Experimental Investigation on Stress-Cracks-AE of the PRCMM for Disaster Prevention

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Abstract. The present study highlighted the experimental investigation on acoustic emission (AE) evolution relations of the porous rock-like composite mineral material (PRCMM). Firstly, we developed an approach experimentally investigational method with combined AE-stress-duration response characteristics of the PRCMM, regarded as a crack-defect medium, employed in the mineral waste. The AE inherent characteristic parameters based on the duration, peak of stress accumulation (PSA) and PSA variation in the AE abnormality monitoring model of cracks recordings of mineral-waste-based specimens were obviously distinguish. It was indicated that the abnormality of loading-unloading-displacement-triggering-damage (LUDTD) was substantially similar. Thereby we concluded three stages applicable to the determination of mechanical properties of the PRCMM. Finally, field applications verified that the approach could greatly enhance the crack activities and ranges, and improved the safety and productions better. It would provide a theoretical foundation for dynamic disaster prevention and mineral waste reutilization.

Introduction

The strong mining-induced shock or vibration produced by coal and rock deformation and failure can easily trigger the tremor, even rock burst and coal-gas outburst disaster happened. Mineral waste reutilization successfully have solved the difficult problems of mined-out-area backfilling, derived dynamic disaster prevention and environment management in the waste mines of gold and gangue [1-4]. Damage in porous soft rocks is associated with the phenomenon of localization under conditions of low stress and temperature [5]. Observational work of failure zones of the behavior of the rock at a macroscopic scale can be considered as strain localization. The description of damage is classical in soils, sands, clays. One of vital observation is a peak of stress accumulation (PSA) in the specimen's response, the strain is concentrated in shear deformation zone [6]. Afterwards, experimental observations utmost focused on damage in soil to explain the strain softening of the specimen's response, including the stable or unstable characteristics on the elastic energy of the specimen.
To predict the initiation of appearance of the shear deformation and relating evolution law, the fractal, bifurcation and lubrication theory has been developed. The shear deformation is regarded as instability of the mechanical system. This experience had subsequently developed for soils and soft rocks. Therefore, it is necessary to test at laboratory for a macroscopic performance of the localization in porous soft rock like sandstone. Moreover, localization in soft porous rocks is defined at the micro-scale by a strong increase of the local density of micro-cracks in comparison to the rock material surface appearance. Inside, the material becomes strongly damaging, which rapidly degrades its inherent mechanical characteristic, which is local strain softening. Therefore, the behavior of the shear bands strongly influenced the specimen's response, and it is important to investigate in detail. Former studies to determine a representative elementary volume (REV) of a jointed rock mass in underground infrastructure. The equivalent geometrical and mechanical property REV sizes were determined based on fracture modeling experiments on a synthetic rock mass. Delightedly, a new achievement was that the ISRM suggested methods on laboratory fracture toughness testing and borehole and surface geophysical tests had completed. Furthermore, analysis of rock mass damage characteristics based on acoustic emission (AE) has significant advantages [4, 6]. It can monitor damage of the surrounding rock and rock engineering in the long-term performance, continuous, real-time means. Particularly, shock wave propagation and attenuation in mined coal and rock medium, micro-crack and energy releasing can also be investigated. The AE characteristics on rock mass deformation and stress triggering modification under compression, tension and shear have been successfully achieved, involving of the properties of porous rock damage, such as limestone, sandstone, coal and granite damage. Fulfilling precursory contributions mainly focused on the relationship between the AE parameters and the constitutive-law on peak strength of rock-coal specimen. Moreover the shear deformation has observed in soils, collapsible loess and sedimentary overlying strata in natural geological structures and in laboratory experiments on soft rocks.

**Experimental Procedures**

**Specimen and Setting**

The aggregate of the PRCCM was mineral-waste which originated from the Wudong mine of Urumchi in the western of China. The component of mineral-waste-based specimens contained sand, coal-powder, thickener agent, gypsum and water, with content ratio of 30:30:15:15:10. The proportion of 0.5-1.0 mm particle size is 3.9%, 0.25-0.5 mm is 29.1%, 0.1-0.25 mm is 67.0%, respectively. It is a typical defects-rock. The gypsum and ferrous powder were cementing substance. The size of rock-coal specimens is 70mm×70mm×70mm, and achieved in the Key Laboratory of Western Mines and Disaster Prevention, Ministry of Education of China.

**Test Apparatus and Procedures**

The uniaxial compression loading employed the YYW-II apparatus, with the maximum range of 10.0kN, and of the loading-rate 0.05mm/s. The deformation-damage and cracks abnormality monitoring model of specimens was applied the advanced AE system. 4 smart AE sensors were arranged. Fig.1 described the laboratory experimental testing and procedures.
Result and Analysis

Relations of the LUDTD

The findings of experimental investigation were that the characteristics on the loading-unloading-displacement-triggering-damage of the PRCMM under uniaxial compression was substantial similar to the natural intact rock. Accordingly, it was obviously indicated that the evolution relations of spatial-temporal-strength on the PRCMM were relatively collaborative. Moreover, the evolution of the LUDTD primarily consisted of three stages, which straightforwardly considered as the initial compaction, elastic-plastic and peak destruction. Before the peak stress, coal specimens improved the growth of stress but the plastic deformation slow of corresponding strain. When rock specimens appeared to slow the growth of stress, the plastic deformation would be improved. Fig.2 demonstrates the variations of loading-displacement. We can be seen that the stress of coal specimen increased twice at the loading accumulation of 3.5kN. After loading acceleration to 3.5kN, the displacement increased slowly, and the stress gradient increased relatively obvious. When the loading accumulated to stress peak, twice pressure-drops happened. Experiment observation showed that the cracks formed through the defects surface.

Also, the loading from 7.0kN to the peak, the displacements of rock specimen increased rapidly. On the contrary, the loading velocity increased relatively slowly, and the gradient of the displacement was flattened obviously. After the stress peak, dual remarkable stress droppings had occurrence due to the strain-softening. At the moment, the caution should be kept enough, otherwise, destabilization often would be occurrence. Meanwhile, micro-cracks gradually formed and propagated, thereby the phenomena of macro- cracks developing and dynamic damage could be observed.
Mechanical properties and damage characteristics

AE is precursory information of coal and rock catastrophic shock. The typical statistical results of stress-stain and AE frequency illustrated in Fig.3. It was indicate that there were obvious distinctions between rock and coal specimens of mechanical properties and damage characteristics.

![Figure 3. Mechanical Characteristics on the PRCMM.](image)

For the rock specimens, before the strength peak, AE nearly impossible occurred at the initial stage of the compaction, and the two trends were almost coincident. A sharp increase of AE appeared at the elastic stage. The amount of AE was very unstable at the later stage of elasticity and plasticity early stage, with a downward trend overall. Near the peak strength, the amount of AE for rock specimens showed a sharp decrease trend generally. For rock specimens, the maximum probability of AE-counts appeared before the strength peak. Characteristics of AE were almost in accordance with the other rock specimens. However, AE amount reduced at about 1.0MPa. Then, AE amount suddenly increased at the latter stage.

In comparison, at the initial compaction stage, the AE of the coal specimen increased slowly before the peak strength. At later compaction and early elastic stage, AE was relatively stable. In addition, at the middle and later elastic stage, the overall trend of AE increased rapidly. Then, the amount of AE characterized fluctuation at the plastic stage. While near the stress peak, AE activities showed a decreasing trend. The peak of the AE releasing rate occurred before stress peak. However, when the stress acceleration arrived to 0.7MPa, the AE amount decreased. The reductions were slower than rock specimens.

Regularity of AE-Stress-Duration

Generally, the evolution regime of rock damage is related to the spatial-temporal-strength and disturbance characteristics. Mogi obtained precursory achievements on the relation between AE frequency and axial compression stress. Bieniawski provided the corresponding relations of rock failure process. According to the Kasier effect, new damage would appear in the strain localization band, it reflected the process of micro-crack triggering growth of rocks under non-uniform loading.

During the experiment under uniaxial compression, the time dependence had taken considerations into the whole experiment exercise in virtue of the non-linear characteristics on the PRCMM damage. Fig.4 illustrated the relations of AE frequency-energy and swelling potential with the duration. It was can be seen that AE happened obvious distinction at distinct stress and loading stage. It indicated that the cracks propagation under suitably stress would result in inelastic behavior. We distinguished 3 stages to determine the mechanical properties of the PRCMM.
1) Compaction stress stage

At this stage, AE rarely occurred with the axial stress increasing. However, AE occurrence of rock specimen hardly could happen and coal specimens appeared a few AE with low energy releasing. It was indicated that the self-sealing characteristics upon AE frequency was similar to the stress or strain.

2) Damage-crack stage

Stress regime of rock specimens presented a smoothing rising with the increasing and stable strain, AE frequency had a growth suddenly with lower energy releasing during swelling heaves or shrinking, the AE frequency and accumulative energy level of coal specimens emerged initially destabilization then increased sharply. Moreover, with the increasingly additional axial loading, the AE frequency decreased then kept quit stable state and self-sealing for a while, the accumulating energy peak would be arrived at the peak stress. AE frequency of rock specimens occurred sudden increasing among their energy decreasing. The AE frequency of coal specimens showed dynamical destabilization and concave motivation of energy releasing occurred.

3) Failure-destabilization stage

Rock specimen was relatively brittle, thus it released continuous AE, and AE rate and energy decreased sharply. The AE frequency of coal specimen would reach its crest after the stress peak because of its inherent fracture toughness and released continuous and rich. The AE regime and stress-strain were approximately coincident and frequency and energy decreased slowly. The vital statistics of AE-stress-time in Table 1 were used to verify the inherent properties, such as brittleness, roughness, toughness, etc., in correspondence various specimens before stress peak.

Applications of site investigation have testified that the rock mass is not failing overall and remains stable with the stress in the rock mass rising. However, attention should be paid because the active AE indicated that new cracks have already extended. These would significantly influence the stability of the subsequent-backfilling zone.

Additionally, Fig.4 demonstrated the AE source location of the rock and coal specimen. The X-shaped conjugate shear failure and the AE sources location were conformed to its destruction. It was indicated that the damage trend complied with the field investigation.
Table 1. Results of AE-Stress-Duration before Strength Peak.

<table>
<thead>
<tr>
<th>Stress/MPa</th>
<th>Time interval/s</th>
<th>AE rate(count/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rock</td>
<td>Coal</td>
</tr>
<tr>
<td>0.0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.2</td>
<td>0.2</td>
<td>48</td>
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<tr>
<td>0.4</td>
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<td>0.6</td>
<td>10</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
<td>6</td>
</tr>
<tr>
<td>1.0</td>
<td>0.91</td>
<td>7</td>
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<tr>
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<td>3</td>
</tr>
<tr>
<td>1.58</td>
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<td>9</td>
</tr>
</tbody>
</table>

Conclusions

1) The AE is an effective precursor signal to experimentally investigate the characteristics of the PRCCM at different stress, the AE characteristic parameters of mineral-waster-based specimens were obviously distinguish it was indicated that the LUDTD under different stress condition was substantial similarity, and the evolution relations of spatial- temporal-strength on the PRCMM were relatively collaborative.

2) We concluded three stages applicable to the determination of mechanical properties of the PRCMM. It had obviously illustrated that the X-shaped conjugate shear failure and the sources location were complied with destruction of intact rock.

References


