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ON THE LAWS FOR TRANSITION FROM BRITTLE TO DUCTILE ROCK FRACTURE

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Abstract: Loading of rock samples in confining pressure conditions is considered. Failure acts by acoustic emission (AE) method, changes in deformations and load during loading are registered. Dependence of AE energy release on confining pressure magnitude is revealed. The found phenomenon is explained on the basis of mutual analysis of information about deformation and failure. It is shown that the extreme character of dependence is connected with the changes of failure process.

Key words: confining pressure; acoustic emission; transition; failure; brittle; ductile.

1. INTRODUCTION

Plastic deformation and brittle fracture (fissuring) with bursts are two neiboughring fields of physical conditions of rocks. They are connected by mutual transition. The margin between brittle and plastic (ductile) behaviour has the definite pressure conditions. Robertson (1960), Handin et al. (1957), and Heard (1960).

Rocks in earth's crust are in complexly stressed condition. That is why much attention to the research of deformation and failure processes in the conditions of thorough compression is paid. Franklin (1971), Bieniawski (1971), Mogi (1971).

For the failure prodiction problems the conditions of transition from plastic deformation to brittle failure are of interest. The experimental results of research of rock samples loading under confining pressure are given below.

2. EXPERIMENTAL METHODS

The experiments were held using triaxial cell. The samples of marble, sandstone and granite of cylindrical form with ratio of height "h" to diameter "d" is equal to 2 were loaded according to Karman scheme i.e. $\sigma_1 > \sigma_2 = \sigma_3$, (σ_1 , σ_2 , σ_3 - three components of principal stresses). The loading was made by the press PR - 500 with the force of 5MN with its pump's constant productivity regime. The regime allows to make identical experimental conditions for sample to sample transition fixed and secures the comparisons of the results. Moreover this regime seems to more extent to correspond to real conditions in the massif. Confining pressure in the cell $\sigma_2 = \sigma_3$ was 0;1;3;5;10;20 Mpa for marble and 0;50;120;230 Mpa for sandstone and granite. Acoustic emission (AE), applied load, deformation - axial and radial were registered.

The schematic diagram of the mechanical apparatus, the AE data acquisition system, and the surface strain mapping system are shown in Fig 1.

For laboratory experiments the system was based on multidimensional analyser of impulses AI 4096-3M (Impulse analyser AI 4096-3M is used in nuclear physics research and is produced by the plants of the Ministry of Nuclear Energy of the USSR) and a computer.

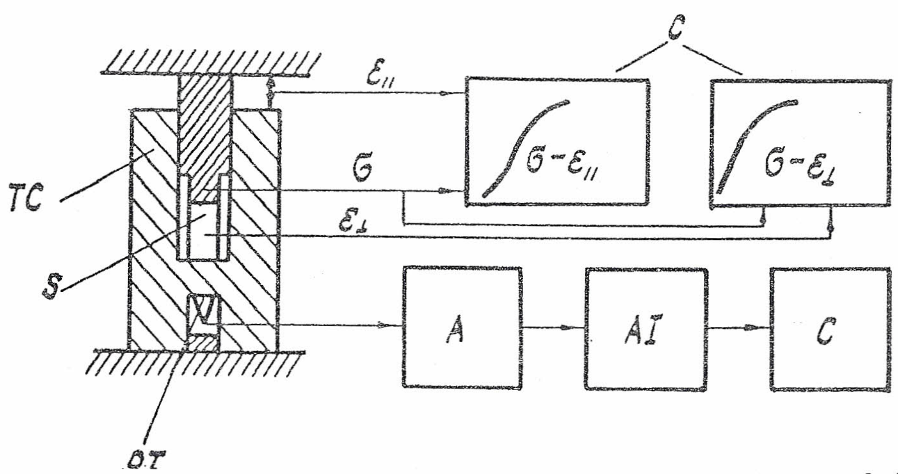

Fig.1. Block scheme of loading and registing complex for sandstone sample test.

The elastic impulse, generated in the sample (S) is transformed into electric signal by the receiving piezotransformer (PT) and after amplifying by preamplifier and main amplifier (A) comes to the unit of analogous digitizer (UPS), which realizes rectangular approximation of the signal by separation its envelope on the given threshold of discrimination (level of background noise suppression) and formation of normalized amplitude and duration impulses, necessary for analog-digital transformer's work.

Wideband piezoelectric tranducers of "longitudinal waves" (Vakar, 1980) were used in experiments. Their design allows to get rid of to considerable extent of reflections. It was reached by application of damping element of alloy in the form of cone (acoustic trap). It was connected with the active element (PZT; 10 ,0mm diameter; 1,5mm wide) by Wood alloy. This unit was mounted into the lid of dynamometer and were placed into lower part of triaxial cell in a special cavity with oil which minimized a back reflection of elastic waves in PZT element. The unit of analogous digitizer does not allow to distinguish between mutually overlapping enents, if their joint envelope does not cross the threshold of discrimination. Along with obvious faults this logics of signal processing has its own advantages, which will be given below. Standardized impulses then followed to the impulse analyzer (AI) which coded every parameter and time of acoustic signal arrival. It accumulates the necessary number of them from 1 to 10^3, and then send them to the computer (C). Time of data transmission was less than 1s, which didn't lead to significant loss of acoustic impulses. So, every event is characterized by three initial parameters: amplitude, duration and generation time. The energy was calculated as $E = \alpha A^2 \tau$, where A, τ - correspondingly amplitude and duration of the acoustic signal, measured using envelope of AS with accuracy to the multiplier α = 5÷6. Frequency range of registration made 7 KHz, which was defined by bandwidth of the analogous digitizer and enabled to register cracks in rocks, having interesting to us linear dimensions of order of 10^{-3} - 10^{-2}m. It is provided on one hand by structural heterogeneity of the tested rock samples, and on the other hand by commensurability of maximal cracks with the sizes of the last.

Transducers and units of elastic impulses amplification were especially designed for the given range. Acoustic emission research of rock failure in laboratory showed that equipment sensitivity must allow to register AE signals with amplitude values from 40 mkV to 0,1 V. That is why a dynamic range of the registering system must be 30-60 dB.

AE data accumulation in computer was performed by files of equal sixe (file means a collection of a certain number of signals, i.e.512) Registration, data processing and data logging were done with the help of the package of system and applied programmes, all owing to give the necessary conditions of registration and processing in the dialogue regime.

3. EXPERIMENTAL RESULTS AND DISCUSSION

As a result of the experiments the well known fact of strengthening of the sample as well as of modulus elasticity with increase of confining pressure was confirmed. It was also confirmed that plastic deformations in the integral deformation of the sample increased with increasing of confining pressure. Fig.2 shows changing of plasticity with confining pressure increase. One can note the progressive increase of plasticity at some of its value.

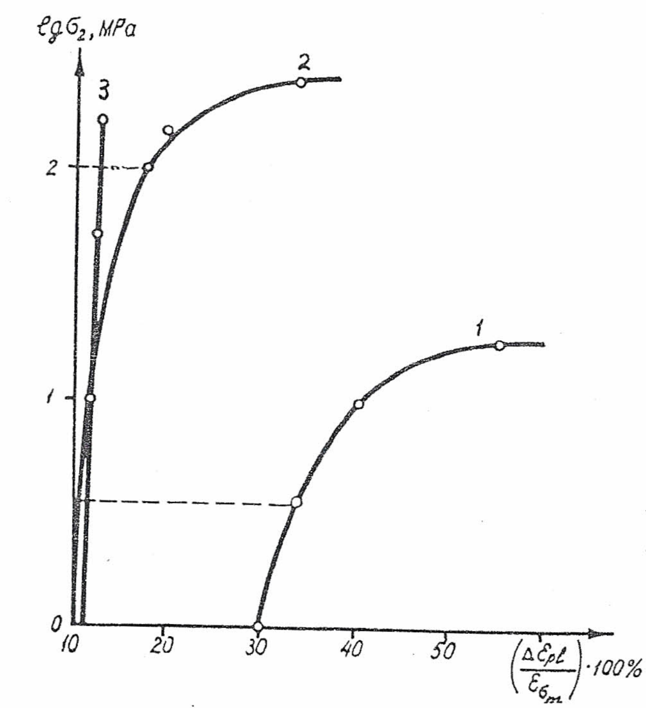

Fig. 2. Laws of plasticity changing $\varepsilon_{\parallel pl} / \varepsilon_{\parallel \sigma_m}$ of rock samples with confining pressure increase $\sigma_2 = \sigma_3$ 1 - marble, 2 - sandstone, 3 - granite. $\varepsilon_{\parallel pl}$ - plastic deformation value, $\varepsilon_{\parallel \sigma_m}$ - general deformation value changed to strength limit.

It is possible to get qualitatively new information when analyzing acoustic emission. Let us consider the integral characteristics of AE i.e. integral energy AE released by the moment of fracture.

These results are shown in Fig.3. For marble and sandstone this dependence has an extremum, moreover it is in the field of $\sigma_2 = \sigma_3$ where the extreme is observed in the dependence $\varepsilon_{II pe} / \varepsilon_{II \sigma m} - \sigma_2$ We may suppose that and for granite the dependence should be with extremum, but with higher confining pressure, which we failed to achieve in the triaxial cell used. The assurance is confirmed by an insignificant part of plastic deformation of granite as compared to sandstone or marble with the same values. The correlation between

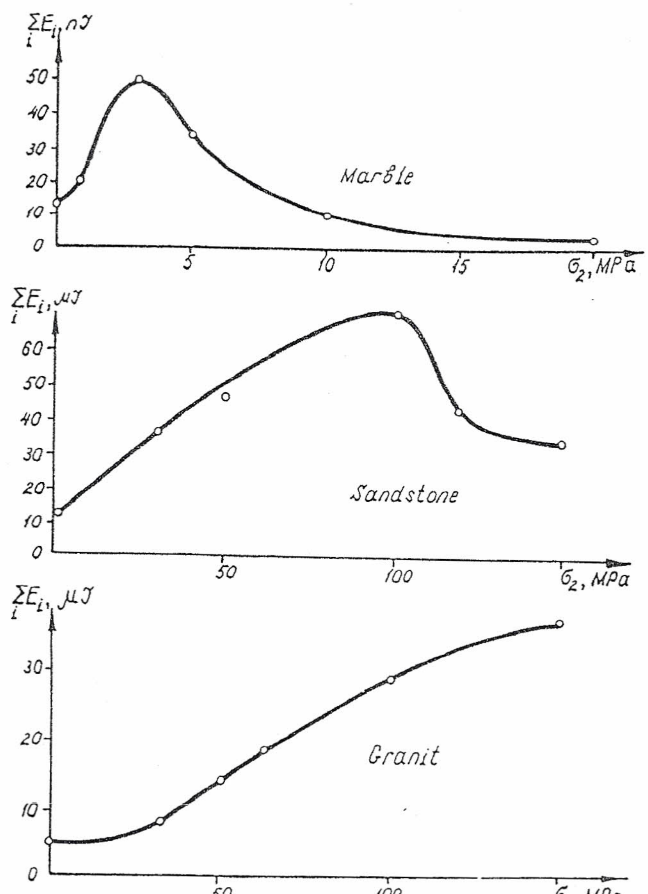

Fig.3. Change of cumulative AE energy release versus on confining pressure value.

integral characteristics of deformation and enegry emission shows that the increasing of confining pressure causes transition from brittle to ductile failure that in its turn strongly influences energy release. To explain this phenomena one can suggest that the tensile cracks (a brittle type of defect) generates pulse with energy higher than the same in size crack of shear (a plastic type of defect) generates. So, it is easy now to explain the experimental dependenc shown on the diagram. When value of confining pressure $\sigma_1 = \sigma_2$ are small and when brittle failure option is preferable, the in ral energy increase and is connected with the increase of stres which are necessary for macro failure. It means that each tensi crack occurs in a zone of higher stresses. At the further incre of confining pressure value $\sigma_2 = \sigma_3$ the share of plastic shears creases and of tensiled ones decreases. This competitive proces leads to the general AE energy release decrease.

The additional information about brittle to ductile transit can be received using analyzing different AE characteristics at ferent values of confining pressures $\sigma_2 = \sigma_3$. It is more convin to examine this phenomena using sandstone sample, because extre of AE energy yield function is obtained for very wide range of fining pressures. (Fig. 4)

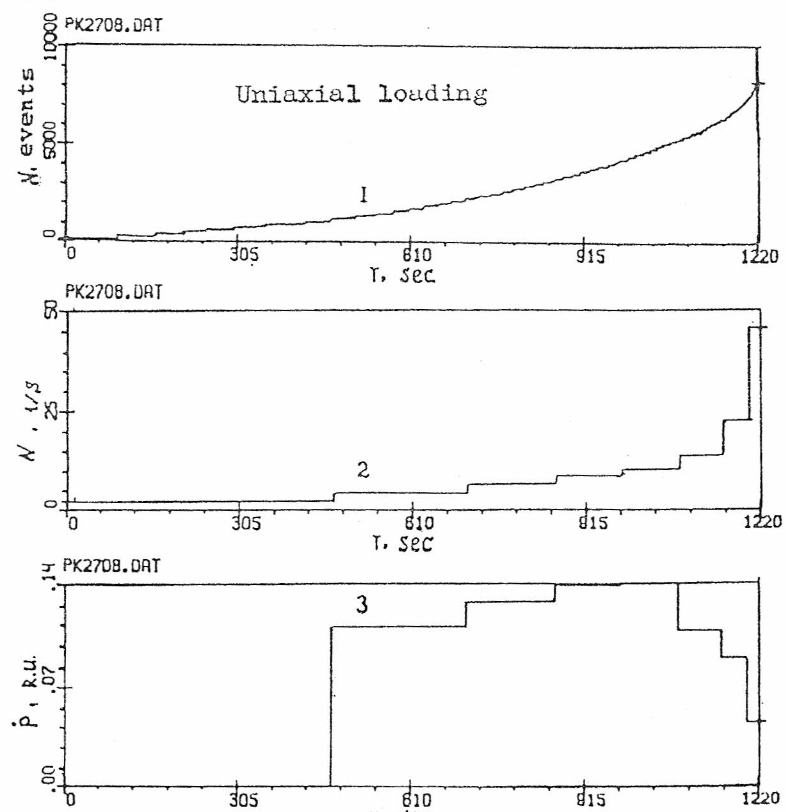

Fig. 4. Dependence of cumulative number of AE events - N (curve 1), their rate N' (curve 2) and loading rate P' (curve 3) on loading time for sandstone sample test.

It can be seen that confining pressure leads not only to the qualitative but also to quantative changes in AE energy release.

As it is known at uniaxial compression of brittle rock the major portion of AE events is generated under the loads close to fractural ones. For brittle rock the dependence shown on Fig. 5.(curve 1) is very typical. The convex dependence confirms the assumption about increase of the share of plastic deformations. It is also supported by the dependence on AE-rate (see curve 2). As it was found the

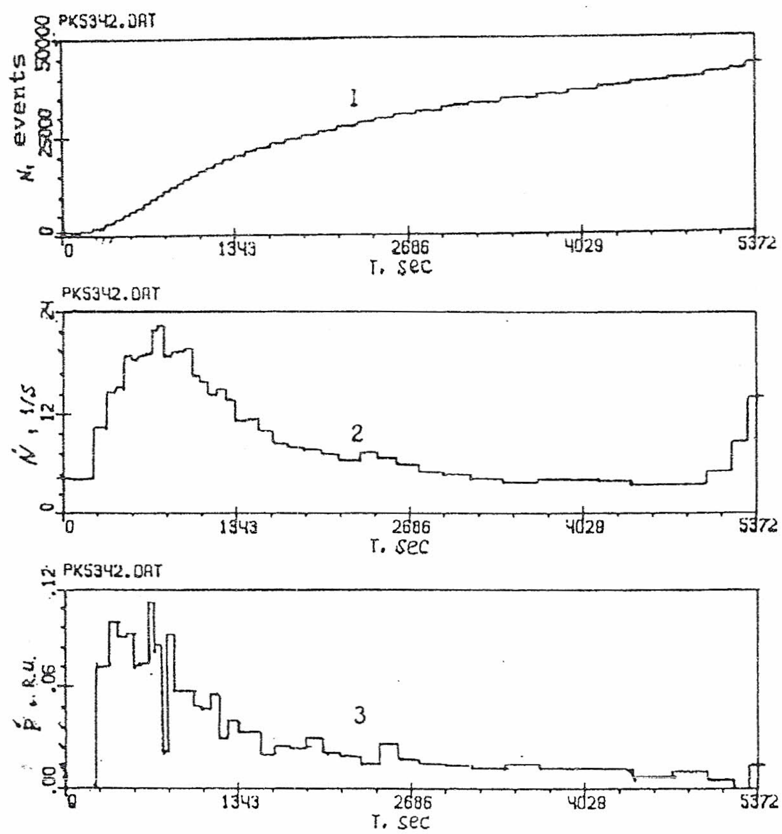

Fig. 5. Multiaxial loading $\sigma_2 = \sigma_3 =$ 230 MPa

extremal dependences for AE-rate are typical for plastic materials not only for rocks but for the other kinds of materials such as metals, polymers, etc. And finally let us examine the reaction of the sample itself at its deformation. The dependences shown on Fig. 5 (curve 3) have two fragments. The first one is characterized by its decreasing. The increase in both cases are the evidents decrease of loading rate are noted in the case of uniaxial compression not long before the fracture, that can be supposed as the development of failure nucleus. The other situation is obtained only at the beginning of the loading. Then the experiment goes to the stage of plastic progression which can maintain the level of load applied. These results confirm the explanation of experimental dependences for integral AE - energy release. It can be seen that for AE energy release in the conditions of confining pressure have a typical extremes N - AE rate and E'- AE energy. The growth of AE-rate-N' at the beginning stage is connected with the usual increasing of fractures under loading enlargening in which there is larger proportion of tensile cracks, preceiding shears. Then when there is the necessary amount of tensile cracks they realize shears as in the elementary (structural) scales so after this during formation of numerous sliding planes. At this stage there is a calm progression with weak AE energy release. It can be noted that the effect of dilatancy which was conditioned by tensile cracks in particular is also observed in the zone of extremum AE energy release.

So, the results show that the confining pressure with uniaxial loading significantly changes the character of deformation process and AE energy release. Brittle rock can be transformed into plastically deformated as the confining pressure changes the mechanism or type of deformation from tensile to shear and by this providing the relaxation of tensions in the vicinity of appeared defects.

4. CONCLUSIONS

In the result of carried out research, was determined that dependence of the integral AE energy release from the confining pressure has a maximum which can be considered as a threshold for brittle - ductile transition.

AE has an information about the character (type) of the coming failure.

The margin of the brittle - ductile transition is found.

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