MEMORY EFFECTS IN ROCKS (REVIEW)

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The ability to store and reproduce information about experienced natural-genetic and technogenic actions is one of the most common qualitative characteristics of rocks and, consequently, can be regarded as their fundamental property. Specific manifestations of this property are called memory effects. They consist in the characteristics of the responses of rocks to the dynamics of various test physical fields related to the prehistory of experienced actions.

The most typical of these characteristics are: the nonreproducibility of the responses of rocks to cyclic thermodynamic actions up to the maximum level of these actions reached in the preceding cycle and the specific character of responses at the time of attaining the indicated levels; the dependence of the character (intensity, sign, etc.) of responses on the regimes (directions, levels, time) of actions in various cycles and the relationships between them; dependence of the intensity of responses and memory relaxation time on the effect of external noise factors; preservation of the main regularities of responses on changing to larger or smaller scales of investigation.

Purposeful investigations of memory effects in rocks have been being carried out for slightly more than 20 years. Nevertheless, rather considerable, mainly experimental, data indicating the prospects of using these effects for investigating the stress-strain and thermal states of rocks have already been accumulated. There are also grounds for using memory effects for predicting dynamic processes in situ and for creating new technologies of strengthening and weakening rocks by the purposeful use of their defects under the effect of cyclic thermodynamic actions.

Despite the aforementioned prospects, facts of the practical use of memory effects in geocontrol are single and completely absent in mining technologies, which is related to the lack of solution of a number of problems of a theoretical, methods, and apparatus character. On the other hand, an analysis shows that a considerable part of the works devoted to investigations of these effects in many respects duplicates one another or contains a number of contradictory results. Therefore, it is important to generalize the experience gained, which will make it possible to attract the attention of investigators to the unsolved problems in the area of the study and use of memory effects, having eliminated unnecessary duplication. This is the main purpose of the present review, the completeness of which, naturally, is limited by the possible length of a journal publication.

ACOUSTIC EMISSION MEMORY EFFECT

The acoustic emission memory effect (AEME) consists in the nonreproducibility of acoustic emission (AE) during cyclic loading of material up to the maximum load of the preceding cycle, when the AE parameters recover jumpwise to the level corresponding to this maximum load.

In rocks AEME was recorded for the first time in 1953 on a sandstone specimen [1]. At present this effect has been established experimentally in rocks of almost all genetic groups as well as in cohesive and granular soils [2-14]. At the same time, the effect is absent in some rocks, for example, in lepite [13].

The AEME was investigated in rock formations of the most different sizes, starting from standard specimens and ending with large blocks in the form of a cube with an edge length of 0.7 m [15, 16]. It was observed also directly in situ during loading of the near-borehole space by means of a pressure meter [12, 17, 18] and cyclic change in the pressure inside underground storages [19].

The main experimentally established regularities of AEME in rocks under uniaxial loading consist in the following [2, 3, 8, 14, 16, 17, 20-24].

1. The memory effect is observed up to the start of dilatancy, i.e., up to values of the compressive stress equal to \((0.7-0.8)\sigma_{\text{com}}\), where \(\sigma_{\text{com}}\) is the compressive strength of rock. If in the \(i\)-th cycle the maximum load exceeds the indicated values, then in the \((i + 1)\)-th cycle the intensity of AE increases starting from the zero value of the load.

2. An increase of the intensity of AE during repeated loading begins somewhat earlier, and its maximum value is established somewhat later than the load reaching its maximum value in the preceding cycle. This tendency intensifies on approaching the ultimate strength.

3. The clearness of manifestation of the effect in the \((i + 1)\)-th cycle increases with increase of the time of holding the specimen in the \(i\)-th cycle and decreases with increase of the time interval between these cycles.

4. With an increase of the number of loading cycles in the stress interval \(\Delta \sigma\), the intensity of AE drops in this interval. This drop is manifested to the greatest degree in the second cycle. In a number of cases this means that the divergence of the graphs of the dependences of the intensity of AE as a function of stress corresponding to the second and third loading cycles begins upon exceeding the maximum value of the load applied to the specimen in the first cycle.

5. The memory preservation time varies from several hours to several years and depends on the type of rock, loading regimes in two successive cycles, and the degree of action in the intervals between these cycles of various noise (memory-*erasing*) factors, mainly such as heating and moistening.

The regularities of AEME in rocks that experienced mechanical actions corresponding to combined stress have been investigated substantially less. In [25-27] it was established experimentally that in the case of loading specimens according to the Karman scheme, the difference of the principal stresses \(\sigma_1\) and \(\sigma_2\) is memorized last. However, this result contradicts the data of [24], in accordance with which a jump of AE intensity in the second cycle is observed under the condition of equality of the ratios \(\sigma_2/\sigma_1\) in both cycles. But in such a case during loading in the first cycle according to the Karman scheme \((\sigma_2/\sigma_1 \neq 0)\) and in the second cycle by uniaxial compression \((\sigma_2/\sigma_1 = 0)\) AEME in general should not occur, although the experimental data given in [26] indicate the opposite.

There are also contradictory experimental data on the effect of the degree of coincidence of the directions of application of the load in the first and second cycles on the character of manifestation of AEME. Thus, it is noted in [28] that the effect occurs when these directions coincide and it is absent in the case of their orthogonality. According to [8], AEME is manifested independently of the degree of the indicated coincidence. It is shown in [29] that the effect is displayed more strongly, the more the directions of load application coincide in the next two loading cycles, remaining here rather significant even in the case of orthogonality of the indicated directions.

According to the data of various investigations, the accuracy of determining the stresses that acted earlier during cyclic uniaxial compression of rock specimens varies from 5 to 20\% [6, 7, 9, 24, 30]. The indicated accuracy increases with decrease of the values of these stresses [22] and it decreases with increase of the natural stress of the rocks [27].

Two schemes of checking stresses with the use of AEME are known. The first of them is possible owing to the fact that the memory is not erased under the effect of dynamic loads accompanying coring [27]. In accordance with this scheme, rock specimens oriented in various directions are extracted from the mass and under laboratory conditions are subjected to uniaxial compression with simultaneous recording of AE. The algorithms used further for interpreting the measurement results are valid provided that the specimens are extracted in the direction of action of the principal stresses and the rocks in the mass are loaded in accordance with the Karman scheme [27, 31]. At any rate, the second of these conditions in one or another degree is not fulfilled in a real mass, which today objectively limits the possibilities of checking by the indicated method.

The second checking system presuming the following: local unloading of the rocks in the mass by drilling a hole; recovery of the initial stress state of the rocks of the near-borehole space by means of a hydraulic sensor into which is pumped the working fluid under pressure; measurement of the intensity of AE during the indicated restoration, from the jumpwise increase of which is judged the acting stresses [12, 17, 18]. Checking by this scheme makes it possible to trace the space—time dynamics of stresses in situ. As for a quantitative evaluation of the latter, here there are certain difficulties with interpreting the measurement results, since the hydraulic sensor does not make it possible to completely recover the initial unequal-component stress state and the regularities of AEME corresponding to such a state have been insufficiently studied.

There are several attempts at a theoretical description of AEME in rocks. In particular, in [32] a phenomenological model is proposed, which, however, does not reveal the physics of the processes underlying the effect. Apparently, the dislocation model of the formation of AEME, explaining its regularities with consideration of the thermoactivation mechanism of occurrence and dynamics of the concentration and mobility of lattice defects depending on the loading prehistory of the