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Computation of EABF and EBF for basalt rock samples

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ABSTRACT

In this study, certain photon absorption parameters including the energy absorption buildup factor (EABF) and exposure buildup factor (EBF) have been investigated for three different basalt samples collected from different parts of Van city. Radiation shielding properties of the basalt samples indicated a strong correlation between photon energy absorption parameters and values of EABF and EBF of basalt samples. It was found that EABF and EBF parameters are related to radiation shielding properties of basalt samples. A new method and algorithm based on ZXCOM was used. Instead of calculating *G–P* fitting parameters for every effective atomic number (Z_{eff}), EABF and EBF were calculated for Z_{eff} by interpolation, using ANSI/ANS 6.4.3 standard data available for Z_{eff}.

1. Introduction

Basalt is a very common volcanic rock, dark colored and comparatively rich in iron and magnesium, which is located at almost every country in the world. Basalt is used for a wide variety of purposes. It has been used in the rock industry to create industrial construction, highway engineering and building tiles for other purposes. Powders and fibers of basalt rocks are widely used of thermal stability, heat and sound insulation [1–3]. Basalt fiber reinforced polymer bars were reported to be an excellent alternative for the reinforcement of bridge girders due to minimizing the weight of the structure and preventing corrosion related damages [4]. The basalt materials researched within this study are now being considered utilized or considered to be used in the construction industry for concrete and thermal and sound insulation material production [5].

To ensure the future competitiveness of concrete as a construction product, it is essential to improve the durability of concrete structures. The uses of basalt aggregates within the manufacturing of concrete for the prefabrication industry have been worked by Ingrao et al. [6]. The results have shown that basalt may be used successfully for preparing radiation shielding concrete, but some parameters such as effective atomic numbers and buildup factors should be noted on the choice of the suitable types of basalt [7].

The basalts are categorized into two main groups such as alkaline and sub alkaline [8]. Three different basalt samples used in this study were taken from different parts of Van city, Turkey. The basalts were taken from volcanic fields that were erupted from extensional fractures in different periods of time in the Pliocene to Quaternary. Volcanology and petrology of these volcanic areas are studied in detail by [9,10].

Since chemical structure, texture and mineralogical assembles of the rocks in the researched area are different, three various samples representing different volcanic areas were obtained and also categorized according to their chemical compositions [5]. The samples were named as CM-1, KYZ-13 and KYZ-24 were used for identifying the impact indicators of basalt aggregates used for concrete production. This is believed to be extremely important, because such indicators must be taken into account for environmental sustainability.

The application of gamma radiation has a vital role in industries, medical, agriculture, and energy sectors etc. The radiation shielding is an essential part of a reactor, accelerator or any radiation facility to minimize the radiation exposure. Therefore shielding materials are composed of several compounds of high-Z elements for attenuation of photon and neutron radiation.

The radiation shielding of a material can be expressed with the effective atomic number Z_{eff}, the energy absorption buildup factor (EABF) and exposure buildup factor (EBF). Exposure buildup factor is a photon buildup factor in which the quantity of interest is exposure. The energy response function is that of absorption in air. Also an energy absorption buildup factor is a photon buildup factor in which the quantity of interest is the absorbed or deposited energy in the shield medium. The energy response function is that of absorption in the material [11]. The basalt has been used as a material for radiation shielding by [12]. Singh has

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studied Monte Carlo simulation of gamma-ray shielding parameters of concretes having basalt–magnetite (BM) [13].

This study is the first attempt to determine EABF and EBF of different basalt samples and investigate the relationship between the physical and chemical properties of basalt samples and EABF and EBF. With this study, the potential of basalt samples in radiation shielding as well as the relationship between physical, chemical and absorption parameters of basalt samples were identified. Z_{eff} EABF and EBF of three different basalt samples at photon energies 0.015–15 MeV were evaluated using the methodology presented in this article.

2. Experimental tests

In the present study, three different basalt samples (CM-1, KYZ-13, KYZ-24), were obtained from volcano-clastic formations located in Van (Erciş, Kocapınar), Ağrı (Patnos, Diyadin) and Bitlis (Adilcevaz) province in the Eastern Turkey. These basalt rocks were first ground to fine aggregate size about 200 mesh and then 15–20 g of these basalt samples were ground in an agate ball mill in order to obtain very fine powder samples to ensure good replication of XRF and ICP-MS data. Chemical analyses of the basalt rock powders are taken by X-ray fluorescence (XRF) instrument. Operating conditions of the Philips PW-2400 XRF instrument were set at 60 kV and 50 mA. All basalt samples were pressed under pressure of 30 MPa into pellets with 13 mm diameters and about 0.5 mm thickness. The particle size and circularity measurements were taken with Malvern MasterSizer Hydro 200MU and micrograph photo taken by Malvern Morphology G3.

X-ray diffraction measurements of basalt samples were taken using Rigaku Ultimo X-ray diffractometer with CuK_α radiation, which has a wavelenght about 1.5406 Å at a scan rate of 0.01°/s. The accelerating voltage was 40 kV and applied current was 30 mA. XRD analyses were studied on powdered basalt samples and achieved XRD patterns are shown in Fig. 1.

The results of chemical analysis of basalt samples are given in Table 1. According to the chemical analysis of basalt samples, all three samples have pure basic character (SiO_2 content between 45–52%). Many researchers have reported that rocks containing SiO_2 in the range of 45–52% are defined as basalts. It should be noted that rocks having SiO_2 content more than 52% should be named as andesite, trachyte, rhyolite, etc.[5] Chemical analysis also indicates that the total percentage of K_2O+Na_2O in the CM-1 sample is higher than the other samples. Therefore, the CM-1 sample is a basaltic rock which is rich in K_2O+Na_2O and can also be named as basanite.

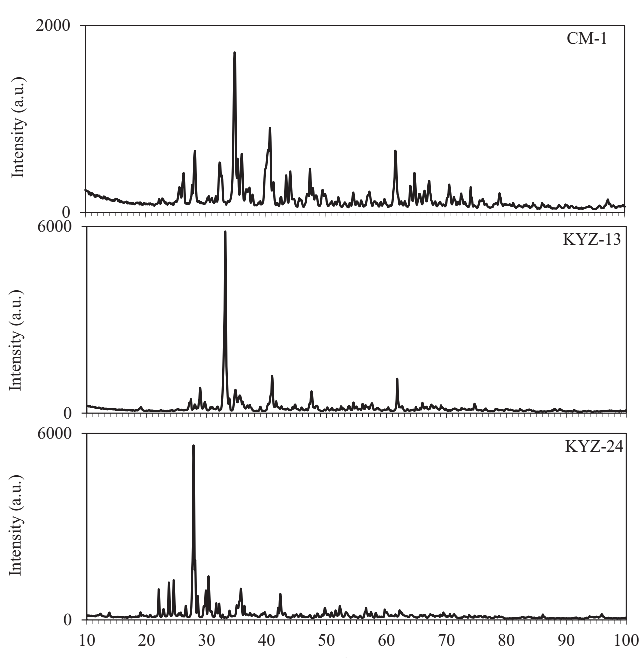

Fig. 1. XRD patterns of basalt samples, CM-1, KYZ-13 and KYZ-24.

Table 1
Chemical composition of basalt samples.

	CM-1	KYZ-13	KYZ-24
SiO_2	41.668	47.790	47.086
TiO_2	2.0800	1.3950	1.7910
Al_2O_3	13.106	16.918	17.574
Fe_2O_3	13.823	10.878	11.493
MnO	0.1920	0.1630	0.1720
MgO	9.7540	7.6190	8.6710
CaO	10.602	11.357	9.9660
Na_2O	5.2610	3.1370	2.9340
K_2O	1.7370	0.5190	0.1210
P_2O_5	1.7770	0.2240	0.1920
Total	100.00	100.00	100.00

3. EABF and EBF calculation methods

3.1. Determination of the effective atomic number (direct method)

In this study, first computational values were obtained by using the state of art program XCOM and database [14] later formed as WinXCOM software [15]. This program calculates the total effective cross-sections as well as the partial effective cross-sections for the incoherent scattering, coherent scattering, photoelectric absorption and pair production. It can also generate the mass attenuation coefficient (μ_t) of the elements, mixtures, and chemical compounds for both standard and selected energies ranging from 1 keV to 100 GeV. The algorithm of the mass attenuation coefficient is presented in [16].

All radiation types have apparently penetrating skill. The mean free path, mfp, is the reciprocal of linear attenuation coefficient having the dimension of length (usually expressed in cm). The mfp of mono-energetic photons is the average distance a photon travels between collisions with atoms of the target material. It depends on the energy of the photons and the material [17]. All formulas of the cross-sections will later be generalized to mixtures as well. The total photon interaction cross section such as the total molecular cross-section $\sigma_{t,m}$, the average atomic cross-section σ_a, the average atomic cross-section $\sigma_{t,e}$, and the total effective atomic number Z_{eff}, are present in [18].

3.2. Determination of effective atomic number (ZXCOM method)

Many authors have measured the Z_{eff} by different values for the incident energy (E_0) and the scattering angle (θ) [19–21]. But, this values for (E_0) and (θ) are important owing to nature of photon interaction.

Looking at the literature, correlation has been studied between the angular change and the Z_{eff} in detail. The choices of the (E_0) and (θ) have been considered by some authors [22–24]. The angular changes must be taken into account in the Z_{eff} calculations. The Direct-Z_{eff} software by Un and Caner [25] has also ignored the scattering angle.