An experimental study of nonlinear flow behavior in fractured porous media by 3D printing technology

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Fluid flow in fractures is an important issue in natural gas and oil engineering. The fabrication of some morphologically controllable fracture models is very useful to understand and identify the evolution of fluid flow in fractures. For example, Suzuki et al. [1] investigated fracture networks with smooth surfaces using 3D printing technology . Based on this, Li et al. [2] improved the models by replacing the smooth fracture surfaces with rough surfaces .

In the present work, by using 3D printing technology, single fractures with controlled morphology are generated, each of them constituted of two parallel planes, one smooth, one of controlled roughness. Varying the fracture openings (mean distance between planes ranging from 0.1 to 0.8mm) and roughness (quantified in terms of Hurst exponent [3], ranging from 0 for smooth planes to 0.8), a series of samples are printed with identical length and width of fractures (typical dimensions are: 4.6 cm long and 1.8 cm wide) using an Anycubic MonoX printer (figure 1)

Anycubic MonoX is a Stereolithographic Apparatus (SLA) printer, using a photopolymerisation process on a UV-sensitive resin [4]. This process has been chosen for its simplicity and two major reasons: a compromise between model scale and precision (printing layer thickness of 50 μm), and printing material properties (mechanical resistance and low X-ray absorption to perform X-ray microtomographic analyses of the samples).

A series of hydrodynamic test are then performed on these samples: under prescribed water pressure gradient conditions, the variations of fluid flow in the fractures are studied to assess the effects of fracture surface roughness and fracture opening on water flow patterns. Following an extensive experimental design, a total of 26 samples are tested.

As expected, for smooth surface fractures, the ratio flow rate/pressure gradient to the mean opening of the fracture satisfies the classical cubic law [5]. In contrast, for rough surface cases, an impact of fracture roughness is observed in the experimental investigation. These observations are coherent with numerous experimental and numerical studies [6]. Primary analyses show an influence of the fractal dimension of the rough plane, quantified in terms of Hurst exponent: when Hurst exponent becomes larger, the effective opening of fracture becomes smaller.

Based on the obtained experimental results, the influence of local wall roughness is taken into account by correcting the mean opening of fracture in the cubic law, via a correcting coefficient (α). This coefficient (α) is defined as the ratio between the fracture opening (mean distance between the walls) and can be linearly related to Hurst coefficient. Finally, the effective opening can be calculated by inversion of the cubic law (figure 2).

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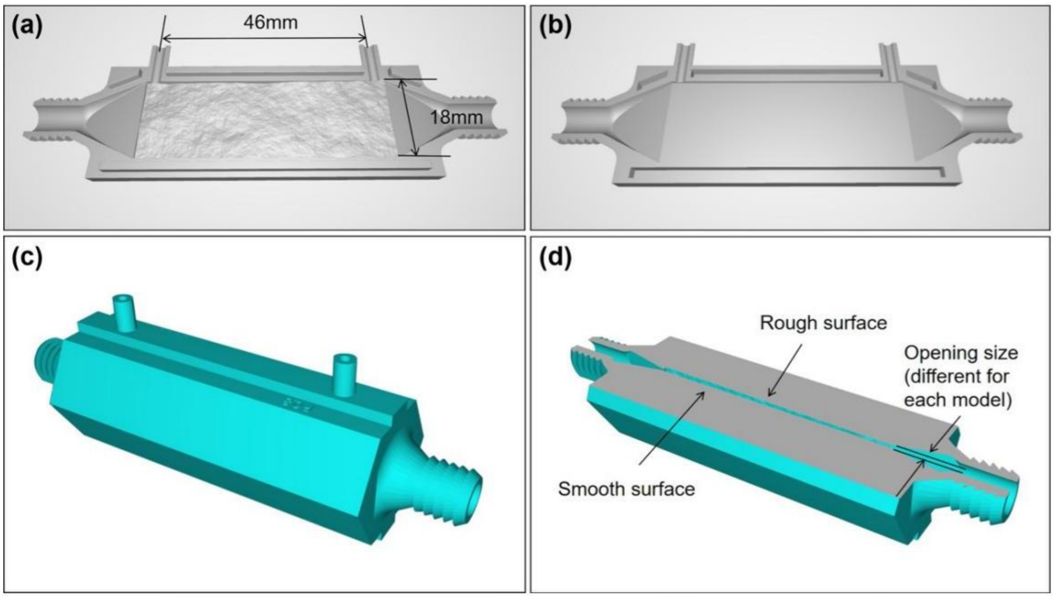

Fig. 1: A 3D printed model of a fissure with controlled surface roughness and opening size

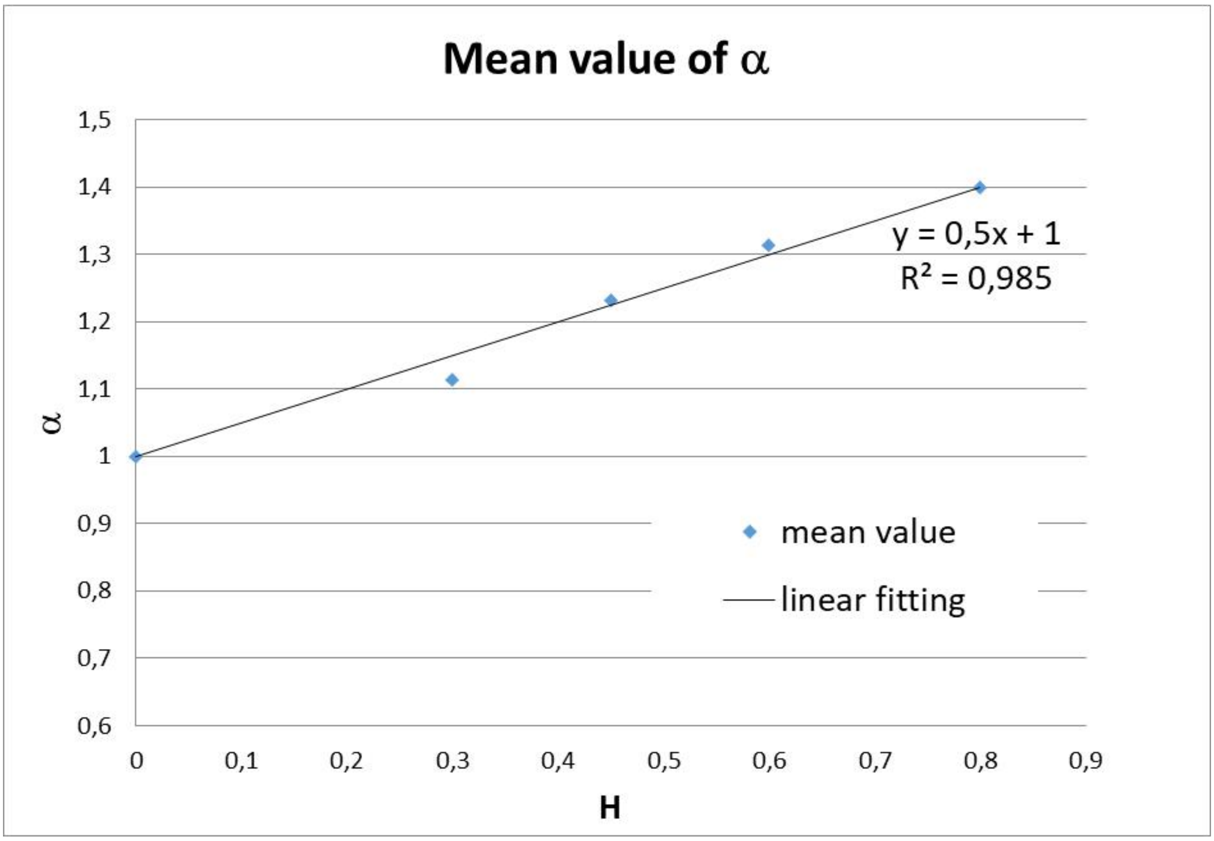

Fig. 2 : Evolution of the correction factor a with Hurst coefficient