International Journal of Rock Mechanics & Mining Sciences 88 (2016) 23–28

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Effect of water saturation and loading rate on the mechanical properties of Red and Buff Sandstones

Eunhye Kim[a,*], Hossein Changani[b]

[a] Department of Mining Engineering and Center for Underground Construction and Tunneling, Colorado School of Mines, CO, USA
[b] Department of Mining Engineering, University of Utah, UT, USA

ARTICLE INFO

Article history:
Received 29 August 2015
Received in revised form
30 April 2016
Accepted 7 July 2016
Available online 22 July 2016

Keywords:
Water saturation effect
Loading rate effect
Porosity effect
Dynamic mechanical strength
Split Hopkinson Pressure Bar (SHPB)

1. Introduction

A number of different parameters influence the mechanical behavior of geomaterials, and understanding the mechanical behavior of geomaterials is important for not only academic research but also various industrial applications.[1] As typical geomaterials are heterogeneous in pore size and are hydrated to various degrees in nature, understanding the fracture behavior of geomaterials of different porosities and water contents under different loading conditions is crucial to understanding the role that geomaterial characteristics play in fracturing processes.[2–4] For example, it is important to know how the porosities and water contents of geomaterials influences how much energy is needed to disrupt them. In addition, as the rate of loading has a significant effect on rock fragmentation processes, including drilling, blasting, hydraulic fracturing, crushing, and grinding, and on failure modes, including rock bursting, impact failure, and others,[5] information about the mechanical properties and behaviors of geomaterials at different loading rates can significantly affect the safety of underground construction, the optimum energy cost, the productivity of excavation and energy extraction, and the design of impact-resistant engineered infrastructures and constructions.[6–9] In the oil and gas industry, the main task of reservoir engineers is to increase the productivity of wells. Induced hydraulic fracturing is a technique that is typically used to generate fractures in rock reservoirs. At the beginning of this process, a device known as a perforating gun is lowered into a well to a designated location in the reservoir rock, and a charge is fired to perforate the steel casing, cement, and rock formation. This perforation stage creates small cracks or fractures in the rock. A mixture of water, sand, and chemicals is then injected into the wellbore under high pressure to keep the fractures open. In all steps of this process, knowledge of the effects of porosity and water content on the dynamic behavior of the reservoir rock may be useful in predicting the geomaterial properties and behaviors.

For many years, many researchers have studied the mechanical behavior of various types of geomaterials under different conditions. While a considerable amount of work has been done on the effect of porosity on the dynamic fracture mechanics of metals, composites, and ceramics,[10] only a very limited amount of work has been done on geomaterials with different porosities under dynamic loading conditions.[11,12] As many engineers and scientists studying rock mechanics thought that the force applied on a rock breaks a rock sample with the similar mechanism in static and dynamic loading conditions, many tests have been performed under static loading conditions. However, some researchers reported that there were significantly different rock failure mechanisms between static and dynamic loading tests.[13–16] Additionally, sometimes it is not easy to obtain relevant rock samples having similar mineral compositions with remarkably different

* Corresponding author.
E-mail address: ekim1@mines.edu (E. Kim).

http://dx.doi.org/10.1016/j.ijrmms.2016.07.005

porosities essential to get accurate rock porosity effect on mechanical properties and behaviors.

In this study, to fill in some of the gaps that exist in knowledge of the effects of porosity and water content on the mechanical strength of geomaterials, we examined and compared the compressive strength, tensile strength, and Young's modulus of dry and saturated Red and Buff sandstones under static, fast, and dynamic loading conditions. Our results provide insights into how the mechanical behaviors and properties of geomaterials are affected by the water content and loading rate.

2. Materials and methods

2.1. Sample preparation

Red (smaller grain size, 4.7–5.5% porosity) and Buff (larger grain size, 18.0–22.7% porosity) sandstone samples with L (length)/D (diameter) ratio of ~0.4 were prepared for tensile tests and with L/D ratio of ~2 for compressive tests using coring, cutting and grinding machines. The Red and Buff sandstone samples were soaked in water for 48 h in a vacuum chamber (25 cm Hg). Half of the fully saturated samples were placed in a dry oven at 105 °C for 48 h to prepare dry sandstone samples.

2.2. Porosity measurements

To estimate porosity, thin section analyses of Red and Buff sandstone samples were performed by TerraTek (Fig. 1). The sandstone samples were impregnated with a low-viscosity fluorescent red-dye epoxy resin under a vacuum to highlight the porosity, mounted on standard (24 mm × 46 mm) thin section slides, and ground to a 30-μm thickness. The thin-sectioned samples were stained with a mixture of potassium ferricyanide and Alizarin Red and digitally imaged under plane- and cross-polarized light using a Nikon polarizing binocular microscope equipped with a Spot Insight digital camera. Void areas stained with pink color were regarded as pore spaces and used to evaluate the porosity of the Red and Buff sandstone samples.

In addition, the porosities of Red and Buff sandstones were estimated with the weight difference between the dry and saturated samples (Table 1). The porosity of rock is the ratio of the porous volume of the rock occupied by air and water divided by the total volume, expressed as follows:

Table 1
Porosities of Red and Buff sandstones estimated from weight differences between dry and fully saturated samples and the 300-point count method using magenta epoxy-stained samples.

Type	Porosity estimated from weight difference (n=40)	Porosity estimated from 300-point count method
Red sandstone	5.5% (±0.03)	4.7%
Buff sandstone	22.7% (±0.04)	18.0%

$$P = \frac{(V_w + V_a)}{(V_w + V_a + V_s)} \quad (1)$$

where V_w is the water volume, V_a is the air volume, and V_s is the volume that the solid material occupies. The rock sample porosities were determined by the water saturation method suggested by the International Society of Rock Mechanics.[17]

2.3. P and S wave velocity measurements

To estimate Young's modulus, the longitudinal (P wave) and transverse (S wave) wave velocities of Red and Buff sandstone samples were measured. P and S wave velocities are intrinsic properties of solid materials. The ultrasonic pulse velocity technique was used to measure the P and S wave velocities of the rock samples. A frequency of 1.0 MHz was used to measure the P and S wave velocities of cylindrical rock samples with 3.175-cm and 5.46-cm diameters and L/D ratio of 2.0. All samples used in this study were prepared in accordance with ASTM D2845.[18] The distance between the two transducers, the sample's length divided by the delay or arrival time, measured by an ultrasonic machine, gave the corresponding wave velocity in the geomaterial specimens. The P and S wave values and calculated dynamic Young's modulus obtained were shown in Table 2. The dynamic elastic properties of these types of sandstones (the dynamic Young's modulus (E), bulk modulus (K), and shear modulus (G)) were calculated as a function of P wave velocity (V_p), the S wave velocity (V_s), and the rock density (ρ) using the following equations:

$$E = \frac{\rho V_s^2 (3V_p^2 - 4V_s^2)}{(V_p^2 - V_s^2)} \quad (2)$$

$$K = \frac{\rho (3V_p^2 - 4V_s^2)}{3} \quad (3)$$

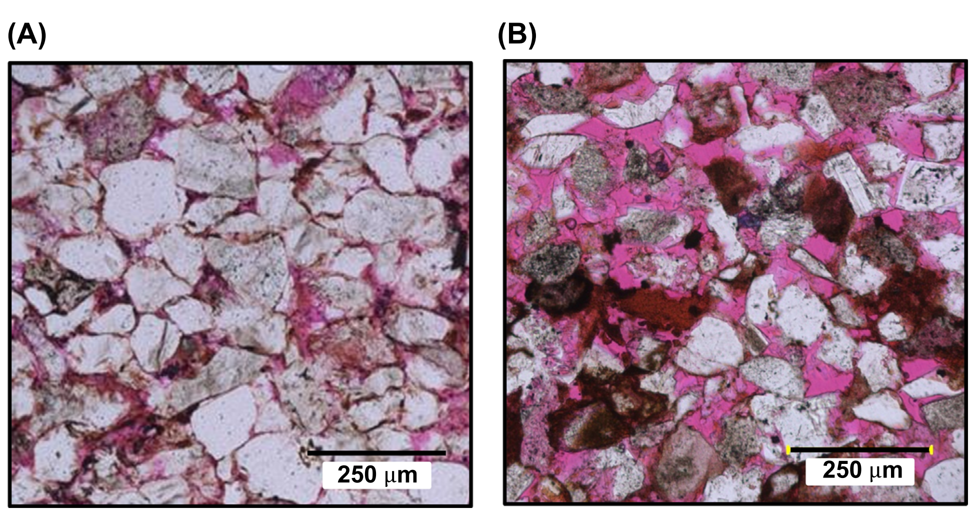

Fig. 1. The magenta epoxy was seen between framework grains: (A) cross-laminated Red sandstone and (B) cross-laminated Buff sandstone. Scale bars indicate 250 μm.