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Electrical and impedance properties of composites: Volcanic basalt rocks

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ABSTRACT

In this work, volcanic basalt rocks, which were collected from different parts of Van city located in Eastern Anatolia, have been discussed in the context of impedance properties. The real and imaginary components of dielectric constants, dielectric dissipation factor, dielectric strength, AC conductivity and *s* frequency exponent parameter have been determined. According to AC conductivity results, it has been determined referring to *s* parameters' values, correlated barrier hopping (CBH) model is valid for all volcanic basalt rock samples at high frequency region. Moreover, the critical frequency that corresponds to the change of conductivity characteristic of all basalt volcanic rocks has been determined. Furthermore, due to their low conductivities Sample-1 and Sample-2 have been suggested as promising materials for electromagnetic radiation shielding applications for the high and low frequency regions, respectively.

1. Introduction

Due to increasing usage of electronic devices, the necessity of electromagnetic shielding becomes inevitable. It has been reported that continuous exposure of electromagnetic radiation causes significant problems on both human health such as asthma, heart diseases, cancer etc. and the work on electronic systems [1–5]. For protection from electromagnetic radiation, volcanic basalt rocks may be used in many industrial applications which require electrostatic dissipation or electromagnetic shielding. As is known, basalt which is a mineral of volcanic origin and comprises more than 90% of all volcanic rocks, is the most preferable material for defense industry and aeronautical applications [6–9]. In this context, the characterization of volcanic basalt rocks has a crucial importance for determining their performance and limits for technological applications. Impedance spectroscopy and high resistance measurements are suitable tools for characterization of their electrical properties. Among other characterization methods, impedance spectroscopy measurements has a special importance due to the possibility of finding correlation between the dielectric properties and the microstructure of the system [10,11]. Also, it is proposed to assess the environmentally the most significant material related to the filler production for the concrete using basalt aggregates [12]. To ensure the future competitiveness of concrete as a construction material, it is essential to improve the sustainability of concrete structures. For this purpose, environmental impact and resource consumption reduction-potentials can be found in the field of concrete construction, especially in raw-material production and concrete manufacturing technology [13]. Some aggregates in concrete are added to change the properties of concrete such as adding basalt fibers to reduce the costs. These fibers are added to be bonded with concrete to make it easier to distribute the loads evenly throughout the concrete element making cracks less likely to occur. Experiments performed with basalt–concrete composites have accepted increase in compressive strength [14]. The results clearly show that basalt rebar having full resistance against corrosion may be good alternative for the reinforcement of concrete structures, like RC bridge girders subjected to environmental attack [15].

In order to investigate the effect of limestone and basalt content in steel-concrete composite beams and test the effect of basalt content on the behavior of composite beams is set up to an experimental program [16]. Also, author concluded to the fact that basalt is denser, more durable, less water absorbing than limestone and proved that basalt improves the strength and stiffness of concrete. The correlations between temperature gradient and

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microwave irradiation for basaltic rock have been researched experimentally by Hartlieb et al. [17]. In this study, impedance properties and conductivity mechanism of volcanic basalt rocks (coded as Sample-1, Sample-2 and Sample-2) have been investigated according to their chemical composition and concentration.

2. Experimental

2.1. Decomposition of materials

The basalt rocks have been ground to fine aggregate size and then 15–20 g of these basalt samples have been ground in an agate ball mill in order to obtain very fine powder samples to ensure good replication of XRF and ICP-MS data. The all basalt samples have been pressed under pressure of 30 MPa into pellets with 13 mm diameters and about 0.5 mm thickness. Chemical analyses of the basalt rock powders have been taken by Philips PW-2400 XRF (X-ray fluorescence) instrument. Operating conditions of the XRF instrument have been set at 60 kV and 50 mA. The particle size and circularity measurements have been taken with Malvern Mastersizer Hydro 200 MU and micrograph photo was taken by Malvern Morphology G3. X-ray diffraction measurements of basalt sample have been taken using Rigaku Ultimo X-ray diffractometer with CuK_α radiation, which has a wavelength about of 1.5406 Å at scan rate of 0.01°/s. The accelerating voltage was 40 kV and applied current was 30 mA.

2.2. Experimental set-up

The chemical compositions and concentrations of volcanic basalt rocks coded as Sample-1, Sample-2 and Sample-3 have been determined by X-ray fluorescence and the results have been given in Table 1.

The dynamic (ac) characteristics and dielectric parameters of Sample-1, Sample-2 and Sample-3 have been determined by impedance spectroscopy measurements which is a very sensitive and non-destructive technique for studying characteristics of batteries, electrodes and corrosion-related problems. This technique is also widely applied to systems modeled by an equivalent circuit to determine their from which physical parameters of the system can be calculated [18].

The dielectric parameters of volcanic basalt have been calculated by the parallel plate capacitance method via HP 4194A Impedance Analyzer within the frequency range of 100 Hz–15 MHz. The samples have been screened from any electric field effects by Faraday cage during the experiment.

3. Results and discussions

The electrical properties of volcanic basalt rocks, such as frequency dependent conductivity and dielectric constant have been investigated by impedance/dielectric spectroscopy. The dielectric spectra of volcanic basalt rocks have been determined within the frequency range of 100 Hz–15 MHz for dc bias of 1 V. The capacitances versus frequency of Sample-1, 2 and 3 have been given in Fig. 1. As is seen from Fig. 1, the maximum capacitance at low frequency has been achieved for Sample-1. According to Table 1, while the lowest SiO_2, the highest ($Na_2O + K_2O$) and Fe_2O_3 contents has been determined for Sample-1, The other two basalt samples (Sample-2 and Sample-3) have also higher SiO_2 and lower ($Na_2O + K_2O$) and Fe_2O_3 contents relative to Sample-1. In this respect, the maximum capacitance value at low frequency for Sample-1 may be related to the SiO_2, ($Na_2O + K_2O$) and Fe_2O_3 content of the basalt. The characteristics of C–f curves obey to exponential decay.

The real parts of dielectric constant of all basalt rocks have been given in Fig. 2. As shown in Fig. 2, the real parts of dielectric constants decrease while the frequency increases. On the other hand, the real part of dielectric constant has its maximum value at low frequencies. Above 200 kHz, the real parts of the dielectric constant of the related materials do not significantly change with frequency.

As is seen from Fig. 2, the maximum dielectric constant has been observed with Sample-1 which has the highest capacitance for low frequency region.

As is seen from Fig. 3, the imaginary parts of dielectric constants decrease while the frequency increases. The magnitude of ε'' in low frequency region is higher than that of high frequency region. Since the magnitude of ε'' is proportional to energy dissipation, it has been deduced that the system is more stable in the high frequency region.

The dielectric strength $\Delta\varepsilon$, has been calculated by Eq. (1).

$$\Delta\varepsilon = \varepsilon_S - \varepsilon_\infty \quad (1)$$

where ε_S is the limiting low frequency dielectric constant and ε_∞ is the limiting high frequency dielectric constant. The dielectric strength and related parameters have been listed in Table 2. The minimum value of dielectric strength has been observed for Sample-2. This may be due to the maximum Al_2O_3 content relative to other basalt rock samples. In other words, the excess Al_2O_3 content in the basalt rock (Sample-2) improves the dielectric properties of the material. Moreover, when the Na_2O contents decrease, the dielectric strength also decreases (Tables 1 and 2). In this respect, the correlation could be made with dielectric strength and amount of the contents of the rocks. In this case, in terms of the

Table 1
Chemical composition (wt %) of used volcanic basalt rocks.

Content	Sample-1	Sample-2	Sample-3
SiO_2	41.27	46.54	46.92
TiO_2	2.06	1.77	1.37
Al_2O_3	12.98	17.37	16.61
$Fe_2O_3^{TOT}$	13.69	11.36	10.68
MnO	0.19	0.17	0.16
MgO	9.660	8.57	7.48
CaO	10.50	9.85	11.15
Na_2O	5.21	2.90	3.08
K_2O	1.72	0.12	0.51
P_2O_5	1.76	0.19	0.22

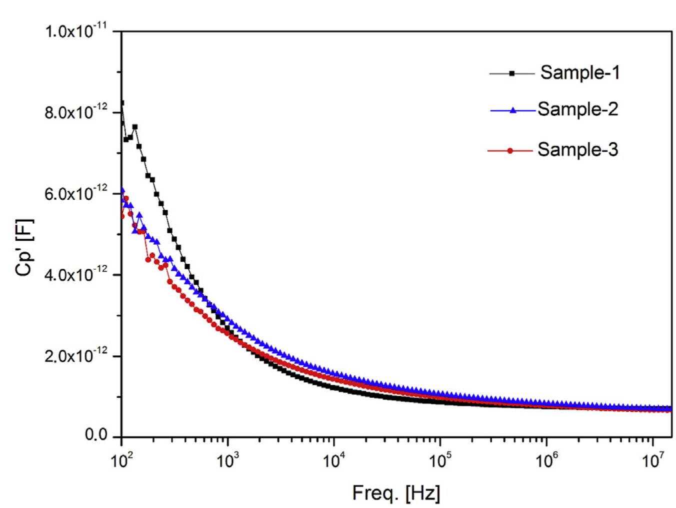

Fig. 1. The variation of capacitance with frequency.