Hydraulic Coupling Numerical Simulation of Heterogeneous Rocks with Random Defects

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ABSTRACT: As the research base damage and water inrush problem, this article obtains from the body micro units, on the basis of seepage of rock mass and rock mechanics theory, considering the heterogeneity of rock, and established the heterogeneity of rock containing random defects of mesoscopic scale on the seepage flow in heterogeneous model by means of FLAC3D simulation software built-in fish language from the model unit randomly in the unit ID number, total group as defects in the model group, while the rest of the unit as a complete set, the different group gives different mechanics parameter values, implement different defect degrees of homogenization model established The results show that the overall bearing capacity of rocks with high defect degree decreases obviously, and the failure of rocks precedes that of intact rocks.

1. introduction
The floor rock mass of coal mine is essentially an heterogeneous body of texture. Under the action of external forces, the nucleation, expansion and interaction of microdefects inside the rock determine the macroscopic deformation and failure characteristics of the rock[1-5]. Although many achievements have been made in the study of rock fracture[6-9]. However, these studies have always been carried out on the premise of homogeneous medium, and seldom involve the rock damage caused by the heterogeneity of the rock itself. The failure of floor rock mass and water inrush in coal mine cannot be better simulated. Therefore, it is more scientific and reasonable to study floor failure and water inrush in coal mine based on the consideration of the heterogeneity of rock.

Considering the heterogeneity of coal floor rock mass material, the material is divided into several small units, among which the mechanical parameters are different. Compared with the macroscopic scale, the scale of cell element is small enough that its mechanical properties can be ignored. Compared with the microscopic scale, the scale is large enough to contain a certain number of pores. The inclusion of different pores in the cell leads to the difference in mechanical properties between cells, and the random combination of all cells constitutes the heterogeneous model, thus achieving
model heterogeneity\cite{10,11}. The heterogeneity of natural rock makes its strength and deformation characteristics distributed discretization in space larger, and the random distribution of defects and fractures in the rock plays an important role in the failure of the rock. Therefore, the study of rock heterogeneity is closely related to the solution of local fracture expansion and overall instability of the rock. Due to the complexity of theoretical analysis to solve the model of heterogeneous characteristics, it is difficult to prepare the experimental model. In this paper, the powerful programming language and image processing function built into the numerical software FLAC3D are used to analyze the hydraulic coupling characteristics of heterogeneous rocks.

2. A numerical simulation method for microscopic heterogeneous rock materials

Random defects such as pores, cracks and inclusions in natural rock internal structures are an aspect of rock heterogeneity \cite{12}. A parameter, defect degree, is used to indicate the degree of heterogeneity of the structure inside the rock. Random defects distribution is used to describe the heterogeneous characteristics of rock mesoscopic scale, to a model unit for a total of 31250, the defect degree of 0, 1%, 5% and 10%, respectively, namely random defect unit number is 0, 312, 1563 and 3125 respectively modeling rock model, as shown in figure 1, figure in red units as random defects, blue unit of the intact rock unit.

![Fig.1 Heterogeneous model with random defective](image)

(a) The defect degree is 0  (b) The defect degree is 1%  (c) The defect degree is 5%  (d) The defect degree is 10%

3. Numerical simulation of hydraulic coupling of heterogeneous rocks with random defects

3.1 Modeling

| Material name | Elastic modulus /GPa | Poisson's ratio | Cohesion/MPa | internal friction angle /\(\degree\) | tensile strength/MPa | Dilatancy angle/(\(\degree\)) | density/kg·m⁻³ |
|---------------|----------------------|----------------|--------------|-----------------------------|----------------------|-----------------|----------|
| Complete unit | 28                   | 0.25           | 4.0          | 49                         | 0.65                 | 5               | 2500     |
| Defect unit   | 20                   | 0.25           | 0.7          | 34                         | 0.25                 | 5               | 2500     |

In order to consider the seepage of rocks with random defects, a model with defects of 0.1%, 5% and 10% is established (Fig.1). The model is divided into 31250 (25*25*50) units with the length, width and height of 500mm, 500mm and 1000mm respectively. The confining pressure applied to the model is 2.4MPa, and the axial displacement controlled loading mode is adopted, i.e., the constant velocity \(v = 5*10^{-9}\) M / step is applied to the upper end face of the model, the water pressure is applied on the bottom end face, and the free overflow surface is set at the top. The model material parameters are shown in Table 1.
3.2 Analysis of simulation results

3.2.1 Failure process analysis of rock samples with random defects under no water pressure

Triaxial compression simulation was carried out on the rock sample with a defect of 5% under no water pressure (Fig. 2). With the increase of load step, the element discrete plastic failure occurs first (Fig. 2 (a) (b)), but the whole element is still in elastic state. When running to 24000 steps, almost all plastic changes occur due to the extension and expansion of the original failure element. When it runs to 30000 steps, the whole rock is destroyed, but it still has some residual strength. It can be seen from Fig. 2 (f) that the final failure mode is obvious shear failure from the upper left corner to the lower right corner.

Fig. 3 shows the stress-strain curve of rock samples with random defects under no water pressure. The peak strength and residual strength of rock decrease with the increase of defect degree. The peak strength of rock without defect and defect degree of 10% is calculated by 22320 steps and 20620 steps respectively, reaching 35.29 MPa and 31.36 MPa respectively, and the residual strength is 14.36 MPa and 12.59 MPa respectively, and the peak strength and residual strength decrease by 11.136% and 12.33% respectively. The results show that the overall bearing capacity of the rock with higher defect degree decreases obviously, and the failure of the rock is prior to that of the intact rock.

With the increase of the defect degree of rock sample, the range of shear band increases gradually when it runs to 24000 steps, and the shear band is mainly diagonal inclined or conjugate shear, the local distribution of shear band is irregular, the shear band of model with small defect is symmetrical distribution, and the model with large defect generates new shear band around the main diagonal shear band, forming shear band network, which is similar to random defect. It is related to the distribution within the rock sample. The shear strain increment (diagonal dip or conjugate shear band) can represent the final failure mode of the rock sample (Fig. 4). Although other parts of the shear band also caused a certain degree of damage, but compared with the final failure zone is not significant.
3.2.2 Failure process analysis of rock samples with random defects under water pressure

Fig. 5 and Fig. 6 show the failure state and stress-strain permeability coefficient curves of rock samples with different defects under the action of water pressure of 2MPa at the bottom of the model. Compared with the failure without water pressure (mainly shear failure, Fig. 2), the plastic failure under water pressure is mainly tensile and shear failure (Fig. 5). The pore water pressure reduces the effective stress of rock, and the shear strength also decreases accordingly. At the same time, the expansion of water pressure intensifies the crack splitting process. When the pore water pressure increases to close to the confining pressure, it is equivalent to the uniaxial loading, and the rock shows columnar splitting failure, that is, the pore water pressure increases its brittleness and makes the rock change from ductile failure to brittle failure. In addition, the peak strength and residual strength of rock sample decrease gradually with the increase of defect degree, which are lower than the corresponding values under anhydrous pressure. In the pre peak stage, the stress-strain curve is weakened by water pressure, and the local changes are nonlinear, but the whole is approximately linear.

The permeability of a (0.01, 0.25, 0.03) and B (0.25, 0.25, 0.03) points at the bottom of the model were monitored throughout the whole process, and the permeability of the two points under different defect degree rock samples had no significant difference. In the non-linear compaction stage, the pores and microcracks of the rock sample are compressed and closed by axial pressure and confining pressure, and the permeability continues to decrease. After the peak point, the specimen suddenly collapses (brittle failure), the stress decreases to the residual strength, and the corresponding permeability coefficient suddenly jumps to a certain value to reach a stable value. However, after the rock skeleton particles are crushed, the crushed particles block the through macro crack channels, and inhibit the growth of permeability coefficient, resulting in the results lower than the initial permeability.
Taking the seepage simulation of rock sample with 5% defect as an example (Fig. 7), the analysis is carried out from the aspects of plastic failure, permeability coefficient and volume strain increment change, pore pressure and seepage vector. The results show that water pressure increases the brittleness of rock, and the permeability and seepage vector appear in the corresponding failure area. The water pressure nephogram shows that the nonlinearity of hydraulic gradient tends to be obvious, the hydraulic gradient at the lower end of the specimen increases and the upper end decreases. From the volume strain increment curve, in the non-linear compaction stage, the volume compression decreases, and the volume strain is positive (the compression is positive, otherwise it is negative); when the axial pressure reaches a certain value, the sample is compressed and cracked, a large number of microcracks appear, the volume begins to expand, the volume strain begins to decrease until a certain value, and the deformation transits into brittle failure and microcrack The gap is continuously connected with each other, which causes the sample to expand rapidly until it is damaged. The skeleton particles are crushed, resulting in the collapse of pores. After the curve is reduced to the lowest point, the phenomenon of "sudden jump" appears again, which slows down the volume expansion.
4. Conclusion

1) Failure analysis of rock samples with random defects under no water pressure: with the increase of load step, discrete plastic failure occurs at first, but the whole defect element is still in elastic state, and then almost all of them undergo plastic change. The ultimate failure of rock is an obvious shear failure zone from the upper left corner to the lower right corner. With the increase of defect degree, the region and range of shear band increase gradually, and the shear band is mainly diagonal inclined or conjugate shear.

2) Compared with the plastic failure without water pressure, the plastic failure under water pressure is mainly tensile and shear failure. Water pressure increases the brittleness of rock, and the rock changes from ductile failure to brittle failure. With the increase of defect degree, the peak strength and residual strength gradually decrease, and are lower than the corresponding values without water pressure. With the compression and closure of pores and microcracks, the stress-strain increases approximately linearly, and the permeability decreases continuously. After the peak point, the specimen suddenly collapses, and the stress decreases to a certain value to reach a stable value, and the corresponding permeability coefficient suddenly jumps to a certain value. Larger permeability and seepage vector appear in the failure area, and the nonlinearity of hydraulic gradient tends to be obvious. The hydraulic gradient at the lower end of the specimen increases and the upper end decreases.

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