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Technical Note

Observations of acoustic emission of three salt rocks under uniaxial compression

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1. Introduction

Acoustic emission (AE) is a physical phenomenon in which part of the strain energy under loading is released by transient elastic waves in the process of cracks propagation and expansion in rocks [1,2]. In the early 1930s, Obert discovered this phenomenon, and it was used for determining the stability of rock mass and forecasting rock burst in mines [3]. Since then, AE monitoring technology as a dynamic non-destructive evaluation procedure has been widely applied and developed in geotechnical engineering, earthquake monitoring and rock failure predication [4].

In order to investigate evolution mechanisms and mechanic properties in the process of rock failure, researchers performed much work on AE characteristics with different rocks [5–19]. For non-salt rocks, Qin et al. [8] indicated that AE properties were dependent on uniaxial stress and failure index. Additionally, AE events were fewer in the elastic stage, and the number of AEs rapidly increased in the plastic stage, moreover, the number of AE events reached the maximum value in the post-peak stage, subsequently reduced gradually. Ma et al. [9] analyzed AE characteristics of rocks containing micro-cracks and artificial cracks. The results suggested AE events of rocks including micro-cracks mainly depended on pores or fissures in mineral particles. Furthermore, number of AE events was low before rock failure. Additionally, Zhao et al. [10] studied the AE characteristics of Beishan granite under uniaxial and triaxial compression. The results show that evolution of AE hit counts in the uniaxial compression test is similar to that in the triaxial compression test. Li et al. [11] presented laboratory test results on spatial and temporal evolution of AE events of granite and marble specimens under uniaxial compression. The results show that spatial correlation length can either increase or decrease depending on the combination of stress release and stress re-distribution. Xu et al. [12] investigated AE properties of skarn under uniaxial compression by cyclic loading, the experimental results suggested AE events rapidly increased in the post-peak stage, and AE events of higher energy produced accompanying the number of AE events sharply enhanced when the stress obviously decreased. Furthermore, skarn still produced abundant AE events in the unloading stage, and AE characteristics of skarn have no Kaiser Effect under cyclic loading due to the differences of original fissures. The above experimental results suggested that variation rules of number of AEs and energy are synchronous in the process of rock failure. However, Wu et al. [13] presented variation rule of number of AEs was not exactly consistent with that of energy in the process of rock failure.

Ren et al. [14] investigated the properties of AE events in salt rocks under cyclic loading. The results suggested number of AEs increased with increasing the upper limit stress, but it was almost constant with changing the lower limit stress. Xie et al. [15] analyzed the relationship between energy release and fractal property of AE events in the process of halite failure. The effects of strain rate on the properties of AE events were analyzed by Jiang et al. [16]. The experimental results indicated that the number of AE events decreased with increasing strain rate, and it increased with decreasing strain rate, further damage evolution equation was obtained under low strain rate. Chen et al. [17] presented the

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characteristics of AE events of halite soaked in saturated brine with different temperatures. The experimental results suggested the accumulated number of AE events slightly increased with increasing the temperature of brine. Alkan et al. [18] investigated the AE properties of rock salt dilatancy boundary in the triaxial compression test. The results presented that the cumulative number of AE events spontaneously increased with dilatancy boundary determined from the minimum pore volume. Moradian et al. [19] investigated the application of AE events for monitoring the shear behavior of the different joints. The number of AEs and energy of AE events were analyzed to examine the relationship between shear behavior and AE.

Understanding the properties of AE events has made some progress for different non-salt rocks under different conditions, which provides important data for geotechnical engineering. However, only AE characteristics of halite were investigated on salt rocks, it is not sufficient to understand AE properties of salt rocks by analyzing a kind of salt rock. Additionally, salt cavern is recognized as an ideal storage place for oil, natural gases and radioactive wastes in the world [20]. Furthermore, Halite, glauberite and gypsum are three main types of rocks in salt deposit. Mechanic properties of these rocks are main effect factors on the stabilities of salt cavern built by solution mining and gas storage operation [21–23]. Nowadays, AE characteristic of rock is expected to be one of effective method for forecasting rock failure. Consequently, the AE characteristics of the three types of salt rocks were investigated under uniaxial compression in the laboratory.

2. Experimental apparatus and methodology

2.1. Rock samples

The tested samples of halite, glauberite and gypsum were taken from Jiangsu, Sichuan and Shanxi, respectively. These samples were processed into the standard cylindrical specimens in size of $\varphi 50 \times 100$ mm in the laboratory. In the experiments, AE characteristic of glauberite containing interlayer was analyzed under uniaxial compression referring to the structure of inhomogeneous rocks. In addition, some gypsum specimens were soaked in brine for 20 days before test in order to study the effect of brine on AE characteristic of gypsum.

2.2. Experimental apparatus and conditions

The experiments were conducted using TYT-600 rock mechanics testing system under uniaxial compression by monotonous loading or cyclic loading. In the process of uniaxial compression, the loading strain rate for specimens was controlled as 0.00002/s. During the loading process, AE data was collected and analyzed by SDAES digital AE monitoring apparatus with four testing channels. Monitoring position arrangements of AE sensors and specimen are shown in Fig. 1.

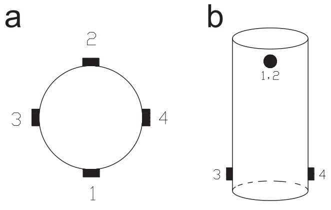

Fig. 1. Position arrangements of AE sensors and specimen. (a) Top view and (b) side view.

Table 1
Specimens and loading conditions.

Rock	Group	Specimen no.	Dry or humid	Loading condition
Halite	①	$1^{\#}$	Dry	Monotonous loading
		$2^{\#}$	Dry	Monotonous loading
		$3^{\#}$	Dry	Monotonous loading
Glauberite	②	$A^{\#}$	Dry	Cyclic loading I
		$B^{\#}$	Dry	Cyclic loading I
		$C^{\#}$	Dry	Cyclic loading I
		$D^{\#}$	Dry	Cyclic loading I
Gypsum	③	$4^{\#}$	Dry	Monotonous loading
		$5^{\#}$	Dry	Monotonous loading
		$6^{\#}$	Dry	Monotonous loading
	④	$7^{\#}$	Dry	Cyclic loading II
		$8^{\#}$	Dry	Cyclic loading II
		$9^{\#}$	Dry	Cyclic loading II
	⑤	$10^{\#}$	Half-saturated brine	Cyclic loading II
		$11^{\#}$	Half-saturated brine	Cyclic loading II
		$12^{\#}$	Half-saturated brine	Cyclic loading II
	⑥	$13^{\#}$	Saturated brine	Cyclic loading II
		$14^{\#}$	Saturated brine	Cyclic loading II
		$15^{\#}$	Saturated brine	Cyclic loading II

Cyclic loading I: increase the upper limit stress and keep the constant lower limit stress.
Cyclic loading II: simultaneously increase the upper limit and the lower limit stress.

2.3. Experimental methodology

In this study, AE properties of the three types of salt rocks were investigated during the uniaxial compression test. For halite, only one group of three specimens was tested under uniaxial compression by monotonous loading. Four specimens of glauberite, as a group, were tested under uniaxial compression by cyclic loading I. For gypsum, 12 specimens were divided into four groups according to different specimen humidity and loading conditions. The loading conditions of the three types of salt rock specimens were described in detail in Table 1.

In these measurements, the threshold of signal acquisition was set as 30 dB to gain a high signal/noise ratio. In particular, considering the validation of the obtained AE signals, the analyzed threshold of halite was set as 60 dB. For glauberite or gypsum, it was set as 40 dB. The sampling frequency was set as 2500 kHz. After the experiments, number and energy of AE events of halite, glauberite and gypsum were analyzed by stress–time and stress–strain curves.

3. Results and discussion

In the experiments, AE data of every group is consistent under uniaxial compression, thus, the specimens No.$3^{\#}$, No.$C^{\#}$, No.$D^{\#}$, No.$5^{\#}$, No.$8^{\#}$, No.$11^{\#}$ and No.$14^{\#}$ are selected to analyze AE characteristics. Specially, glauberite specimen No.$D^{\#}$ contains a mudstone interlayer in thickness of 1 cm, the other glauberite specimens are pure without any interlayer.

3.1. Effect of rock types

In general, stress–strain curves of rocks during uniaxial compression are divided into four stages: pressure consolidation stage, elastic deformation stage, plastic deformation stage, post-peak stage [24]. In the study, four specimens of the three types of salt rocks were analyzed with halite No.$3^{\#}$, glauberite No.$C^{\#}$ and No.$D^{\#}$ and gypsum No.$5^{\#}$. The AE properties are analyzed on the basis of the four deformation stages of rocks as described in Table 2. The number and energy of AE events were analyzed with the variations of stress–strain and stress–time curves as shown in Figs. 2–5.

The experimental results suggested the structures of the three types of salt rocks are compact, original pores and fissures are few.