Laboratory research of hydraulic fracturing with tangential loading of borehole wall

MV Kurlenya, AV Patutin*, LA Rybalkin, SV Serdyukov and TV Shilova
Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences,
Novosibirsk, Russia

E-mail: *andrey.patutin@gmail.com

Abstract. Under study is transverse fracturing of an organic glass block through secondary shearing stress applied to the borehole wall. To this effect, a system composed of a press sealer and a collet anchor manufactured in two options has been designed. It is shown than an anchor with a circular groove allows reducing breakdown pressure and enables effective transverse fracture at the borehole bottom.

Hydraulic fracturing method is a primary way to increase the effectiveness of borehole mining technologies employed in solid minerals mining in underground conditions. Taking into account previous experience one can conclude that it is practically useful to create in a borehole one or several parallel to each other transverse cracks. The hydraulic fracturing method can be employed to soften the hard coal bed top [1], to increase gas-recovery [2], to create impervious screens [3] and to extend effective area of thermal action and in-situ leaching on rock mass [4].

Well-known methods to create a hydraulic fracture across the borehole axis are based on employment of slot initiators formed in rock by jet or mechanical slot generators. The main drawback of the method is the necessity to cut in the rock mass a fracture initiator, which requires additional time and energy-consuming operation. To increase the effectiveness of the directional hydraulic fracturing in uncased borehole a slotless method is suggested. This method implies that energetically beneficial direction of the fracture propagation is set by anchors due to non-destructive changes of the stress condition of rock masses near the borehole [5]. Buoyant force of the working fluid pressure influencing the sealer is transmitted to the anchor’s contact to the rock mass. It creates the additional tangential loading on the borehole walls, which causes the rocks tension along the borehole axis and formation of a transverse crack. This work is aimed at the experimental test of the slotless method of directional hydraulic fracturing in laboratory setting.

To implement the described approach we have developed a directional fracturing tool general view of which is shown in Figure 1.

The tool consists of a collet anchor 1, pressure sealer 6, tube 8, screw nut 10, draft 9 with the inner channel 5 and a hydraulic output 11. The anchor is made in two variants: one with the ring groove b, forming the sharp indenter point a and another—without the groove. As for the first variant coupling of the anchor and the borehole walls takes place along the indenter impressing in the model’s materials with the contact area 2–4 times less than the borehole’s cross section. In the second variant the anchor’s coupling area exceeds the cross section in 2–4 times.

When the experiments are being performed the tool is inserted all the way in the borehole bottom, after that, the draft 9 is screwed in the anchor 1 and placed in the operating position. Then, the sealer
6, plate 7, tube 8 and screw nut 10 are set, and the fracture interval is sealed. The output 11 is connected with a hydraulic station by a high-pressure hose. The working fluid is injected in the fracture between the borehole bottom and the sealer through the input 11 and canal 5.

**Figure 1.** Plain view of the hydraulic fracturing tool: а—hydraulic fracturing tool: 1—wedge anchor; 2—cone; 3—pad; 4—screw joints; 5—fluid channel; 6—sealer; 7—washer; 8—tube; 9—draft; 10—screw nut; 11—hydraulic input; b—improved wedge anchor: 12—indenter; 13—ring groove; c—standard wedge anchor.

The fluid pressure in the isolated interval (P) extrudes the tool from the borehole with the power $\pi R^2 P$, where $R$ — borehole’s radius. The power is transmitted to the anchor creating the tangential loading on the anchor contact with the borehole. The loading and the fluid pressure at the borehole bottom cause the model’s material stretching along the borehole axis [6]. In the variant with the indenter the loading is localized along the output line formed by the edge crack indenter, and its value approaches $PR/2$. When the standard anchor is employed the tangential loading is distributed along the area $2\pi R L_a$, where $L_a$ is the length of the anchor’s contact with the borehole wall ($L_a \approx 1.5R$). In this case the tangential loading does not exceed $P/2$, therefore, employment of the suggested approach is preferable [7].

Figure 2 shows the laboratory bench scheme to carry out the experiments. It consists of a model, hydraulic and measuring systems. The model is a 250×400×600 mm plexiglas slab with the holes (the so-called boreholes) drilled in it. Their diameter is 16 mm and depth is equal to 80–120 mm.

**Figure 2.** Laboratory bench scheme for the study of directional hydraulic fracturing.

The hydraulic system of the bench contains the hydraulic fracturing tool A1, shown in Figure 1, the high-pressure manual pump MP with the backflow prevention valve PV1 at the output, syringe pump SP for precise injection, valve PV2, pressure gauge PG, drain tank T and high-pressure connection hoses.
The measuring system of the bench includes the pressure sensor PS, crate A2, equipped with the module A3, as well as analog-to-digital converter A4 and computer A5. There is a strain-gage pressure sensor LH-412/400 (Tenzopribor, Russia), able to measure the working fluid’s rapidly changing pressure from 0 to 40 MPa in the frequency range 0-1500 Hz with an accuracy of ±0.8%. The sensor PS electric signal goes to the measuring module outputs of the equipment SCC (National Instruments, USA) set in the crate SCC-2345 (A2). In the work SCC-SG04) (A3) module is used to connect the bridge sensors. The output signal of the module SCC is transmitted to the input of the analog-to-digital converter NI DAQPad-6015 (A4) through the tool bus of the crate A2. Through the USB port the digitized data is transmitted to the computer A5, where the files are saved in txt format. Data collection and measuring system management is organized in LabView (National Instruments, USA).

The laboratory tests on the directional hydraulic fracturing are carried out according to the following methodology:
1) the fracture tool is installed in the prepared model, the hydraulic and measuring parts of the bench are attached;
2) the continuous recording of the sensor PS output signal with the discretization interval 1 m/sec;
3) fracturing interval is filled with the working fluid up to pressure 1.0 MPa;
4) the working fluid pressure is getting increased by syringe pump SP in the fracture interval until a crack is formed. The crack formation is recorded by the sudden drop of pressure on the pressure gauge PG. After that the working fluid is not supplied while the hydraulic system is kept closed. In case when the fracturing is performed with the help of the anchor without the ring groove a longitudinal crack is formed along the well (Figure 3a). If there is an indenter point a cross crack is formed (Figure 3b).

![Figure 3. Hydraulic fracturing cracks formed in experiments: a—transverse crack; b—longitudinal crack.](image)

The laboratory test results on the hydraulic fracturing performed with the developed tool are presented in the table.

The averaged pressures of the plexiglas fracturing are: in case of the longitudinal hydraulic fracturing—21.71±5.09 MPa, in case of the cross hydraulic fracturing—16.01±4.39 MPa. Confidence intervals correspond with the possibility of 0.9. There is a significant difference in the fracture pressures in both fracture schemes. It is not connected with the characteristics of the medium as the experiments are performed on the one material. It is likely that the difference is caused by different quality of borehole boring as well as the influence of the industrial micro crack sizes on the plexiglas resistance to the hydraulic fracturing. The second reason is the possible difference in the boreholes’ distances from the free surfaces. Thus, the longitudinal fracture in the area of the transverse cracks appeared due to the abnormally low pressure 7.65 MPa. It is important to mention that when the...
Fracturing is performed with the indenter a transverse crack is formed in all the experiments. The obtained data display the working efficiency of the directional hydraulic fracturing.

Results of laboratory tests on hydraulic fracturing cracks’ orientation and pressure.

| Fracture scheme | Crack orientation | Crack output at model’s edge | Fracture pressure, MPa | Shut-in pressure, MPa | Crack diameter, mm |
|-----------------|-------------------|-------------------------------|------------------------|-----------------------|--------------------|
| Anchor with indenter | longitudinal | no                            | 13.44                  | 2.99                  | 91–104             |
|                   |                   | yes                           | 16.52                  | 2.00                  | 114–174            |
|                   |                   |                               | 18.01                  | 0                     | –                  |
|                   |                   |                               | 21.13                  | 0                     | –                  |
|                   |                   |                               | 33.17                  | 0                     | –                  |
|                   |                   |                               | 20.37                  | 0                     | –                  |
|                   |                   |                               | 29.35                  | 0                     | –                  |
| Anchor with indenter | transverse | yes                           | 19.02                  | 0                     | 214                |
|                   |                   |                               | 14.22                  | 0                     | –                  |
|                   |                   |                               | 14.80                  | 0                     | –                  |

Acknowledgements
The research was carried out in Institute of Mining SB RAS and supported by the grant of the Russian Scientific Foundation, project № 15-17-00008

References
[1] Lekontsev YM Sazhin PV 2008 Application of the directional hydraulic fracturing at Berezovskaya Mine J. Min. Sci. 44 (3) 253–258
[2] Huang B Cheng Q Chen S 2016 Phenomenon of methane driven caused by hydraulic fracturing in methane-bearing coal seams Int J Min Sci Technol http://dx.doi.org/10.1016/j.ijmst.2016.05.042
[3] Kurlenya MV Shilova TV Serdyukov SV Patutin AV 2014 Sealing of coal bed methane drainage holes by barrier screening method J. Min. Sci. 50 (4) 814–818
[4] Vorobiev AE Chekushina TV Pogodin ML Odincova ES 2000 In situ leaching of gold in Russia Min. Inf. Anal. Bull. 12 45–48
[5] Shilova TV Serdyukov SV 2005 Protection of operating degassing holes from air inflow from underground excavations J. Min. Sci. 51 (5) 1049–1055
[6] Azarov AV Kurlenya MV Patutin AV Serdyukov SV 2005 Mathematical modeling of stress state of surrounding rocks around the well subjected to shearing and normal load in hydraulic fracturing zone J. Min. Sci. 51 (6) 1063–1069
[7] Serdyukov SV Kurlenya MV Patutin AV Rybalkin LA Shilova TV 2016 Experimental Test of Directional Hydraulic Fracturing Technique J. Min. Sci. 52 (4)