The Photon Attenuation Coefficients and Thermal Conductivity of Volcanic Rocks

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The linear attenuation coefficient (μ cm^{-1}) of photon propogation and the thermal conductivity have been determined for some volcanic rocks, which are commonly used materials in building constructions especially as a cladding stone. The linear attenuation coefficient calculated using XCOM is compared with the measurement. Thermal conductivity has been extracted from P-Wave velocity measured using a Pundit apparatus. The relation between thermal conductivity and the attenuation coefficient are also investigated.

Key words: Thermal Conductivity; Attenuation Coefficients; Radiation Shielding.

1. Introduction

There are several volcanic crater lakes (e. g. the Golcuk crater lake) formed due to volcanic eruption in the Isparta region, located in the south of Turkey. Pyrolastic rocks, tuff stones, tracyhandesite and ash tuffs are the main rocks of the volcanic activity as outcropped in the region. Bilgin and Sargin [1] used the term welded tuff for the tuff stones for its well-bonded structure. They are in porphiritic texture, and phenocrystals consist of sanidine, oligioclase, pyroxene, amphibole and opaque minerals. On the other hand Fragoulis et al. [2] used the term “Zeolitic tuffs” for the tuff stones outcrops at Kimilos island in the egean sea close to the Isparta region. Ay-rose andesites of the Balıkesir area are also investigated to establish the difference in properties of both andesites. Both andesites (Ay-rose andesite and trachyandesite) contain phenocrystals of biotite lie in a devitrified groundmass of feldspar and have large and abundant phenocrystals of biotite, augite and much altered feldspar, again in a groundmass of microlites oligioclase crystals enclosing crystals of pyroxene and feldspar [1]. Although both andesites have similar characteristics, they are outcropped in different places and have different chemical properties (see Table 1). Trachy andesites and welded tuffs generally used in buildings as a masonry wall construction. The tuff stone and tracyhandesite are commonly used in building construction and exhibit good mechanical properties such as high strength and durability. Having higher insulating characteristics also makes them an ideal choice as a cladding stone and decorative materials in building construction. On the other hand welded tuffs have small value of thermal conductivity coefficient which is the quantity of heat transmitted, due to unit temperature gradient, in unit time under steady conditions in a direction normal to a surface of a unit area. Due to this, they have higher insulation characteristics which also makes them an ideal choice as a cladding stone. Also they are easily carved for decorative purposes. Porosity, permeability, texture and mineral composition of these building rocks are the most important factors affecting weathering and deterioration of them by water and gases in atmosphere. Tuff stone is also preferred because of its rich, earth tone colors, easy workability, durability and availability. Therefore these stones are used as load-bearing walls, often with decorative exterior treatment in building construction. Thus they have been the predominant building stone for 1000 years. It can be seen in

Table 1. Chemical composition in percent (%) of some volcanic rocks obtained by X-ray fluorecence [7].

Stones	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	TiO_2
Tuff stone	4.41	58.31	16.01	2.95	1.13	1.67	5.2	–
Ay-rose andesite	6.034	60.286	16.753	5.068	2.779	3.314	2.552	0.581
Trachyandesite	2.901	63.086	15.515	3.658	1.21	4.012	5.212	0.57

Stones	Density ($g\,cm^{-3}$)	P-Wave Velocity (m/s)	Thermal conducticity at 300 K(W/mK)	Attenuation coefficient (μ cm^{-1}) at 1.33 MeV
Tuff stone	1.4	2300	0.2706	0.042
Ay-rose andesite	2.24	3600	0.5905	0.146
Trachyandesite	2.35	4860	1.2576	0.159

Table 2. Physical properties and measured thermal conductivity and linear attenuation coefficients obtained at 1.33 MeV photon energy.

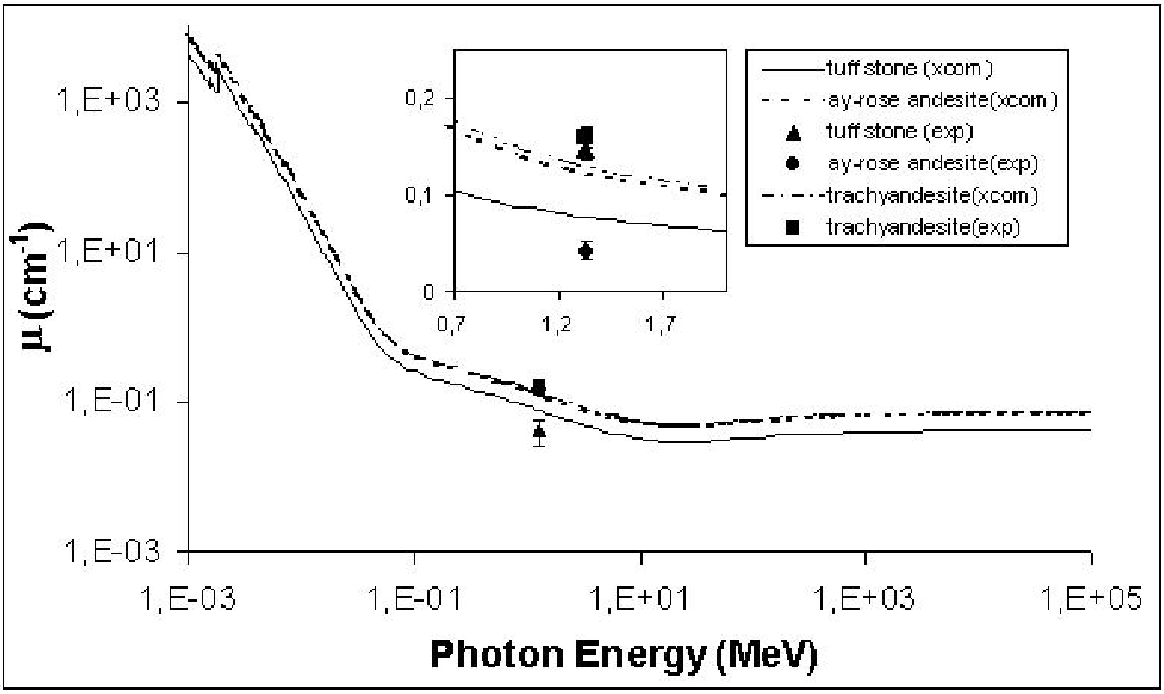

Fig. 1. The calculated and measured linear attenuation coefficients for tuff stone and two different andesites.

many ancient buildings such as schools, churches and mosques, constructed in XVI century that these rocks were used as building stones. These volcanic rocks can also be used in the area of radioactive waste disposal as a shield material. There is a current research project on the coupled thermo-hydro-mechanical processes in fractured porous media [3]. The materials used in a building construction especially for critical buildings such like accelerators, power stations and also hospitals, are very important for radiation shielding. For the choice of shielding materials against radiation the linear attenuation coefficients (μ) which are defined as the probability of a radiation interacting with a material per unit path length, is an important quanity and this has to be known. The magnitude of the linear attenuation coefficient depends on the incident photon energy, the atomic number and the density (ρ) of the materials [4].

In this paper the results of measurement the photon linear attenuation coefficients and the thermal conductivity of some volcanic rocks which are commonly used materials in building construction will be presented. The linear attenuation coefficients have been both measured and calculated using XCOM computer code and the thermal conductivity of the rocks were determined from the measured P-wave velocity.

2. Materials and Methods

The calculation of the total mass attenuation coefficients (μ/ρ) have been performed using the XCOM program. The XCOM (version 3.1) is a computer code developed by Berger and Hubbell [6] to calculate the mass attenuation coefficients (μ/ρ) for elements, compound or mixture, at energies from 1 keV to 100 GeV. With a known density (ρ) of the materials, the linear attenuation coefficients (μ) were extracted. As the XCOM code uses the chemical properties of the volcanic rocks, they were obtained by X-ray fluorecence [7] and the results are tabulated in Table 1. The

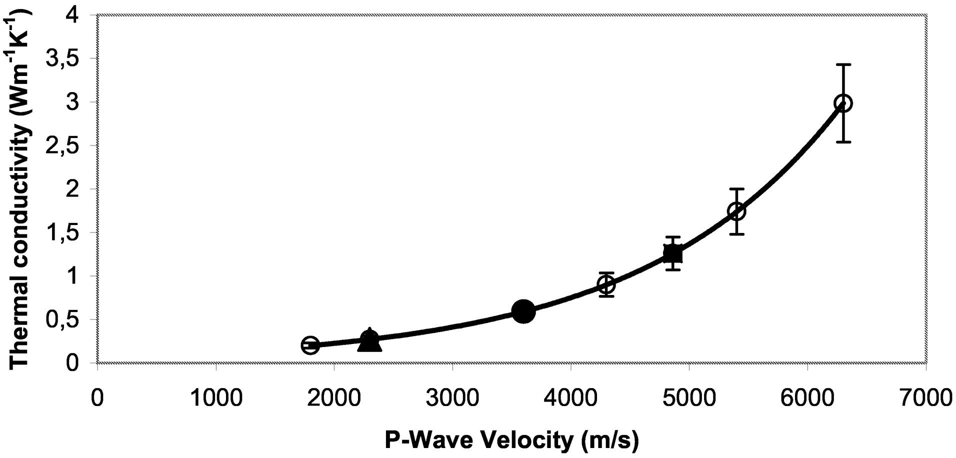

Fig. 2. The thermal conductivity as a function of P-Wave velocity (full dots represent rocks used in this work).

measurements as detailed elsewhere [8] have been performed using 0.1 μCi activity of ^{60}Co source which emits 1.33 MeV γ-rays. If N and N_o are the measured count rates in G-M respectively with and without the absorber of thickness x(cm) the linear attenuation coefficients (μ) can be extracted by the standard equation:

$$N = N_0 e^{-\mu x}.$$

Plotting N_0/N (in log scale) versus x, would give straight lines and μ is obtained from the slope of the line.

Although the thermal conductivity of materials in a solid state can be determined also by different methods [9] it was extracted from the P-wave velocity measured Pundit apparatus in this study. Determining the thermal conductivity from P-wave velocity with a measurement is easier than its direct measurement as it takes longer time and requires larger plates to prepare. The P-wave velocity is measured on oven dried prismatic samples of $5 \times 5 \times 16$ cm^3 in dimension. The rock was oven dried and its bulk density is found from its bulk volume. The bulk volume of regular specimen is calculated using Archimedes principle, from the difference between dry and submerged sample weights. During the tests a thermostatically controlled, ventilated drying oven capable of maintaining a temperature of 105 °C for a period of at least 24 hours is required. After determining the bulk volume and the grain mass, the oven-dry sample is pulverized and its grain volume is determined by the displacement of an equivalent volume of water in a volumetric flask (picknometer). The thermal conductivity versus the P-wave velocity has a correlation coefficient $R^2 = 0.9944$ (almost unity) and this means that the thermal conductivity of any rock can be calculated via laboratory determined P-wave velocity, from the exponential relationship [10];

$$Y = 0.0681 \times e^{0.0006X},$$

where Y and X represent the thermal conductivity in $\mathrm{W\,m^{-1}K^{-1}}$ and the P-Wave velocity in units *m/s* respectively.

3. Results and Conclusion

Two main properties of rocks used as a building materials namely heat insulation and radiation absorption have been investigated. In Table 2 some physical properties and the experimental result on the linear attenuation coefficient, the P-Wave velocity and the thermal conductivity for tuff stone, ay-rose andesite and trachyandesite are given. The calculated results of the linear attenuation coefficient (μ) for all rocks and the comparison with the measurements obtained at 1.33 MeV are given in Fig. 1 where it can be seen that they are in good agreement. There are no big differences between the two andesites but for the tuff stone a smaller value for the linear attenuation coefficient (μ) was obtained. As can be seen from this figure, the attenuation coefficient depends on the incident photon energy and it decreases with the increasing photon energy. Figure 2 shows the thermal conductivity as a function of the P-wave velocity. The thermal conductivity increases exponentially with increasing P-wave velocity. This relation has a very high correlation coef-

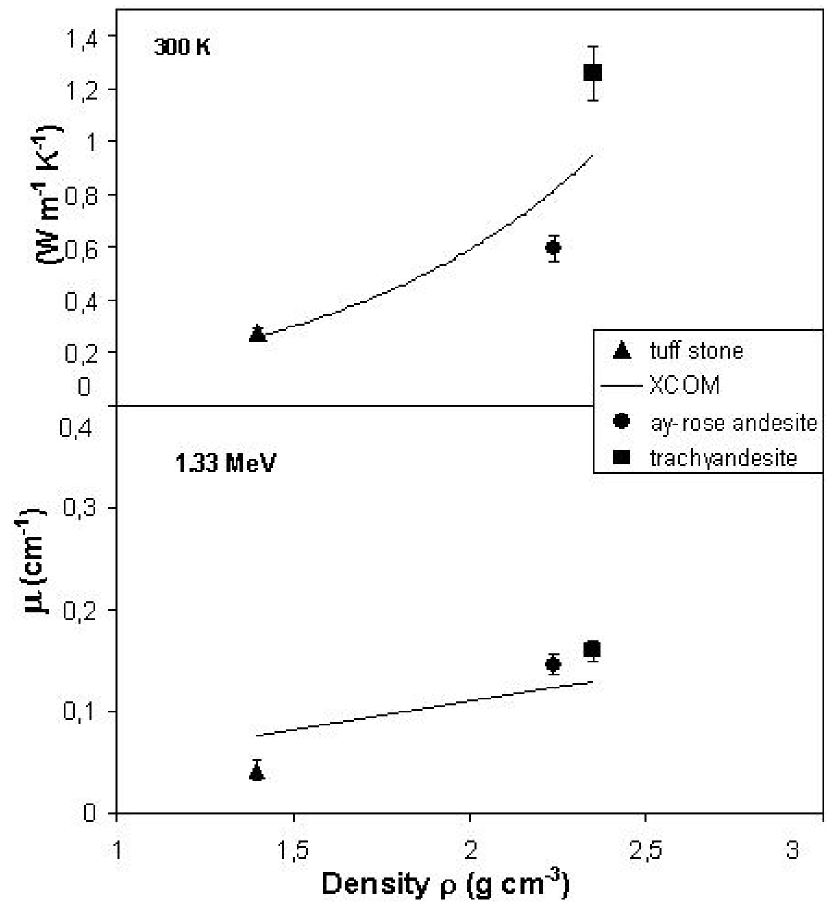

Fig. 3. The thermal conductivity (upper) and linear attenuation coefficient (lower) as functions of the stones' density.

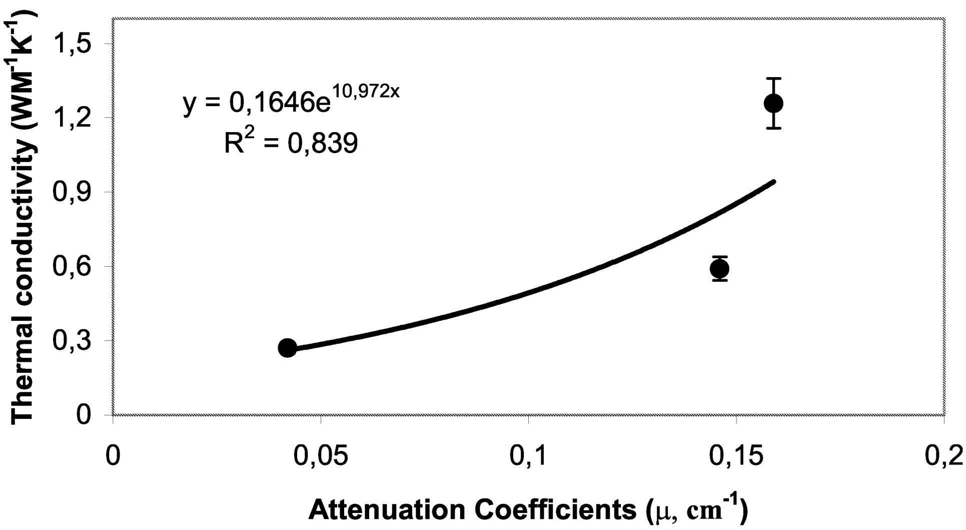

Fig. 4. The variation of the thermal conductivity with linear attenuation coefficient for three types of volcanic rocks.

ficient. In Fig. 3 the thermal conductivity (upper) and linear attenuation coefficient (lower) are displayed as a function of the rocks' density. As can be seen from this figure, both thermal conductivity and linear attenuation coefficient depend on the material's density. The thermal conductivity varies exponentially with the density of the rock (upper). The relation between the thermal conductivity and the density is not well correlated due to different densities and various porosity values of various minerals. The linear attenuation coefficient increases with increasing density as expected, and the measurements and calculations are in good agreement. In Fig. 4 the thermal conductivity of volcanic rocks and their attenuation coefficients are compared. It can be seen that meaningful exponential relation is found between them (correlation factor $R^2 = 0.84$). The differences could be the results of the different minerological constituents and structural textures of rocks. It can be concluded that the thermal conductivity of any rock can readily be calculated from the laboratory determined P-wave velocity. The tracyhandesite is a better shielding material than the other rocks investigated here and it can be used for this purpusose in building construction.

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