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Research Paper

Experimental investigation of thermal effects on dynamic behavior of granite

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HIGHLIGHTS

- Temperature significantly influence the dynamic behavior of granite.
- Density variation (within 5%) can be ignored during thermal treatment.
- Wave velocity and Young's modulus decreases as temperature increases monotonously.
- Energy absorption ability varies as temperature increases with its maximum at 400 °C.

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ABSTRACT

A systemic understanding of the thermal effects on the dynamic behavior of granite is significant to thermal engineering applications such as waste disposal engineering and underground coal gasification. In the present study, scanning electron microscope (SEM) tests were carried out to evaluate the thermal effects on the geophysical properties of granite. The results show that the density decreases slightly as the temperature increases from 25 °C to 400 °C but that it decreases sharply as the temperature increases further to our maximum tested temperature of 800 °C. The defect rate increases slightly as temperature increases from 25 °C to 400 °C and then increases sharply as the temperature further increases to 800 °C. Next, ultrasonic wave tests were performed to evaluate the thermal effects on the wave velocity and P-wave modulus. The results show that both the wave velocity and P-wave modulus decrease sharply and linearly below the temperature of 400 °C, before deceasing nonlinearly as the temperature increases to 800 °C. Finally, split Hopkinson pressure bar (SHPB) tests were adopted to investigate the thermal and loading rate coupling effects. The results show that the dynamic strength decreases linearly as temperature increases but increases as the impact pressure increases. However, the dynamic energy absorption capacity increases below 400 °C but then decreases as the temperature increases to 800 °C. The thermal effects on energy absorption capacity are more obvious for granite under a smaller impact pressure.

1. Introduction

A systemic understanding of thermal effects on the mechanical behavior of granite is very important for thermal engineering applications, e.g., the development and utilization of geothermal energy, deep disposal of nuclear waste and volcano stability assessment. The variation of physical and mechanical properties of granite after high-temperature treatment has become a major issue of interest in recent years [1–3].

The mechanical properties of rock (rock mass) have been extensively studied [4–9]. Brace and Martin conducted triaxial testing for six kinds of rock and found that the degree of damage increases as the loading rate increases [10]. Grady et al. tested shale with different oil contents and found that the dynamic strength of oil filled shale increased as the loading rate increased [11]. Moreover, the rock was damaged in three patterns: the tensional pattern, shear pattern and mixed pattern [11,12]. Dai et al. conducted Brazil splitting tests to investigate the dynamic tensional behavior of rock and showed that the crack propagation in the rock is significantly related to the loading rate [13]. Li et al. modified the traditional SHPB setup and systemically tested the dynamic behavior of rock under an intermediate loading rate [14,15]. Yin further concluded

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that the dynamic behavior of rock can be classified into four categories: the experiential model, element model, damage model and combination model [16]. A detailed review of dynamic experimental techniques and mechanical behavior of rock was conducted [17,18], but most of the previous research on the dynamic behavior of rock was performed at room temperature.

The thermal effects on rock properties have attracted increasing attention recently due to the development of deep earth engineering [19–21]. The variation in the mechanical properties, e.g., elastic modulus, compressive strength and Poisson's ratio, of granite under different temperatures were investigated experimentally [19]. Alm et al. investigated the mechanical behavior of thermally treated granite and analyzed the micro-defect generation process [20]. Liu and Xu measured the mechanical properties of granite under high temperature and found the threshold value of physical transformation [21]. Luo et al. introduced the thermal-mechanical coupling equation to investigate the thermal effects on the micro-defect of rocks [22]. Recently, image processing techniques have been widely used to analyze the mechanisms underlying thermal effects. Zuo et al. conducted scanning electron microscope (SEM) tests to analyze the thermal crack initiation [23]. Micro-CT was introduced to investigate the thermal damage and failure mechanical behavior of granite after exposure to different high-temperature treatments [3]. Most of the previous research on the dynamic behavior of thermal-treated granite used only one or two technologies, e.g., SEM, ultrasonic measurement or SHPB. Since the mechanical properties of granite change markedly due to their different natural constituent contents, it is inappropriate to compare the experimental results obtained using different technologies on different granites. However, systemic research on the dynamic behavior of thermally treated rock has not yet been explored.

In this paper, the thermal effects on granite were observed by scanning electron microscope tests, and a graphical analysis was conducted to investigate the thermal effect on the defect rate. Subsequently, the ultrasonic measurement was conducted to obtain the thermal effects on the wave velocity and elastic modulus. Finally, SHPB tests were performed to investigate the thermal effects on the dynamic compressive stress-strain relationship, dynamic compressive strength and dynamic compressive energy absorption capacity of granite.

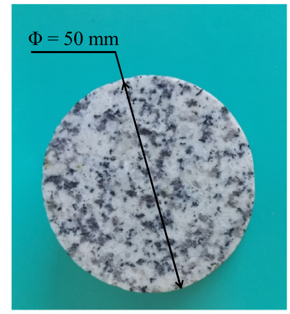
2. Rock sample

The rock samples in the present study are from Zhejiang Province, China. These rocks consist mainly of mica, feldspar, quartz and other minerals, which form an interlocking, somewhat equigranular matrix of feldspar and quartz with scattered darker mica, as shown in Fig. 1(a). The rock was cored from a geological exploration project at the depth of 50–70 m underground.

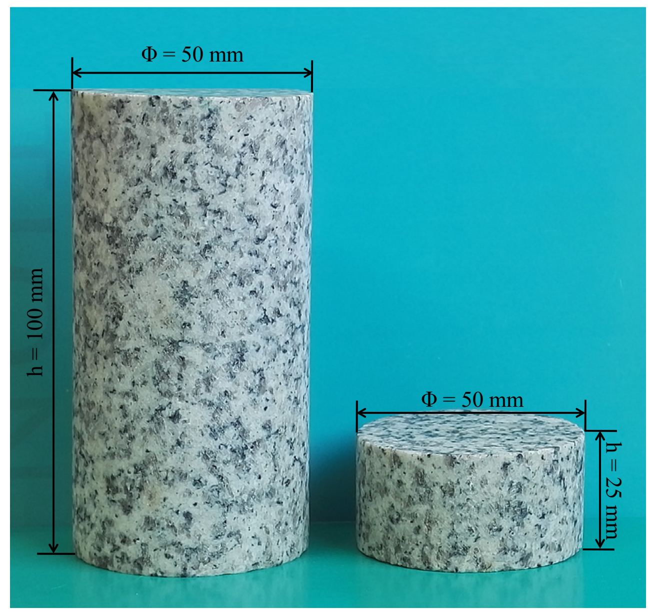
Fig. 1(b) shows two kinds of specimens prepared for the tests. Cylindrical specimens with a diameter of 50 mm and a height of 25 mm were designed for the dynamic SHPB tests, while those with a diameter of 50 mm and a height of 100 mm were designed for the ultrasonic test. The integrity and homogeneity of the rock samples were carefully examined, and two end surfaces of specimens were ground with a maximal roughness of 0.05 mm.

3. Thermal treatment

The thermal treatments were performed in the rock mechanic lab of Beijing University of Technology. Fig. 2 shows the heating machine, which can supply a maximum of 1200 °C with a maximum error of ±1.0 °C. The heating program can be set according to the experimental requirement, and it has a maximum heating



(a) Cross section



(b) Geometric dimension

Fig. 1. Rock specimen for ultrasonic and dynamic tests.

Fig. 2. Thermal treatment machine.