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Discontinuous cyclic loading tests of salt with acoustic emission monitoring

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ABSTRACT

The majority of experimental rock fatigue tests have been conducted with the continuous cyclic loading path. In this paper we report the results from the fatigue tests of salt with discontinues cyclic loading path containing zero loading stress intervals (ZLIs) of different duration. We show that the application of such intervals strongly changes the mechanical response of the salt samples including the fatigue life and the residual strain prior the failure, both reducing with the ZLI increase. The acoustic emission (AE) activity (energy) evolution with time is also very strongly dependent on the ZLI length and increases with its growth as does the residual nominal strain. This suggests that the ZLIs accelerate the material damage characterized by the formation of microcracks and other defects. The damage occurs (is accumulated) due to the residual stress relaxation and associated creeping (rate/time dependent plastic deformation) during the ZLIs. In the conventional fatigue tests (with no ZLIs) the AE rate on the contrary decreases with the loading-unloading cycling, which shows a fundamental role of the loading history in the fatigue performance of salt and likely other rock types as well.

1. Introduction

Fatigue performance of materials is important for various industrial design and engineering construction applications [1–3]. The effects of stress and environment on fatigue have been largely investigated for different materials [4–9]. In the conventional fatigue tests (CFTs) a continuous cyclic loading-unloading is applied to a specimen. In the strain ageing tests of metals and crystalline crystals, two loading-unloading cycles are generally applied with a zero or very low loading interval (ZLI) between the cycles [10–14]. These tests have shown a strong influence of the ZLI on the stress-strain curves measured (on the mechanical performance of materials).

Rock salt, as an ideal media for oil and gas storage [15–18], has been attracting a growing attention from researchers and policy makers, especially in China. Owing to the periodic production-injection operations and seasonal changes in temperature, the behavior of salt under cyclic loading-unloading becomes one of hot topics. The gas pressure path data in gas storages [16,19,20] suggest that the surrounding rock undergoes considerable stress variations including periods of ZLIs [16], which were shown to influence the mechanical response of the rock [21,22]. However, the mechanism of this influence remains not clear. In this paper we present new results of uniaxial compression tests with discontinuous (containing ZLIs) cyclic loading of salt specimens and monitoring the acoustic emissions (AEs). The evolution of both the counting rate and the energy of AEs' was shown to be strongly dependent on the duration of the ZLIs. This is explained by the different rate of damage (e.g., micro-cracks) accumulation which is particularly important during the ZLIs and is due to the relaxation of the residual stresses and associate plastic deformation.

2. Experimental conditions and methodology

We use natural salt rock samples collected from the Khewra salt mine in Pakistan. They are characterized by a high purity of NaCl (greater than 96%) having {1,0,0} major cleavage plane which can be seen in Fig. 1a. Small amounts of K_2SO_4 (around 3.1%), some mud and other undissolved substances (less than 0.9%) are also present (Fig. 1). The grain size is typically between 5 and 30 μm.

Samples are shaped into cylinders, 50 mm in diameter and 100 mm long and are subjected to a discontinuous cyclic axial loading until the failure using a conventional mechanical rigid testing machine (MTS 815; MTS, MN, USA, [23,24]). The ends of the samples are separated from the steel platens by a pair of Teflon

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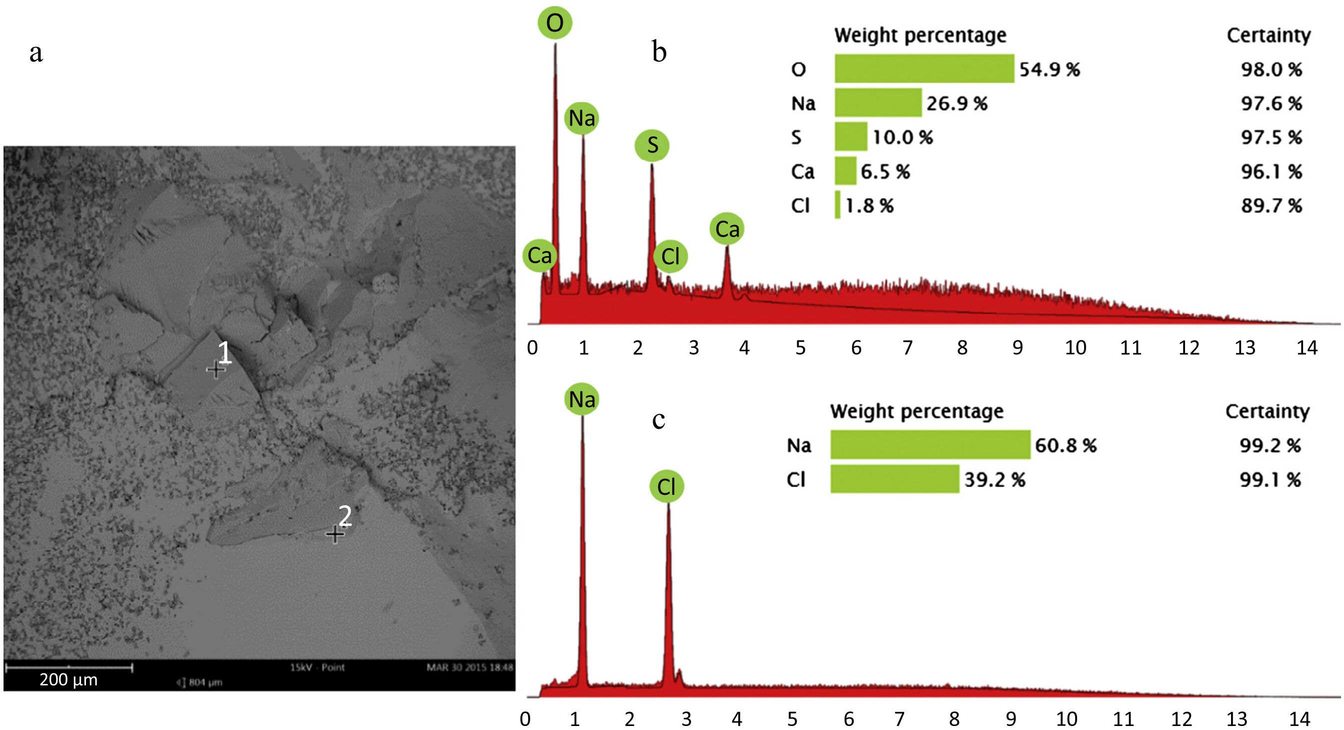

Fig. 1. SEM image of rock salt sample showing the microstructure (a) and the component analyses result at two points in (a): 1 (b) and 2 (c).

gaskets with lubricant between them (Fig. 2a) to reduce the interface friction that strongly affects the sample stress-state [25,26]. The upper and lower limits of the applied stress are σ_{max} = 34.8 - MPa (which is 85% of the uniaxial compression strength, UCS, Fig. 2c) and $\sigma_{min} \approx 1.5$ MPa, respectively, which gives the R-ratio of 0.043. The loading-unloading velocities are ±2 kN/s (the velocity gradually reduces when approaching the limit stress values). The loading path includes the loading-unloading cycles separated by the ZLIs of different length Δt. Two loading paths shown in Fig. 3 are applied in different tests. One or more duplicate tests were conducted to enhance the reality of the results.

To characterize the material damage and its evolution, we monitor the AEs in the frequency range 100–400 kHz using two pairs of piezoelectric receivers (sensors) micro30 (Physical Acoustics, NJ, USA). They are fixed on the sample surface at 1/4 and 3/4 the height (Fig. 2a and b). The AE threshold was set to 45 dB. All the experiments were performed under the room temperature of 22 ± 1 °C.

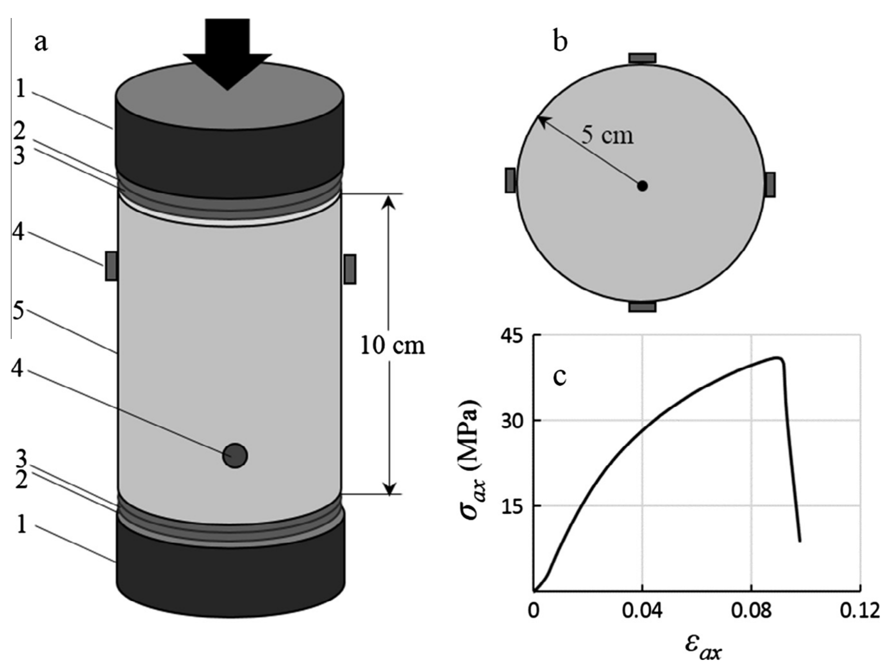

Fig. 2. Scheme of the test setup (a), position of AE sensors, in front view (a) and top view (b), and a typical stress-strain curve (c) from uniaxial (single-cycle) compression test. 1, Steel platens; 2, Teflon gaskets; 3, lubricant; 4, AE sensors; 5, salt sample σ_{ax} and ε_{ax} are the axial stress and strain, respectively.