Thermal Conductivity of Some Marble Stones Available in South Aceh District

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Abstract. Thermal conductivity is a fundamental property for insulating purposes when they are used as a building material. It controls the temperature distribution within the building. In this paper, the thermal conductivities of marble samples from the South Aceh District are reported. The samples were collected from three different areas in South Aceh District. The thermal conductivities of the samples were determined by using laboratory measurements. The results showed that samples of marble stones existing in South Aceh District have low thermal conductivity values. It revealed that marble stones existing in South Aceh District are appropriate to be applied as thermal insulating material.

1. Introduction
Thermal conductivity is a value defining how well heat is conducted through a material [1]. It is a fundamental property for a material when it is used as a building material for an insulating purpose [2]. It controls the temperature distribution within the building. The highest level of consumed energy within buildings generally comes from air conditioning. Thus, the selection of appropriate building materials for energy efficiency is needed in the early stage of the building design process.

Natural stones are one of those materials used as a building material with high preference because of their decorative appearance [3-6]. Generally speaking, using marble as a building material can reduce the thermal loads in buildings. Since the last decade, marble has been utilized for decorative and construction material. Marble floors are considered able to absorb heat from the environment. However, a scientific report on the thermal properties of marble floors is still limited. Marble is a natural rock produced by limestone metamorphosis due to high temperatures and pressures in the innards of the earth. The South Aceh District is one of the promising areas of abundant marble deposits. The appearance and mineral composition of South Aceh marble were stated in the previous study [7-8]. Still, the information about the thermal properties of South Aceh Marble has not been published yet.

There are many studies regarding the thermal conductivity properties of building material [9-15]. The findings show that all materials have thermal conductivity even if in a small number. Materials with low thermal conductivities and densities can be obtained by porous insertion. The thermal conductivity of material generally depends on some factors such as mineralogical composition, microstructure, porosity, saturation, pressure and temperature [16-17]. From a number of these studies, almost no one discussed the thermal conductivity of natural stones, especially marble. In the present study, the thermal conductivity of marble stones from the South Aceh District is reported.
2. Material and Method

In this study, the thermal conductivity of marble stone from three different areas in the South Aceh District is measured. Figure 1 representing the marble collected from Gunung Kerambil (GK), Meukek (M), and Alur Kering (AK). Those marble samples were prepared in a square shape with a flat surface, in accordance with the apparatus test that is 15 cm in length, 15 cm in width and 1 cm in thick.

![Figure 1. Test Material](image)

The thermal conductivity of the sample was determined based on laboratory measurements using the heat flow method. The process and devices used to measure the thermal conductivity of materials are displayed in Figure 2.

![Figure 2. Thermal Conductivity Measurement Process](image)

The measurements were conducted by turning on the heating element and measuring the temperature rise over time. Heat transfer occurs through the surface of test material with surface area (A) as the object is given heat with a temperature difference (T1-T2). The parameter measured is the amount of heat flowing (Q) through the material and temperatures different between the two surface sides of the material. Data on the heat flow rate (Q) and temperature difference (∆T) were recorded every 1 minute for 30 minutes with two times of repetition. The value of thermal conductivity is calculated using the empirical formula of Fourier's Law, which is expressed in equation 1 as follows:
\[
\frac{\Delta Q}{\Delta t} = -kA\frac{\Delta T}{\Delta x}
\]

Where \(\frac{\Delta Q}{\Delta t}\) is the amount of heat transferred per unit time (W), \(k\) is conductivity (W/m.K), \(A\) is the cross-sectional surface area (m\(^2\)), \(\Delta T\) is the temperature difference (K) and \(\Delta x\) is the thickness of the marble sample (m) [5]. Based on the thermal conductivity data, the thermal resistance (R) of the sample test can be calculated using the following relation in equation 2 [8].

\[
R = \frac{l}{k}
\]

3. Results and Discussion

3.1. Heat transferred (Q)
The thermal conductivity \((k)\) is defined as the rate of heat transferred \((Q)\) in an object with a temperature gradient \((\Delta T)\) [18]. The heat transferred measured are tabulated in Table 1.

| Time (s) | Q(\(10^4\)W) |
|----------|----------------|
|          | GK             | AK              | M    |
| 0        | 0.04           | 0.04            | 0.04 |
| 5        | 1.38           | 1.32            | 1.29 |
| 10       | 2.71           | 2.63            | 2.62 |
| 15       | 4.05           | 3.96            | 4.26 |
| 20       | 5.38           | 5.28            | 5.63 |
| 25       | 6.72           | 6.61            | 6.94 |
| 30       | 8.05           | 7.92            | 8.15 |

Based on data in Table 1, it observed that the heat flow rate is significantly increased with time. The amount of heat transferred per time \(\left(\frac{\Delta Q}{\Delta t}\right)\) can be graphically demonstrated in Figure 3. As Expected, a high correlation \((R^2=1)\) between the rate of heat flow and time was determined. It can be seen that the heat flow rate in the material test from Gunung Kerambil, Meukek, and Alur Kering are increasing with the time.

![Figure 3. Relationship of Heat Flow Rate and Time](image-url)
3.2. Temperature Differences ($\Delta T$)
Heat transferred in building materials occurs when there is a temperature difference between the outer surface and the inner surface. Table 2 shows the temperature difference of the sample test during the thermal conductivity measurement.

| Time (s) | $\Delta T$ (K) |
|---------|----------------|
|         | GK  | AK  | M   |
| 0       | 12,05 | 8,49 | 15,60 |
| 5       | 11,78 | 7,90 | 15,70 |
| 10      | 11,28 | 7,62 | 15,70 |
| 15      | 10,88 | 7,34 | 15,70 |
| 20      | 10,58 | 6,95 | 15,70 |
| 25      | 10,37 | 6,79 | 15,70 |
| 30      | 10,16 | 6,69 | 15,60 |

Data in Table 2 demonstrates that the temperature difference generally decreases with time. The higher the temperature difference, the greater the heat flow and respectively. Heat insulation itself is a way to reduce heat by using an insulating material.

3.3. Thermal Conductivity ($k$)
The thermal conductivity calculated for each marble sample from South Aceh District is displayed in Table 3.

| Sample Code | $k$ (W/mK) | $R$ (m$^2$K/W) |
|-------------|------------|----------------|
| GK          | 2,02       | 0,22           |
| AK          | 2,30       | 0,20           |
| M           | 1,28       | 0,35           |

In this study, the thermal conductivity of each marble from South Aceh District is 2,09 W/mK, 2,30 W/mK and 1,28 W/mK. The thermal resistance obtained are 0,22 m$^2$K/W, 0,2 m$^2$K/W, and 0,3 m$^2$K/W. In reference, the thermal conductivity of marble ranges between 1,59 and 4,0 W/mK [18]. Thus, the measured thermal conductivity value for marble from Gunung Kerambil and Alur Kering area is close to the thermal conductivity value of marble stated in reference. However, marble from the Meukek area shows a lower thermal conductivity value. A high thermal conductivity value indicates a large number of heat energy transferred within materials. The material that has a high thermal conductivity value is a good conductor while those that have a low thermal conductivity $k$-value are good insulators. Consequently, marble samples from South Aceh are bad conductors and good isolators. Those are appropriate to be used as a building material for insulating purposes.

4. Conclusion
In this study, the data of the measurement of thermal conductivity South Aceh marble were presented. The thermal conductivity of each marble from South Aceh District is 2,09 W/mK, 2,31 W/mK and 1,28 W/mK. The thermal resistance obtained are 0,22 m$^2$K/W, 0,2 m$^2$K/W, and 0,3 m$^2$K/W. Based on the results, it can be concluded that the marble sample from South Aceh District has a low thermal conductivity which means they are bad heat conductors and a good insulator. It revealed that marble stones existing in South Aceh District are appropriate to be applied as the thermal insulating material.
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