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Computational study of flow anisotropy in sheared fractures with self-affine surfaces

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Characterization of the hydraulic conductivities of rock masses is imperative for the development and engineering of various underground installations like geothermal power plants, waste repositories or tunnelling. The intrinsic permeability of intact rock is extremely low; however the rock mass usually contains a dense network of fractures with a relatively high hydraulic conductivity, which determines the hydraulic properties of the rock mass. Conventionally, in order to estimate the hydraulic conductivities of fractures, the cubic law for laminar fluid flow in a parallel plate model with constant aperture is applied. However, the surface of natural fractures is rough, which strongly affects the hydraulic properties of fractures and causes deviation from the analytical result. To enhance fluid flow in a fractured rock mass, well bores in an intact rock mass are pressurized with fluid to reduce effective normal stresses on pre-existing fractures to enable shearing. The shearing motion of rock enhances hydraulic anisotropy, since the rocks become more conductive parallel to the shearing direction and less conduction perpendicular to the shearing direction.

In the current work, we present a numerical study of hydraulic anisotropy introduced as a result of shearing of algorithmically generated fractures. A rough surface can be mathematically described as self-affine structure with a correlation between heights of asperities and their spatial distribution. Fractures are generated by displacing two identical fractal rough surfaces incorporating dilation to obtain an aperture distribution. To investigate the geometrical and hydraulic properties of generated fractures, we use a finite element method to solve the Reynolds equations in a simplified 2D model. We identify a regime, where a simplified hydraulic fracture model is permitted. Using the 2D model, we make a statistical study of the hydraulic anisotropy for a representative set of 1000 algorithmically generated fractures. For the purpose of validation, we solve the 3D Navier-Stokes flow equations using the finite volume method and compare it with 2D simulation results. Thus, the two independent methods used in conjunction, facilitates the quantification of the impact of fracture tortuosity and roughness on the hydraulic behavior. On the basis of flow simulation results, we conclude that the magnitude and the scatter of hydraulic anisotropy between the fractures increase with increasing shear displacement. Invariably, all sheared fractures show a larger flow permeability perpendicular to the shearing direction as compared to parallel direction.