Hydro-chemical model in a single fracture in the framework of DDA

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Introduction

Understanding the basics of material flow through rock fractures and its effect on the fracture is essential for oil production, geothermal energy production, waste disposal, carbon dioxide geosequestration, and coal mining (Roy and Singh,2016). DDA is a typical discontinuous numerical method which has been widely used in the investigation of the hydro-mechanical coupling process in fractured rock mass. However, the present researches failed to consider the chemical effect on the rock fissures by acidic or alkaline groundwater. Therefore, a dissolution model is adopted to depict the solute exchange in the hydro-chemical process, and embedded into the framework of DDA by using finite difference method. The method is validated through a singe fracture flow. The numerical results are compared with the experimental measurement, which demonstrates its effectiveness and possibility of its application in more complex discrete fracture network.

Theoretical basement

DDA is a powerful numerical method proposed by Shi, which can be applied to analyze the movement and deformation of blocky system in condition of both static and dynamic. The principle of minimum potential energy controls the numerical calculation in every step. And contact theory ensures that blocks do not penetrate each other.

Much laboratory effort has been made to study the hydro-chemical effect in fractured rock mass, and many simplified mathematical models were proposed based on some assumptions and laboratory observations. Here, a single dissolution model is adopted and chosen to be embedded into the DDA framework due to its assumptions being well compliant with the numerical fractured rock model in DDA. The fracture flow is assumed to have following characteristics: 1) the rock matrix is homogeneous; 2) the fracture flow is laminar flow; 3) the dissoluble rock mineral will not precipitate in the fracture; 4) the change of temperature and density of the fracture fluid is neglected. Based on the assumptions, the chemical dissolution along the fracture is simplified as the following process, as shown in Fig.1.

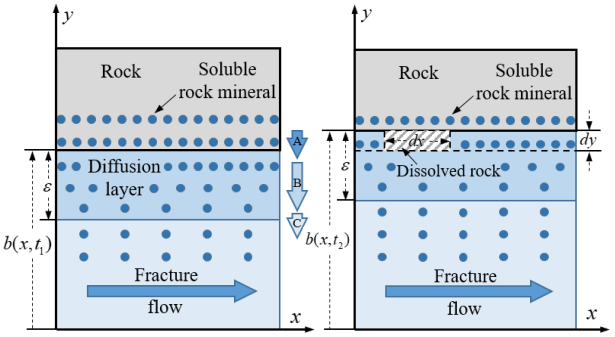

Fig.1 Simplified solute exchange in the hydro-chemical process

A diffusion layer with thickness ε is assumed existing adjacent to fracture surface, as shown in Fig.1(a). The soluble rock minerals are released from the rock into the diffusion layer, and then diffuse to center of the fracture fluid. The concentration of the rock minerals at the boundary between diffusion layer and rock surface is considered to be the saturation concentration. The Fick law could be used to depict the diffusion of the rock minerals in the diffusion layer. And the solute transport with the fracture solution can be expressed by convective-diffusive equation. Therefore, the governing equation of the fracture mineral is expressed as the following equation:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - U\frac{\partial C}{\partial x} + \frac{D\cdot(C_s - C)}{\varepsilon \cdot b(x,t)} \tag{1}$$

where C is concentration of the solute at the center of fracture fluid; D is the diffusion coefficient; C_s is the saturation concentration; $b(x,t)$ is the fracture aperture, which is related to dissolution time t and position x. The governing equation is embedded into DDA framework and solved by finite difference method.

Validation Model

To validate the accuracy of the hydro-chemical calculation, we adopt a single fracture model which is formed by two DDA blocks, similar to the laboratory dissolution test conducted by Zhou et al.(2006), as shown in Fig.2 and Fig.3, respectively. In the indoor tests, the difference between the water head at the inlet and outlet was 4.7cm. The Mohr

Zconcentration of the injected solution (*Nacl*) was $0.005 mol \cdot cm^{-3}$, consistently. And the total injected time was 125 hours.

The input parameters for numerical sample are listed in Table.1. The boundaries for the numerical calculation are Dirichlet boundary. It should be noted that the concentration of the outlet is updated after every calculation step, although it is Dirichlet boundary in every step.

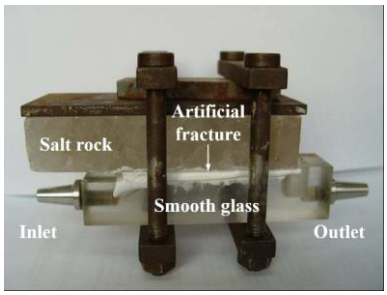

Fig.2 Indoor hydro-chemical Experiment (Zhou et al.,2006)

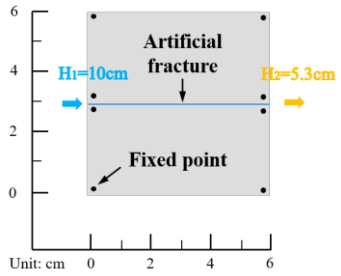

Fig.3 DDA validation sample

Table.1 Numerical input parameters

DDA block	Density (kg/m^3)	Poisson's ratio	Young's modulus (GPa)	Maximum displacement ratio	Fracture length (cm)	Initial aperture (cm)	Total time (h)
	2160	0.2	10	0.001	6	0.001	125
Hydro-chemical calculation	Diffusion coefficient (cm^2/s)	Mohr density (g/mol)	Saturate concentration (mol/cm^3)	Inlet concentration (mol/cm^3)	Initial outlet concentration (mol/cm^3)	Inlet water head (cm)	Outlet water head (cm)
	2.0×10^{-5}	58.5	0.0054	0.005	0.0	10	5.3

The simulated dissolving process is shown in Fig.4. The stable state of the solute concentration along the fracture is shown in Fig.4 (1). It can be seen that the concentration of the inlet is 0.0054 mol/cm^3. The dissolution of the rock mineral along the fracture raises the solute concentration in the fracture until it gradually increases to saturation concentration. The dissolution induced enlargement of the fracture aperture is shown in Fig.4 (b)-(e). The majority of the dissolution in the numerical model occurs mainly near the inlet. As the dissolution time increases, the larger the surface of the fracture surface in contact with water where dissolution occurs, and thus the greater the mass of rock salt dissolved away.

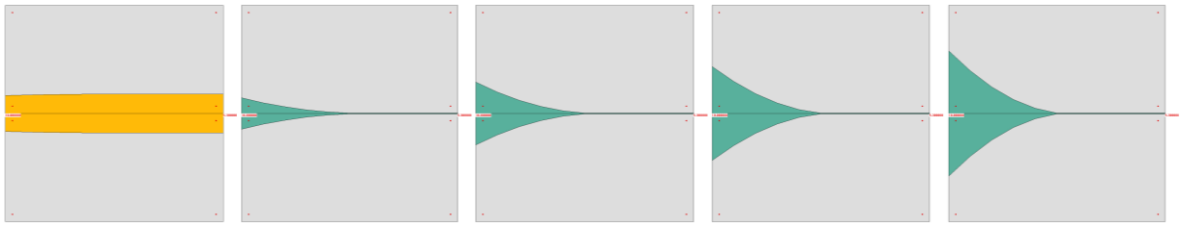

Fig.4 Distribution of solute concentration and the enlargement of aperture along the fracture

The numerical result after injection and dissolution for 125 hours is compared with the indoor test, as shown in Fig.5. It can be seen that the experimental data agrees well with the numerically calculated values.

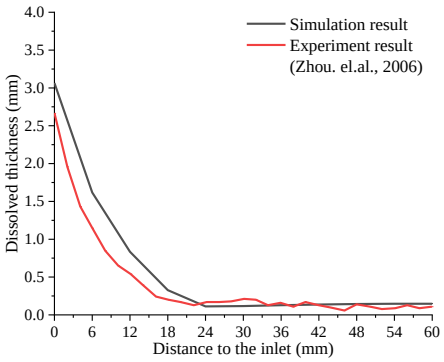

Fig.5 Dissolved thickness along the fracture

Summary

In order to effectively depict the chemical effect on the rock fracture by the fissure flow, a simplified dissolution model is embedded into DDA method. Through comparison with the experimental measurement, the dissolution model can well reproduce the enlargement of fracture aperture during hydro-chemical process. This method will be applied in a more complex discrete fracture network in the future.

References

Roy, D. G., and Singh, T. N., 2016, Fluid Flow through Rough Rock Fractures: Parametric Study: International Journal of Geomechanics, v. 16, no. 3.

Zhou, H., Tang, Y. C., Hu, D. W., Feng, X. T., and Shao, J. F., 2006, Study on Coupled Penetrating-Dissolving Model and Experiment for Salt Rock Cracks: Chinese Journal of Rock Mechanics and Engineering, no. 05, p. 946-950.