International Journal of Rock Mechanics & Mining Sciences 69 (2014) 50–58

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Characterizing the mechanical tensile behavior of Beishan granite with different experimental methods

Jianfeng Liu [a], Liang Chen [b,*], Chunping Wang [b], Ke Man [b], Lu Wang [a], Ju Wang [b], Rui Su [b]

[a] State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu 610065, China
[b] CNNC Key Laboratory on Geological Disposal of High-level Radioactive Waste, Beijing Research Institute of Uranium Geology, Beijing 100029, China

ARTICLE INFO

Article history:
Received 17 November 2012
Received in revised form
30 April 2013
Accepted 17 March 2014
Available online 15 April 2014

Keywords:
Tensile strength
Damage evolution
Acoustic emission
Beishan granite

ABSTRACT

This work investigates with different test methods the mechanical tensile behavior of Beishan granite, especially the damage evolution process. The granite is taken from the Beishan site, a potential Chinese area for high-level radioactive waste repository. In the work, three widely used tensile testing methods are employed, namely the Brazilian test with simplified ISRM standard (Type I), the Brazilian test with the China standard (Type II), and the direct tensile test. An acoustic emission test system is also used to capture the microcracking process under different loading conditions. Even though the tensile strength obtained by the three testing methods is similar, some difference can still be noticed. The highest value of average tensile strength (11.24 MPa) is obtained by the indirect method proposed by IRSM, which is about 22% higher than the indirect method with China standard (9.15 MPa) and about 18% higher than the direct tensile test (9.53 MPa). The damage evolution process is further analyzed based on the recorded AE events. It is revealed that in direct tensile testing, the AE events accumulated mainly along the failure surface, whereas in indirect tests the location and variation of AE events are much more complex. Moreover, due to the stress concentration induced by the steel bars placed between the flat plate and the specimen, the accumulation of AE events around the loading surface is more significant in the indirect test with the China standard than the accumulation recorded in the IRSM method. The recorded AE events give rise to a reasonable explanation of the macroscopic mechanical behavior of granite, and are also valuable for understanding the damage evolution process of granite induced by tensile stress.

1. Introduction

Deep geological disposal of high-level radioactive waste (HLW) is considered worldwide as the safest and most feasible method for protecting human beings and the environment over extremely long periods of time [1,2]. The conceptual design of repositories generally relies on a multi-barrier system, which typically comprises the natural geological barrier and an engineered barrier system. As the last barrier to the biosphere, the natural geological barrier, namely the surrounding rock (including granite, salt, tuff and clay), plays a critical role in ensuring the long-term safety of the HLW disposal project. In brittle rocks, such as granite, damage by microcrack growth is commonly considered as the main mechanism causing inelastic deformation and failure of the rock. The microcrack growth may not only result in degradation of mechanical properties, but also affect hydraulic characteristics such as permeability [3]. Moreover, the coalescence of microcracks may provide a potential pathway for nuclide migration in HLW repository. Therefore, the investigation of the physical–mechanical characteristics of the surrounding rock, especially the damage evolution mechanism, is essential in the feasibility analysis of HLW repository.

The initiation and growth mechanisms of microcracks, as well as their impact on material behavior, have been extensively studied in the laboratory [4–9]. However, the emphasis is mainly attributed to material damage induced by compressive stress [3]. Indeed, because of the stress redistribution during the excavation process, both compressive and tensile stress zones are distributed in the surrounding rock. In particular, because the rock is less resistant to tensile stress, tensile cracks are more easily initiated and propagated, and are often observed in rock mass immediately after drilling or blasting in the circumference of a borehole or a repository with internal pressure. Furthermore, the induced damage under tensile stress condition is essentially related to the opened cracks, which is especially unfavorable to the safety and stability of the project. Hence, the tensile mechanical behavior of the surrounding rock is of special interest for the geological disposal of high-level radioactive waste.

* Corresponding author. Tel.: +86 1064942856.
E-mail addresses: chenliang@briug.cn, liujf@scu.edu.cn (L. Chen).

http://dx.doi.org/10.1016/j.ijrmms.2014.03.007
1365-1609/

In order to investigate the mechanical behavior of rock under tensile stress condition, different testing methods have been proposed. It is commonly considered that the direct tensile testing of rock mass provides more rational and reliable results [10]. However, this has been rarely employed in the laboratory due to the frequently unavoidable bending stress, torsion moment and the anomalous concentrated stresses [11,12]. These factors are usually caused by the eccentricity of the machine axial loads or unsuitable connection between the rock specimen and the machine caps during testing. The difficulties associated with the direct tensile test have led to a number of indirect methods to estimate tensile strength. The indirect tension test, also named the Brazilian test, was developed by Carneiro and Barcellos [13] in Brazil in 1952, which is generally recognized as a convenient and easy method to estimate the tensile strength of rock mass. It allows an experimental setup similar to the one used for axial compression. The Brazilian test was officially proposed as a method for determining the tensile strength by the International Society for Rock Mechanics (ISRM), which suggested that two steel loading jaws should be applied in contact with the disk specimen, with the radius of jaws 1.5 times of the specimen radius [14]. The Brazilian test was also standardized to obtain the tensile strength of concrete materials by the American Society for Testing and Materials [15]. It should be mentioned that the set-up and loading process of the Brazilian test is somewhat different in China. According to the China standard, two steel bars with 1 mm diameter are employed for a hard rock specimen, or two pieces of bakelite or chipboard for a soft rock specimen [16,17]. Since stress distribution or effective volumes are different in these tests, they do not necessarily provide the same results for the tensile strength. Therefore the testing results should always be reported along with the information about the testing method and specimen dimensions. With the proposed method, a considerable number of research studies have been performed. Wijk [18] discussed the theoretical background of two indirect tensile strength testing methods: the Brazilian test and the point load test. Cho et al. [19] performed dynamic tension tests on Inada granite, and analyzed the fracture processes under various loading conditions to verify the differences between the dynamic and static tensile strengths. Liu et al. [10] carried out the direct and indirect tensile tests on salt rock, and concluded that the tensile strength of salt rock determined by direct tensile test was more precise than by indirect tensile test. A flattened Brazilian disc specimen was used by Wang et al. [20] and You and Su [21,22] to test the tensile strength of brittle rocks, showing that the loading angle must be greater than a critical value to guarantee crack initiation at the center of the specimen. Mishra and Basu [23] used the block punch test to predict the Brazilian tensile strength of granite and concluded that prediction by the block punch index is more precise than by the point load strength. The acoustic emission (AE) test, as an effective non-destructive method for monitoring the rock behavior from micro-cracking to macroscopic failure, is also widely used for rock damage testing both in the laboratory and in situ [24–26]. Despite these research advances, the tensile mechanical properties and damage evolution characteristics under different tensile loading conditions are still not fully understood.

The objective of this work is to investigate the mechanical tensile characteristics of Beishan granite, especially the micro-cracking process and its impact on mechanical behavior. The granite is taken from the Beishan site located in the Gansu Province, which is currently considered as the most potential area for China's waste repository [2]. In order to gain a comprehensive understanding of the mechanical tensile characteristics, three types of widely used tensile test have been employed in the work. Meanwhile, a three-dimensional acoustic emission (AE) test system has been employed to capture the microcraking processing in different testing methods. The experimental results indicate that

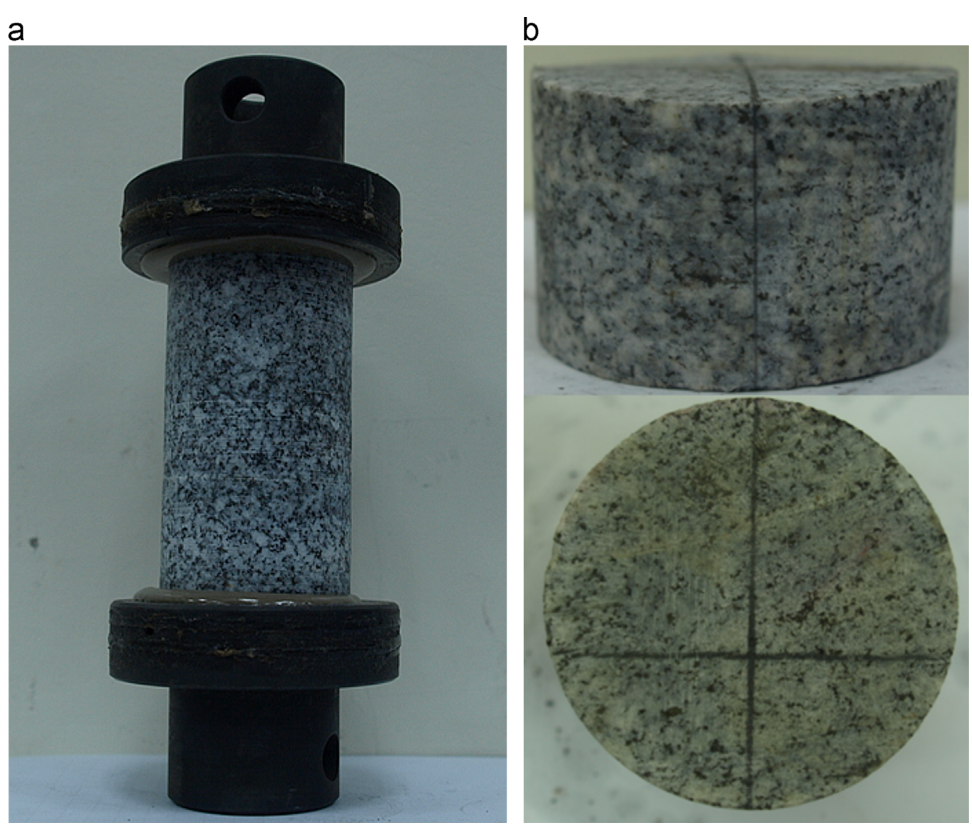

Fig. 1. Granite samples for tensile tests: (a) sample for direct tensile test and (b) sample for indirect tensile test.