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Experimental study on the infrared thermal imaging of a coal fracture under the coupled effects of stress and gas

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ABSTRACT

Coal and rock dynamic disaster in deep coal mining is a typical phenomenon of coal and rock failure under the coupled effects of stress and gas. Gas and stress have increasingly contributed to the occurrence of dynamic disasters. A more thorough understanding of the characteristics and mechanism of infrared thermal images of coal and rock under the coupled effects of stress and gas is needed. In this paper, infrared radiation experiments of coal fracture under the coupled effects of stress and gas were conducted with an air sealed cylinder. The variation law of infrared radiation during coal failure under the effect of gas was studied. Three main findings were obtained from the experiments. (1) The infrared radiation temperature is strongly affected by gas during the failure process of coal samples. The infrared radiation temperature of coal fracturing without gas show a decreasing—increasing steadily—increasing abruptly trend. In contrast, in the fracture of coal with gas pressure via the exchange of heat between gas and the coal surface, the infrared radiation temperature at the coal surface has a decreasing—decreasing rapidly—rising trend. (2) The effects of different confining gas pressures on the fracture of coal induce various trends in the infrared radiation temperature. In the early stage of loading, a higher confining pressure of gas results in a smaller decrease in the infrared radiation temperature. Moreover, at the end of loading, the infrared radiation temperature at the surface of the coal body increases with an increasing confining gas pressure. The infrared radiation temperature has a minimum value during the loading process. When the confining pressure of gas is 0.2, 0.4 and 0.6 MPa, the infrared radiation temperature is a minimum at 74.1%, 67.1% and 58.3% of the load ratio, respectively. (3) Cloud maps of the infrared thermal image of the failure of gas-containing coal and contours of the infrared radiation temperature (which reflect the occurrence, expansion, rupture position and evolution of the crack temporally and spatially) can be used to predict the form and strength of the deformation and failure of gas-containing coal and locate precisely the position of a coal and rock dynamic disaster.

1. Introduction

Coal and rock dynamic disasters, such as coal and gas outburst and rock burst, are occurring increasingly frequently with increasing mining depths (Yu and Cheng, 2012; Peng et al., 2013). Ground stress and gas pressure escalate gradually in deep mining, and the erosive effect of gas on coal makes the process and mechanism of coal failure increasingly complex. A coal and rock dynamic disaster in deep coal mining is a typical phenomenon of coal and rock failure under the coupled effects of stress and gas (He et al., 1996; Xie et al., 2014; Hu et al., 2016). Gas and stress have increasingly contributed to the occurrence of dynamic disasters, and outbursts and rock bursts have gradually become a unified phenomenon. The dynamic monitoring of gas-containing coal is one method of evaluating the hazards of the dynamic disasters of gas-containing coal. When coal and rock dynamic disasters occur, the energy present in the coal and rock mass is released in the form of elastic energy, sound energy, heat energy and electromagnetic energy. Thus, there are a variety of geophysical methods for detecting coal and rock dynamic disasters, such as the acoustic emission method (Ohnaka and Mogi, 1982; Kong et al., 2015; Wang et al., 2017), microseismic method (Liu et al., 2012), electromagnetic radiation method (Wang and He, 2000; He, 2003), surface potential method (Li et al., 2013) and infrared method (Luong, 1990; Li et al., 2016). As a non-contact monitoring method with high accuracy, high reliability and convenient operation, the infrared method has widespread application prospects for monitoring the spatial and temporal evolutions of coal rock failures via infrared temperature measurements and infrared thermal imagery (Luong, 1990).

Scholars have made remarkable progress in applying the infrared method to the prediction of rock deformation and failure as well as the prevention of natural and engineering disasters (Ouzounov et al., 2007; Mineo et al., 2015; Liu et al., 2011). Luong (1990), (1987) first used infrared thermal imaging technology to study the phenomenon of infrared radiation in the process of rock and concrete rupture. Gornyi et al. (1988), Tronin et al. (2002), and Ouzounov et al. (2006) analysed thermal infrared satellite imagery and found that a large area of thermal infrared anomalies was present before strong earthquakes occurred around the world. Brady and Rowell (1986) found that under the action of a load, coal can produce an electromagnetic signal that can be detected in the infrared band. Wu et al. (2004), Wu and Wang (1998) found that before rupture, the position of the abnormal band of the thermal image corresponds to the location of the rupture, and the nature of the rupture is closely related to changes in the infrared radiation temperature; he thermal effect of the infrared radiation temperature strengthens with the effect of the micro-rupture when coal samples are loaded to 70% of their strength. Wu et al. (2016, 2015) explored abrupt anomalies of the infrared temperature field in the process of rock failure. They found that the abnormalities of the anomalies mainly appeared at the peak after the fracture stage. Additionally, a plastic-peak rupture stage was observed after the deformation, and rupture of the sample surface exacerbated the

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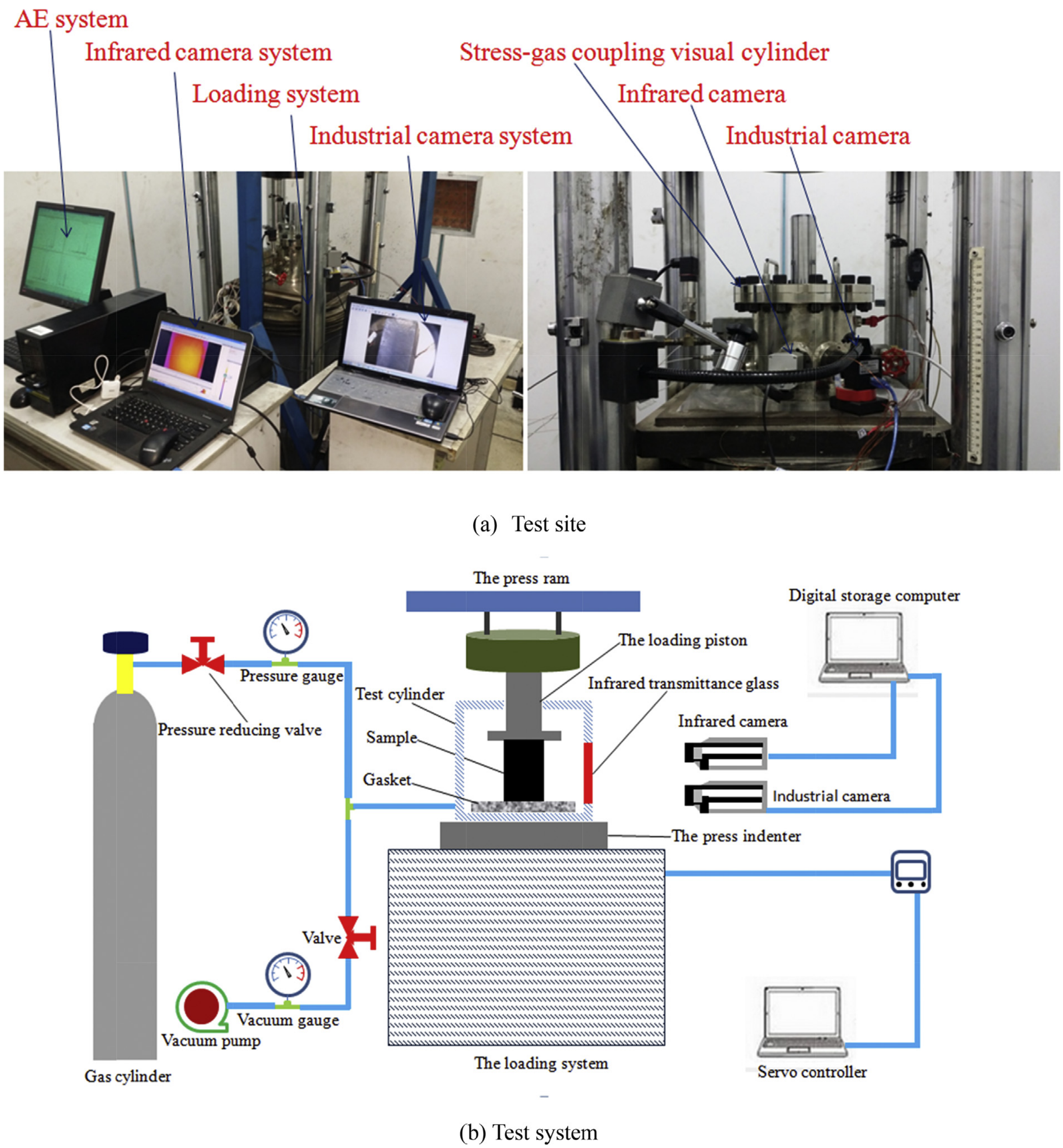

Fig. 1. Infrared test of failure under the coupled effects of stress and gas.

development of the infrared-temperature field mutation. Zhang and Liu (2011) selected a circular hole rock as a sample and analysed the temporal and spatial evolution characteristics of thermal radiation during the rock fracture process via numerical simulation. The pressure and tensile stress of the sample corresponded to the heating and cooling zones of the thermal image during the loading process. Ma et al. (2007) used an infrared thermal imager to study the temporal and spatial distribution characteristics of a thermal field before and after the failure of compressional faults and extension faults and analysed the cooling time as a precursor to destabilization failure. To make better use of the average infrared radiation temperature method in predicting the deformation of rock under uniaxial compression, Sun et al. (2017) proposed a new thermal infrared experimental device for controlling a sample.

For the infrared phenomenon of damage to coal, Ma et al. (2017) studied the quantitative relationship between the stress change and infrared radiation change during the process of cracking under loading. The results indicated that infrared radiation of the uniaxial loading coal sample is typically emitted with the control effect and can be used to monitor the fissure development and rupture condition of the coal-bearing rock mass. Ma et al. (2013) conducted uniaxial loading experiments on coal and mudstone samples. They measured the temperature change in the borehole of the coal body using an infrared thermometer and obtained the characteristics of the temperature change of the sample. They also analysed the temporal and spatial evolution characteristics of the infrared radiation temperature of the sample during compression. Zhao and Jiang (2010) analysed acoustic, thermal and strain precursory anomalies during the uniaxial and cyclic loading of impact-prone coal samples. The thermal infrared precursor typically occurs between the acoustic emission precursors and strain precursors. Yang et al. (2016) studied the variation law of internal infrared radiation temperatures during the loading and unloading of