International Journal of Mining Science and Technology 24 (2014) 151–156

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

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

Effect of specimen size on energy dissipation characteristics of red sandstone under high strain rate

Li Ming[a], Mao Xianbiao[a,b,*], Lu Aihong[a,c], Tao Jing[b], Zhang Guanghui[b], Zhang Lianying[d], Li Chong[e]

[a] *State Key Laboratory of Geomechanics and Deep Underground Engineering, China University of Mining & Technology, Xuzhou 221116, China*
[b] *School of Mechanics & Civil Engineering, China University of Mining & Technology, Xuzhou 221116, China*
[c] *State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology, Xuzhou 221116, China*
[d] *School of Civil Engineering, Xuzhou Institute of Technology, Xuzhou 221008, China*
[e] *School of Mines, China University of Mining & Technology, Xuzhou 221116, China*

ARTICLE INFO

Article history:
Received 21 July 2013
Received in revised form 20 August 2013
Accepted 10 September 2013
Available online 22 February 2014

Keywords:
Red sandstone
Slenderness ratio
SHPB
Impact failure
Energy dissipation

ABSTRACT

In this experiment, red sandstone specimens, having slenderness ratios of 0.5, 0.7, 0.9 and 1.1 respectively, were subjected to blow tests using a Split Hopkinson Pressure Bar (SHPB) system at a pressure of 0.4 atmospheres. In this paper, we have analyzed the effect of slenderness ratio on the mechanical properties and energy dissipation characteristics of red sandstone under high strain rates. The processes of compaction, elastic deformation and stress softening deformation of specimens contract with an increase in slenderness ratio, whilst the nonlinear deformation process extends correspondingly. In addition, degrees of damage of specimens reduced gradually and the type of destruction showed a transformation trend from stretching failure towards shear failure when the slenderness ratio increased. A model of dynamic damage evolution in red sandstone was established and the parameters of the constitutive model at different ratios of length to diameter were determined. By comparison with the experimental curve, the accuracy of the model, which could reflect the stress–strain dynamic characteristics of red sandstone, was verified. From the view of energy dissipation, an increase in slenderness ratio of a specimen decreased the proportion of energy dissipation and caused a gradual fall in the capability of energy dissipation during the specimen failure process. To some extent, the study indicated the effects of slenderness ratios on the mechanical properties and energy dissipation characteristics of red sandstone under the high strain rate, which provides valuable references to related engineering designs and academic researches.

1. Introduction

Rock dynamic impulsion is one of the most important problems in engineering, such as mining excavation, tunnel excavation, civil works and blasting engineering [1,2]. It is well known that the mechanical properties of rocks under dynamic load are noticeably different from those under static load [3]. For this reason, it has become the focus of rock mechanics research. Substantial achievements in this field have been obtained with the development of experimental conditions and technologies [2–14]. The special feature that slenderness ratio has an effect on the mechanical properties and failure modes of limestone were demonstrated by Li, in which limestone specimens of different slenderness ratios were tested using pneumatic shock simulation [15]. Scholars from Japan analyzed the size effect of specimens of high-strength concrete or ordinary concrete with a slenderness ratio of 2.0 using drop-weight tests [16]. In 2008, Hong analyzed the size effect on impact mechanical properties, fracture states and energy dissipations on specimens of limestone, sandstone and granite respectively by using the SHPB system [17]. The results showed that the size effects on rock mechanical characteristics were very complicated, because of variations in the composition and structure of different rocks; that is to say, there are differences in the development and extent of microcracks and their distribution.

Many tests have been carried out to study the mechanical properties of red sandstone under static load, while studies under dynamic load are fewer in number [18]. As an important building material, red sandstone has become the object of study, especially its destruction and capability for energy dissipation under dynamic load, which could provide valuable references for excavation and construction projects. In this paper, the mechanical properties and energy dissipation of red sandstone specimens with different ratios were tested and analyzed using the SHPB method. The research findings are very important for real conditions in the long-term.

---

* Corresponding author. Tel.: +86 516 83885058.
E-mail address: xbmaocumt@163.com (X. Mao).

2095-2686/$ - see front matter © 2014 Published by Elsevier B.V. on behalf of China University of Mining & Technology.
http://dx.doi.org/10.1016/j.ijmst.2014.01.002

2. Impact tests on red sandstone specimens

2.1. Specimen preparation

Specimens, with a diameter of 50 mm, were taken from a quarry in the south of Xuzhou. These specimens were divided into four groups having different slenderness ratios: 0.5, 0.7, 0.9 and 1.1 respectively. Each group included 8 specimens. Before processing, the cylindrical specimens with the same diameter of 50 mm and different heights were cut using a core-drilling machine and a cutting machine. A grinding machine was used finally to ensure that the two ends of the specimens were flat and parallel (Fig. 1).

2.2. Experimental instrument and method

Fig. 2 illustrates the SHPB system developed by China University of Science and Technology. The SHPB system consists of a power source, the elastic press rod, and testing and analyzing instruments. In the experiments, the impact load was 400 kPa. The punch, pushed by high-pressure gas collides with the incident bar, which generates an incident pulse in the bar. Part of the pulse is reflected and the other remains so that when the pulse arrives at the ends, the reflected signal and the transmitted signal are enhanced.

Fig. 3 shows the waveform obtained from the test. It is clear that the incident signal waveform, which is approximately half a sine curve, is consistent with the transmitted signal, while the reflected signal has a W-shape with two obvious troughs.

3. Effect of slenderness ratios on the mechanical properties of red sandstone

3.1. Effect on the dynamic stress–strain curves

Fig. 4 illustrates the full stress–strain curve of a red sandstone specimen under impact load. The curve could be divided into five sections as follows:

(1) Adjusting stage

Specimens of different slenderness have almost the same stress–strain curve which rises like a zigzag. The strain is about 1.5×10^{-4} in this stage. Under external load, the system can be adjusted, including self-adjustment with the pressure bar to the specimen.

(2) Compaction stage

Original cracks begin to close due to external load, for which the curve is an incremental upward concave shape for which $d^2\sigma/d\varepsilon^2 > 0$. At this stage, the influence of slenderness ratio begins to emerge. The strain increment decreases gradually with the increment of slenderness ratio. Strain increments are 5.3×10^{-4}, 3.8×10^{-4}, 2.5×10^{-4}, and 1.6×10^{-4} respectively.

Fig. 1. Red sandstone specimens.

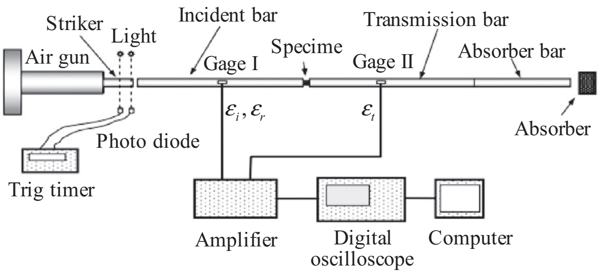

Fig. 2. The SHPB system.

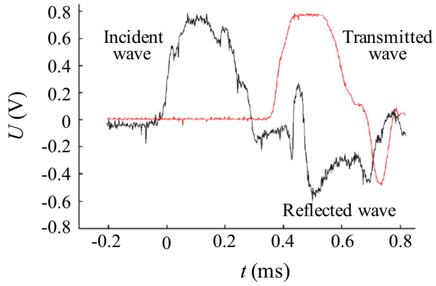

Fig. 3. Waveforms of red sandstone samples from the SHPB test.

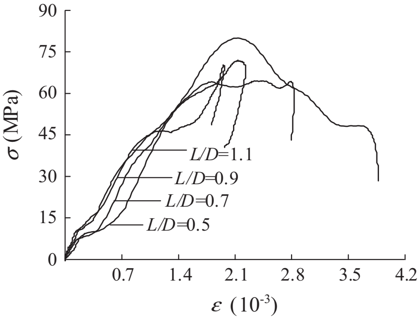

Fig. 4. Dynamic stress–strain relationship of red sandstone under different length to diameter ratios.

(3) Near-linear elastic stage

Curves are approximately straight lines for which the slope is constant, about 40 GPa. However, elastic strain decreases gradually while slenderness ratio increases. The elastic strains are 10.7×10^{-4}, 4.5×10^{-4}, 3.7×10^{-4}, and 3.2×10^{-4}.

(4) Non-linear reinforcement stage

The number of microcracks increases and expands rapidly. The effect of slenderness ratio becomes striking. When $L/D = 0.5$, it becomes a typical reinforcement stage in which the slopes of the curves decrease. In this stage, the deformation of specimens is mainly plastic deformation and the strain increment is about 3.5×10^{-4}. When $L/D = 0.7$, the curve is divided into two stages at a strain of 10.5×10^{-4}. Both of the stages are downward concave, where specimens are strengthened twice. The strain increment of this stage is 8.5×10^{-4}. When $L/D = 0.9$, the curve is initially downward concave and the strain increment is about 10.5×10^{-4}. After this point, the curve tends to go upward concave and specimens enter the hardening stage where the corresponding strain increment is about 2.5×10^{-4} [19]. Finally, the curve goes upward concave, which indicates that specimens enter the second hardening stage and the strain increment, which is very small, is about 0.5×10^{-4}. When $L/D = 1.1$, the curve, which is typically downward concave with a strain increment from 7×10^{-4} to