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Electrical properties and mineralogical investigation of Egyptian iron ore deposits

M.M. Gomaa[a,*], A.A. Shaltout[b], M. Boshta[b]

[a] National Research Centre, Geophysical Sciences Dep., El Behooth St., 12622 Dokki, Cairo, Egypt
[b] National Research Center, Physics Division, El Behooth St., 12622 Dokki, Cairo, Egypt

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ABSTRACT

Electrical properties and X-ray diffraction of 20 hematite sandstone samples of the most economically interesting Egyptian iron ore deposits have been investigated. Samples were collected from two different areas in Egypt (Aswan and Bahariya). Complex impedance measurements in the frequency range from 10 Hz to 100 kHz were performed at room temperature (~20 °C). The observed dielectric behavior was characterized by Maxwell–Wagner interfacial polarization at low frequencies and bulk polarization at relatively higher frequencies. The frequency dependence on conductivity shows a classical relaxation behavior followed Jonscher's universal law. The measured electrical properties vary strongly with the frequency and sample composition. The difference in the electrical properties may be attributed to the fluctuations in the concentration of the sample constituents and to the degree of heterogeneity of the grains. The XRD-patterns of Egyptian iron ore deposits prove that the main phases are hematite and quartz.

1. Introduction

The electrical properties of materials consisting of a mixture of metals and dielectrics are extremely sensitive function of the relative concentrations of the components. Furthermore, the electrical properties of the material depend on the components in which they are distributed throughout the volume of the material which can be explained by X-ray diffraction. In addition, the electrical response of multicomponent system depends basically upon the volume fraction and electrical properties of each individual component [1,2]. Due to the presence in a mixture, the individual components will interact, leading to the development of a region of distinct electrical and physical properties. AC measurements yield information which can be used to determine the conduction process applicable. Three main conduction models are applicable to materials, the hopping model, the variable hopping model and the band theory [3,4]. Recently, the DC electrical properties of various materials have been extensively studied, but relatively little work has been carried out on their AC electrical behavior [5,6]. The effective electrical properties of mixtures depend basically on the particle size [7], particle shape [8], the effective conductivity and dielectric constant of the interstitial constituents [9], heterogeneity and randomness of the mixture, and the frequency of the applied field [10].

The composite properties of rocks vary appreciably with frequency [11]. At low frequency range, the effective conductivity is gradually increasing function of frequency, while the effective dielectric constant is much more strongly dependent on frequency [12,13]. Electrical characteristics have been interpreted as being caused by geometric or textural heterogeneities of the rock system [12,14], or were related to electrical and electrochemical processes developed at the interfaces between rock grains [1,15]. Interactions between charged particles give rise to double layer around these particles. Polarization of such layer by an applied electric field has been pointed out as the main mechanism for the anomalous behavior observed in rocks [16,17].

Knight and Abad [18] observed a power law dependence of the dielectric constant on the frequency and that was related to the texture of the sandstone samples. The power law response is thought to be due to the random nature of the constituents within the samples [19,20]. Dry sandstone samples without a metallic component at room temperatures are good dielectrics with conductivity value of the order of $10^{-10}\,\mathrm{S\,m^{-1}}$ and a relative dielectric constant of the order of several units. For a combination of sand and hematite, the interface gives rise to large values of dielectric constant with strong frequency dependence [21,22], which can be explained by surface conductivity and polarization processes. In the absence of an applied electric field, ions are free to move. When an oscillating electric field is applied, the ions polarized around the rock grains give rise to large dipoles and to large apparent dielectric constants [21–23]. As the frequency increases, ions have

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* Corresponding author. Tel.: +20 115985275; fax: +20 233370931.
E-mail address: mmmsgomaa@yahoo.com (M.M. Gomaa).

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less time to polarize and contribute more to the conductivity, since they are more in phase with the applied oscillating electric field.

The addition of a small amount of conductor to the sample may increase the conductivity and decreases the dielectric constant. The air is one of the important factors in representing the dielectric properties of the mixture. These effects come from physical reactions of the grain interface and can be considered as surface contributions to the complex electrical conductivity of a porous system [21,22]. The most probable polarization mechanism is the orientation polarization of molecules or hopping of ions along the surface [21,22,24]. Chelidze et al. [22] concluded that the polarization of non-conducting particle coated with a conducting one and embedded in an AC field leads to high dielectric values at low frequencies. This explains why the addition of small quantities of conductor to a porous rock causes a strong dielectric values at low frequencies.

Hematite as a rock occurs in many types of igneous, metamorphic and sedimentary rocks. The largest and most economically important hematite deposits are mainly of sedimentary origin, forming from the weathering of iron bearing minerals. In these sedimentary deposits, hematite is thought to have precipitated from lakes or seas by organic and/or chemical processes. The hematite often occurs with intermixed layers of quartz or chert. This study has thrown the light upon the nature of Egyptian iron ores, its group minerals, its crystal structure and their relation with the electrical properties. The iron ore deposits of these localities vary greatly in their mineralogical and chemical composition.

In the present work, the electrical properties and the X-ray diffraction of 20 iron ore deposits from East Aswan (Eastern Desert) and Bahariya Oasis (Western Desert) were demonstrated. The electrical measurements have been measured in a dry condition in the frequency range from 10 Hz to 100 kHz at room temperature (~20 °C). Mechanisms of conduction and polarizations were presented under different constituent concentrations of the present samples. XRD patterns were also demonstrated in order to investigate the different phases of the different constituents and understand the crystal structure of the different natural pattern of these samples.

2. Samples

2.1. Aswan iron ore deposits

Aswan iron ore deposits in the eastern desert of Egypt have been chosen for the present study in order to understand the composition and texture of this sediment. The heavy minerals in the Nubian sandstone in Aswan have been found to be mainly iron ores, zircon, tourmaline and futile [10]. Attia [25] considered that the Nubian sandstone is of marine origin. Lithologically, Aswan sandstone is essentially composed of conglomerates, sandstones, sandy shales, clays and quartzitic bands [10,25]. The iron ore bands are often associated with ferruginous sandstones and clays. Nakhla and Shehata [26] supposed that the iron ores of east Aswan are composed of cryptocrystalline hydrated hematite (Fe_2O_3–nH_2O), microcrystalline hematite, clay minerals, cryptocrystalline and amorphous silica, quartz possesses a sub angular to sub-rounded form and some other ingredients. X-ray diffraction proved the presence of hematite and quartz with the occasional presence of chamosite in some ore specimens. According to pervious semi-quantitative spectrographic analysis [26] of iron ore samples there is a wide range of variation in chemical composition. A brief outline on the geochemical nature of the most important elements present in Aswan iron ore deposits are Fe, Si, Ca, Mg, Mn, P, S, Cu, Ti, Ni, Cr and Zr.

2.2. Bahariya iron ore deposits

Bahariya iron ores deposits in the western desert of Egypt have been also chosen for the present study and it represents the second source of iron ore in Egypt. The Bahariya iron ore deposits are generally capped [25] by an alluvial cover and/or quartzite. The upper part of the ore body is usually composed of hard goethite with some pockets of manganiferous hematite or conglomerate. The lower part is composed of manganiferous hematite with some pockets of hard goethite, and may be changed, especially at its lower parts, into pisolitic and oolitic goethite without manganese pockets. The main minerals associated with the ore include halite, gypsum, barite, quartz and clayey material.

3. Experimental work

3.1. X-ray diffraction

The X-ray diffraction measurements have been carried out by using Siemens 500 instruments. The applied current in the X-ray tube was 36 mA and the applied voltage was 45 kV. Cu target was used in Siemens 500 instruments. X-ray diffraction measurements were carried out overnight at interval of the diffraction angle ($\Delta\theta = 0.01$). The peaks of these XRD patterns correspond to those of the theoretical patterns from the ASTM data file to determine the crystal structures, lattice parameters, and crystal planes ($h\,k\,l$) for all phases found on Egyptian iron ore samples.

3.2. Electrical measurements

Electrical and dielectric properties of 20 hematitic sandstone samples of Egyptian iron ore deposits in Aswan and Bahariya have been investigated. Complex impedance measurements were carried out at room temperature (~20 °C). Data were performed in the frequency range from 10 Hz up to 100 kHz using Hioki 3522-50 LCR Hitester Impedance Analyzer. The measurement system was discussed elsewhere [27–29]. In order to measure the electrical response of the sample under investigation, the effect of heterogeneity and randomness of the mixture was eliminated by grinding the samples. The samples were grinded for 3 min (600 rpm) by MiniMill 2, PANalytical, Netherlands (particle size ~1 μm), Afterwards, the samples were pressed at 120 kN for 1 min by pressing machine (Herzog hydraulic HTP40, UK). The samples become like a homogenous pellets produced by the mentioned press tool. Samples dimensions were in the order of 3-mm thickness and 40-mm diameter. The homogenous pellet samples were measured electrically at a relative atmospheric humidity (~50%). The samples were initially evacuated and measured in an isolated chamber. A voltage of 1 V was applied and the current density in the sample was $\cong 4 \times 10^{-6}$ (μA cm^{-2}). The complex relative dielectric constant is given by,

$$\varepsilon* = \varepsilon' - i\varepsilon''; \quad \varepsilon' = \frac{C_p}{C_0} \quad \& \quad \varepsilon'' = \frac{G_p}{\nu \cdot C_0} \quad \& \quad C_0 = \varepsilon_0 \times \left(\frac{A}{d}\right) \tag{1}$$

where A, d, C_p, G_p, ν, ε', and ε_0 are the cross sectional area of the sample, sample thickness, the parallel capacitance, the parallel conductance, the angular frequency, relative dielectric constant and the permittivity of free space (8.85×10^{-12} F m^{-1}), respectively. The measured parameters are both series and parallel capacitance and resistance at different frequencies. In the series mode, the complex impedance Z is given by,

$$Z = R_s - iX_s; \quad X_s = \frac{1}{\nu C_s} \tag{2}$$

where R_s is the series resistance (real impedance), X_s is the reactance and C_s is the series capacitance. The complex resistivity ρ^* is given by,

$$\rho^* = Z \times \left(\frac{A}{d}\right); \quad \sigma = \frac{1}{\rho^*} \tag{3}$$

For the parallel model,

$$\rho = R_p \times \left(\frac{A}{d}\right); \quad \sigma = \frac{1}{\rho} \tag{4}$$

where R_p, σ are the parallel resistance and conductivity.

4. Results and discussions

4.1. Results of electrical properties

Generally, the increasing of conductor constituents increases the conductivity and decreases the dielectric constant. The conductivity increases due to the increase of conduction paths between the