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Study on the Mechanism of Mechanical Impact on Heterogeneous Plate Rock

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Abstract. The numerical model for mechanical impact breaking of heterogeneous rocks is established by LS DYNA through secondary development, and the RHT (Riedel Hiermaier Thomas) model is used to characterize the mechanical properties of rocks. The research results indicate that during the process of mechanical impact rock breaking, the rock undergoes multiple changes in compressive-tensile stress, which exacerbates the damage and crack propagation of the rock. There is a phenomenon of interlayer distribution and boundary layer ambiguity in the propagation of stress waves inside heterogeneous rocks.

Keywords: Crack propagation; Stress waves; Impact; Plate rock.

1. Introduction

Advancing into the depths of the Earth is a strategic technological issue that must be address. However, due to the anisotropy, heterogeneity, non-transparency properties of natural rocks, as well as high surrounding rock stress and other environmental conditions, the mechanism of mechanical impact breaking hard rocks during the mining process of deep strategic mineral resources is still not fully developed [1-2]. Numerical simulation method is an important means to study the mechanism of mechanical impact rock breaking, which can solve many problems that cannot be explored by experimental methods. Deng et al. [3] used discrete element numerical simulation to investigate the crack formation and propagation characteristics of rocks under dynamic indentation of spherical teeth, as well as the influence of loading rate on rock fracture effect. Li et al. [4] studied the influence and significance of chisel rod diameter, impact angle, and velocity on rock fragmentation through numerical simulation, and analyzed the initiation and expansion of fracture zones during rock fragmentation. Liu et al. [5] conducted numerical simulations to study the damage evolution, crack propagation, and specific energy of rock breaking caused by ball tooth rotational impact. Zhao et al. [6] numerically simulated the rock breaking process of a hammerhead and studied the mechanical properties, crack propagation, and energy evolution characteristics of sandstone under impact load. Zhang et al. [7] studied the crack distribution of cement mortar slabs under the impact load of a falling hammer using the continuous discontinuous element method (CDEM), as well as the cracking effects of different impact velocities and hammer shapes. Ji et al. [8] conducted numerical simulations to study the failure modes of rocks under different impact velocities, tool inclinations, and rock types. Zheng et al. [9] numerically simulated the rock breaking process of a hydraulic impact hammer and analyzed the effects of factors such as piston impact velocity, blade shape, rock strength, and confining pressure on energy transfer efficiency and damage characteristics.

However, the research on the mechanism of mechanical impact rock breaking mentioned above has the following shortcomings: Few scholars have studied the influence of rock heterogeneity on the propagation of mechanical impact rock breaking cracks, most numerical simulations are conducted under the assumption of homogeneous rocks, which makes it difficult to study the cross medium propagation characteristics of shock stress waves in depth. Resulting in limited guidance provided by existing research results for the engineering application of mechanical impact rock breaking. In summary, establish a numerical model for mechanical impact on heterogeneous plate-like rocks. Based on the test results of rock engineering, the model parameters of the rock are

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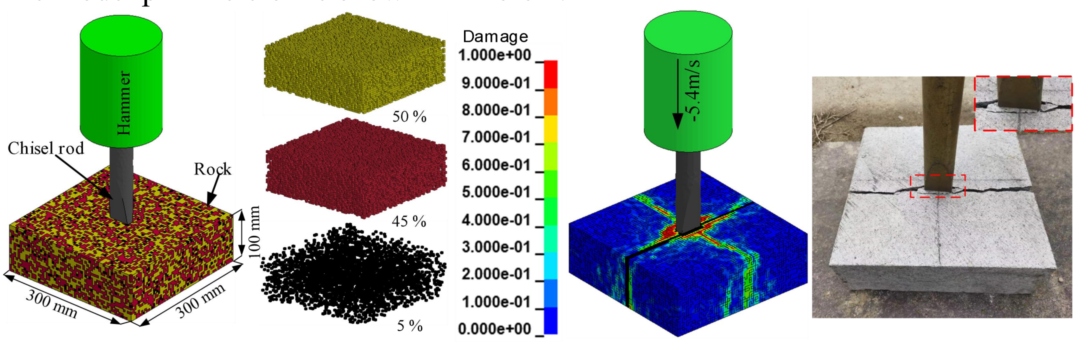
continuously adjusted through trial-and-error methods. The corrected numerical model is validated through mechanical impact rock breaking experiments, and the mechanism of mechanical impact crushing of heterogeneous plate-like granite is studied.

2. Numerical Model and Calibration

By simplifying the experimental setup, a mechanical impact rock breaking model is established, in which the impact hammer and chisel rod are modeled using rigid bodies, while the rock is modeled using RHT [10]. The impact hammer and chisel rod are in automatic surface-to-surface contact, and the chisel rod and rock are in erosion surface-to-surface contact. Fixed constraints on the rock bottom surface. Most natural rocks are composed of multiple minerals, resulting in their heterogeneous and anisotropic characteristics. Considering the computational cost of the numerical model, Matlab was used to modify the homogeneous granite model to a heterogeneous rock containing three main components. The different colored rock units in Fig 1(a) represent ores with different properties, and the rock units with different properties maintain common node operations to ensure the effective transmission of stress and strain generated by the impact of the chisel rod inside the rock. Whether numerical simulation can accurately reflect the real process of rock fragmentation is a concern for many scholars. To verify the accuracy of the numerical model for rock breaking by chisel rod impact established in this article. The rock breaking process of chisel rod impact is simulated. The chisel rod impact rock breaking results were used to verify the accuracy of the numerical simulation. As shown in Fig 1(b), under the same conditions, the experimental and simulated rock breaking characteristics of the chisel rod impact have a high degree of agreement, which once again proves that the chisel rod impact rock breaking model established in this paper can accurately simulate the actual rock breaking process of chisel rod impact. The model parameters are shown in Table 1.



(a) Numerical model (b) Comparative verification

Fig. 1 Numerical model and comparative verification

Table 1. Main parameters of RHT model

Parameters	50%	45%	5%
ρ (Kg/m3)	2660	2700	2600
G(GPa)	21.9	24.17	8
f_c (MPa)	167.8	119	48
f_t^*	0.04	0.1	0.1
f_s^*	0.21	0.18	0.25

3. Results and Discussion

As shown in Fig 2, under the same conditions, the fracture effect of heterogeneous rocks shows a straight-line shape, while homogeneous rocks show a vertical cross shape. Moreover, from the distribution of damage on the surface of rocks, the damage of homogeneous rocks extends relatively

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regularly in all directions with the impact point as the center, while the distribution of damage in heterogeneous rocks is more complex. The reason for this phenomenon is that the structural strength of the three types of ores that make up heterogeneous rocks is inconsistent, resulting in discontinuous damage transmission of rock units, which in turn leads to irregular distribution of damage around the edge of the fracture zone in heterogeneous rocks. Combining the experimental results in Fig 1(b), it is shown that the results obtained by simulating mechanical impact rock breaking using homogeneous rocks are greater than the actual rock breaking effect.

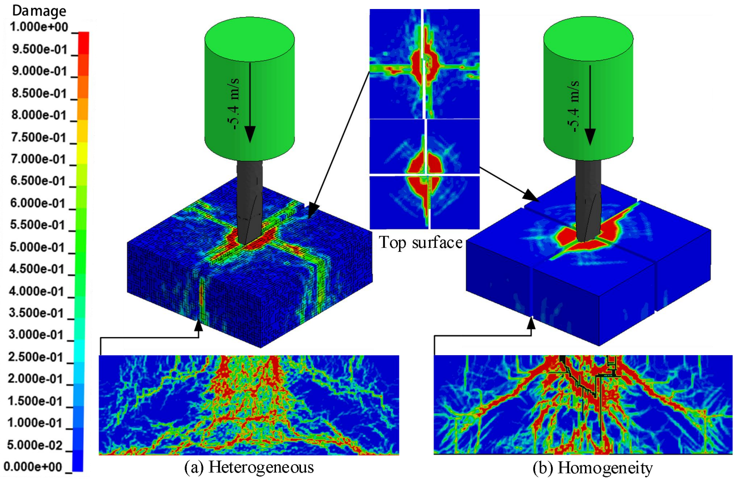

Fig. 2 Comparison of damage effects between homogeneous and heterogeneous rocks

A negative maximum principal stress indicates that the rock is subjected to compressive stress, while a negative value indicates that it is subjected to tensile stress. As shown in Fig 3, the rock unit undergoes multiple compression tension transformations during a single hammer impact rock breaking process. Moreover, the fluctuation amplitude of the maximum stress of rock units is relatively large in the time domain of high-frequency velocity changes. By analyzing the failure process of rock units based on the corresponding damage curves, it can be concluded that the damage value of the rock unit below the impact point of the chisel rod during a single drop hammer impact rock breaking process rapidly accumulates to complete damage during repeated compression tension transformations. Moreover, the cumulative speed of damage to the rock unit is mainly related to the number and magnitude of changes in the compressive tensile stress it is subjected to, and the accumulation of damage values in the rock unit mainly occurs during its stage of bearing tensile stress.

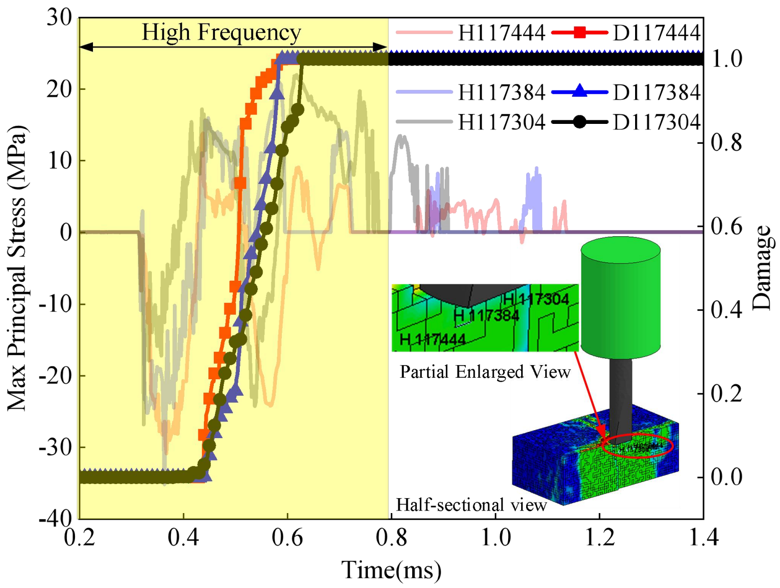

Fig. 3 Rock element stress and damage diagram

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As shown in Fig 4, Rx represents X% of minerals in heterogeneous rocks. At the 331μs, the stress wave generated by the impact of the chisel rod on the rock propagates from hard rock to soft rock, creating a certain stress concentration zone below the interface. When stress waves are transmitted from soft rock to hard rock (331-347μs), some of the stress waves continue to propagate into the interior of the rock through the soft hard interface, while most of the stress waves reflect at the interface. At this point, there is not only a stress difference between the stress concentration areas, but also a significant stress difference at the interface. Moreover, the reflection phenomenon of stress waves at the soft hard interface gradually decreases with the decrease of rock hardness difference. The stress wave generated by the impact of the chisel rod at 361 μs is reflected at the bottom of the soft rock. At this point, the tensile stress concentration zone between the stress concentration area below the impact point of the chisel rod and the reflected stress wave at the bottom of the soft rock undergoes deformation, evolving from a flat shape to a slender shape approximately perpendicular to the interface. The overall distribution of cross-sectional stress in soft hard rock is roughly the same as the stress distribution at 347 μs, except that a radial tensile stress concentration area appears below the interface at this moment. Observing the damage cloud map at this moment, damage cracks approximately perpendicular to the interface appear at the hard soft rock interface, while the damage at the soft hard rock interface is mainly concentrated in the soft rock area. This phenomenon is the main reason for the fine and mixed damage cracks in the heterogeneous rock shown in Fig 1(a). The stress concentration and stress reflection phenomena at the boundary during the propagation of stress waves from hard soft and soft hard are the main reasons for the interlayer distribution of stress waves and the irregularity of stress layer edges in heterogeneous rocks.

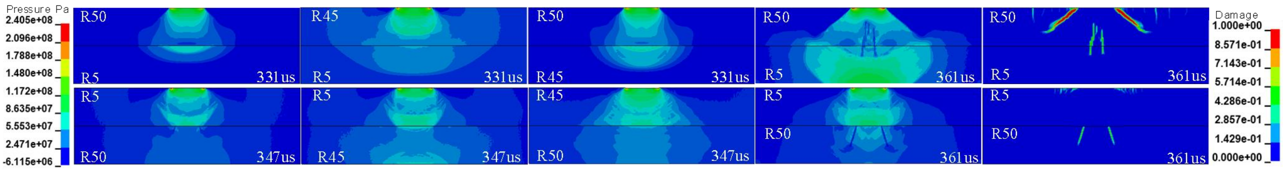

Fig. 4 Distribution of stress and damage in heterogeneous rocks

4. Conclusion

1) Heterogeneous rocks can more accurately reproduce the fracture process of rocks under impact loads. 2)The rock is subjected to multiple changes in compressive tensile stress during the impact breaking process of the falling hammer method, which exacerbates the damage and crack propagation of the rock. 3)During the propagation of stress waves inside heterogeneous rocks, there are transmission and rebound phenomena, which is decreases as the difference in rock hardness decreases.

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