Journal of Mineral Resources Engineering, 7(3): 101-124, (2022)

Imam Khomeini International University

Vol. 7, No. 3, Autumn 2022

نشریه مهندسی منابع معدنی

Journal of Mineral Resources Engineering (JMRE)

Research Paper

Numerical Analysis of Effect of Different Shapes of Pore on Tensile Crack Growth

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Received: 13 Jan. 2021 **Accepted: 12 Jun. 2021**

Abstract: Recent development in eXtended Finite Element Method (XFEM) opened new avenues thorough crack propagation problems. However, it ability to predict crack path in micro scale medium of a real porous rock is always questionable. In this work, numerical modeling of the effect of pore size on crack growth and comparison of the effect of different pore shapes and location has been developed using the finite element method to compare the maximum strength of reservoirs and complex rock models. The results showed that the equivalence of the main pores in the sample with simple geometric shapes such as circles, ellipses and angled shapes can well simulate the mechanical behavior of materials and crack growth in Phenomena such as hydraulic fracturing.

Keywords: Numerical modeling, Pores' size, Pores' shape, Pores' location, Hydraulic fracture.

How to cite this article

Rezanezhad, M., Lajevardi, S. A., and Karimpouli, S. (2022). *"Numerical analysis of effect of different shapes of pore on tensile crack growth"*. Journal of Mineral Resources Engineering, 7(3): 101-124.

DOI: 10.30479/JMRE.2021.14904.1481

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INTRODUCTION

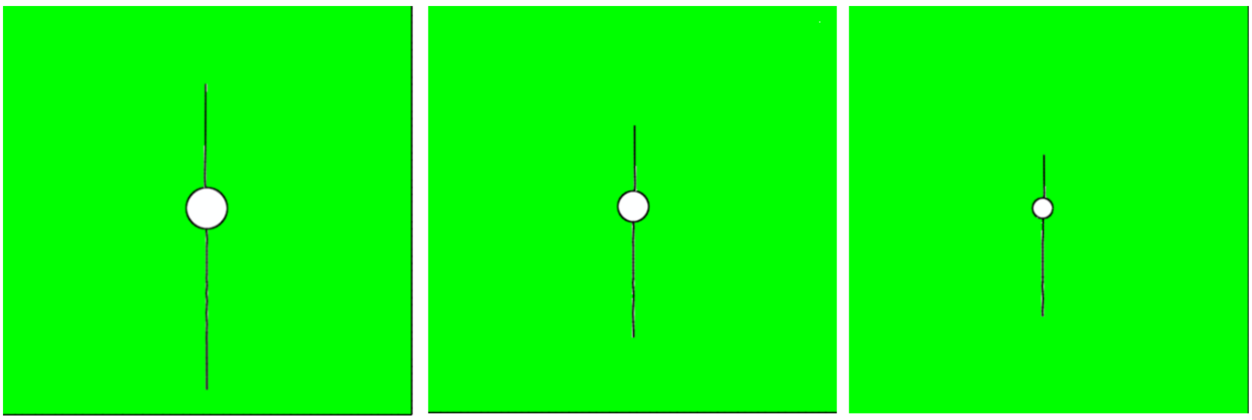
Today, numerical modeling of oil and gas reservoirs has gained a special role in oil reservoir engineering and geomechanics. Therefore, the construction of numerical models that are suitable for porous and high pressure underground space has a very important role in the numerical analysis of rock and fluid behavior of hydrocarbon reservoirs. Wu et al. [1] investigated the mechanical and fracture properties of rock containing pores under uniaxial compressive loading and analyzed and compared five different shapes of pores. Experimental results showed that the mechanical properties of the samples are greatly weakened by pores and the degree of degradation depends on the shape of the pores. They found that the sample with the circular pores and the sample with the rectangular pores had the most and least stability, respectively. Zeng et al. [2] performed numerical modeling and laboratory study of sandstones containing different pore shapes under uniaxial pressure. Their results showed that the shape of the pore has a significant effect on uniaxial compressive strength and type of failure; but it has the least effect on the elastic modulus. In another study conducted by the authors of the present article, changes in the distance of the pore from the crack tip are numerically modeled and its effects on maximum strength, onset and how the crack spreads in porous rocks have been investigated [3]. In that paper, the rules regarding the minimum angle required to deflect cracks to pore are presented. Also in another study, the same research group investigated the effect of the location of pore on the crack and analyzed the arrangement of circular porosity in complex rock models [4]. The results showed that the pores located on the sides of the cracks are of the resistant pores and increase the maximum strength of the rock samples.

METHODOLOGY AND APPROACHES

In the present study, the finite element method has been used to simulate and analyze the effects of size, shape and porosity angle on hydraulic fracture. In all models, the properties of Granite and multiple partitioning methods with their separate enrichment have been used. First, the effect of pore size changes on the mechanical properties of porous materials is investigated. At this stage, a circular pore is used to facilitate and properly evaluate the changes. In the continuation of the research, since the real environments of the rock have pores in irregular shapes and with sharp corners that are located at different angles, an attempt have been made to change the pore shape from a circle to an elliptical or a rectangle pore. In the final part, in order to have a preliminary understanding of the complex and real environment of the rock, the effect of pores arrangement on the crack growth is discussed.

RESULTS AND DISCUSSION

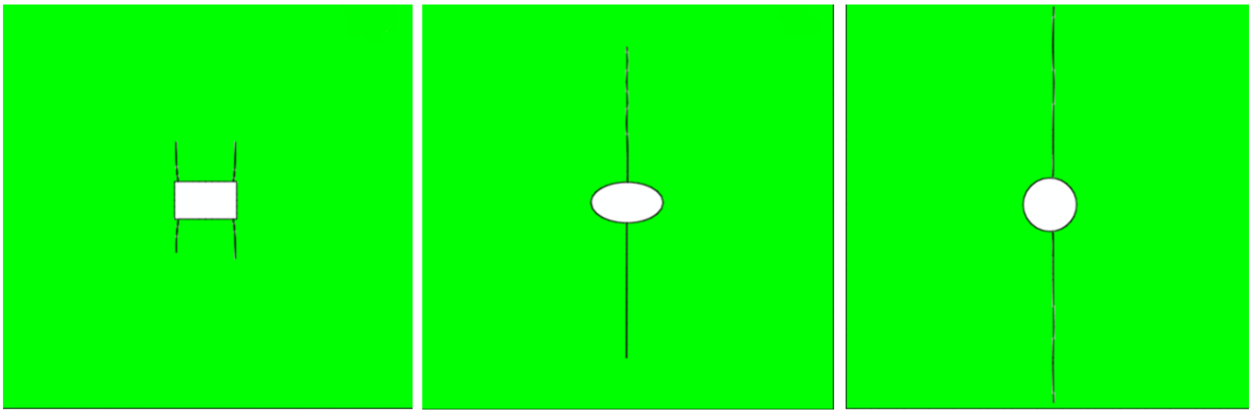
In the first stage, by changing the pore size, the amount of stress intensity factor was calculated and the crack growth method was presented. Figure 1 shows the growth rate of cracks with changes in pore size. As it is known, as the diameter of the pore increases, the destructive effects of pore increase and the initial crack in the sample is allowed to grow and expand which reducing the strength of the rock.



(A) **(B)** **(C)**

Figure 1. Crack growth of pore with different size; **A:** 1st sample with 2r=40 mmT, **B:** 2nd sample with 2r=30 mm and **C:** 3rd sample with 2r=20 mm

In investigating the effect of pore shape on crack growth, two parameters of geometry and placement angle are very important parameters and have a great impact on the results of stress distribution in porous specimens. By applying constant and equal tension to the specimens, as shown in Figure 2, in the specimen containing a rectangular pore, cracks have grown from the sharp corners of the pore and in elliptical and circular shapes from the top and bottom of the pore. Also, the length of the crack created in the sample containing circular pore is more than the rest and has expanded near the boundary of the rock sample, which has decreased with changing the pore shape into elliptical and rectangular, the rate of crack propagation has decreased.



(A) (B) (C)

Figure 2. Crack growth in samples containing a pore with different shapes as **A:** rectangular, **B:** elliptical and **C:** circular

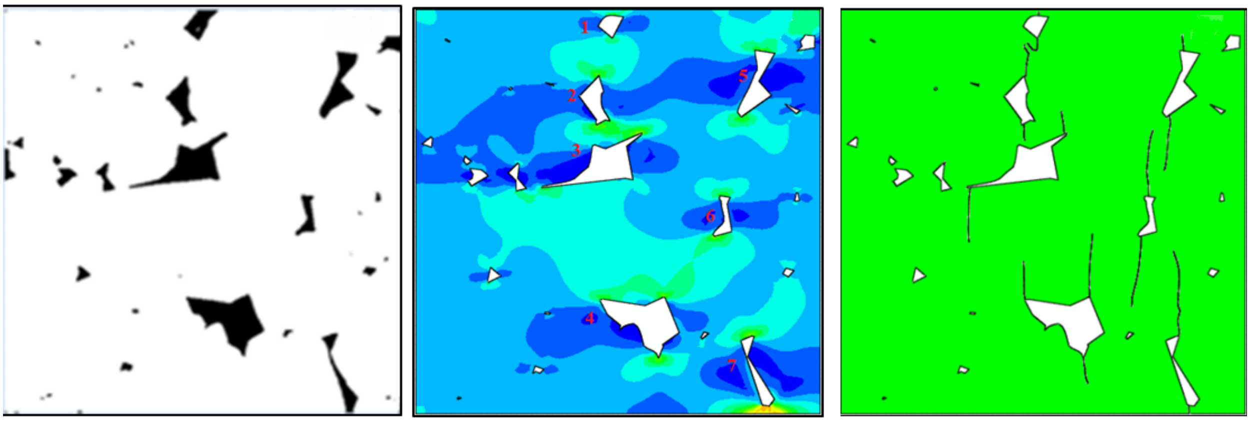
Table 1 shows the crack growth parameters by changing the shape and angle of the pore in equal sizes. As can be seen in this Table, the sample containing the rectangular pore at a zero degree angle is the strongest sample and the sample containing the elliptical pore at the 90 degree angle is the weakest sample.

Table 1. Comparison of crack growth parameters with changing geometry and pore placement angle

Pore shape	Pore placement angle (degree)	Von-Mises Stress (MPa)	Reaction force (N)
Rectangular	**0**	**0.885**	**836.3**
	45	1.408	719.6
	90	1.085	759.3
Circular	-	1.029	777.3
Elliptical	0	1.008	795.8
	45	1.093	744.4
	76.2	1.585	714.7
	90	**1.677**	**699.7**

To model the crack growth in the real rock environment, the image of Fontainebleau sandstone was used according to Figures 3A. Figure 3B shows how the stress is distributed in the simulated model. As can be seen, larger pores play a major role in the sample because the stresses in them are very high. There is also a concentration of stress in the sharp corners of the pore, so that according to Figure 3C, after the displacement, failure has occurred in larger pores, and therefore the small pores can be ignored.

The results showed that the different shapes of pores and its arrangements have a great effect on the growth process of cracks and fractures. Finally, by modeling a real rock sample and equating the main porosities with simple geometric shapes, a more accurate understanding of how each of the parameters affecting crack growth in phenomena such as hydraulic fracture was obtained.



(A) (B) (C)

Figure 3. A: Microscopic image of Fontainebleau sandstone [5], **B:** Stress distribution and **C:** Crack growth path in the sample

CONCLUSIONS

✓ In the identical pore size, the pore in the form of an ellipse is more destructive than the pore in the form of a rectangle.

✓ If the pore is located in front of the crack tip, in the identical pore size, the circular pore is more destructive than the elliptical and horizontal rectangular pores.

✓ If the pore is located on the sides of the crack, in the identical pore size, the circular pore is more resistant than the elliptical and horizontal rectangular pores.

✓ By equating real pore with simple geometric shapes, a better understanding of crack growth phenomena in processes such as hydraulic fracture can be achieved.

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