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Compressive deformation and energy dissipation of crushed coal gangue

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ABSTRACT

Crushed gangue, an inhomogeneous and discontinuous medium, is accompanied with the absorption and dissipation of energy under compression. In order to study the compressive deformation and energy dissipation of gangue in the loading process under conditions of different particle sizes, loading rates, and first-time stress loads, a SANS testing machine and steel cylinder were used to conduct experiments in this paper. The following conclusions were drawn from the investigation: 1) The gangue underwent three separate stages of compressive deformation, which included rapid, slow, and stable; 2) The energy density of the gangue increased nonlinearly as the strain increased, and the dissipated energy accounted for 10%, 20%, and 70% of the total energy, respectively, of the three compressive deformation stages; 3) Particle size and loading rate had significant effects on the deformation and energy dissipation of the gangue. The smaller the particle size or loading rate were, the more energy was required to produce the same level of deformation; 4) When the second stress load was smaller than the first-time stress load, the strain of the gangue increased approximately linearly. When the second stress load was greater, the strain of the gangue showed a logarithmic increase with the stress. Furthermore, under a greater first-time stress load, the gangue presented smaller strain under secondary compression, showed more resistance to deformation, and consumed more energy to produce the same deformation.

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1. Introduction

Solid backfill coal mining is a new method of green mining in which backfill material is transported by a special handling system and processed through a tamping device behind a hydraulic support at the mining face. This method can not only control the overlying strata deformation effectively, but dispose gangue or other solid wastes cosmically as well [1–4]. Based on the control effects, the author comes up with the idea that dynamic hazards caused by hard roof, such as rock burst, coal and gas outburst and shockwaves, can be prevented by solid backfill mining. Many researches have proved that energy saltation is the main reason for these dynamic hazards and energy saltation is caused by deformation or breaking down of hard roof [5]. With application of backfill mining method, hard roof deformation will release less energy, in the meantime, the crushed gangue backfilled into the goaf will absorb the energy. This will be able to reduce the chance of dynamic hazards [6]. Therefore, it is necessary to study the deformation and energy dissipation laws of gangue backfill materials under compression, and the factors that contribute to the deformation and energy dissipation.

So far, studies have been conducted worldwidely to investigate the mechanical compaction characteristics of gangue samples with different particle sizes [7–9]. However, there have been few studies on energy dissipation characteristics of samples mixed with crushed gangue. Xu Wenbin [10] investigated energy dissipation characteristics of cemented backfill under triaxial compression and concluded that an increase in confining pressure improved the energy consumption required for backfill failure, and that pre-peak energy consumption, post-peak energy consumption, deformation energy per unit volume, and total energy consumption of backfill had a quadratic function relationship with confining pressure. Deng Daiqiang [11] used an INSTRON rigidity servo testing machine to perform splitting tensile tests on backfill with different cement-sand ratios and found that backfill only needed to absorb a small amount of energy to cause tensile failure, and tensile failure acted as a dominant factor affecting the fracture properties of backfill. Xia Changjing [12] used a Split Hopkinson Pressure Bar (SHPB) to perform impact tests on artificial rock with different porosities and concluded that at the same impact velocity, as the porosity increased, the amount of energy dissipated in the rock increased, and the amount of energy dissipated by the critical failure of the rock decreased. Zhang Zhizhen [13] performed uniaxial compression tests on red sandstone specimens at four loading rates and discovered elastic energy and dissipation energy evolved and distributed with stress. Zhang Jixiong [14], Huang Yanli [15] researched on gangue deformation laws under compression and time correlation properties. However, they neither study crushed gangue deformation under different loading rate and first-time stress load nor the energy dissipation during compression.

Gangue is a typical inhomogeneous and discontinuous medium, and due to its many fissures, is in weak equilibrium [16]. The fissures and gaps between gangues under compression undergo a series of changes, which are accompanied by the absorption and dissipation of energy.

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Moreover, under different geostresses and engineering actions, the deformation failure and energy dissipation characteristics of gangue show complex changes depending on particle size, gangue ratios, and first-time stress load. According to the laws of thermodynamics, energy conversion is an essential feature of the physical processes of substances, and physical destruction is a state instability phenomenon driven by energy [17–19]. Therefore, studying and establishing energy absorption and dissipation characteristics of gangue backfill under initial compaction and the strata stress of the goaf are of great significance in studying the prevention and mechanism of hard roof induced dynamic hazards by using solid backfill mining method.

This paper studied gangue backfill in the goaf of Jining No.3 Coal Mine and proposed fundamentals of energy dissipation calculations for crushed gangue according to status and actual stress state of gangue in solid backfill mining working face. Using a SANS testing machine and self-made steel cylinder, the effects of the gangue particle size, loading rate, and first-time stress load on the compressive deformation and energy dissipation of gangue were studied.

2. Testing apparatus and test scheme design

2.1. Design basis

Crushed gangue are transported to the back of the working face through backfill conveyor, and then pushed and consolidated with a tamping device. The interaction relationship between gangue backfill body and roof is shown in Fig. 1.

The main reason why hard roof can lead to dynamic hazards is the energy release during the deformation or break of hard roof. From the diagram above, it is obvious that gangue backfill body can support the hard roof to reduce the deformation and energy release. At the same time, the compression of gangue will consume part of the released energy, so the risk of dynamic hazards is lowered. Therefore, when the hard roof deformation is small (also the gangue deformation under compression is small) and the energy consumed by the gangue backfill body is large, there is little chance of dynamic hazards.

Due to different gangue diameters, backfill technique, backfill height, and distinct rupture mode, the stress status, deformation and energy dissipation are unique but can be divided into three conditions below:

(1) Different gangue diameters.
Gangue, with different diameters, will have different deformation and energy dissipation. To determine how gangue diameters influence deformation and energy dissipation, gangue compression experiments with different diameters are conducted.

(2) Different stress loading rates.
When the amount of backfill gangue is relatively low, the tamping device is simply used to push gangue into the goaf rather than offer extra compaction force. Meanwhile the backfill body is not subjected to extra force until the roof breaks. When the roof breaks, it is rotates from the break point and falls down to the backfill body so as to exert pressure on the backfill body. The roof falls freely before contacting the gangue backfill body. With the increase of the distance between the break point and backfill body, the stress loading rate applied to the backfill body is different. The larger the distance is, the greater the impact force the backfill body suffers, and the impact force loading rate is more quickly as well. So the deformation and energy dissipation characteristics of gangue under different stress loading rates should be tested.

(3) Different first-time stress loads.
If the large quantity of backfill gangue is required, the tamping device is used to push and tamp the gangue into the goaf densely. Assuming that the tamp force of tamping device is P, then, the gangue experiences the first-time stress compaction force from 0 Mpa to P and return to 0 Mpa again. After that, with the deformation of roof and overlying strata, the gangue compaction force gradually increases from 0 MPa to the initial rock stress. Therefore, it is necessary to test the deformation and energy dissipation characteristics of gangue under different first-time stress loads.

2.2. Test scheme design

According to the experiment design basis, a design was created using the single-variable method to test the influences of eight particle size fractions, six loading rates, and seven first-time stress loads on the energy dissipation characteristics of gangue. The test scheme is shown in Table 1.

The first-time stress loads were applied from 0 MPa, 0.5 MPa, 1.0 MPa, 1.5 MPa, 2.0 MPa, 2.5 MPa, and 3.0 MPa at a rate of 1.0 kN/s, then decreased to 0 MPa at once, and then increased to the testing system's limit finally.

2.3. Experimental apparatus and samples preparation

(1) Experimental apparatus
A SANS testing machine was used as the experimental apparatus, which provided a maximum axial force of 300 kN with a measurement range of 0–250 mm. The compactor was a self-designed

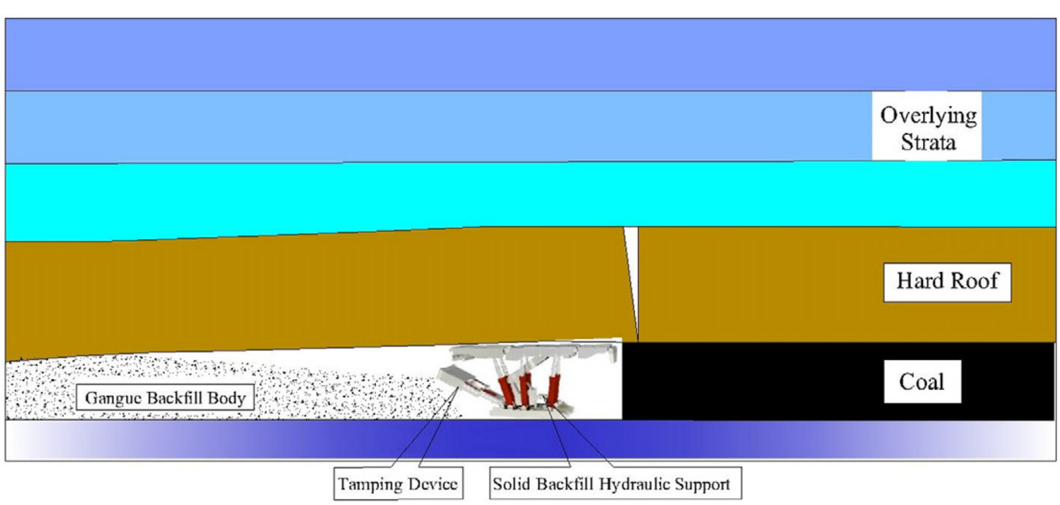

Fig. 1. Interaction relationship between gangue backfill body and roof.

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