Research on Failure Characteristics and Supporting Mechanisms of Surrounding Rock in Coal Rock Tunnels

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Abstract. The failure mechanism of anchored coal-rock composites was investigated through uniaxial compression experiments, which examined the mechanical characteristics and failure features of the samples under varying loading rates and coal-rock height ratios in order to clarify the specimens' anchoring mechanism. The findings of the study demonstrate that the coal-rock system makes adequate adaptive adjustments at lower loading rates, suppressing crack development. As the procedure of loading rate increases, the stability of one's anchored coal-rock composite deteriorates, leading to a significant increase in both the reach of their highest strength and kinetic energy about those anchored coal-rock composites. An anchor is a rod's extra stress that improves the coal-rock system's mechanical performance. The outcome is able to offer theoretical guidance with the anchoring support of coal-rock roadway roofs.

Keywords: coal-rock combination; characteristics of destruction; bolt support; crack propagation; different height ratio

1 Introduction

Because of the slow depletion of surface-level resources, deep mining of mineral resources has emerged as an unavoidable direction, bringing about challenges like high ground stress and dynamic ground pressure, thereby emphasizing the stability and safety issues of surrounding rock during the mining process[1]. The application of anchor rod support technology has brought about significant improvements in the stability of coal-rock roadway roofs. Hence, it is practically important to investigate how anchor rods affect coal-rock roadway failure characteristics[2].

Li et al. studied the mechanical characteristics as well as unstable processes of composite bodies with various coal-rock ratios through uniaxial compression tests[3]. Ma et al. explored the mechanical characteristics of coal-rock composite structure and found that the majority of cracks in these bodies appear within the coal component[4]. Wu et al. exhaustively describe the characteristics and traits of coal-rock composite bodies and the anchoring mechanism, revealing that under uniaxial compression tests,

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it restricts the initiation of cracks[5]. Huang et al. examined how loading rate affects the mechanical attributes associated with composite coal-rock[6].

In conclusion, the failure features of coal-rock masses have been extensively studied by numerous scholars. The loading rate within the solid coal-rock system has changed as a result of the mining rate's influence on the stability of coal-rock mass roads. Interaction rock and coal at various height ratios. Investigation of damage in anchored coal-rock composite bodies requires in-depth research. Through the preparation of anchored coal-rock composite specimens, mechanical properties and breakdown patterns under various loading rates and coal-rock height ratios are being investigated, exposing the mechanism of interaction between anchor rods and coal-rock composites. The research findings presented in this paper can serve as theoretical references for anchor rod support in underground coal mine engineering's coal-rock highway roofs.

2 Experimental Introduction

The significant lithological differences in on-site samples impact the generalizability of research results. To achieve a more uniform density of the coal-rock material and reach the expected experimental outcomes, conduct coal-rock similar proportion tests. The final mass ratio for coal was determined to be cement: sand: coal dust: water at 6.17:5.5:75.46:8.15, and for rock, the mass ratio of quartz sand: cement: gypsum: water was 5:2.5:2.5:1.2. A water-reducing agent was added at a 1% dosage. Coal and rock specimens were poured into standard specimens that were 50 mm by 100 mm each in order to determine the physical mechanical properties of the coal and rock monomers. It was noticed the experiment does not consider the impact of anchor rod deformation damage on the strength of the coal-rock composite.

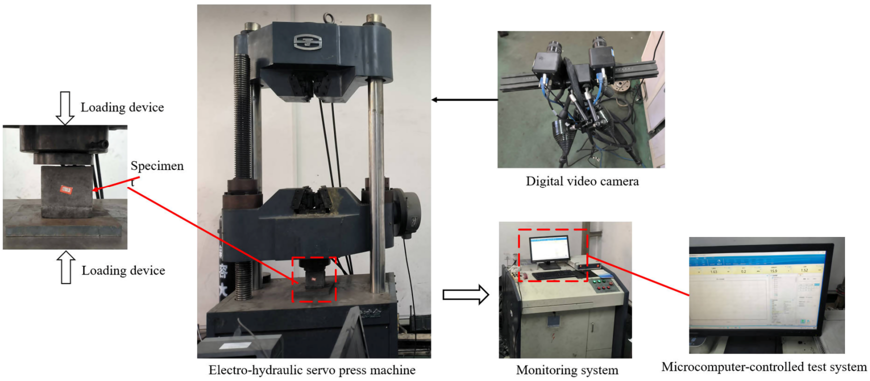

Fig. 1. Test system.

Figure 1 displays the WAW-600C computer-controlled hydraulic control universal testing machine used in testing loading systems. It applies a maximum load of 600 kN. The coal-to-rock height ratios are 2:1, 1:1, and 1:2, with corresponding specimen numbers A, B, and C. Table 1 lists the mechanical and physical characteristics of rock as well as coal monomers. The coal-rock unit acts as weaker surrounding rock with mechanical properties. The experimental loading procedure involves displacement control, with 0.05, 0.10, 0.15, and 0.20 mm/min loading rates, corresponding to specimens labeled D, E, F, and G. The designation "W" is used for specimens without anchoring. Ensure three sets of parallel experiments for each loading rate.

Table 1. Coal rock monomer's physical and mechanical properties.

Specimen type	Density /(kg·m^{-3})	Cohesion /MPa	Compressive strength/MPa	Elastic modulus /MPa
Coal	1,300	0.35	0.93	132
Rock	2,500	1.17	5.80	384

3 Experimental Results and Analysis

That anchored coal-rock composite fails by a combination of shear and tensile failure under uniaxial compression. Figure 2 illustrates the coal-rock combination body's damage failure mode. The failure deformation of specimens A-G with a loading rate of 0.2 mm/min is substantially higher than that of specimens tested at 0.05 mm/min and 0.1 mm/min in uniaxial compression examinations during anchored specimens regarding that coal-to-rock height ratio of 2:1.

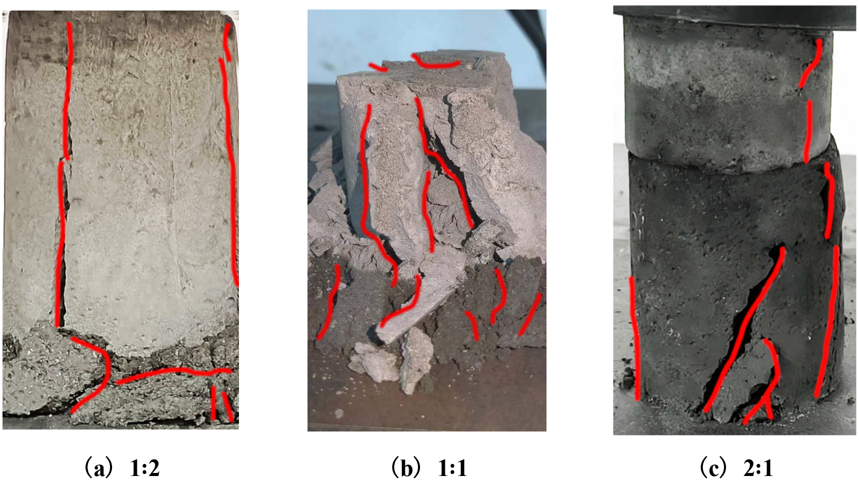

Fig. 2. Mechanism of damage failure on coal-rock combination body.

When the coal-to-rock height ratio is 1:1, the anchored specimen B-D exhibits microcracks forming within the coal body during the early loading phase. With continued loading, these microcracks propagate, leading to axial cracks appearing first at the corners, after which the coal body's center begins to break, ultimately resulting in a crack penetrating through the coal body. At a 1:1 coal-to-rock ratio, this breakdown pattern is most noticeable. While the height ratio of rock to coal is 1:2, anchored specimen C-D exhibits penetrating cracks in the coal aligned with the direction of rock fractures, all penetrating axially but stopping at the contact between rock and coal. When the coal reaches its load-bearing capacity, the rock is still able to bear the load. The damage and failure extent associated with an anchored sample, which has a coal-to-rock height ratio of 1:2, is less than those with ratios of 1:1 and 2:1.

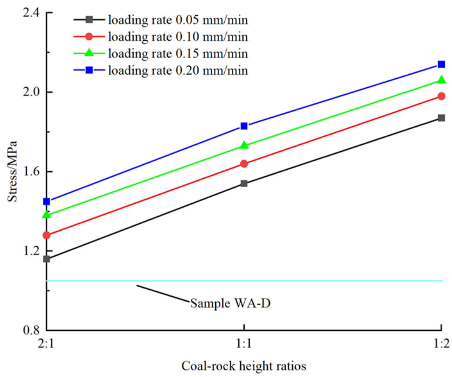

Fig. 3. Relationship between compressive strength of specimens and height ratio of coal to rock.

Figure 3 displays the relationship between the compressive strength of specimens and the height ratio of coal to rock. Figure 4 displays the coal-rock composite's compressive strength fitting curves. Specimen A-D has the lowest strength at 1.16 MPa, whereas specimen C-G has the highest stress at 2.14 MPa. The compressive strength and elastic modulus of specimens are mainly influenced by the coal body portion.

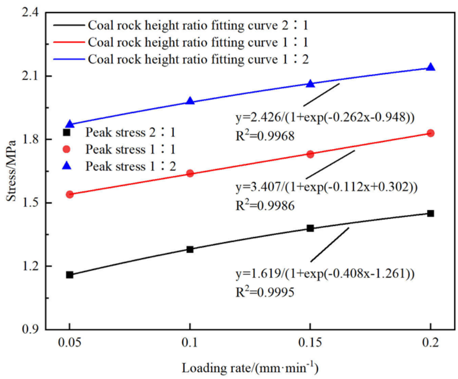

Fig. 4. Compressive strength fitting curve.

Average uniaxial compressive strength about anchored specimens A-D, A-E, A-F, and A-G increased by 0.24%, 0.37%, 0.48%, and 0.56%, respectively. The load-bearing capacity of specimen A-F exceeds that of specimen A-E, with specimen A-D showing the lowest uniaxial compressive strength. While the loading rates raised by 2, 3, and 4 times, the strength of the anchored coal-rock composite compared to the unanchored specimens increases by 10%, 19%, and 25%, respectively, with the specimen loaded at 0.2 mm/min showing the most significant strength improvement.

At loading rates of 0.05 and 0.1 mm/min, the coal-rock system exhibits comparable failure behavior. When loading at a rate of 0.05 mm/min, for example, the anchored specimen exhibits a considerable quiescent time from the initial loading till failure instability, during which the internal stress unevenness keeps growing. Because of tensile layer cracking and expansion, unstable areas emerge in deep coal-rock areas as cracks progressively spread toward the specimen's depth. Layered spalling results from the anchored specimen releasing stored energy through free face rupture at a loading rate of 0.15 mm/min. Even when the coal component of the anchored specimen partially fails, the rock component does not reach the stress peak of a single rock unit, and the anchor has not yet completely lost its ability to support loads. The specimen displays more noticeable and sudden failure characteristics during the coal-rock system's instability stage when the loading rate is 0.2 mm/min. The strength of the coal-rock composite increases as the loading rate gradually increases. The strain rate strengthening effect, which is frequently seen in brittle rocks, is the phenomenon where the specimen's strength increases with the higher loading rate. A greater degree of specimen fragmentation results from the abrupt release of the remaining energy in a catastrophic failure way after the specimen reaches its maximum strength.

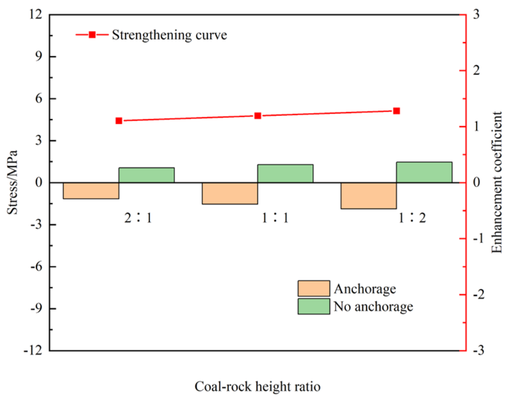

Fig. 5. Strengthening curve.

When the loading mechanism is not in use, the coal-rock system is in a stable equilibrium state. The coal-rock composite is at a quasi-stable phase because coal-rock units have accumulated little elastic energy during the initial loading stages and have accumulated energy at comparable amounts. As the load is applied continuously, decreasing the system's stability and forcing the composite to enter a sub-stable phase. The coal-rock system's critical state of failure instability is reached when the coal-rock composite hits the stress peak.

The strengthening curve is shown in Figure 5. For anchored specimens, cracks form in the rock bridge between the anchor rods and extend to the end face. Due to the anchoring and strengthening effect of the anchor rods on the Due to the anchor rods having a strengthening and anchoring effect in nearby rock, the surrounding rock in the anchorage area remains relatively stable. By applying anchor rod support to the specimen, a certain strength anchor body is formed, enhancing the mechanical performance in nearby rock. The coal-rock unit that anchors the rod anchorage area is less prone to failure compared to specimens without anchors, thereby increasing the specimen's compressive strength.

4 Conclusions

(1) Under equivalent loading rates, the anchor rod enhances the strength of the coal body. Even after the coal body becomes unstable, the anchor rod continues to act as an anchor.

(2) At lower loading rates, the coal portion of the anchored coal-rock composite maintains relatively better integrity after failure. With higher loading rates, the thicker the rock mass, the higher the anchored coal-rock composite's strength.

(3) The presence of anchor rods limits the deformation of the anchored specimens, making it challenging for tiny cracks within the specimens to develop and propagate. This suggests that the anchor rods function as anchors during uniaxial compression, enhancing the stability of the specimens.

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