Research

Research Study on the Influence of Natural Cracks on Hydraulic Crack Propagation in Coal and Rock Mass

Farzand Ali1* Liang Wei Guo1*
1Department of Mining, Taiyuan University of Technology, Taiyuan 030000, Shanxi, China.
2State key laboratory of in-situ modification for deposits to improve mining Taiyuan University of Technology, China.

*Corresponding author
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Abstract: With the aim of study how natural fractures affect the extension and morphology of hydraulic fracture in coal and rock mass, the effect features were studied about natural fracture on hydraulic fracture extension and morphology using specimens made of similar materials that containing artificial present fracture as the research objects and indoor simulation equipment’s, injecting fracturing fluids on fixed displacement and based on analyzing the fracturing curves. The study had shown that: the initiation pressure reduced because of the existence of natural fractures in coal and rock mass, the hydraulic fracture morphology presented three cases: that were the hydraulic fracture spread along natural fracture surface, stopping or continuing to spread after bypassing the natural fracture. This study has some theoretical guidance on the determination of the extraction range and yield prediction of coalbed methane through research.

Keywords: hydraulic fracturing, hydraulic fracture propagation, natural fracture, coal and rock mass.

1. Introduction:

Considering that its introduction, hydraulic fracturing has been established as the premier production enhancement procedure in the Petroleum[1] and Mining industries and has continued to extremely control low-permeability reservoirs as one of the most vital area development operations. In extremely high permeability reservoirs, hydraulic fractures have a dual function: to stimulate the well as well as to provide sand control. In modest permeability reservoirs, the fracture accelerates production without affecting the well reserves. Hydraulic fracturing technology transformation measures is the primary means of increasing production of coalbed methane wells at home and abroad[2]. Fracture The hydraulic fracture propagation in the process is affected by
many factors, understanding the hydraulic power; The expansion law of cracks in coal-rock reservoirs, effectively exerting fracturing, the role of measures in the production of coalbed methane reservoirs is extremely important. By The coal rock mass is filled with natural layers such as bedding, cleats, joints, and fissures. Defects, resulting in a complex diversity of hydraulic fracture patterns, especially Is the case where the vertical and horizontal stresses in the formation are equivalent. Next, the existence of natural fractures in coal and rock layers, from the cracks in hydraulic fracturing, crack fracturing and fracture morphology plays a crucial role. M.geng, L.ji, L.B.Colmenares, [3]–[7] Using cement and quartz sand Pour test specimens or natural rock samples, simulate with A4 paper when pouring Natural fractures of different occurrences, the influence of natural fracture on the hydraulic fracture extension is systematically studied by using true triaxial fracturing device.

In the past, the research on natural fractures focused on the field test and theoretical analysis of oil and gas exploitation. In contrast, the experimental study on the fracture initiation characteristics of natural fractures in the process of coal seam permeability-increasing exploitation was rarely reported. In this paper, through laboratory experiments, the influence of the existence of natural fractures on the fracture initiation characteristics of coal rock hydraulic fracturing is simulated in order to provide some reference for the determination of the influence range of coalbed methane (gas) extraction and gas production prediction in China.

There are few researches on the opening, extension, and morphological characteristics of hydraulic fractures by natural fractures. The existing researches mainly focus on the following two aspects.

1. The influence of natural fracture on the opening and extension of hydraulic fracture. Generally, the three-dimensional principal stresses are not equal to each other, and the horizontal in-situ stresses of different layers are also different. For hydraulic fracturing, the relative size of the three-dimensional principal stress determines the direction of fracture extension, while the size and distribution of the minimum horizontal in-situ stress affect the fracture geometry. The distribution of natural fractures in coal and rock mass reduces the tensile strength of the rock and then affects the starting position and extension of hydraulic fractures [8] The research of D. A. Chuprakov. [9] shows that natural fractures are easy to cause a large amount of filtration of fracturing fluid and then produce multiple hydraulic fractures, which are easy to turn along the natural fractures. J. A. Rueda Cordero. [10] used the large-scale true triaxial experimental system
to simulate the hydraulic fracture shape under the influence of natural fracture. The experiment shows that the hydraulic fracture expansion of a random fracture reservoir can be divided into main fracture multi branch fracture mode and radial network expansion mode. K. Ogata, K. Senger, A. Braathen [11] found that under certain conditions, natural fractures will preferentially open and connect with each other to form hydraulic fractures. At this time, hydraulic fractures no longer strictly extend along the direction of the maximum principal stress. The calculation results of Ren LAN et al. [12] show that the tension initiation pressure of hydraulic fractures along natural fractures is significantly lower than that of the rock mass, and the hydraulic fractures of fractured reservoirs tend to crack along natural fractures.

2. Study on the morphological characteristics of hydraulic fractures by natural fractures. If the reservoir is homogeneous, the direction and shape of hydraulic fractures are controlled by the characteristics of the present-day in-situ stress field. When there are natural fractures in the reservoir, the tensile strength of the natural fractures is deficient or zero, which will destroy the homogeneity of the rock, which will inevitably affect the production characteristics of the fracture.

In the actual stratum, the coal rock mass cannot be homogeneous, there are a lot of natural fractures in it, especially the natural fractures of various origins near the shaft. In hydraulic fracturing [13], the existence of natural fractures will interfere with the expansion of hydraulic fractures and have a great impact on the initiation and extension process of hydraulic fractures, which is manifested as low fracture pressure of hydraulic fractures [14], There are sudden turning and secondary cracks in the process of extension. In practice, the natural fractures are distributed in three dimensions in the formation, and the extension path and production form will be more complicated after intersecting with the hydraulic fractures. When the hydraulic fractures do not form the through fractures along the natural fracture surface, it is easy to form the network fracture intersecting with the natural fracture surface [15].

2. Experimental simulation of the effect of natural fractures on hydraulic fracture propagation

2.1. Experimental equipment’s and specimen preparation.

An indoor hydraulic fracturing test can be carried out with natural rock sample or artificial rock sample. In view of the limitation of the source and processing conditions of natural rock sample, this test uses the cubic specimen made of cement, gypsum, coal powder and clear water
to carry out hydraulic fracturing simulation test. The experimental site is the State key laboratory of in-situ modification for deposits to improve mining Taiyuan university of technology.

(1) Experimental equipment. Test piece forming mold, hydraulic cylinder (range 50 MPa), multi-function true triaxial fluid-solid coupling test system pump, fracturing tube, vertical drilling machine and other auxiliary equipment, fracturing fluid is mixed with clear water.

(2) Specimen materials and ratios. Cement: Gypsum: Pulverized coal: Clear water = 2:1:1:2. The ratio is the test result of the mechanical properties of the simulated raw coal. The test results obtained by the mechanical properties test: compressive strength 5.38 MPa, elastic modulus the amount is 0.78 GPa and the Poisson ratio is 0.25.

(3) Manually preset natural cracks. In order to effectively analyze the influence of natural cracks on the crack initiation characteristics of hydraulic fracturing cracks, it is proposed to pre-manufacture a single “natural crack” in the test piece for analysis. Specific steps: Firstly, the cement, gypsum, coal powder and clean water are uniformly mixed according to the ratio. Pour into a 200 mm × 200 mm × 200 mm cube specimen forming mold, and then place the vertical mold of the log blue paper sheet processed to 130 mm × 80 mm × 0.18 mm at the bottom, 90° to the side of the mold (Figure 1). In Figure 1, θ is the approach angle (the angle between the “natural crack” and the main crack), and σH and σh are the maximum horizontal principal stress and the minimum horizontal principal stress, respectively.

(4) processing and manufacturing of test piece: the mold for forming test piece is demolded after
2 days of standing, and then the test piece is formed after 14 days of curing period. Figure 2 is a schematic diagram of the formed test piece.

![Figure 2 Molding Specimens](image)

After the processing of the overall dimensions of the test piece, cut and polish it. Use a vertical drilling machine to drill a hole with a diameter of 16 mm and a length of 110 mm in the center of the test piece and clean it with alcohol and cotton ball. After drying, put in a 110 mm long fracturing pipe, in which the length of the open hole section is 20 mm, and the solid section of the fracturing pipe and the borehole wall are sealed with epoxy resin glue.

2.2. Test process

Experiment preparation. First, fix the test piece on the reaction frame with auxiliary equipment, then use the hydraulic cylinder to load the confining pressure on both ends of the test piece at the same time, until the stress difference is 1 MPa, stop loading (ensure that the direction of the maximum horizontal main stress is perpendicular to the plane where the artificial preset fracture is located), and finally connect the hose that exhausts the air to the fracturing pipe to pump the fracturing fluid to start the experiment.

Experimental process: The vacuum pump in the multi-functional true triaxial fluid solid coupling test system is used to continuously pump fracturing fluid into the fracturing pipe at a constant displacement of 3.2 mm/s, and the fracturing condition of the test piece is observed until the pressure water flows out of the fracture, the pump is stopped and the test is completed.

Data collection: The multi-functional true triaxial hydraulic fracture test system is used to collect the injection pressure and displacement during the opening and extension of hydraulic
fractures. Take out the samples after fracturing, observe the traces of fracturing fluid on the fracture surface of the samples, and determine the fracture shape formed by fracturing. Fig. 3 is the schematic diagram of the experimental device.

![Experimental device diagram](image)

**Figure 3 Schematic diagram of the experimental device**

3. **Experimental results and Analysis:**

3.1. **Experimental Result**

Under the same test conditions, 6 samples with the same ratio were tested for fracturing, and the similar test results were obtained. Fig. 4 is the curve of water injection pressure with time of test piece 1, and the physical figure of test piece after fracturing.

During the test, the change curve of water injection pressure with time is shown in Fig. 4. It can be seen from Fig. 4 that after water injection, the fracturing fluid is pumped into the fracturing pipe, and the water pressure rises rapidly as the open hole section is gradually filled with fracturing fluid. At 14.4s, the water pressure rises rapidly to the maximum value of 1.11 MPa, and the test piece is opened under the action of water pressure the hydraulic fracture is formed. After that, the water pressure began to drop, and the reason was analyzed: after the crack began to extend, the newly injected water filled the new crack, resulting in the drop of water pressure. When the hydraulic pressure fluctuates in the process of hydraulic fracture extension, it shows that the extension path changes greatly, and the preset fracture interferes with the extension of hydraulic fracture till crack.
Figure 4 Pressure time curve of hydraulic crack morphology and water injection (Specimen 1)

Figure 5 Pressure time Curve of Hydraulic crack morphology and water injection (Specimen 2)

Figure 6 Pressure time Curve of Hydraulic crack morphology and water injection (Specimen 3)
From the injection pressure time curve in Fig. 5-6, it can be seen that the fracturing fluid starts to pump in, and the water pressure rises rapidly. When it reaches the peak point, the hydraulic fracture begins to occur. With the continuous pumping of fracturing fluid, in order to fill the new hydraulic fractures, the injection pressure curve began to decline, and the fractures then extended. After encountering the natural fracture, the water pressure curve fluctuates in different degrees, which indicates that the natural fracture affects the extension path of the hydraulic fracture, until the hydraulic fracture extends to the edge of the test piece, water flows out, and the experiment ends. The hydraulic pressure curve of the two specimens of specimen 2 and specimen 3 is similar to that of specimen 1, indicating that the existence of natural fractures affects the fracture path of the specimen and causes the fluctuation.

The hydraulic fracture form after the fracture of the specimen 2 can be obtained: during the hydraulic fracturing process, the crack extends along the direction of the maximum principal stress, and the crack morphology changes obviously after encountering the natural crack, and some of the hydraulic cracks stop at the natural crack. Some extend along the natural crack surface, and the specimen fractures along the crack surface after the specimen is fractured. The fracture extends to the surface of the test piece, and the fracturing fluid flows out from the crack that has been generated. Stop the experiment.

The hydraulic fracture morphology of the specimen is shown in Figure 4. It can be seen that the hydraulic fracture extends along the direction of the maximum principal stress. However, when the hydraulic fractures encounter the pre-set artificial fractures, the fracture morphology no longer presents ellipse shape, and the extension path also changes; some of the hydraulic fractures stop at the natural fractures; some of them bypass the natural fractures and then extend; some of them extend along the natural fracture surface. Fig. 5 and Fig. 6 are the pump injection pressure time curve of specimen 2 and 3 and the physical figure of hydraulic fracture after fracture of specimens.

However, there is no similar crack pattern on the other end, which may be due to the non-uniformity of similar materials caused by the casting process, which causes the crack to extend in the direction of extension.
In Figure 6, although the fracture extension path of the cracked specimen extends along the direction of the maximum principal stress, it is different from the fracture pattern of the first two specimens: the fracture extension occurs at both ends of the fracturing tube, the specimen may be heterogeneous due to the forming process, and the hydraulic fracture only appears at one end. When the hydraulic fracture meets the natural fracture, the extension path becomes to bypass the natural fracture and then extend, that is, it extends perpendicular to the direction of the minimum principal stress. After stripping the test piece, it is found that part of the hydraulic fracture extends along the natural fracture surface for a certain distance. The reason why it does not break along the natural fracture surface is that the size of the test piece is small, the hydraulic fracture that bypasses the natural fracture and then extends to the edge of the test piece, and the fracturing fluid has flowed out.

3.2. Analysis of experimental results:

The water injection pressure-time curve shows that after the pumping of the fracturing fluid, the water pressure rises rapidly, and hydraulic cracks begin to occur. With the continuous pumping of the fracturing fluid, the water pressure drops, in order to fill the newly generated hydraulic cracks. After that, the water pressure curve fluctuated several times because the existence of natural cracks affected the normal extension of the hydraulic crack and changed the original extension path.

According to the hydraulic fracture morphology after fracturing, it can be concluded that the hydraulic fracture extends along the direction of vertical minimum horizontal principal stress, but the natural fracture interferes with the extension of hydraulic fracture in different degrees, and then affects the fracture morphology of the specimen. After fracturing, it is found that there are more complex hydraulic fractures near the natural fractures with regularity, the crack shape is no longer elliptical.

Based on the above experimental results, it is found that the hydraulic cracks have three kinds of extensions after encountering natural cracks: the hydraulic cracks bypass the natural cracks and then extend, the hydraulic cracks stop after the natural cracks, and the hydraulic cracks extend along the natural crack planes. The effect of natural cracks on hydraulic fractures is fully reflected in the pressure-time curve.

4. Conclusion

In this paper, the influence of natural fracture on hydraulic fracture is simulated in the laboratory, it can be seen that the cracks in coal plainly go beyond those in bordering rocks, and
also show complicated morphology. Both straight and also upright cracks create in coal and also interweave with each other, creating a linked network. In the fracturing procedure, the bigger the variation of shot stress is, the much better the inner cracks establish. The proliferation of cracks is an alternate vibrant procedure. First cracks arise near the wellbore, after that overlap the weak airplane of coal in a cyclic development (expand-- quit-- prolong once more) till the shot stress is low sufficient to split the coal. However, due to the limitation of specimen size, when the fracturing fluid flows out from the fracture extending to the edge of specimen, the research on hydraulic fracture is also finished. This experiment failed to simulate the large-scale hydraulic fracturing experiment, and the next step is to simulate the large-scale specimen fracturing in order to provide more theoretical support for the coalbed methane production.

References:


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Conflicts of Interest
There are no conflicts to declare.
Farzand Ali

(Researcher) Taiyuan University of Technology

Email: farzandali81@gmail.com

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