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Sealing of hydraulic fracturing interval with polymer bridges in coal seam

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Abstract. The paper describes in-seam hydraulic fracturing with packing of intervals in uncased holes using solidifiable polymer materials. The idea of this approach includes the usage of two pipe columns nested in one another. The external column is employed for hole cleaning and for delivery of hydrofracturing facilities in the selected interval of the hole. The internal column is composed of five separate hydraulic channels, allowing the polymer bridge components and breakdown fluid to be injected independently. Using the mathematical modeling the authors analyze stress distribution on hole walls in the vicinity of isolated interval depending on elastic properties of polymer bridges.

1. Introduction

With the advance of the directional drilling technologies more elongated holes with a length of more than 400 m are used for pre-mine drainage of coal. A year of degassing increases the gas drainage of the holes to 70% and, thus, improves the safety of coal mining with modern high-productive longwall machines [1, 2]. At the same time, despite the evidential success, current operation of gas drainage boreholes has faced some problems, such as gradual decrease in recoverable coalbed methane due to violation of initial conditions in rock mass by narrow pattern arrangement and mutual effect of drainage boreholes. In this case in-seam hydraulic fracturing creates the opportunity to keep the overall methane flow rate at wider spacing of holes [3]. Additional well tests make it possible to choose efficient intervals for hydraulic fracturing, including estimation of the deformation characteristics in coal and rock mass [4, 5].

One of the problems of hydraulic fracturing application is sealing of a fracture interval in a hole with the cross-section along the borehole axis that can vary greatly in size and shape [6]. In this case regular inflatable packers are of low use. The reason is that their cord-reinforced expendable shells fail to shut down the whole borehole in which the maximum and minimum cross-sections can vary by 3 times. The increase in length of inflatable packers to 5 m and more complicates in-seam operation, and reliable sealing of fracturing intervals is not ensured due to high fluid pressure that can reach several hundred bars.

In present paper authors consider sealing of fracturing intervals with unremovable bridges made of a solidifiable material to be the only method of multi-stage hydraulic fracturing in such conditions. This is a kind of a return to the early hydrofracturing methods in oil production based on the modern engineering solutions and polymers.

2. Multi-stage hydraulic fracturing

The approach includes solution of such technical problems as:

- Delivery of downhole equipment and polymer materials in the preset interval of a hole prone to breakout;
- Sealing of a fracturing interval in a variable cross-section hole;
- Pressure injection of working fluids (suspensions) with proppant in hole;
- Drilling-out of polymer bridges to recover connection between the fracturing interval and the hole bottom/mouth.

The proposed method of sealing with unremovable bridges includes pre-sealing of a set interval with a formwork made of phenol resins readily spumescent when mixed with catalysts. The unremovable bridges are created by polymerization of the two-component mixture of rigid polyurethane or organomineral resins at high cohesion with rocks [7].

In the developed engineering solution of the downhole pack for coal degassing stimulation by multi-stage hydraulic fracturing two unconnected pipe columns nested one in another are used. The external column equipped with centering skid and ring cutter is employed for cleaning and washing-out of the hole, as well as delivery of hydrofracturing tools in preset intervals.

The internal column with five separate hydraulic lines can have a cartridge design (all lines are pipes, e.g. Figure 1) or mixed type design (breakdown fluid feed line is pipes, the other lines are flexible high-pressure hoses). The internal column is freely rotatable and movable along the external column. A multi-point injector is mounted at the end of the internal column. It feeds formwork and polymer bridge materials in the required intervals of hole or injects breakdown fluid (suspension with propant) under pressure in the fracturing interval.

(a) (b)

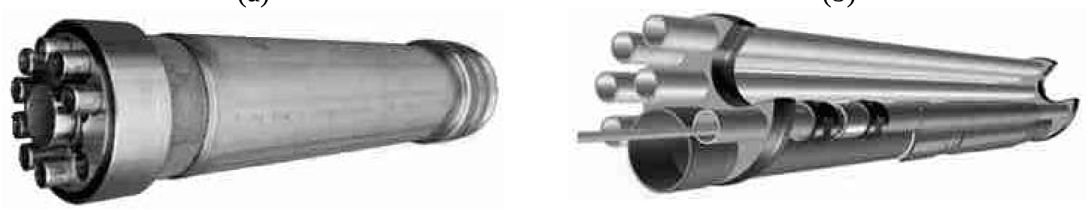

Figure 1. Multi-channel cartridge-design pipe columns (HMPS by SOLEXPERTS, Switzerland): general view of column width central fluid feed line (a); cartridge with off-set fluid feed line (b).

The sequence of multi-stage hydraulic fracturing suing the developed engineering solution is in detail described in [7].

3. Mathematical modeling results

For the estimation of the effective stresses on the borehole walls at the sealed interval the following problem was considered. A hole had a cylindrical form and *a* radius in a uniform isotropic medium with elasticity modulus $E_1 = 3.6 \cdot 10^9$ Pa and Poisson's ratio $v_1 = 0{,}3$; E_2, v_2 are the elasticity modulus and Poisson's ratio of polymer bridges with a length *H* installed in the hole. In the interval *h*, the fluid pressure is *P* (Figure 2).

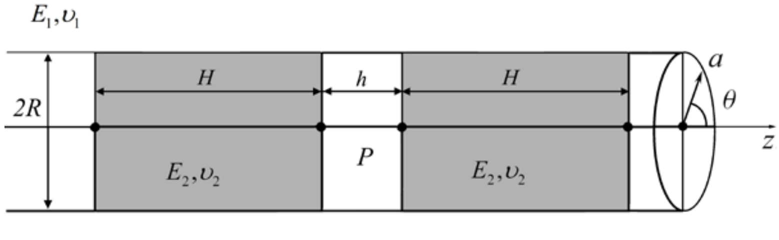

Figure 2. Problem formulation to calculate effective stresses.

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The problem was solved by the finite element method (FEM). Firstly, we tested FEM and compared the obtained results and the analytical solution. Figure 3 illustrates calculation of axial and circumferential stresses normalized to the fluid pressure P in the radial loading of the hole interval equal to $2a$. In this case, the analytical solution is obtained using the scheme from [8]. The positive stresses are tensile. The results show that the numerical and analytical solutions are similar, thus, the selected numerical method can be used to solve the set problem.

(a) (b)

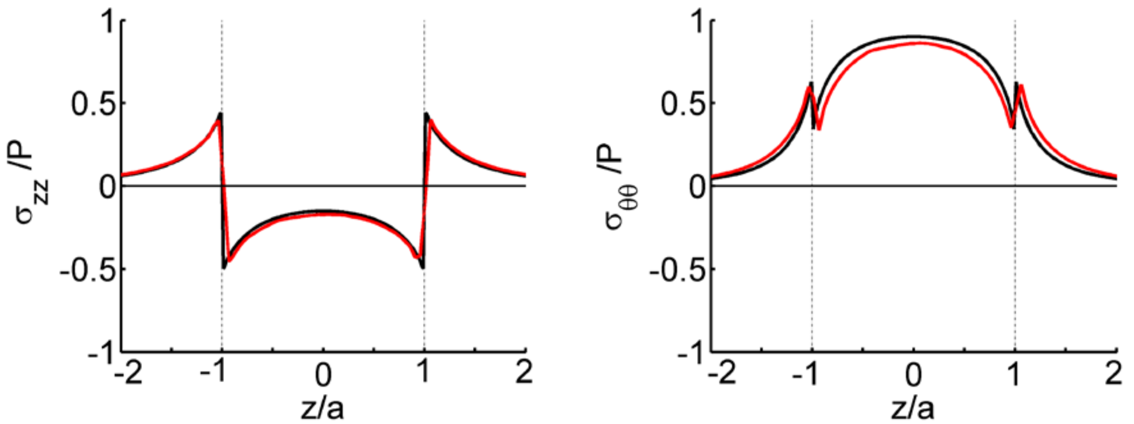

Figure 3. Axial σ_{zz} (a) and circumferential $\sigma_{\theta\theta}$ (b) stresses on the borehole walls, normalized to fluid pressure P: red—numerical solution, black—analytical solution.

At the second stage, we assessed influence of polymer bridges on stress distribution on the borehole wall under fluid feed. It is assumed that the fluid exerts the pressure P on the sealed interval in the hole and on the surface of the polymer bridges from the walls in this interval. The analysis included two cases with the bridge's elastic modulus E_2 higher ($2.5 \cdot 10^{10}$ Pa) and lower ($2.5 \cdot 10^{8}$ Pa) than the enclosing rock elasticity modulus E_1. Poisson's ratio was assumed as 0.3 for all materials, the bridge length was $H = 0.4$ m, and the bridge-to-bridge interval length was $h = 0.01$ m.

The calculated stresses are plotted in Figure 4, with red and black color illustrating data for the low and high elastic moduli, respectively. It is seen in Figure 4 that as the elastic modulus decreases the axial stresses σ_{zz} and the circumferential stresses $\sigma_{\theta\theta}$ slightly grow outside the bridge-to-bridge interval. A change in the elastic modulus has no effect on σ_{zz} stresses within the bridge-to-bridge interval. Also note that σ_{zz} exceeds $\sigma_{\theta\theta}$ in value.

(a) (b)

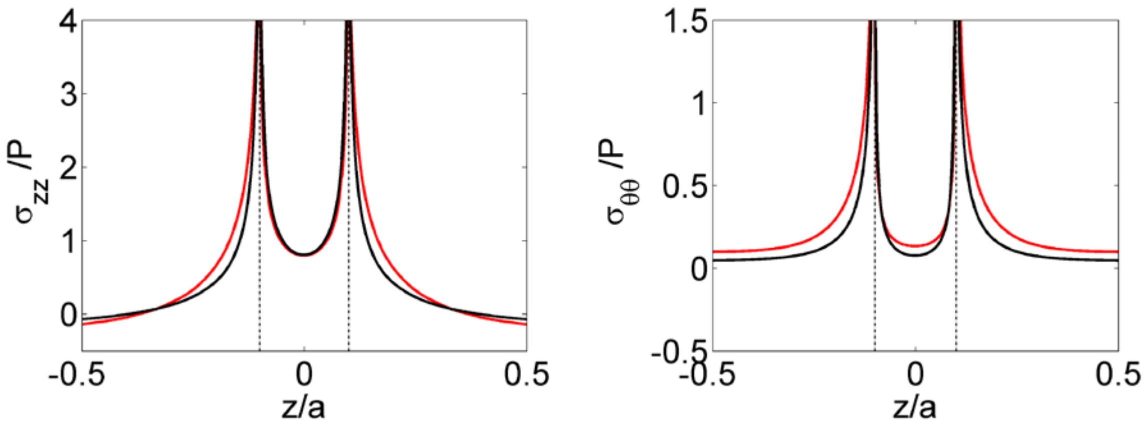

Figure 4. Axial σ_{zz} (a) and circumferential $\sigma_{\theta\theta}$ (b) stresses on the borehole wall normalized to fluid pressure P: red—$E_2 = 2.5 \cdot 10^{8}$ Pa, black—$E_2 = 2.5 \cdot 10^{10}$ Pa.

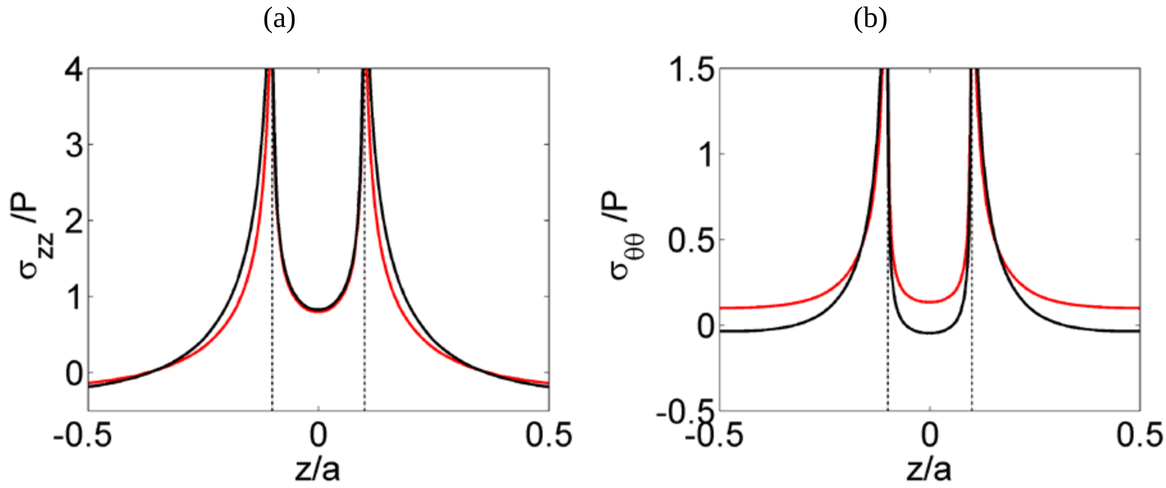

Figure 5. Axial σ_{zz} (a) and circumferential $\sigma_{\theta\theta}$ (b) stresses on the borehole wall normalized to fluid pressure P at $E_2 = 2.5{\cdot}10^8$ Pa: red—$\nu_2 = 0.3$, black—$\nu_2 = 0.1$.

Figure 5 presents the comparison between stresses for two different ν_2 at $E_2 = 2.5{\cdot}10^8$ Pa. It is shown that an increase in Poisson's ratio of the bridges results in higher $\sigma_{\theta\theta}$ in the vicinity of the bridges. On the other hand, the change in Poisons' ratio causes no considerable alteration in the axial stresses σ_{zz}. Additional numerical calculations showed that effect of the Poisson's ratio of polymer bridges decreases with increasing elastic modulus.

The experimental calculation results show that the chemical compounds of the polymer bridges should be carefully selected in order to design and perform hydraulic fracturing based on the proposed engineering solution. Note that the numerical calculations were carried out in the framework of the linear theory of elasticity.

4. Conclusions

The authors have proposed the new method for sealing of hydraulic fracturing intervals in holes of variable cross-section using irremovable bridges made of polymer materials. This method and the developed engineering solutions facilitate in in-seam multi-stage hydrofracturing in gas drainage boreholes.

Using numerical methods effective stresses on borehole walls are modeled mathematically as functions of elastic properties of the polymer bridges. It is shown that using two closely spaced polymer bridges creates favorable conditions on borehole wall for the transverse fracturing. In the framework of the linear theory of elasticity the following results were obtained:

1) As the elastic modulus decreases the axial stresses σ_{zz} and the circumferential stresses $\sigma_{\theta\theta}$ slightly grow outside the bridge-to-bridge interval. A change in the elastic modulus has no effect on σ_{zz} stresses within the bridge-to-bridge interval; but it is found that a decrease of the elastic modulus leads to an increase of the circumferential stresses $\sigma_{\theta\theta}$.

2) An increase in Poisson's ratio of the bridges results in higher $\sigma_{\theta\theta}$ in the vicinity of the bridges. On the other hand, the change in Poisons' ratio causes no considerable alteration in the axial stresses σ_{zz}. Test results showed that effect of the Poisson's ratio of polymer bridges decreases with increasing elastic modulus.

Acknowledgements

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