Reliability of representing fracture permeability with statistical roughness parameters.

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Introduction

The surface roughness of fractures has significant influence on the fluid flow properties if its host rock, via the spatial distribution of open apertures (Brown, 1987). However, a complete description of surface topography is not as feasible as a statistical representation due to heterogenous rock properties. Previous studies have theoretically and numerically identified several prime statistical roughness parameters and investigated the potential linkage between fracture and flow properties (Kang et al., 2015; Ma et al., 2018). Nevertheless, few studies have attempted to validate the practicability of these statistical parameters in real-world scenario. In particular: 1) how to determine a set of fracture roughness parameters and 2) whether these parameters can reliably represent the fracture permeability under various normal stressing levels. In this study, we conducted both lab experiment and numerical simulation based on single-fractured granite rock to demonstrate the robustness of statistical representation model in describing the fracture roughness and characterizing the flow capacity.

Methodology

The experimental flow measurements are conducted on granite rock with artificial single fracture along the axial direction. Before testing, the digitalized surface topography is obtained by 3D laser scanning to perform subsequent statistical analysis. Then, we measure the steady-state hydraulic permeability under 8 confining pressure stages (5,7,9,10,12,15,20,25MPa) with constant injection pressure (2MPa).

We conceptualize the fracture as a combination of smooth surface and rough surface. Synthetic fractures are generated using roughness parameters obtained by statistical analysis, based on spectral synthesis method (Ruan and McLaughin, 1998). The reduction of aperture height due to increasing pressure and compression of surface are modeled with the truncation of overlapped surfaces (Ma et al., 2018). Then fracture flow simulation is performed on real aperture profile and synthetic profile separately, based on lubrication approximation and cubic law.

Results

We compute probability density distribution and power spectral density of rough surface. Results indicate the roughness can be characterized with parameters: aperture variance (4.1606×10^{-8} m^2), autocorrelation length (Lx/20 in x direction; Ly/13 in y direction) as well as normal distribution.

We firstly simulate on real apertures and infer for the compression displacement for each confining stress magnitude through matching the normalized simulated permeability with experimental results. The consistency obtained between simulation results of real aperture and experimental data, as is shown in Fig.1 with solid black line and dashed red line suggests that this empirical effective pressure-compression relation could be used to understand the potential of fracture elastic properties from flow measurements. Then we also compare permeability simulation results from 50 realizations of synthetic fracture profiles. Assuming that synthetic aperture experiences the same displacement as real profile, we observe that the permeability decline curves (in dash-dotted blue) are similar to the results from real surface. The synthetic profile tends to slightly under-predict the permeability under low stress condition while slightly over-predicting under high-stress condition. The threshold of this happens around η = 2.3-2.5.

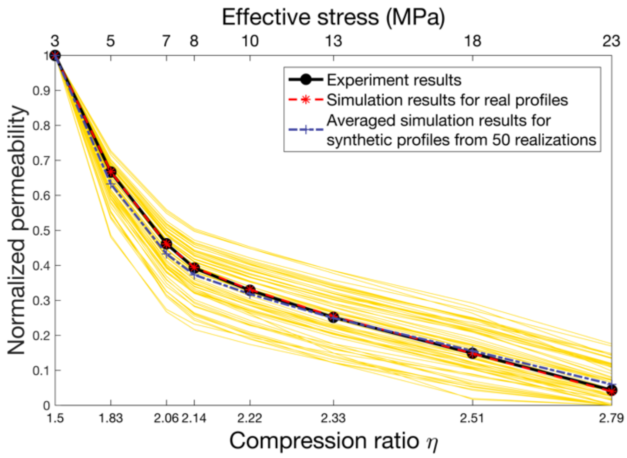

Figure 1: Comparison of the normalized permeability between experimental data (in black), simulation from real surface (in dashed red) and from ensemble of synthesized aperture distributions (in dashed blue). Results for individual realization are demonstrated with yellow lines.

Conclusions

In this study, we carry out experimental flow measurements on a fracture in a granite core and characterize the roughness of fracture with a set of statistical parameters with normal distribution. Robustness of relating fracture permeability with these parameters is tested by comparing experimental and numerical simulation results. We observed a high degree of agreement among experimental flow measurements, simulations on digital fracture profile and simulations on synthesized fracture profile with the same statistics. This suggests that the statistical roughness characterization parameters (correlation length and height variance) provide a promising and convenient way to represent the roughness of a fracture. Given the correlation length and height variance of a fracture, we can predict its permeability change and fluid production under changing static effective pressure conditions.

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References

Brown, S. R. (1987). Fluid flow through rock joints: the effect of surface roughness. Journal of Geophysical Research: Solid Earth, 92(B2), 1337-1347.

Kang, P. K., Brown, S., & Juanes, R. (2016). Emergence of anomalous transport in stressed rough fractures. Earth and Planetary Science Letters, 454, 46-54.

Ma, J. H., Li, Y. E., & Cheng, A. Dependency of flow and transport properties on aperture distributions and compression states. Geophysical Prospecting.

Ruan, F., & McLaughlin, D. (1998). An efficient multivariate random field generator using the fast Fourier transform. Advances in water resources, 21(5), 385-399.