An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)
©2014 China University of Mining and Technology Press, Xuzhou, ISBN 978-7-5646-2437-8

Experimental Research of Rock Strength and Permeability Characteristics under Different Confining and Hydraulic Pressure

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Abstract In deep coal mining process, rock failure and seepage mechanism under high ground stress and high hydraulic pressure is very complicated. Rock strength and permeability characteristics are bases to study deep coal floor water inrush problems. Rock stress-seepage coupling tiaxial compression tests under different confining and hydraulic pressures were conducted. Based on test results, confining pressure and pore pressure coupling effects on rock strength were studied. Permeability and strain relationship under different confining and hydraulic pressure was analyzed. As the study, rock strength increases with confining pressure increases. Hydraulic effects decrease with hydraulic pressure increases. Based on this study, further study can be done to reveal rock constitutive relation under different confining and hydraulic pressure to improve coal floor water inrush mechanism.
Keywords rock strength, permeability, confining pressure, hydraulic pressure, water inrush

Introduction

Even though rock strength and permeability characteristics are bases to study deep coal floor water inrush problems, there are very few research results for sedimentary rock with considerations of pore water pressure and confining pressure (Xing 2004). In water inrush gestation process, rock mass strength and permeability characteristics are influenced by coupled physical and chemical interaction between rock and water. Rock strength responses the material ability to resist rock damage. Rock strength is affected by rock particle composition and structure also affected by the surrounding stress and hydraulic environment. Rock strength is the result of stress and seepage coupling effect on rock material.

Triaxial compression tests under different confining and hydraulic pressures were conducted to obtain rock strength parameters. Confining pressure and hydraulic pressure coupling effects on rock strength were studied.

Rock permeability is also related to rock failure process and rock stress-hydraulic environment. Rock permeability changing rules under different damage condition and different confining pressure are basis to study water inrush problem. In the study, permeability tests under different confining pressures were conducted. The whole stress strain process permeability characteristics were studied. According permeability tests, confining pressure effect on rock permeability ability can be analyzed.

Stress-seepage coupling tests

Triaxial compression tests were conducted by MTS815 Flex Test GT at water conservancy and hydropower institute of Sichuan University. The maximum axial load is 4600 kN. Maximum confining pressure and maximum hydraulic pressure both are 140MPa. Maximum seepage difference is 30 MPa. Vibration load control methods are axial load, confining pressure and seepage pressure, or their combination (Liu 2012, Zhu 2002).

Rock samples were taken from Changhua coal mine in Shanxi Ningwu coal field. Fine sandstone rock samples were with the diameter 50mm, and height 100mm. Test confining pressures (σ_3) are 4 MPa, 8 MPa, 12 MPa and 16 MPa. Hydraulic pressures (P_w) are 0 MPa, 3 MPa, 6 MPa and 9 MPa. Osmotic pressure difference in penetration test is 3 MPa.

Stress-seepage coupling tests include four different tests: normal triaxial compression tests of saturated rock; triaxial tests under different pore water pressure and confining pressure; whole stress strain process permeability tests; damaged rock permeability tests.

Permeability test was conducted according to the transient method. Confining pressure and axle pressure are loaded by the rock mechanics servo system. The permeability test system is composed by upstream pressure vessel, rock sample and downstream pressure vessel. Main measurement variables are pressures of vessels.

Strength Characteristics

Curves of fine sandstone rock strength σ_1 to confining pressure σ_3 under different hydraulic pressures are shown in fig. 1. Fine sandstone rock strength increases with confining pressure increases.

For saturated fine sandstone, rock strength and confining pressure fit to exponential relationship, rock strength confining pressure effect increases with confining pressure increases. For damaged fine sandstone when the hydraulic pressure is 0 MPa, rock strength and confining pressure fit to linear relationship, rock strength confining pressure effect keeps stable with confining pressure increases. When the hydraulic pressure is 3 MPa, rock mass strength and confining pressure fit to logarithmic relationship, rock strength confining pressure effect decreases with confining pressure increases.

Damaged sandstone rock strength to pore pressure curves are shown in fig. 2. Under different confining pressure, damaged rock strength decreases with pore pressure increases.

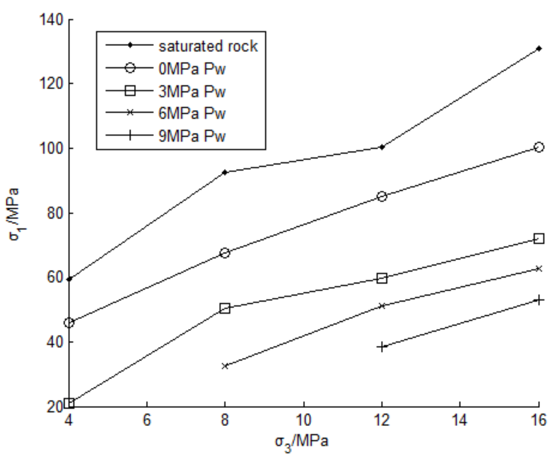

Fig. 1 Fine sandstone strength confining pressure effect

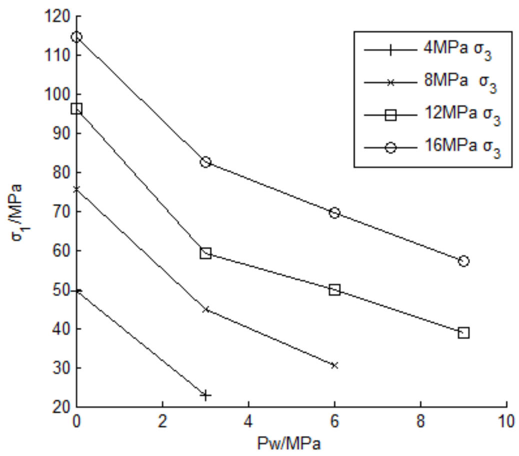

Fig. 2 Fine sandstone strength pore pressure effect

From rock strength hydraulic pressure effect curves, rock mass strength and hydraulic pressure fit to negative exponential relationship, pore pressure effect decreases with hydraulic pressure increases.

Permeability characteristics

Curves of stress-strain and permeability-strain of fine sandstone under confining pressure of 4MPa and osmotic pressure difference of 3MPa are as shown in fig. 3.

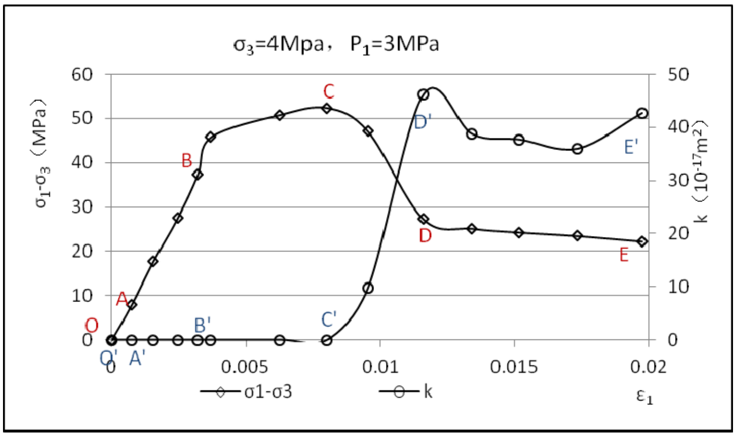

***Fig. 3** Whole stress strain permeability curves*

The whole stress strain process can be divided to 5 phases which are marked by O/A/B/C/D/E in fig. 3. In normal trixial compression test, the second principle stress is same as the third principle stress, $\sigma_2=\sigma_3$. At the beginning step, confining load is 4MPa, axial load is same as confining load, $\sigma_1=\sigma_3$. Then the axial load is increased gradually to break the rock sample. The deviatoric stress, $\sigma_1-\sigma_3$, is the difference between axial load and the confining load.

OA phase is the initial compression phase. AB is the linear elastic phase, deviatoric stress-strain is a linear relationship. Deviatoric stress is 37.26 MPa at the B point. BC is nonlinear phase, the increase rate gradually decreases. Deviatoric stress achieves the peak value 52.39 MPa at the C point. CD is Strain softening phase, the deviatoric stress decreases to 27.23 MPa. DE is residual strength phase, at the end of the test the deviatoric stress is 22.27 MPa.

As same as the stress-strain curve, the permeability curve also can be divided to 5 phases which are marked by O'/A'/B'/C'/D'/E'. Rock at different damage phase has different permeabilities. Before the peak point C, the O' C' phase permeability values are too tiny to be measured. At the C'D' phase, permeability increases suddenly, while at the D' point the permeability value is $46.2\times10^{-17}m^2$. After the D' point, rock strength condition is residual strength, rock permeability is between $36\times10^{-17}m^2$ to $42.7\times10^{-17}m^2$.

The permeability suddenly increases when the rock strength achieves the peak point. After the strength peak point internal micro cracks evolve to macroscopic fractures, the rock sample is damaged. Permeability achieves to the peak point at the end of the strain softening phase. Permeability keeps basically stable at residual strength phase.

Fine sandstone permeability values under different confining pressures are shown in fig. 4. Rock permeability decreases with confining pressure increases. Confining pressure effect decreases with confining pressure increases as curves become flat with high confining pressures.

Confining pressure effect is caused by the mechanical effect of the confining pressure to rock skeleton. The rock permeability is influenced by rock skeleton deformation caused by the confining pressure. As confining pressure increases, lateral deformation is formed to compress rock pore and fracture space which leads effective permeable channels decreased. Permeability decreases while effective permeable channels decrease.

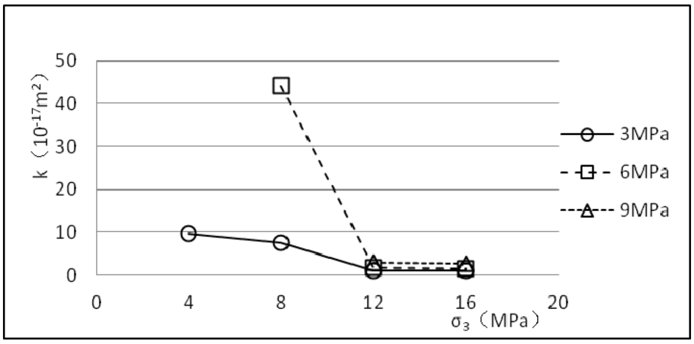

Fig. 4 *Permeability confining pressure effect*

Conclusions

As the study, following conclusions can be obtained:

Rock strength increases with confining pressure increases. Rock strength confining pressure effect decreases with confining pressure increases.Damaged rock strength decreases with pore pressure increases. Rock strength pore pressure effect decreases with pore pressure increases.

Permeability achieves to the peak point at the end of the strain softening phase and keeps basically stable at residual strength phase.

Rock permeability is related to effective permeable channels of rock skeleton. With confining pressure increase, lateral deformation is formed and the rock permeability decreases.

Acknowledgements

This paper is supported by the Key Program of National Natural Science Foundation of China (51034003).

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