International Journal of Rock Mechanics & Mining Sciences 88 (2016) 77–86

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Damage effects and mechanisms in granite treated with acidic chemical solutions

Shengjun Miao [a,b,*], Meifeng Cai [a,b], Qifeng Guo [a,b], Peitao Wang [a,b], Mingchun Liang [a]

[a] School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, China
[b] Key Laboratory of High-Efficient Mining and Safety of Metal Mines, University of Science and Technology Beijing, Beijing 100083, China

ARTICLE INFO

Article history:
Received 27 February 2016
Received in revised form
21 June 2016
Accepted 7 July 2016

Keywords:
Granite
Rock-chemical solution interaction
Mechanical parameters
Damage effect and mechanism
Aging features

ABSTRACT

Uniaxial and triaxial compression tests as well as splitting tests were conducted on granite specimens after acidic solution erosion at a variety of different pH values and flow rates. The responses of strength loss, deformation behavior and mechanical parameters of the granite were compared and analyzed. The effects of acidic chemical corrosion on microscopic structures, defect morphology and mineral elements of the granite were observed and analyzed under scanning electron microscopy (SEM) and electron spectroscopy. The aging that resulted from the interactions between the granite and chemical solutions were analyzed based on the mass and elastic wave velocity data of the specimens and pH value of the solutions at different soaking times, along with ion chromatography detection results of the solutions' chemical constituents and concentrations after soaking. Based on the results of X-ray diffraction for the mineral composition and X-ray fluorescence to determine the chemical elements and compounds in granite, the chemical reactions between granite and acidic solutions as well as the damage mechanism underlying the interaction were discussed in the theoretical context of chemical kinetics.

1. Introduction

The flow of groundwater exerts lubricating, softening, sliming, scouring and migration effects on a rock mass. In addition, the groundwater chemically reacts with the rock mass, having effects such as dissolution, hydrolysis, ion exchange and redox reactions.[1,2] These effects lead to the degradation of the rock macro mechanical properties through an erosion of mineral particles and crystals, a weakening of particle bonds strength, and an alteration of the mineral components, including the microstructural and physical properties.[3,4] The investigation of water-rock interactions has become the forefront of research in geotechnical engineering, including the study of nuclear waste disposal, mineral resources exploitation, slope effects and the characteristics of dam foundation.

In recent years, a series of studies on the effects of water and various chemical solutions on the macroscopic and microscopic structures and physico-mechanical parameters of different stones have been performed. Feucht and Logan[5] analyzed the effects of chemically active solutions (NaCl, $CaCl_2$ and Na_2SO_4) on shear behavior of sandstone, including the friction coefficient and strength. Karfakis and Akram[6] investigated the effects of chemical solutions on rock fracturing. Dunning et al.[7] analyzed the role of the chemical environment in frictional deformation, including stress corrosion cracking and comminution. Taking the Brezouard granite (Vosges, France) as an example, Sausse et al.[8] investigated the evolution of crack permeability during fluid-rock interaction. Tang and Wang[9] studied the mechanism and applied quantitative methods to evaluate the chemical damage in water-rock interactions based on the tensile strength and fracture mechanics of a variety of rocks after soaking in different chemical solutions. Li et al.[10] studied the changes that took place in the mineral components due to acidic solutions with different pH values and proposed a chemical damage model. Feng et al.[11] and Chen et al.[12] studied the mechanism of meso-failure, the evolution of damage and associated variables in sandstone using real-time computerized tomography (CT) during triaxial compression with chemical corrosion. Heggheim[13] studied the chemically induced enhancement of the weakening of chalk by seawater. Yao[14] and Yao et al.[15] performed a macro-meso-mechanical experiment on limestone under coupled chemical corrosion and water pressure, and provided an account of the meso-fracturing process. Min et al.[16] studied the chemically and mechanically mediated influences on the transport and mechanical characteristics of rock fractures. Feng et al.[17] systematically studied the coupled chemical-stress effect on the meso-mechanical characteristics, damage and mechanisms in a constitutive model of intact and pre-cracked rocks.

* Corresponding author at: School of Civil and Environmental Engineering, University of Science and Technology Beijing, Beijing 100083, China.
E-mail address: miaoshengjun@ustb.edu.cn (S. Miao).

http://dx.doi.org/10.1016/j.ijrmms.2016.07.002
1365-1609/

Brzesowsky et al.[18] investigated the compaction creep of sands over time, taking into consideration the chemical environment, applied stress and grain size.

Currently, the published research on the chemical reactions and micro damage mechanisms of rock under chemical corrosion and water pressure is comparatively scanty.[19] Therefore, a series of tests and measurements were conducted to investigate the damage effects, aging features and the mechanisms underlying both in granite undergoing erosion by acidic solutions with different pH values and flow rates, the results of which provide a large data set for the establishment of a constitutive damage granite model in a hydro-chemical environment.

2. Experimental design

2.1. Preparation of rock specimens and chemical solutions

Some regular and approximate cube phyllic granite samples obtained from Sanshandao Gold Mine, China, were used in the experiment. In ensuring the integrity of specimens, 3–5 cm thick surface was removed from the rocks to eliminate the influence of weathering during transport and storage. The sizes of the specimens were 50 mm × 100 mm (the cylindrical specimen) and 50 mm × 25 mm (the disk specimen).

Distilled water and three kinds of NaCl solutions with pH = 7, pH = 4 and pH = 2 were prepared. The chemical solution concentration was 0.01 mol/L, and the acidic solutions were made by concentrated hydrochloric acid.

2.2. Hydro-chemical soaking device

It was necessary to develop a hydro-chemical environment to study the chemical, physical and mechanical response mechanisms of rock-chemical solution interaction. Three sets of hydro-chemical environment soaking devices were assembled. The device (Fig. 1) is composed of a solution container and a self-priming booster pump and tubes. The solution container is made of polyvinyl chloride to withstand the corrosion of strong acid and alkali. It consists of an inter vessel and an outer vessel, whose dimensions are 500 mm × 350 mm × 350 mm with a wall thickness of 15 mm. The container is used to soak specimens to simulate the chemical and physical effects on rock in groundwater. The self-priming booster pump is used to set the solution flow rate by adjusting the pump power. Also, a certain flow pressure was formed to achieve the erosion and permeation of groundwater on rock.

2.3. Soaking experiments

The specimens were grouped and numbered before soaking; the size, mass, porosity and wave velocity of specimens were measured. Then the specimens were placed into different containers with water or different acidic solutions. To reduce the impact of flow rate differences of different locations and the influence between specimens, several rules were set as follows. (1) The specimens were placed separately and crosswise in the central of container. (2) The flow direction was perpendicular to the axial direction of specimens. (3) The soaking specimen number of each group was 5–8. (4) The chemical solution volume corresponding to a specimen was 2 L.

After all preparations completed, the self-priming pump was turned on to achieve the circulation of solution in container, pump and tube. Three circulation conditions (hydrostatic state ($v = 0$), low flow rate ($v = 200$ mm/s) and high flow rate ($v = 400$ mm/s)) were set by self-priming pump. The soaking experiments were carried out at room temperature (about 23 °C). The effect of temperature on the rock-chemical solution interaction was ignored in the little fluctuate of temperature during soaking. The total soaking duration was sixty days, and different tests and measurements were conducted at multiple time points during the soaking process.

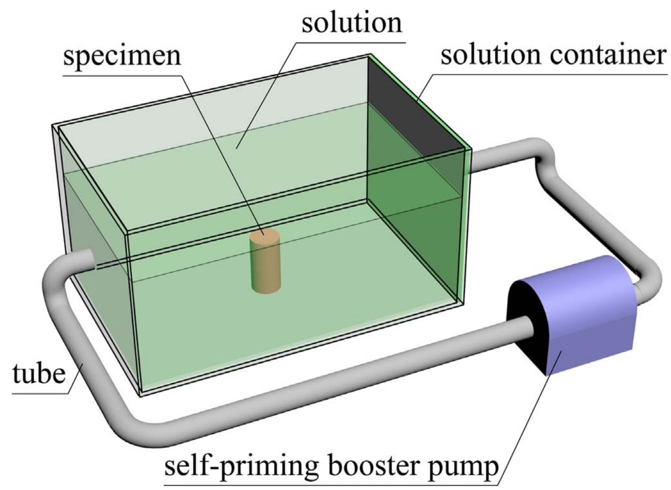

Fig. 1. Sketch of hydro-chemical environment soaking device.

3. Damage to the mechanical properties of granite after treatment with acidic solutions

3.1. Uniaxial compression test

3.1.1. Deformation behavior of granite under uniaxial compression

The granite cylindrical specimens were soaked in water at different flow rates and the acidic solutions. After 60 days soaking, the specimen's stress-strain curves and deformation behavior under uniaxial compression were obtained (Fig. 2).

As shown in Figs. 2 and 3, after the effects of water and acidic solutions, we have:

(1) As shown in Fig. 2(a), the initial compressive phase is very short for the specimen in natural dry state, indicating the granite is quite dense. After the effects of water and acidic solutions, some specimens show obvious concave downward trends in this phase, e.g. the curves (pH = 2, pH = 7) in Fig. 2 (a) and (c), the curves (pH = 2, pH = 4) in Fig. 2(b), especially the specimens soaked in the NaCl solution with pH = 2. The contrastive results indicate that the corrosion induced by the acidic solution prolong the initial compressive phase.

(2) According to Fig. 2(a), the stress-strain curve of natural dry specimen presents an almost linear trend before peak without a distinct yield point. After the application of water and chemical solutions, some stress-strain curves begin to swerve with obvious yield when the stress achieves the yield strength, e.g. curve (pH = 4) in Fig. 2(a), curves (pH = 2, pH = 7) in Fig. 2 (b), and curves (pH = 2, pH = 4) in Fig. 2(c).

(3) As shown in Fig. 3, the peak strength decreased with a decrease in the pH value or increase in the flow rate. Compared with natural dry granite, the uniaxial compression strength of the granite after the application of the NaCl solution with $v = 400$ mm/s and pH = 2 has the maximal drop, 41.38%.

(4) As shown in Fig. 2(a), the stress-strain curve of natural dry granite rapidly drops down after damage, presents a high stress drop and a brittle failure. After soaking in water and