Studying Electromagnetic Signal of Rock Effected by Acoustic Impact under Uniaxial Compression

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Abstract. Physical modeling in vitro is a way to carry out basic laws of mechanoelectric transformations in a rock massive. In this paper we examined how rock mechanical properties influenced on parameters of electromagnetic signals (EMS) excited by the determined acoustic impulse under uniaxial compression. It has been determined that sulphides and quartz in rock samples from the Tashtagolsky iron-ore deposit (Western Siberia, Russia) promote transformation of a mechanical energy to an electromagnetic field energy which is expressed in an augmentation of an EMS voltage. An EMS voltage reduction at the change of the stress-strained state of the sample in the course of an uniaxial compression is observed with quantity augmentation of containing of high-conducting magnetite in rocks. The obtained results are important for a physical substantiation of the method of monitoring of the stress-strained state of rock massive by mechanoelectric transformation characteristics.

INTRODUCTION

Catastrophic dynamic phenomena in the form of technogeneous earthquakes, mountain and tectonic bumps, rock massif falls, etc. accompany mining of iron-ore deposit in rock massif. Development of the deeps and mass blast of ore blocks aggravate a problem of the geodynamic events forecast. The reliable forecast of mining-and-geological and geomechanical conditions of mining work performance is necessary for the accident preventions.

The measurements executed on rock samples show that electromagnetic radiation is a good precursor for maximum strength test of samples and can be used for rock massif stress analyzing [1]. Experimentally proved increase in electromagnetic activity of rock samples at a predestruction phase corresponding loading 0.8 – 0.9 P_{max} is the cornerstone of such investigations [2]. However, both for laboratory research samples, and for rock massif, mechanoelectric transformation process occurs at all stages of deformation, since the microcrack origin moment and finishing with destruction. Parameters of the electromagnetic signal change depending on a deformation stage [3].

The electromagnetic radiation arising from the mechanical effect on rock is a subject of researches in many countries of the world.

Japanese researchers, as well as in our work, registered synchronously electromagnetic and acoustic signal (AS) of granite samples during monotonous loading [4]. It is established that electromagnetic signal (EMS) emission is connected with emergence or growth of microcracks. It was noticed that EMS occurs for several microseconds before generation of the acoustic signal. This delay is due to the EMS emitted with a speed of an electromagnetic wave. Thus, the origin of EMS corresponds on time to a crack creation. This fact can be used for definition of crack locations.

The Czech researchers confirmed in their work the dipolar mechanism of EMS generation in the course of mechanical effecting on rock [5]. They thought that crack creations are followed by electric charge redistribution because of the weak chemical bonds. Electric charges create the dipolar moments. Crack board fluctuations change the dipolar moments, and, therefore, create the electric and magnetic moments.

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The Israeli scientists conducted in their works studying of EMS of rock and model samples under loading [6]. Studying of transparent model samples allowed for to figure out sequence of cracks origin, their growth and interactions. It is established that EMS duration changes at certain stages of loading.

The Polish researchers took measurements of EMS from the coal samples, gray dolomite, sandstone and magnesite under uniaxial compression [7]. The measurements executed on rock samples showed that EMS is a good precursor for maximum durability determination of materials strength and for definition of stress-strain state of the rock massif. It was shown in laboratory researches on coal samples where EMS and AS were observed just before destruction.

It was shown in Tomsk polytechnic university that EMS generation in rocks is caused not only by microcrack creations and also by acoustic wave running through them [8,9,10]. At the same time, as it will be shown below, influence of material properties at EMS generation by applying acoustic waves is similar to influence of material properties on parameters of EMS excited at mechanical action. In the presented work EMS generation was created by acoustic wave in different time of the sample stress-strain state.

In this regard the goal of this research is to identify how rock sample mechanical properties influence on parameters of EMS excited by the determined acoustic impulse under uniaxial compression.

METHODS AND MATERIALS

The test samples of magnetite ore were selected on the Tashtagolsky iron ore deposit (Western Siberia, Russia) from the depth of 660 meters. Samples were cut out from core material and had the cylinder shape with a diameter of 42 mm and height of 80 mm. The end faces of a sample were polished to flatness. It provided coaxiality of a sample and press plates and load uniformity on a sample end face. Petrographic data of the rock samples are provided in table 1.

TABLE 1. Petrographic data of analyzed rock samples.

Sample number	Sample mass, g	Sample extent, cm^3	Magnetite mass in sample, g	Magnetite mass in sample, g	Ultimate strength, kN
1	456	110	302	66	167
2	399	109	172	43	261
3	384	109	137	36	120
4	401	109	177	44	273
5	434	109	256	59	131
6	463	104	362	78	213

Experimental works were conducted on an installation which block diagram is showed on figure 1. Uniaxial compression was performed on the automatic press with servomotor. Mobile (1) and the basic (2) plates generate load to 50 tons. The load value and value of an axial deformation were written in the computer memory (CM) (8). The determined acoustic signal was introduced into a sample through acoustic contact (mineral oil) by applying a piezoelectric transducer (3). The acoustic signal that has moved through a sample was registered by means of the piezoelectric sensor (7). EMS is generated in a sample during acoustic wave motion. The EMS electric component was received by the electric field sensor (6) and registered by means of a Multi-I/O-card (5).

The electric field sensor (EFS) consisted of two copper plates whose length was 3 cm and width was 1 cm and thickness was 0.3 cm. The plates were bent so that the spacing between the sample side surface and the plate plane was 2 mm. Each plate was connected to its own input of a differential amplifier (DA) with input resistance more than 30 MΩ. DA is a two-input electronic amplifier whose output signal is the difference between the input voltages. In the DA, noise was suppressed and the useful signal arrived at an intermediate amplifier (IA) with a gain equal to 100. Having passed through the IA, the signal arrived at the input of a Multi-I/O-card, whose input resistance (1 MΩ) is significantly greater than the output resistance of the IA (2 kΩ).

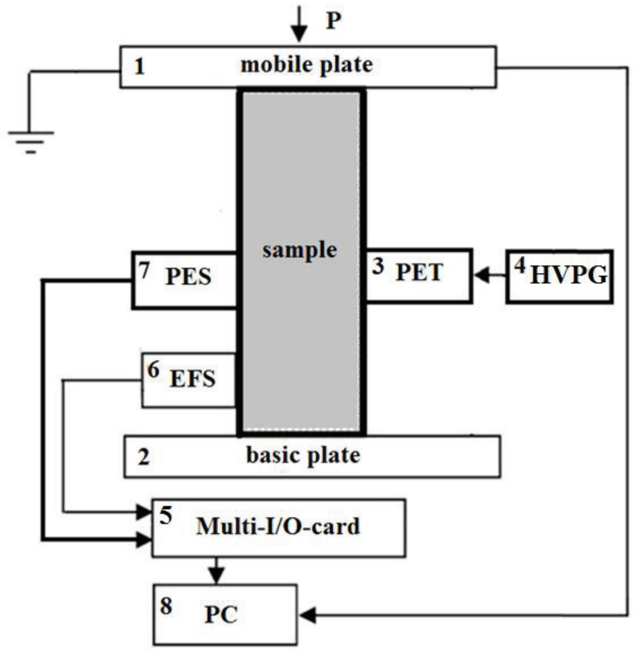

FIGURE 1. Block diagram of experimental installation for electromagnetic signal recording under deterministic acoustic influence in uniaxial compression of samples: 1 – Mobile plate; 2 – basic plate; 3 – piezoelectric transducer (PET); 4 – high-voltage pulse generator (HVPG); 5 – Multi-I/O-card; 6 – electric field sensor (EFS); 7 – piezoelectric sensor (PES); 8 – personal computer (PC).

Stepwise uniaxial compression of rock samples was carried out in the research process. The loading rate between the steps was 0.3 kN/s and remained constant. A typical loading curve for sample 2 to failure is shown on Fig. 2. The loading stages are shown by arrows in the figure. Five-fold deterministic acoustic excitation was carried out at each stage.

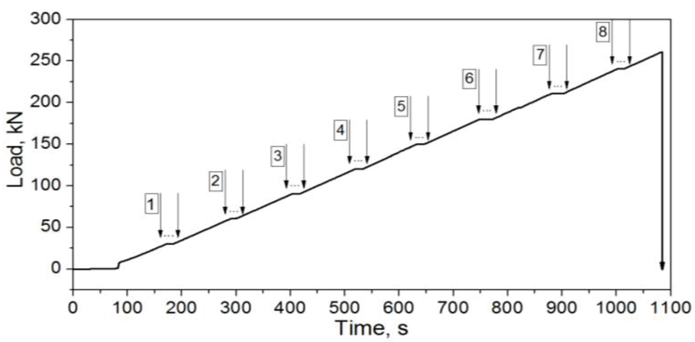

FIGURE 2. Loading curve for sample 2

Amplitude change oscillogram of the electromagnetic responses at acoustic impact on the loading stages of the sample 2 is shown on Fig. 3 (a). The stage numbering under uniaxial compression is given by the numbers on Fig. 3 (a). Also amplitude change oscillogram of the electromagnetic responses at first five-fold deterministic acoustic excitation is shown on Fig. 3 (b). It is seen that the amplitude of the electromagnetic response varies for each acoustic excitation in, but also under increasing compressive loads.

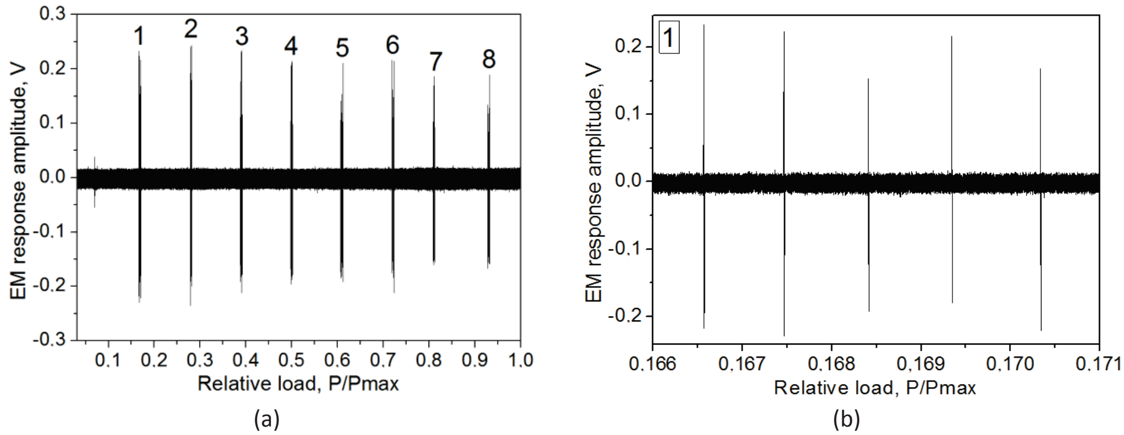

FIGURE 3. Amplitude dependence of electromagnetic responses at acoustic impact on the loading stages of the sample 2. (a) and amplitude change oscillogram of the electromagnetic responses at first five-fold deterministic acoustic excitation (b).

To test the magnetite samples for a phase structure definition we did an X-ray-phase analysis with use of the x-ray ARL X'TRA diffractometer. It carried out not only the phase structure but also a quantity of known phases.

RESULTS AND DISCUSSION

The study samples had differences in the texture structure in our experiments. There are healed and unhealed cracks of different orientations and sizes. As a result, the heterogeneity of the composition, mineral spots, and structure imperfection leads to an increase in the number and length of the electric double layers, which leads to an increase in the number of dipoles, emitting electromagnetic pulses [6]. This fact contributes to the active transition of mechanical energy into electromagnetic energy at acoustic impacts of rock samples. The dependence of electromagnetic response peak amplitude for sample 2 shown on Fig. 4 (a) and for sample 5 on Fig. 4 (b). Five-fold deterministic acoustic excitation was carried out at each stage of loading and it is revealed that the amplitude of the electromagnetic response changes. An attempt was made to analyze the dependence of the electromagnetic response amplitude from different numbers of acoustic excitations.

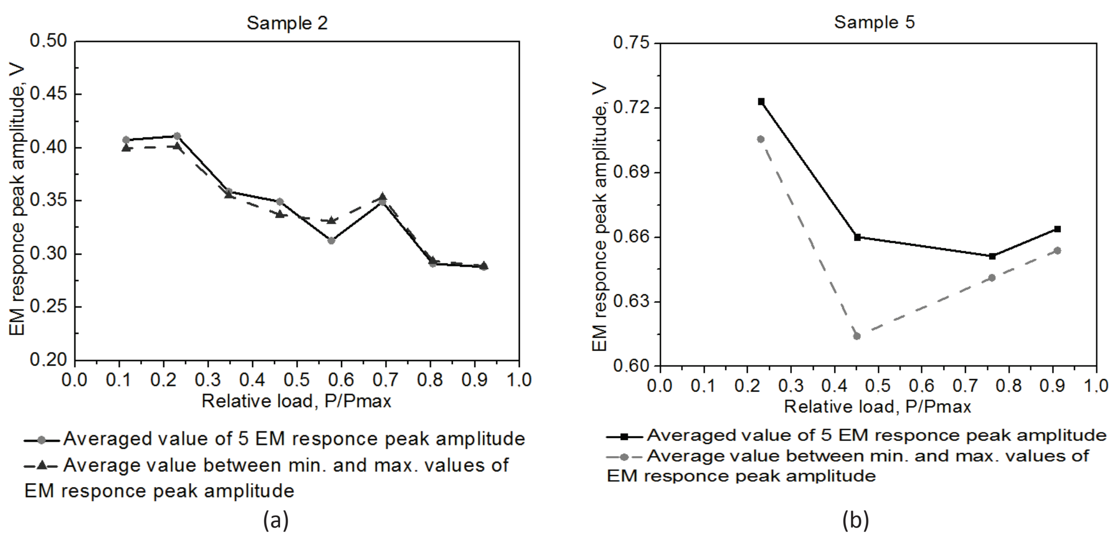

FIGURE 4. Amplitude dependences of an electromagnetic response on a loading stage uniaxial compression of a sample 2 (a) and a sample 5 (b).

On Fig. 4 we see that the EMR amplitude of sample 5 exceeds the electromagnetic response amplitude of the sample 2.

Analysis results showed that regardless of the number of acoustic excitations, the tendency of electromagnetic response amplitude change remained. So, for sample 5 having 59 % of magnetite, the amplitude first decreases with increasing load until the load is 0.45 of ultimate strength. Since this load, the electromagnetic response amplitude begins to grow to ultimate strength 131 kN. For sample 2, having 43% of magnetite, the dependence course of the amplitude and onloading stage is shown on Fig. 6. The amplitude reduction of sample 2 is observed at the initial stages of loading. This continues to loading 0.5 of ultimate strength. Then the amplitude increase of electromagnetic response happens to loading 0.7 of ultimate strength. Amplitude decreases again, and then growth and destruction.

It is known that on rock strength the great impact is exerted by the following factors: a structural and textural structure, existence of the mineral spots having various durability, healed and unhealed cracks. Ultimate strength decreases, than it is more than heterogeneity [11,12]. On the other hand, the quantity of mechanoelectric transformation sources increase, than it is more than heterogeneity [8]. It was expressed in amplitude increase of electromagnetic response spectral components for a sample 5.

It should be noted that the quartz existence [9], having piezoelectric properties, exerts a great influence on EMS amplitude of rock samples. The X-ray-phase analysis has shown an existence in samples of minerals of quartz, pyrites, chalcopyrite and calcite. Percentage of quartz and sulfides is revealed in the samples which are incidentally taken for the analysis. It is equal for a sample 2 - 15% of quartz (SiO_2) and 7% of sulfides (FeS_2 and $CuFeS_2$). For a sample 5 - 31% of quartz and 15% of sulfides. It is known that existence of quartz in magnetite samples induce electric charge under the influence of mechanical forces. It causes the big amplitude of EMR. The more the quartz content in a sample, the higher amplitude of EMR. Polarization effect influence of pyrite and chalcopyrite electro conductive minerals is important. Dependence of EMR peak-to-peak amplitude on relative loading for three magnetite samples with the different content of magnetite, quartz and sulfides is presented on Fig. 5.

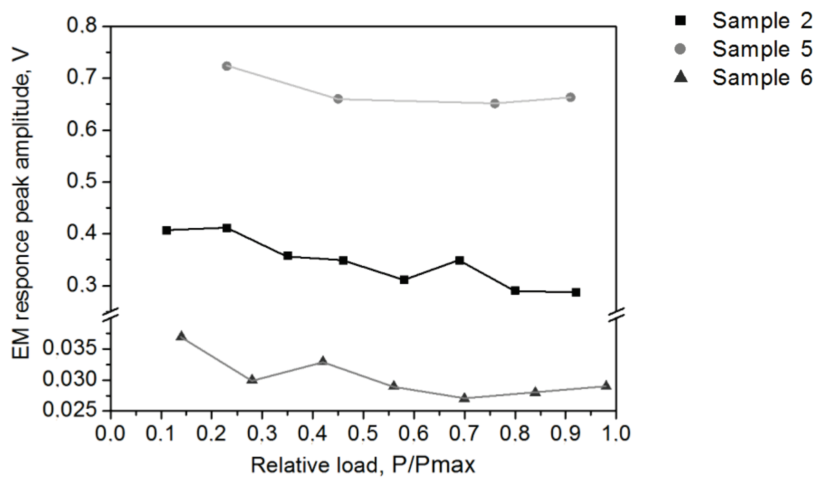

FIGURE 5. Dependence of EMR peak-to-peak amplitude on relative loading.

It is possible to draw a conclusion by the received results that the difference in EMR amplitude for magnetite samples 5 and 2 is caused by the mineral spot content of quartz and sulfides. The more the content of these minerals in a sample, the higher EMR amplitude. In a sample 6 incorporating large amount of magnetite (78%) and a small amount of quartz (1%), EMR amplitude 10 times less in comparison with EMR amplitude of samples 5 and 2.

CONCLUSION

Thus, the study has shown that response to EMR presence of defects at repeated acoustic wave motion through object of control allows monitoring evolution of defect accumulation in the stress-strained state. There are suppositions to development of a condition monitoring method of object in the context of destruction.

Electromagnetic response amplitude contraction at change of the stress-strained state in the process of uniaxial compression is observed with expansion in the number of content in rocks of a high-conductivity mineral of magnetite. At the same time existence of quartz and sulfides in the magnetite samples is conductive to operating transition of mechanical energy to energy of the electromagnetic field which is expressed in increase of amplitude EMR.

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