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Study on Bearing Capacity and Acoustic Emission Characteristics of Continuous-Discontinuous Gangue Ratio Scheme

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Abstract: *In order to study the compaction of filling gangue in goaf after solid filling in coal mine, coal gangue with different particle sizes was selected to carry out confined compression test by continuous gradation and single particle size ratio scheme. At the same time, acoustic emission instrument was used to monitor the internal damage of gangue. The conclusions are as follows: 1) The gangue has better stability than the single ratio scheme in the continuous grading scheme; 2) Large-size gangue produces more energy when it is destroyed, and acoustic emission activities are more frequent. The conclusion of this experiment can better help to grasp the law of overlying strata movement after solid filling in coal mine, so as to better control the roof activity.*

Keywords: *Gangue compression, Acoustic emission, Mechanical properties*

1. Introduction

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Coal mining has broken the original rock stress and original structure of rock strata, resulting in increasingly serious problems such as surface subsidence, building (structure) cracking, railway damage and solid waste accumulation, which seriously affects the high-quality coordinated development of ecological environment and economy in mining areas. Among them, coal gangue is the most discharged solid waste. A large amount of coal gangue is accumulated on the surface after discharge, occupying a large amount of land, and is one of the main pollution sources. Solid filling coal mining uses solid waste such as gangue solid waste to fill the goaf, which can control the movement and fragmentation of rock strata, reduce the discharge of gangue and the damage to the ecological environment of the mining area. Solid filling mining has become one of the main ways to realize green mining. Gangue bulk material is the main factor to control strata movement in solid filling mining. The bearing and deformation characteristics of gangue bulk determine the effect of controlling strata movement and have a direct impact on the management of surface subsidence roof[1-2]. Therefore, it is of great scientific significance to study the confined compression deformation characteristics of gangue particles and reveal the fracture evolution mechanism of granular materials.

In view of the compaction characteristics of gangue granular materials, domestic and foreign scholars have carried out a lot of research. Based on the confined confined compression test of gangue, Yu Yang calculated the strain energy per unit volume during the deformation of gangue, and analyzed the influence of different particle sizes, different loading rates and different initial loading stresses on the energy dissipation and deformation failure of gangue[3]. Yanli Huang used PFC software to study the macroscopic mechanical behavior and microscopic particle motion law of coal gangue with different gradations under different enclosure conditions and loading rates[4].

In this study, the bearing capacity of gangue with continuous grading scheme and single particle size scheme is compared and analyzed, and the law of compaction bearing capacity of gangue bulk is preliminarily clarified, which provides a certain guiding significance for solid filling mining.

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2. Test preparation and result analysis

In order to study the bearing capacity of solid filling gangue bulk in goaf, different proportion schemes were selected to carry out the confined compression test of gangue, and the bearing capacity of gangue with different proportion schemes was compared. The particle size distribution of gangue required for the experiment is 5-30mm, and the ratio scheme of gangue is designed by using talbol continuous gradation and single particle size ratio.

2.1. Instruments Required for Experiment

Before the test, the required coal gangue was crushed by a Jaw crusher, and then the 5-10 mm, 10-15 mm, 15-20 mm, and 20-30 mm particle size groups required for the experiment were screened by particle size screening. In this experiment, a 170mm × 125mm (high × diameter) steel cylinder is used to control the quality of gangue loading. The rock mechanics servo system transmits the pressure to the gangue in the steel cylinder through the indenter, and records the stress and strain changes during the process. The acoustic emission monitoring system monitors the crushing of gangue. Figure 1 is the instrument diagram required for the test process.

(a) Jaw crusher (b) Steel cylinder (c) Rock servo machine (d) Acoustic emission system

Figure 1: Instruments required for the experiment

2.2. Experimental Scheme

After crushing the coal gangue, the crushed gangue with particle sizes of 5~10 mm,10~15 m,15~20 mm and 20-30 mm were selected by grading the particle size of the particle size sieve. Figure 2 is gangue with different particle sizes and particle size sieves. After screening, the gangue mixed according to different Taibo grading loading schemes is loaded into a steel drum, and a total of 2400 g of gangue is loaded. The grading scheme is shown in Table 1. The axial loading stress is set to 15 MPa, and the loading rate is constant to 0.1kn / s. The confined compression characteristic test is carried out. The compaction test stops when the stress reaches the set value. In order to control the experimental variables to maintain the consistency of the water content of the gangue, the gangue is dried and dewatered before the experiment.

Table 1: Gangue ratio scheme

Gangue ratio scheme		Quality of gangue with different particle sizes(g)			
		20~30mm	15~20mm	10~15mm	5~10mm
continuous grading	0.3	661(27.5%)	422(17.6%)	538(22.4%)	779(32.5%)
	0.4	703(29.3%)	433(18.0%)	532(22.2%)	732(30.5%)
	0.5	743(31.0%)	444(18.5%)	526(21.9%)	687(28.6%)
	0.6	787(32.8%)	453(18.9%)	519(21.6%)	641(26.7%)
	0.7	830(34.6%)	460(19.2%)	512(21.3%)	598(24.9%)
Single ratio	5~10				2400(100%)
	10~15			2400(100%)	
	15~20		2400(100%)		
	20~30	2400(100%)			

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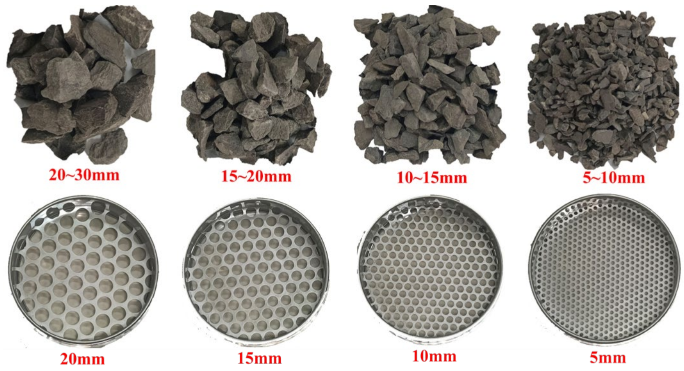

Figure 2: Each particle size gangue material and particle size sieve

2.3. Test result analysis

2.3.1. Instantaneous compaction deformation characteristics of gangue bulk

Figure 3 shows the stress-strain relationship curve during the instantaneous compression process of gangue. During the test, the degree of compaction and crushing of gangue gradually increased, but the rate of strain increase showed a decreasing trend. With the increase of stress, the instantaneous compression process of gangue can be divided into compaction stage (0-2.5MPa), crushing and re-compaction stage (2.5-7MPa) and stable compaction stage. In the compaction stage, the small particle size gangue inside the steel cylinder is subjected to axial pressure to produce downward force. Firstly, a large range of slip occurs to fill the gap between the gangue particles, which limits the slip space of the large particle size gangue after compression, so that the large particle size gangue is broken. When the axial pressure is 2.5-7MPa, it is the crushing and re-compaction stage. At this stage, most of the voids between the gangue are filled and no longer slip, and the remaining voids gradually decrease with the increase of stress. When the pressure is 7-15 MPa, it is a stable compaction stage. At this time, the overall structure of the gangue tends to be stable, and the stress-strain curve tends to be gentle. The compression deformation is more difficult, and the strain increase rate decreases with the increase of stress, and finally tends to be stable.

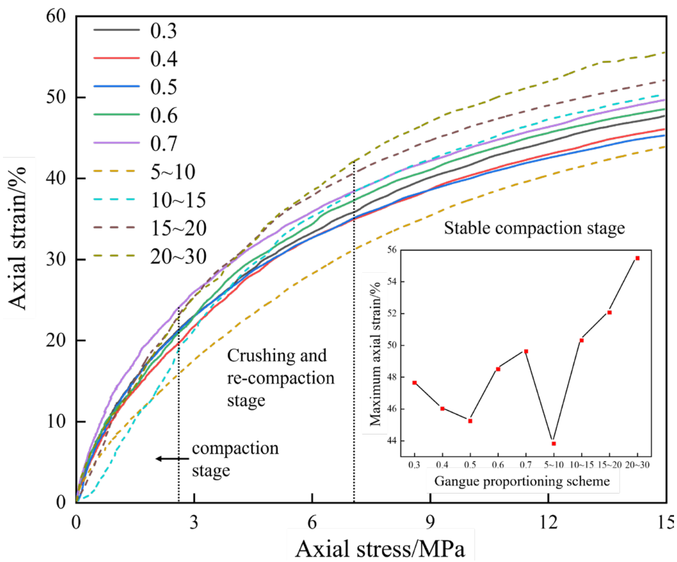

Figure 3: Stress-strain curves of different gradation gangue

After the test, the gangue in the steel cylinder is screened again. Table 2 is the statistics of the quality and crushing rate of gangue with different particle sizes after screening. According to the statistical results, it can be seen that the crushing rate is proportional to the porosity of the gangue particles in the continuous grading, and when the porosity is similar, the larger the proportion of large-sized gangue, the higher the degree of gangue crushing. When the ratio is single, the crushing rate of gangue increases with the increase of particle size, the minimum is 41.21%, the maximum is 77.25%, which is quite different from the maximum crushing rate of 29.33% of continuous grading, indicating that the continuous grading

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gangue has stronger crushing resistance. This is due to the complementary of gangue with different particle sizes in continuous grading, which is easy to form a sfig structure after bearing pressure. There is less sliding between gangues in the structure, which reduces the extrusion of gangues.

Table 2: Quality and crushing rate of gangue with different particle sizes after test

Gangue ratio scheme		Quality of gangue with different particle sizes(g)					percent reduction(%)
		20~30mm	15~20mm	10~15	5~10mm	0~5mm	
continuous grading	0.3	410	377	400	590	623	25.96
	0.4	328	347	474	669	582	24.25
	0.5	399	367	457	625	552	23.00
	0.6	432	315	470	557	626	26.08
	0.7	205	377	468	646	704	29.33
Single ratio	5~10	0	0	0	1411	989	41.21
	10~15	0	0	831	763	806	65.38
	15~20	0	661	633	486	620	72.46
	20~30	546	463	394	395	602	77.25

2.3.2. Acoustic emission response characteristics of instantaneous compaction of gangue granular

The acoustic emission monitoring system is DS5-16B full information acoustic emission signal instrument. The AE frequency response range adopted in the test is 100~400kHz and the sampling frequency is 1MHz. Two sensors are used to collect acoustic emission signals. Each sensor is equipped with a preamplifier, and a fixed threshold value of 40dB is selected to reduce the impact of noise on acoustic emission monitoring results. In the process of compression and crushing of gangue, the information of acoustic emission characteristics is collected. When the axial pressure is 15MPa, the strain, AE energy and cumulative energy curves of mixed gangue with different gradations are shown in figure 4. At the same time, based on the acoustic emission energy characteristics of mixed gangue with different gradations, the AE energy-cumulative energy curve is shown in tabure 5. It can be seen from figure 4 and Figure 5.

1) The overall trend of energy change of 9 kinds of graded gangue is similar, which can be roughly divided into three stages: front, middle and back. The acoustic emission signals in the early and late loading stages are less, and the acoustic emission signals in the middle loading stage are more. In the early stage of loading, under the action of external pressure, the pores between the gangue are mainly compacted, and the gangue is less broken. The acoustic emission signal is mainly derived from the friction AE, so the energy changes little. In the middle stage of loading, the gangue is squeezed with each other, resulting in relative sliding, and the gangue is broken more. The acoustic emission signal is composed of friction AE and broken AE, and the energy changes greatly. In the later stage of loading, the gangue finally forms a relatively stable compression entity under the action of external pressure. The main source of acoustic emission signal becomes frictional AE again, and the energy is relatively stable.

2) According to the AE energy, cumulative energy, and strain-time curves, it can be seen that the AE energy and cumulative energy change with the change of the void ratio of the mixed gangue and the proportion of the large-size gangue in the continuous gradation of Taibo, and the change law is similar to the maximum strain of the gangue, that is, the void ratio of the mixed gangue is small. The AE energy distribution range is wide, and the maximum AE energy and cumulative energy increase when the void ratio is close to the proportion of large-size gangue. When the porosity is small, the acoustic emission energy is small, indicating that the degree of gangue crushing is low; when the proportion of large-size gangue is large, the acoustic emission energy is high, indicating that the energy generated by the crushing of large-size gangue is greater than that of small-size gangue.

Due to the similar particle size of single particle size ratio, the AE energy of gangue slip phenomenon in the early stage of loading is the combination of friction AE and broken AE, showing a different increasing trend from that of continuous gradation. With the increase of particle size, the AE energy and cumulative energy show a significant increase, and the decrease in the later stage of loading is more severe, indicating that the AE energy of single particle size ratio mainly comes from the broken AE energy generated by gangue crushing, and once again shows that the energy generated by large particle size gangue crushing is greater than that of small particle size.

3) According to figure 5, the cumulative energy of acoustic emission of the nine schemes is 6.04×10^6, 10.67×10^6, 10.3×106, 17.6×10^6, 24.9×10^6, 4.65×10^6, 4.74×106, 29.2×10^6 and 35.7×10^6, respectively. The cumulative energy is not only related to the size of the strongest acoustic emission, but also to the

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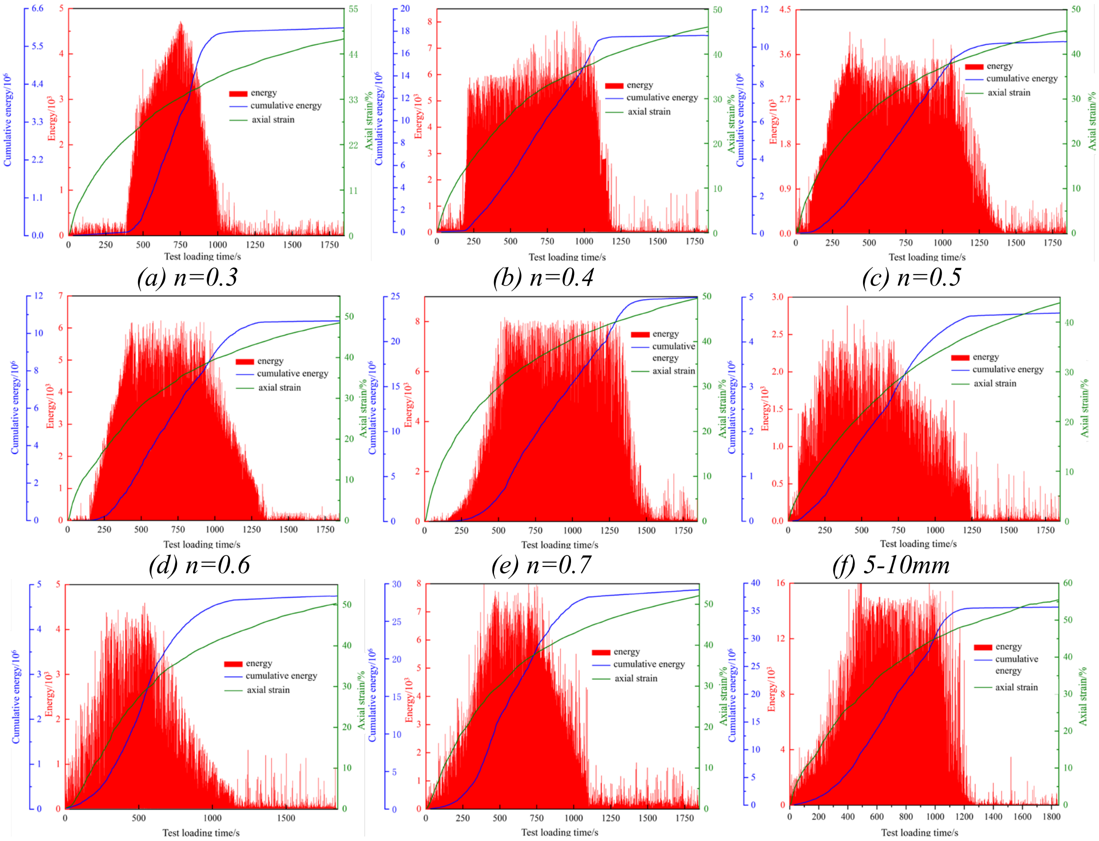
duration and the total number of events. According to the AE energy and cumulative energy diagram, it can be seen that the energy of the gradation with large particle size gangue is greater than that of the gradation with small particle size gangue, and the gradation with large particle size accounts for a relatively high proportion. The acoustic emission parameters are the highest in each stage, indicating that the acoustic emission activity is more frequent when the large particle size gangue is crushed under pressure.



(a) n=0.3 (b) n=0.4 (c) n=0.5

(d) n=0.6 (e) n=0.7 (f) 5-10mm

(g) 10-15mm (h) 15-20mm (i) 20-30mm

Figure 4: AE energy, cumulative energy and strain-time curve of gangue compression process

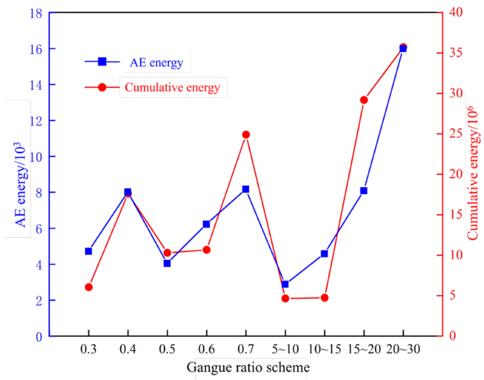


Figure 5: Acoustic emission AE energy, cumulative energy

3. Conclusions

1) The stress-strain curves of 9 kinds of gangue ratio schemes show an exponential relationship in the process of confined compression test. The degree of compression of gangue is different in different schemes. The continuous grading scheme is better than the single particle size scheme, and the anti-deformation ability of small particle size gangue is stronger than that of large particle size gangue. The crushing rate of continuous gradation is significantly lower than that of single particle size, indicating that the compressive capacity of large particle size gangue is less than that of small particle size gangue.

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2) In the early stage of compression, the acoustic emission signal is less, and the energy is mainly generated by friction. In the middle stage of compression, the acoustic emission signal is stronger, and the energy is provided by the friction of gangue and the crushing of gangue. In the later stage of compression, the acoustic emission signal is stable, mainly generated by friction. The more the proportion of large particle size gangue, the stronger the acoustic emission energy signal, indicating that the more energy generated during the compression process, the greater the compression deformation of gangue, and the more unstable the overall structure.

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