NEW SENSOR PHENOMENON IN ROCKS STRUCTURES UNDER UNIAXIAL DEFORMATION

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Abstract. An earlier unknown phenomenon in non-homogeneous systems – rocks and concrete, is experimentally established, involving the generation of micro-particles under the influence of high uniaxial deformations. It has been demonstrated that the amounts of emitted particles are reproducible for a specific rock and concrete type, increasing with uniaxial stress. Prior to macro-failure, the concentration of generated microfractures increases exponentially. This effect leads to the development of innovative robotic platforms, sensor devices, and technologies. Particle monitoring serves for early detection and prediction of catastrophic events in critical infrastructure. The results are significant for addressing numerous issues in the future forecasting of seismic activity, preventing landslides and collapses, monitoring the condition of dam walls, bridges, large energy facilities, and more.

Keywords: particles emission process, monoaxial deformation, rock structures, integrated indicator of failure events, seismically active regions.

1. INTRODUCTION

In recent years, the study of nanoscale particles, the creation of nanomaterials and nanotechnology has been a priority area of scientific research throughout the world. Mineral extraction is also associated with the formation of micro- and nano-sized mineral particles at various stages of extraction and processing. The appearance of fine particles during the destruction of rocks negatively affects the ecology, but under certain conditions it can be used to control the mechanical condition of rock massifs. Therefore, fundamental research to reveal mechanisms of fine particle formation and structural changes in rocks is essential [1–5 and references to therein].

To solve the assigned tasks, complex studies are used, including an analysis of existing methods for assessing and monitoring the stress-strain state of

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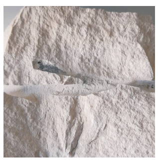
the rock mass, a review of laboratory emission methods for uniaxial compression of geomaterial samples, theoretical and experimental studies of the processes of deformation and destruction of scales, experimental studies in laboratory conditions using the laser spectrometry method and computer modelling, [4–5].

2. RESEARCH METHODOLOGY

The main goal of the research is to definitively establish the registered regularity through a correct and reproducible experimental method. Therefore,

Table 1. Types of rock samples used for the study

Dolomite – Used as a refractory material, flux, and in rare cases as an ore for mining magnesium. In Bulgaria, dolomites are exposed in the Balkan Mountains, Sredna Gora Mountain, Strandzha Mountain, etc.	
Gypsum – It is widely used as a building material, raw material for the production of mineral fertilizers, in medicine, etc. In Bulgaria there is a deposit near the village of Koshava.	
Granite – The most common intrusive rock in the continental crust. It is widely used as a building material, in the case of metalworking and as a facing decorative stone. There are more than 50 places for granite mining in Bulgaria.	
Limestone – It is formed at the bottom of sea basins in the form of layers of different thickness. During metamorphosis, they turn into marbles.	
Concrete – is a composite building material obtained as a result of the hardening of a mixture of cement, water and sand.	

the approach should prove the existence of an emission process of mineral micro particles under high uniaxial deformation of rocks.

The object of study are different types of rock samples, delivered from different mountain areas.

The research methodology includes the following sequence of actions: 1. A cubic specimen is cut from a rock structure with an arbitrary configuration with high-speed machines with a diamond coating on the cutting part, cooled by mineral oil or water jet (Fig. 1). 2. A hole with a diameter of 6 mm is

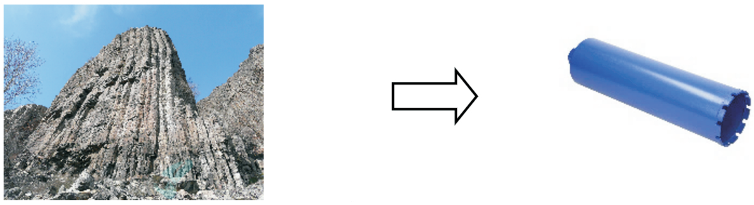


Fig. 1. Extraction of a sample

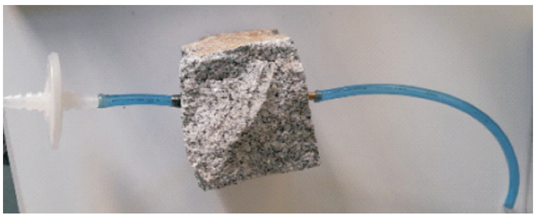


Fig. 2. Preparation of measuring hole ⌀6

formed in the sample (Fig. 2). 3. The measuring volume providing information on the emission of microparticles is connected with hoses – its inlet is connected to an air filter, and the outlet with a hose is connected to the inlet of an electronic counter of aerosol micro- and nanoparticles. A pump is built into the counter to suck air from the measuring volume. The air filter does not allow the passage of particles from the environment larger than 0.20 μm, unrelated to the new phenomenon (Fig. 3). 4. The sample with the measuring volume is placed between the support plates of a press, creating uniaxial pressure from the initial (zero) value to that of its destruction. Uniaxial pressure occurs at a constant low loading rate (Fig. 4). 5. Throughout the experiment, the emission parameters of the particles – quantity and sizes in the range 0.3 μm – 10 μm are registered and recorded with a program developed by us (Fig. 5).

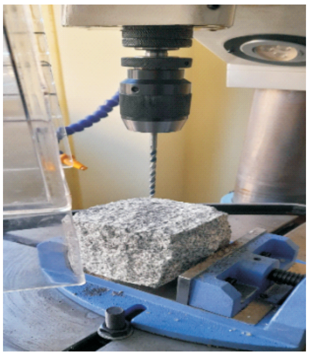


Fig. 3. Preparation of laboratory research

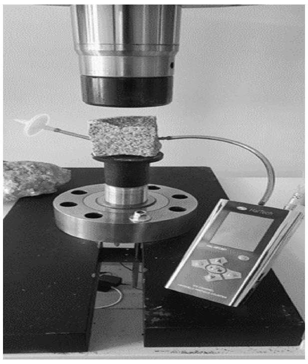


Fig. 4. Preparation of the system for laboratory research

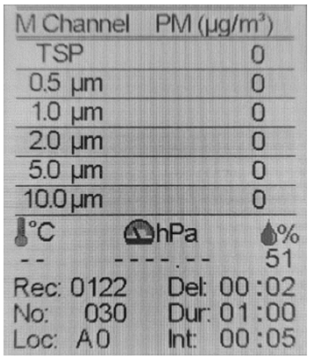


Fig. 5. Particle registration program

The methodology thus described is fundamentally correct. It puts the different types of rock and concrete samples under the same conditions during the research, which allows a comparative analysis of the processes determining the new pattern.

3. USED EQUIPMENT

In the experimental setup for studying the generation of finely dispersed microparticles during uniaxial deformation of rock samples, specialized measuring equipment is required. The pressure is applied with a modern hydraulic press model Bernardo BHP 200 with a maximum pressure of 200 t. (Fig. 6).

Fig. 6. Bernardo BHP 200 hydraulic press

The press is equipped with a Sika electronic pressure gauge with digital indication and accuracy 0.1% up to 500 bar. The output of the manometer indicates the uniaxial load of the rock specimens from the hydraulic press, the output of which is compatible with the computer system.

Fig. 7. Sika electronic pressure gauge

In addition, the use of precise measuring equipment with a Laumas strain gauge up to 100t and accuracy up to 0.1% equipped with a digital indicator and software is also applied. (Fig. 8).

Fig. 8. Laumas Tensometer up to 100t

To measure the emission of microparticles arising from the uniaxial deformations from the surface of the rock samples, an aerosol particle counter completely newly designed, integrated with the most modern technology, handheld laser particle counter Haltech Hal-HPC601 is used. (Fig. 9).

Fig. 9. Haltech Hal-HPC601 Particle Counter

This device allows the determination of the concentration of particles in the range from 0.3 µm to 10.0 µm. The functioning of this modern apparatus is combined by an internal microprocessor (MCU) allowing the measurement of six different particle sizes, which are configured depending on the measurement, and the registration of the scattered optical radiation is realized with the light source laser diode.

4. EXPERIMENTAL RESULTS

The experiments are carried out with cubic samples of granite and limestone. The two materials are mined from the town Belovo, Belovo municipality, Plovdiv region, which is located on the right slope of the Maritsa river valley, in the section between Yadenitsa and Rakovitsa rivers. From the rock structures, which have random configuration, 5 identical samples are cut. The granite test bodies with a height of h = 100 mm and equal lateral ribs of size 100 mm are subjected to uniaxial deformation at a low constant loading rate.

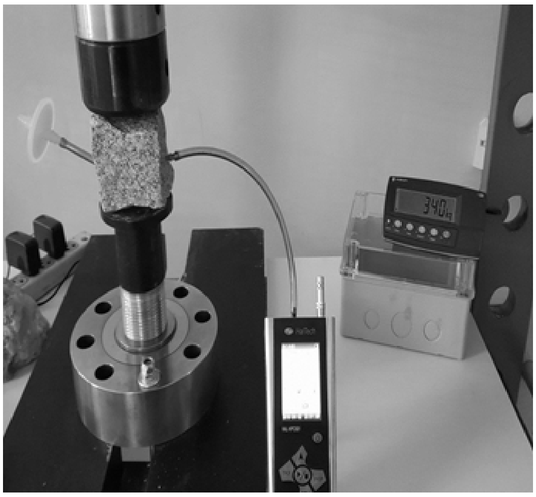


Fig. 10. An experimental production

With the help of a particle counter, the parameters of the emission processes of the specific type of test body are measured. The strength of the samples under uniaxial deformation is about 60 MPa. The measurement of the number of particles and their dispersed composition is carried out in an interval of 60 s – a constructively embedded parameter in the counter.

Figures 11 and 12 show the results of the experiments, respectively, for granite and limestone, where the stress (σ) created by the press is plotted

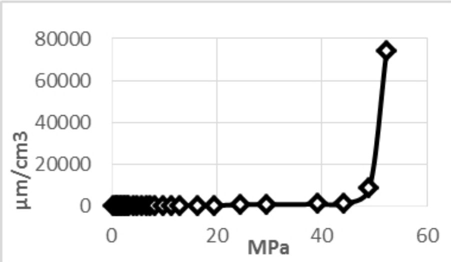


Fig. 11. Granite

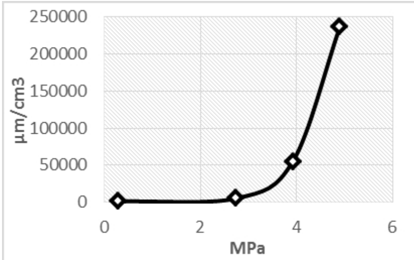


Fig. 12. Limestone

on the x-axis in units of MPa, and on the y-axis of the graphs is the number of particles generated, normalized in $\mu m/cm^3$. The microparticles that the counter registers are respectively in the ranges a) 0.3–0.5 µm; b) 0.5–5.0 µm and c) above 5.0 µm. As can be seen from Fig. 11, when the pressure approaches a value of 45 MPa, a strong increase in the number of particles emitted by the granite is seen in all these three ranges. When the uniaxial deformation reaches values around 50–55 MPa, a sharp increase in the emission of microparticles starts, corresponding to an occurring destructive process. Upon reaching a pre-critical state of the rock structures, an exponential increase in the emission of microparticles is observed. Similar are the graphical dependencies (Fig. 12), for the limestone samples.

It should be noted that the plots of Fig. 11 and Fig. 12 are not sporadic or statistical in nature, but are a reproducible regularity. Specimens are observed where the particle emission differed from that typical of Figures 11 and 12. This dispersion of results could be explained by the pre-experimental state of the rock structures.

The obtained experimental results categorically prove the existence of the phenomenon of generation of nano- and micro-particles from rock structures with sizes from 0.3 µm to 5.0 µm at high uniaxial deformations. As the stress increases to a level preceding the failure of the specimens, a sharp increase in particle emission occurs. The intensity and composition of the emissions are determined by the mineral composition of the studied rocks, as a functional dependence has been established between the emission of the emitted fractions and the degree of loading.

A previously unknown phenomenon in solid-state structures is experimentally established, consisting of the emission of microparticles under the influence of uniaxial deformations. The size and amount of nanoparticles depend on the physicomechanical properties of the substance and the pressure values.

5. CONCLUSION

The key question is the practical utility of the new regularity. On its basis, innovative sensor technologies are planned for early notification, registration of pre-emergency and emergency conditions through permanent monitoring of the amount of microparticles generated. It serves as an innovative instrumental method for assessing the stress level of mountain massifs, underground and construction facilities, and last but not least, predicting catastrophic processes. The experimental set-up itself is essentially a device of universal applicability in the sensorics of geodynamic processes. A sufficiently deep hole is drilled in a rock mass or ore structure in which the two air ducts are located. One is connected to the air filter and the other tube is connected to the laser particle counter. The uncomplicated measuring system formed in this way determines the on-line stress-strain state of mountain massifs and engineering facilities through field testing. The results are particularly important in the field of seismology and volcanology.

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