Mechanical compression effect on gas filtration through the crack filled with acrylate composition

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Abstract. Hydraulic fracturing is a promising method used for increasing the permeability of a coal seam. Formation of an extensive network of drainage cracks contributes to increased gas recovery of coal. In order to challenge this problem, it is proposed to screen mine workings with an additional crack filled with acrylate polymer containing solid inclusions, which prevents the closure of crack edges under the impact of rock pressure. The paper presents the results of experimental studies of acrylate screen gas permeability dependence on rock pressure.

1. Introduction
Advancement of mining technologies have prompted an increase in the efficiency of underground coal mining with methane extraction from gas-bearing coal seams (coalbed methane, CBM), which has enabled deeper and more gassy seams to be mined. For methane capture at levels required for safe and cost-effective operation of a coal mine, it is critical to carry out degasification of coal seams by hole drilling in advance of mining. In some cases additional methods for intensifying gas extraction are applied. Among them is in-mine hydraulic fracturing [1, 2], which involves isolating the interval of a degassing well and pumping high-pressure fluids into such intervals until rock failure is initiated by the induced fracturing. In the context of dynamic geomechanical conditions of underground mining operations, aggravated by natural jointing and low coal strength, hydraulic fracturing may have a complex evolution pattern within the failure zone that propagates into the mine workings either by intersecting system of open natural fractures or directly. This enhances trends in methane and air exchange between the degassing well drainage zone and mined-out space. As such, the cross-flows can be eliminated by applying a polymer composition over an expansive surface area of the mine workings, which is a labor- and material-intensive operation. Erecting a thin impervious partition (screen) between the mine workings and the working interval of the degassing borehole instead would be more technologically advantageous [3, 4].

This paper presents results of the laboratory studies of forced nitrogen filtration through a porous cylindrical sample containing a screen (a discontinuity filled with acrylate composition) across the filtration flow. The sample was exposed to lateral and axial compression, simulating the stress state of the rock mass. The study of the filtration blocking screens revealed the effect of irreversible formation of permeable ‘windows’, or contact zones, resulted from partial closing of the fracture edges in the sample under compression.
2. Method for sample preparing and experimental procedure

The experimental cylindrical samples were made from a porous medium - soft abrasive material with ceramic bonds and a grain size of 250–315 microns. The samples comprised two identical cylinders 45 mm high and 45 mm in diameter each (Figure 1a).

![Figure 1. Composite porous sample with a transverse failure (a) and VARIOTITE, a three-component acrylate composition (b).](image)

The cavity of the permeability (filtration) blocking screen (the failure mode of discontinuity) in the sample was filled with VARIOTITE hydrogel (TPH Bausysteme GmbH, Germany) (Figure 1B). This is a three-component, water-swelling-capable elastic hydrogel based on methacrylate (water absorption of 100 % to the volume of the polymer), whose elongation to failure is 1000 %.

The laboratory experiments were conducted using a specialized setup with a test chamber providing separate control of the axial and uniform lateral compression of a composite cylindrical sample, and ensuring the gas pumping through it (i.e. filtration of gas) [5]. The volume of filtered gas was measured by an automatic electronic-optical system [5]. The measurement results, specifically, gas volume and input pressure were recorded and stored in the PC memory.

The failure cavity in the composite sample was not filled in the first (background) series of experiments. The axial and lateral loads were equal (from 1 to 5 MPa), the pressure drop between the end faces of the sample was 0.005–0.05 MPa.

In the second series of the experiments, the failure cavity was filled with an acrylate compound. For this purpose, we used the sample whose parts were joined together so that the end faces had a gap of 0.2–0.6 mm and their butting position was fixed with adhesive tape. Preparation of the acrylate composition was carried out in a glass container, taking into account its viability time as short as 3–4 min, which however was long enough to collect the necessary amount of acrylate with a syringe and make an injection into the gap cavity by puncturing through the adhesive tape. After the composition was cured, the sample was placed in the test chamber. The preset values of axial and triaxial compression were equal to those in the first series. The pressure drop at the sample ends was increased to 0.1–0.5 MPa.

The coefficient of permeability to gas was determined from the condition of the stationary (steady-state) flow regime, given a linear gas flow, according to the formula [6, 7]:

\[
K_g = \frac{2 \cdot 10^4 V \mu_a P_2 L}{t S} \left( \frac{1}{P_1^2} - \frac{1}{P_2^2} \right),
\]

where \(K_g\) is the coefficient of permeability to gas, \(10^{-3} \text{ µm}^2\) (mD); \(P_1\) is the inlet pressure of the test chamber, MPa; \(P_2\) is the outlet pressure (equal to atmospheric pressure), MPa; \(V\) is the volume of gas that passed through the model, \(\text{cm}^3\); \(t\) is gas filtration time, s; \(\mu_a\) is dynamic nitrogen viscosity under filtration conditions, MPa•s; \(S\) is cross-sectional area, mm²; \(L\) is the model length, mm.
3. Results and discussion
Results of the first series of experiments on the study of permeability parameters during transverse composite failure showed a decrease in the sample permeability under increasing triaxial compression of the model (Figure 2a). Higher $K_g$ values for low gas filtration pressure gradients are associated with the Klinkenberg effect (i.e. gas molecules slip effect in porous media) [8]. In the second series of the experiments, the dependence of permeability to gas on compression differed from the first series (Figure 2b), which increases exponentially with the increasing axial compression, while the effect of lateral compression is similar to that observed in the first series. This is explained by the addition of axial compression causing the growth of the contact zone between the fracture edges, while the contact pads form permeable “windows” in the acrylate impervious screen.

![Figure 2.](image)

The addition of low density proppant material (hollow aluminosilicate microspheres) to the acrylate composition is proposed for reducing the extent of contact zones when the crack edges tend to close [9, 10]. Preliminary experiments have shown that acrylate admixed with proppant improves the impervious properties of the screen, which, however will complicate the composition injection into its cavity through high-pressure hoses. Future laboratory tests are planned to be conducted on filling the impermeable screens with the acrylates mixed with solid inclusions (proppants).

4. Conclusions
An increase in the mechanical compression of the gas filtration blocking screen filled with an acrylate composition causes an enhancement of its pervious characteristics. This is accounted for the formation of filtration channels at the contact of crack edges due to their proximity to each other. The proposed problem solution consists in the addition of proppant material to the acrylate composition.

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