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Experimental investigation of the spatio-temporal localization of deformation and damage in sylvinite specimens under uniaxial tension

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ABSTRACT

In this work, the digital image correlation method and the acoustic emission technique are used to study the spatial–temporal localization of deformation in sylvinite under direct uniaxial tensile loading. The distribution of local strain fields over the lateral surface of the specimen subjected to quasistatic tension is analyzed. It has been found that the process of deformation in sylvinite specimens under quasi-static tension, proceeds as a sequence of two forms of spatial–temporal localization: a system of equidistant stationary areas of localized strain field and a single stationary dissipative localized structure, in which the deformation grows in an avalanche-like manner and ends in macro-fracture. The transition from one localization form to another occurs around the highest possible stress and is accompanied by a sharp decrease in the concentration parameter. The concentration parameter characterizes the degree of interaction between the defects at different scale levels through their elastic fields and can be estimated from the acoustic emission data.

1. Introduction

Geomechanical stability analysis of stopes and development workings in potassium salt mining is based on the laboratory estimates of the mechanical properties of salt rocks subject to uniaxial compression and tension tests. The indirect methods of evaluating the critical mechanical properties of rocks in tension, such as splitting method and "Brazilian test", are of frequent use in studying quasiplastic rocks, but give quite different results, which are difficult to compare [1]. Modern technological solutions allow researchers to carry out direct experiments on quasiplastic rock specimens under uniaxial tension and to investigate the specific features of the deformation process using the non-destructive methods.

Earlier, in [2], it has been shown that the plastic flow in some rocks under quasistatic compression remains localized over the whole period of the deformation process up to the sample fracture. The forms of macrolocalization are governed by the strain hardening laws operating at the corresponding stages of the process. The acquired information on the forms of strain

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Nomenclature

K	concentration parameter
L	characteristic size of defects
l	average distance between defects
E_{AE}	energy of acoustic emission pulse
σ	current tensile stress
E_{el}	Young's modulus
V	specimen volume
N	number of acoustic emission pulses
DIC	digital image correlation
AE	acoustic emission
p	defect-induced deformation
δ	structural scaling parameter

macrolocalization in rocks under uniaxial compression does not differ from the previously obtained data for alkali-halide crystals [3]. The experiments with sylvinite specimens revealed only a single zone of localized strain field, which moved over the specimen surface at the velocity of 10^{-5} m/s (at strain rate 6×10^{-5} s^{-1}). This single deformation wave corresponds to a linear stage of strain hardening. For other stages of the strain flow in sylvinite under compression load the forms of localization cannot be registered because of cracking and spalling occurring at the lateral rock faces.

This work is devoted to investigation of the spatial–temporal forms of macrolocalized strain field of sylvinite under quasistatic tension over the whole period of the deformation process up to the moment of the main crack formation. The method of digital image correlation (DIC) is frequently applied for reconstructing the displacement and strain fields on the specimen surface. Today, this non-destructive and non-contact method is widely used for studying the strain localization processes and fracture of rocks, concretes and cement-based materials [4–7]. For our investigation in addition to DIC we also employed the acoustic emission method (AE). This method allows us to monitor the damage accumulation process during loading and to estimate the ratio of the defect characteristic sizes to inter-defect spacing. The investigation of the forms of strain localization in quasiplastic rocks such as sylvinite under conditions of tensile loading will extend our knowledge about the spatial–temporal realization of inelastic deformation. This empirical information can form the basis for reconsideration of existing approaches to the construction of constitutive models, which describe the behavior of quasiplastic rocks under quasistatic loading and are used for simulation of geotechnical constructions in mining.

2. Experimental methods and materials

2.1. Materials and loading condition

Mechanical tests were performed on prismatic specimens with lateral size of 30×30 mm and height of 90 mm. The typical crystallite size of the main constituent minerals (halite and sylvite) was about 0.5 mm. The specimens were tested in the electro-mechanical testing machine having a capacity of 250 kN. The direct tension mode was realized via a special reversing device, which converted a compressive force into tensile force. The device and the prepared specimen are shown in Fig. 1. The experiments were performed at room temperature. To eliminate the error associated with the specimen bending in the reversing device, the measurements of longitudinal (axial) strains were made on the specimen surface with two cantilever sensors, which were placed symmetrically with respect to the specimen center. The displacement velocity was $1.6 \cdot 10^{-6}$ m/s ($\sim 2 \cdot 10^{-5}$ s^{-1}).

2.2. Used nondestructive testing techniques

A digital optical system LaVision Strain Master was used to track surface displacements caused by specimen deformation. The algorithm for processing the video data stream is based on the digital image correlation method. This method allows us to recover with a high degree of precision the evolution of the surface displacements and strains in the specimen made of different materials under different types of loading. The mathematical algorithm of the DIC method is presented for example in [8,9]. The Strain Master System consists of a digital camera, LED backlight, a synchronization system and a personal computer with special software. The elements of this system are shown in Fig. 2. The digital camera has a resolution of 1600×1200 pixels and it is set at a distance of approximately 30 cm from the specimen. Pixel in the recorded images represents an approximately 7.4 μm square on the specimen surface. Images are acquired with the frequency of ten frames per second. The displacement and strain fields were calculated for the surface area of the specimen measuring 54.5 mm by 29 mm.