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SIMULATION OF AFTERSHOCK SERIES FROM ROCK SAMPLES

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Summary : In presented paper we aimed our effort at the laboratory simulation and study of "aftershock" sequences of SA-impulses from rock samples. The samples were loaded repeatedly with constant loading rate. After reaching the desired load levels, the samples were subjected to constant loading level. During the time interval of constant load, the series of released SA pulses were treated as (simulated) aftershock series.

Key words : Seismoacoustic emission, aftershock serie, loading level.

The model samples of fine-grained magnesite were loaded uniaxially. The samples had the form of rectangular prisms with dimensions 100 x 100 x 250 mm.

Resistance tensometers, fixed on centres of 4 vertical model faces in a "cross" position, were used for recording the model stress/strain features (Fig. 1).

Monitoring of SA emission was realized by 8 piezoelectric accelerometers, which had a practically constant sensitivity within the frequency range of 1-100 kHz.The pick ups were glued on the model surface by a molten mixture of paraffin and rosin. SA signals, recorded by accelerometers, were digitized and stored by four double-channel transient recorders DL 912 (Datalab) operating with the sampling frequency of 10 MHz (Fig. 2).

The repeated loading of samples was effectuated under following conditions: The loading rate $\frac{d\sigma}{dt}$ was kept constant for all loading cycles, $\frac{d\sigma}{dt}$ = 3 MPa $min.^{-1}$. As concerns the aftershock series, the treated sample was loaded (in the first loading cycle) continuously up to the value of 71 MPa, equal appr. to 50% of its compression strength limit . After relieving, the sample was compressed again (Fig. 3) up to the value of 90.4 MPa, equal to appr. 2/3 of compression strength. The sample was kept at this load level for 82 minutes, during which the SA emission was monitored. After that, the sample was loaded up to the value of 115 MPa (appr. 85 % σ_{STR}) and kept there for 64 minutes. During that time again, SA emission was monitored. The critical load value σ_{STR} = 135 MPa was reached by further loading, leading to the brittle rupture of the sample.

Acoustic emission during the rock sample loading with linear compression increase in time is usually characterized by an increase of the number (frequency) of radiated pulses as the loading approaches the critical value of strength. This experimental phenomenon has been used as a criterion for the classification of rocks as concerns their susceptibility to sudden brittle fracture [Buben, 1968, 1972; Rudajev and Buben, 1972; Šimáně *et al.* 1976; Vavro, 1970]. Unlike that, acoustic emission taking place from a loaded model after a quick sample loading and subsequent maintaining a constant load, is characterized by a hyperbolic decrease of the pulse number with time, which is analogous to the Omori-Utsu relation for aftershock sequences of natural earthquakes [Utsu, 1961]. A similar phenomenological description of these both processes enables us to consider treated model sequence as a model of actual afterquake series.

Analytically, the aftershock sequence N(t) (Fig. 4) is described by relation :

$$N_i(t) \qquad {}_{o} \; {}_{i}$$

(N_o is the frequency during the 1st time interval after attaining the maximum stress, N_i is the number of pulses occurring within the i-th time interval t_i, p is a parameter characterizing the decrease rate of the number of pulses with time.)

The aftershock sequence occurring at a lower stress level (denoted by A) is described by the relation $N/t/ = 1306\ t^{-0.78}$ within the time interval of 10^3 s. For the aftershock sequence at higher load (denoted by B), the relation $N/t/ = 5236\ t^{-0.98}$ holds true for the same time interval. The number of pulses at higher stress, characterized by the coefficient N_o, is nearly 4-times higher. Unlike the assumed decrease rate of the pulse number with time, this decrease is faster for a higher model loading than for lower compression. This result points to the difficulties in interpretation of aftershock sequences based only on the value of the exponent p.

This way of interpretation of seismoacoustic emission is applied, for example, in Polish coal mines [Kornowski, 1989]. There, the method has been modified for routine observation of the stress state of the rock mass. In this case, emissions are excited by a small explosive charge and recorded at a constant distance from the source. The decrease rate of the aftershock sequence and its transient time are primarily used for the evaluation of stress state of the investigated area.

However, as illustrated in Fig. 4, the decrease of the pulse number with time does not match, in its pure form, the theoretical relation, which is quite evident at a higher loading of the model. This can be explained, apart of other reasons, by the fact that the SA pulses are not created only as a consequence of sample relaxation. Their occurrence is probably affected also by a new mechanism connected with the process of sample's final breakdown. Obviously, the sample stress exceeded the so-called long-term strength, what can lead to spontaneous breakdown (failure) without further loading the sample.

In the Fig. 5 the results of ultrasonic sonography are presented. The effectuated ultrasonic sonography of samples enabled the propagation velocity of the ultrasonic P-wave in cross direction and its alterations with load to be determined. These measurements have revealed:

- more than a 10 % increase of the P-wave velocity during the initial loading phase was observed,

- there is good reproducibility of measurements in various loading cycles,

- in the sections of additional loading always an increase of the wave propagation velocity was observed.

Fig. 5 illustrates also alterations of velocity due to stress relaxation of the loaded sample. In sections III and V, where the load was constant, in the first case the velocity increased, which is obviously connected with the consolidation of the sample, while in the second case (section V) the velocity decreased (from 7660 ms^{-1} to 6400 ms^{-1}). This decrease confirms the conclusion drawn from the interpretation of the aftershock sequence, i.e., that the ultimate (long-term) strength limit had been attained and the final breakdown (failure) of the sample can occur.

The Kaiser effect [Kaiser, 1953] was observed during the performed experiments, which means that during the repeated loading of rock samples the first occurrence of acoustic impulses depends on the maximum value of preceeding load of the sample. The location of foci of acoustic pulses revealed an outstanding spatial clustering of these foci, which points to the fact that the seismoacoustic emission depends in particular on the structure of the investigated rock. This fact documents the ambiguity of opinions concerning the validity of the Kaiser effect and, at the same time, it makes it difficult to generalize results obtained on small laboratory samples to the actual situation within the rock massif (namely the determination of the maximum paleostress of massif).

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