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Thermal conductivity of limestone from Gaziantep (Turkey)

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Abstract

In this study, thermal conductivity (TC) of limestone from Gaziantep, Turkey, was investigated. The limestone samples were collected from different parts of the city representing Gaziantep and Fırat formation which are clay and chalky limestone. TC of the samples was measured for saturated, partially saturated and dried conditions. Water absorption, dry unit weight and apparent porosity of the samples were also measured to correlate with TC. Measurements showed that TC was increased with increasing the water content of samples. The TC of the samples decreased while the porosity increased. Relationships between TC and both dry unit weight and porosity were driven. There was a very good exponential relationship between TC and saturation degrees of sample, porosity and density. Moisture content increased TC up to 113%.

1. Introduction

Limestone cover extensive areas in the Gaziantep region, Turkey (see Fig. 1). They have been used as construction materials in an extensive area such as concrete aggregate, highway construction, building face stone, etc. Since Gaziantep is in the region of mild climate, more attention has been given than before to reducing energy consumption while to maintain or improve comfort conditions in buildings. To this end, effort has been concentrated on improving the efficiency of heating appliances and the thermal insulation of buildings. Thermal characteristic of the local limestone is also an important parameter in the design of engineering equipment and facilities buried in the ground as these devices usually generate or absorb heat. Unfortunately, experimental data for thermal conductivity (TC) of limestone from Gaziantep is scarce and uncertain. Engineers generally have difficulties to make economic and efficient design in the region. Therefore, determination of TC of the limestone will be very useful and contribute to preparation of better and efficient project for thermal insulation for houses and buried structures.

Previous studies reported that the type of rock, porosity and moisture content (MC) have the maximum influence on TC of rock [1–4,6]. The TC of rocks, commonly used as aggregates in concrete, and other construction industry ranges from 1.163 to 8.6 W/mK [1,2,5,6]. In addition, the TC of rock depends not only on its composition but also on its degree of crystallization. Rocks with crystalline structure show higher heat conduction than amorphous and vitreous rocks of the same composition [4,5]. Quartzite, sandstone and other quartzose rock have the highest TC; granite, gneiss, limestone and dolomite have intermediate, while basalt and dolerite demonstrate lowest conductivities [1,6]. Mineralogical character of the rock would greatly influence the TC of ordinary dense concrete [7]. Khan [8] reported that the TC of concrete increased with the increase in MC. From dry state to 50% degree of saturation, the rate of increase was more significant, beyond which it was less significant. Demirboğa et al. [9] found a good exponential relationship between TC and density and reported that TC was increased with increasing of density.

In this study, four different groups of limestone representing Gaziantep and Fırat formation were studied to determine their TC in different MC. The effect of the porosity, MC, water absorption and density on the TC was also investigated.

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Fig. 1. Location of Gaziantep.

1.1. Geology of Gaziantep

Majority of limestone found in Gaziantep are middle upper Eocene age reefal limestone named as Fırat formation (Tmf) and middle upper Eocene age clayey and chalky limestone named as Gaziantep Formation (Tmga) [10]. Geological map of the city prepared by the General Directorate of Mineral Research and Exploration, Turkey, is shown in Fig. 2. Thickness of limestone around the region is almost varying from 500 to 1000 m.

2. Materials and methods

Samples were taken from different parts of Gaziantep, representing Gaziantep and Fırat formations. A scanning electron microscope equipped with energy dispersive X-ray spectrometer (SEM-EDX) was used to determine element content in limestone samples as shown in Fig. 3. It can be seen from the figure that limestone is clayey and chalky. The samples were grouped according to their apparent porosity. Four different groups of limestone were prepared. For each test and each group three samples of 110 × 160 × 40 mm prisms were used.

TC measurements were made in three different MC. These are oven dried (OD), partially saturated (PS) and fully saturated (FS).

(1) OD samples were dried in an oven at 110 ± 10 °C and weighed at 24 h intervals until the loss in weight did not exceed 0.5% in a 24 h (ASTM C 332) for TC as dried condition.
(2) Samples were FS by immersing in water at room temperature for a period of 24 ± 4 h (ASTM C 127-93).
(3) For PS condition, samples were left in water until its water absorption value reaches approximately 50%.

Absorbed water can be obtained by several methods such as capillarity imbibitions [10,11], complete immersion

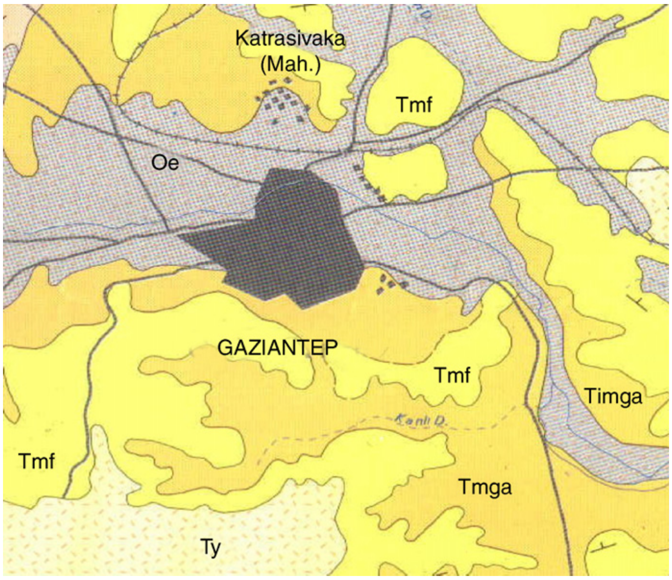

Fig. 2. Geological map of Gaziantep, Turkey.

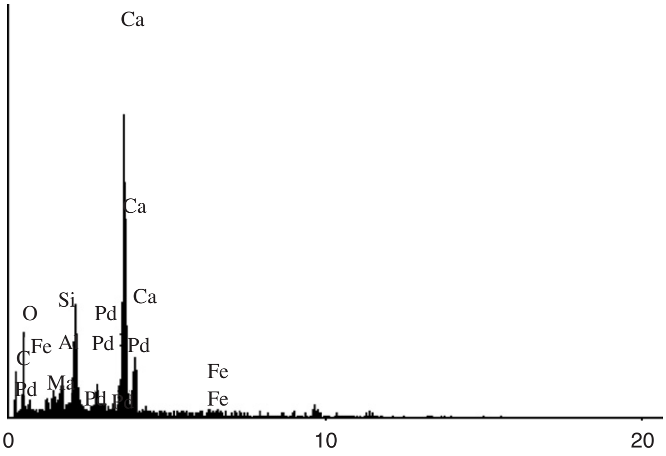

Fig. 3. EDX spectrum of the limestone sample.

Fig. 4. Picture of QTM 500 device.

in water for 24 h [12]. Differences between these methods can be obtained when macroporous and microporous stones are compared [10,13]. Different behavior is recorded in the water absorption due to the fact that in the immersion test, air is trapped within the microporous sample, giving low water absorption results. In this study, the volume of water absorbed is obtained by complete immersion in water for 24 h.

Apparent porosity was determined from water absorption of the sample. Apparent porosity was determined by dividing volume of absorbed water to the apparent volume of the sample [14]. Mathematical model for apparent porosity and TC was driven. In addition, OD density (ODD), PS density (PSD) and FS density (FSD) of samples were determined. Relationship between densities and TC were developed.

The specimen surfaces were smoothed before measuring their thermal conductivities. Other conditions such as humidity (60%) and room temperature (24 °C) were kept same during the testing of all samples. A quick TC meter (QTM 500) based on ASTM C 1113-90 hot wire method was used to measure the TC [15]. QTM 500 device (See Fig. 4) is a production of Kyoto Electronics Manufacturing Co. Ltd., Japan. Measurement range is 0.0116–6 W/mK. Measurement precision is ±5% of reading value per reference plate. Reproducibility is ±3% of reading value per reference plate. Sample size required is two pieces of 100 × 80 × 40 mm or more. The standard measuring time is 100–120 s.

This method has wide applications [16–20] in determining TC of refractory materials where, instead of measuring heat flow, the temperature variation with time at certain locations is measured. Being transient in nature, this method takes only a few minutes in contrast to the earlier methods involving steady-state conditions.

3. Principle of measurement

The probe consists of single heater wire and thermocouple. When constant electric power (energy) is given to the heater, the temperature of the wire will rise in exponential progression. Temperature rising curve is plotted in linear line in Fig. 5 with time axis scaled in logarithm. The angle of this line increases if the sample has less TC, and decreases if it has higher TC. Therefore, TC of a sample can be determined from the angle of the rising temperature graphic line.

$$\lambda = \frac{q \bullet \ln (t_2/t_1)}{4\pi (T_2 - T_1)}$$

λ; thermal conductivity of sample	[W/mK]
q; generated heat per unit length of sample/time	[W/m]
$t_1.t_2$; measured time length	[sec]
$T_1.T_2$; Temperature at $t_1.t_2$	[K]

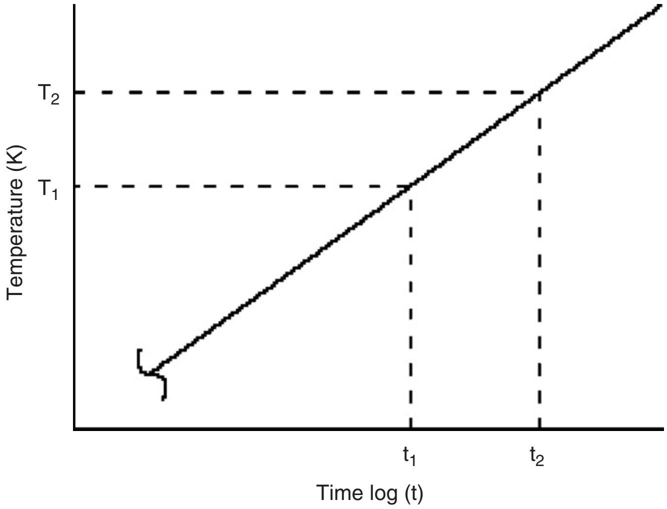

Fig. 5. Relationship between time log (*t*) and temperature (*K*).

3.1. Test results and discussions

3.1.1. Effects of density on TC

As it can be seen from Fig. 6(a) that TC increased with increase of ODD for limestone. Same trend was also observed for PSD and FSD conditions. TC of OD samples were changed between 0.9264 and 2.5158 W/mK. Densities of the OD samples were between 1699 and 2321 kg/m^3.

There was a good reasonable relationship between TC and ODD. Taking into account the heterogeneous nature of the rock, the general relationship between TC and ODD is plotted. A correlation coefficient (R) of 0.99 indicates a very good exponential relationship between TC and ODD. Since $R^2 = 0.98$, it can be said that 98% of the variation in the values of TC is accounted for by exponential relationship with ODD (see Fig. 6(a)). For the ODD, the following mathematical model for TC (λ in W/mK) and ODD (δ in kg/m^3) of limestone was found:

$$\lambda = 0.4682e^{0.0007\delta}. \tag{1}$$

As it was mentioned by previous studies [9,17], TC is a function of densities. Additionally, Demirboğa [16], Uysal et al. [20], Akman and Taşdemir [21] and Blanco et al. [22] also reported that the TC decreased due to the decreasing of density. Lu-shu et al. [23], Demirboğa et al. [9]

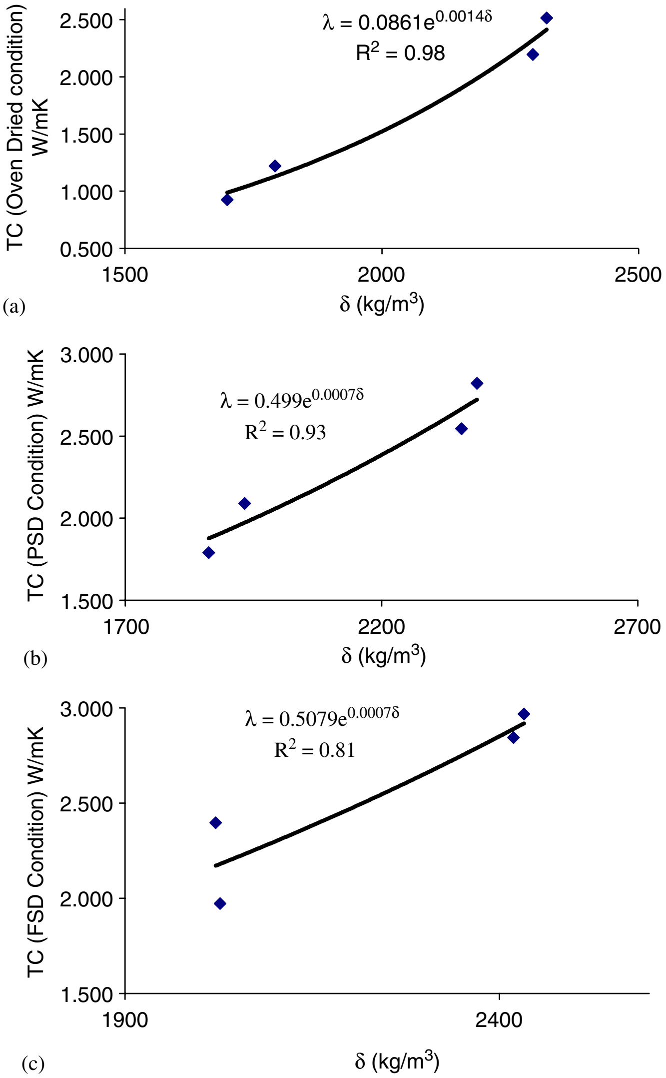

Fig. 6. (a)–(c) Relationship between densities and TC. (a) ODD, (b) PSD, (c) FSD.

experimentally formulated a correlation between the density and TC, and reported that the TC increased with increasing density.

Similar trend was also observed for both PSD and FSD conditions. However, correlation coefficients of 0.96 and 0.90 for PSD and FSD are an indication of reduction in the confidence interval when compared to the ODD condition. Mathematical Models for predicting TC from both PSD and FSD is given below. TC (λ) can be determined from Eqs. (2) and (3) for PSD and FSD conditions, respectively. In these equations, the unit of δ must be in kg/m^3 so that the unit of TC (λ) will be W/mK.

$$\lambda = 0.499e^{0.0007\delta}, \quad (2)$$

$$\lambda = 0.5079e^{0.0007\delta}. \quad (3)$$

All models developed for prediction of TC from densities of different MC for limestone were exponential. General expression for exponential model is given in Eq. (4). In this equation, constant b is equal to 0.0007 for all models but constant a is changing for different MC of samples.

$$\lambda = a\,e^{b\delta}. \quad (4)$$

3.1.2. Effects of apparent porosity on TC

TC correlates well with porosity (negative correlation with correlation coefficient of 0.91 for OD and PS, and 0.96 for FS conditions). Even though apparent porosity of the sample LS2 was higher than that of SL1, TC of LS2 was greater than LS1 (Fig. 7). It is probably due to the texture of LS2 that it contains large gravel particles and results in higher density (see Fig. 8). As it was discussed above, TC increases with increase in density. In addition, it may partially be due to the crystalline structure of gravel. Since the TC of crystalline silica is about 15 times more than that of amorphous [24], it is reasonable for the limestone containing gravel with crystalline silica to have higher conductivity [25,26]. Eqs. (5)–(7) were developed for limestone samples including LS2 that contains large

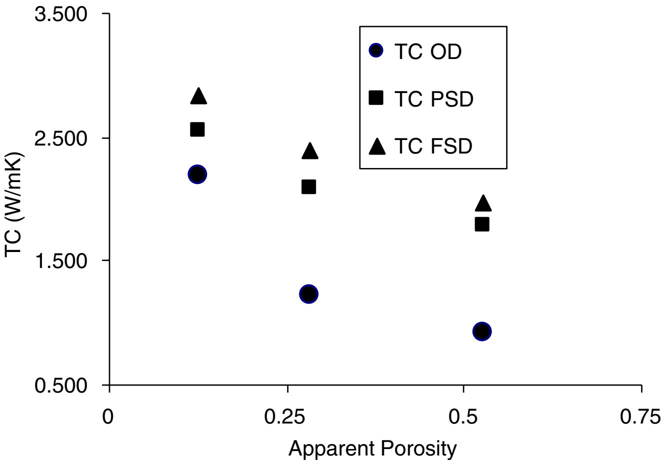

Fig. 7. Relationship between apparent porosity and TC

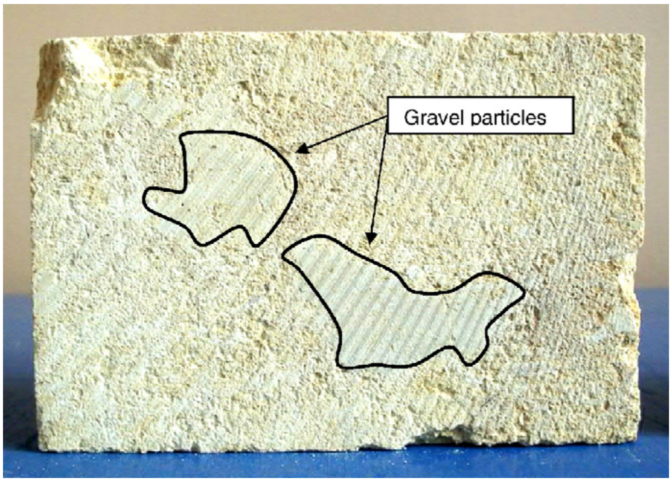

Fig. 8. Picture of sample containing gravel particles (LS2).

gravel particles.

$$\lambda = 3.0907\mathrm{e}^{-2.4195\delta} \quad \text{for OD condition,} \tag{5}$$

$$\lambda = 3.0316\mathrm{e}^{-1.0342\delta} \quad \text{for PS condition,} \tag{6}$$

$$\lambda = 3.3222\mathrm{e}^{-1.0066\delta} \quad \text{for FS condition.} \tag{7}$$

When the correlations were developed by excluding sample LS2, correlation coefficients of 0.95, 0.98 and about 1.00 were obtained for ODD, PSD and FSD conditions, respectively. It can be seen from Eqs. (5)–(10) that there was an exponential relationship between TC and apparent porosity for all conditions.

$$\lambda = 2.5655\mathrm{e}^{-2.0582\delta} \quad \text{for OD condition,} \tag{8}$$

$$\lambda = 2.7626\mathrm{e}^{-0.854\delta} \quad \text{for PS condition,} \tag{9}$$

$$\lambda = 3.145\mathrm{e}^{-0.9002\delta} \quad \text{for FS condition.} \tag{10}$$

3.1.3. Effects of MC on TC

Fig. 9 shows that when MC increase from 0% to 50%, TC increases by 16%, 12%, 71% and 94% for LS1, LS2, LS3 and LS4, respectively. MC has great influence on the TC of samples that has high porosity. Even though density and porosity of LS4 was lower than the other samples, the increase in TC was the highest. In general, materials having high insulation properties with high porosity should not be in contact with water. When MC increased from 0% to 100%, TC was increased by 30%, 18%, 96%, and 113% for LS1, LS2, LS3 and LS4, respectively. Increment ratio from 50% to 100% MC was lower than those of increment ratio from 0% to 50% MC. Similar results were also reported by Khan [8] for concrete.

3.1.4. Effects of water absorption on TC

In order to determine the relationship between the water absorption and the TC, simple regression analyses were performed and results are shown in Fig. 10(a)–(c). According to this figure, there is an exponential relationship between the water absorption and TC for all conditions. It can be seen from the figures that these relationships are highly significant because of a correlation coefficient (R) of 0.99, 0.98 and 0.97 for OD, PS and FS conditions, respectively. Since R^2 was 0.99, 0.96 and 0.94 for these three different conditions, exponential relationship can be used for OD, PS and FS conditions (See Fig. 10(a)–(c)). TC can be predicted by using the following equations:

$$\lambda = 3.2767\mathrm{e}^{-0.0643w} \quad \text{for OD condition,} \tag{11}$$

$$\lambda = 3.0908\mathrm{e}^{-0.027w} \quad \text{for PS condition,} \tag{12}$$

$$\lambda = 3.3205\mathrm{e}^{-0.0246w} \quad \text{for FS condition.} \tag{13}$$

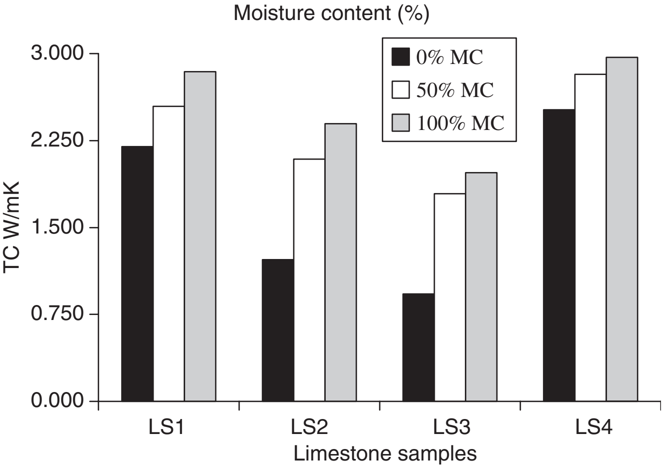

Fig. 9. TC of lime stones with different MC.

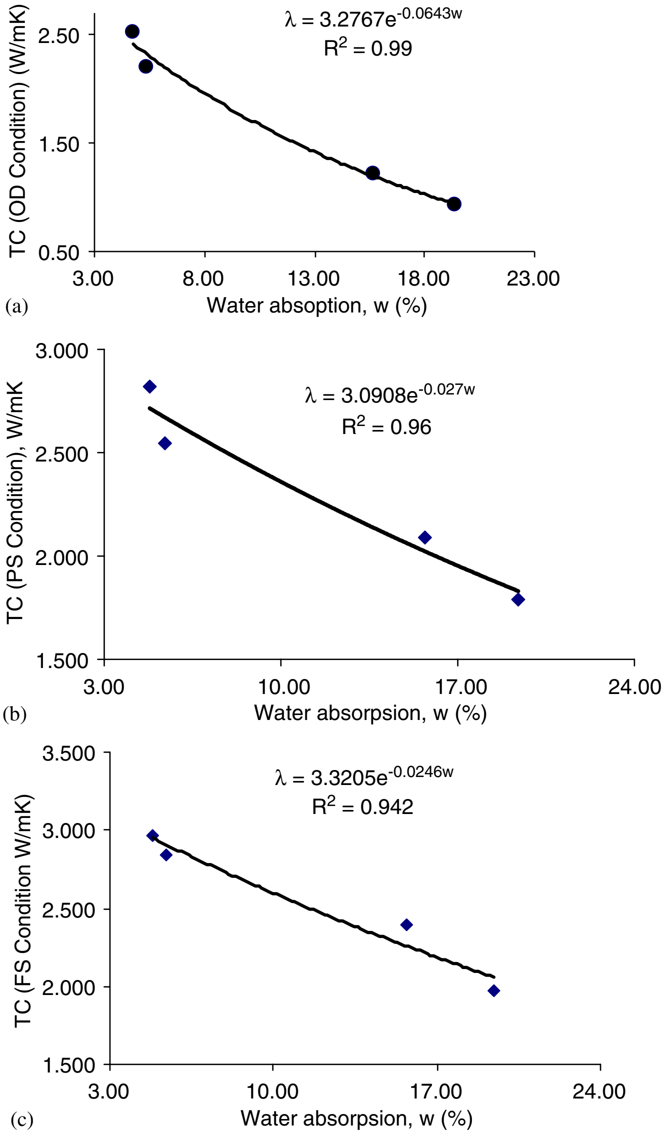

Fig. 10. (a)–(c) Relationship between absorption and TC. (a) OD condition, (b) PS condition, (c) FS condition.

4. Conclusions

(1) Thermal conductivity of limestone samples were increased with increasing of density for OD, PS and FS conditions. TC values were between 0.9264 and 2.5158 W/mK for OD, 1.790 and 2.821 W/mK for PS and 1.973 and 2.968 W/mK for FS densities.
(2) There was a good exponential relationship between densities and TC.
(3) There was a negative correlation between TC and apparent porosity with correlation coefficient of 0.91 for OD and PS, and 0.96 for FS conditions.
(4) TC increased when the water content of samples increased. The TC was higher when the moisture content of samples were between 0% and 50% than those of the samples having moisture content between 50% and 100%.
(5) There was an exponential relationship between the water absorption and TC for all conditions.

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