pores and the size of the pores increase, the gas density within the rock will also increase. Accordingly, the effective thermal conductivity of the rock increased, as can be seen in Figure 5. Because the thermal conductivity of minerals in rock is much higher than in gases.

Shore D hardness test samples, as can be seen in the graphic in Figure 6, it was observed that the hardness generally increased as the density increased. According to the results obtained in Batman stone, it was seen that Shore D hardness increased as the density increased. In the literature research, it has been observed that as the density of these stones increases, both their mechanical strength and hardness increase [14, 15]. Figure 7 shows the variation of Batman's stone capillary coefficient calculated with the help of Eq. (8) with its bulk density.

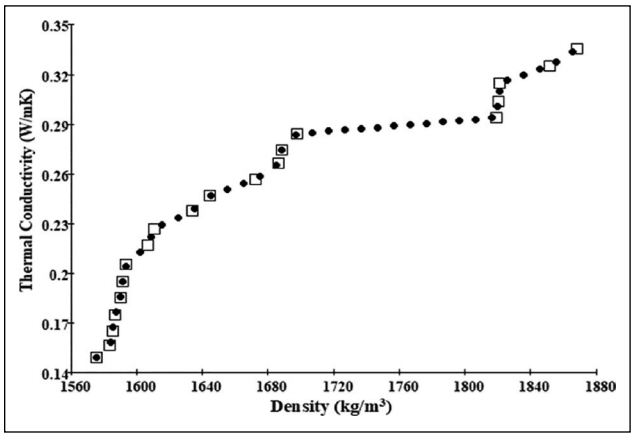

Figure 5. Variation of the thermal conductivity of the stone in Batman region with density.

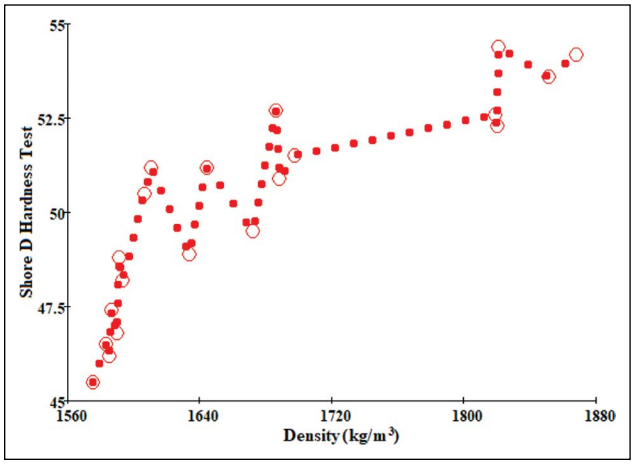

Figure 6. Variation of Shore D hardness test of the stone in Batman region with density.

CONCLUSIONS

Some physical and chemical properties of stones extracted in Batman region were determined in this study. In particular, it has been observed that the density of these stones varies according to the chemical composition, pore structure, and distribution. Shore D hardness of stones with density of 1560 kg/m^3 to 1880 kg/m^3 showed an increasing trend from 45 to 55. It was observed that the capillarity coefficient and thermal conductivity coefficient increased with the increase in density. While the heat conduction coefficient is 0.14 W/m·K at low densities, it has increased up to 0.35 W/m·K at high densities. When compared with the studies conducted with the stones in the Southeastern Anatolia region, it was observed that the heat conduction coefficient values gave compatible results. When compared with the studies conducted with the stones in the Southeastern Anatolia region, it was observed that the thermal conductivity coefficient values gave compatible results [16].

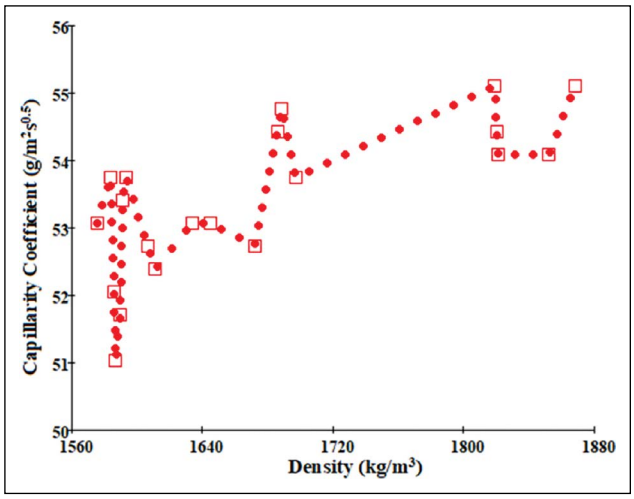

Figure 7. Variation of the capillarity coefficient of the stone in Batman region with density.

In addition, the porosity of Batman stone decreased from 45% to 25% with increasing density. The thermal conduction coefficient has changed according to the solid and gas phase ratios in the stone. Gases, moist areas, and solid minerals in the stone affect the thermal conduction coefficient. The results found in the mechanical tests show that these stones comply with the standards according to the intended use in the construction industry. The fact that Batman's stone is economical and its use for decorative purposes will increase its value in the future. In addition, some physical and chemical properties of this stone were characterized by experimental studies, theoretical models, and statistical analysis.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The published publication includes all graphics and data collected or developed during the study.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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