Laboratory tests of the packer sealing elements

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Abstract. The test bench to study sealing elements made of elastomers is designed and manufactured. The relationships of their geometric parameters vs. axial load and probable reasons for jamming of sealing devices under packing in wells are established. The solutions to improve performance of sealants (packers) are worked out and proposed.

1. Introduction
Application of the directed and interval hydraulic fracturing tends to grow at Kuzbass coal mines. We consider some factors affecting the performance of hydrofracturing in a rock mass, disregarding the detailed description of the process, which, no doubt, contributes to higher safety of underground mining operations.

Hydrofracturing in wells drilled in a rock mass can be realized, given that a section of this well is properly sealed [1–4]. Special facilities are available to guarantee this condition. They are inflatable sealers of Taur- type and mechanical sealers capable to vary its external diameter under axial compression [5]. The imperfection of an inflatable sealer is a relative small increment of the external diameter (8.0 mm), this drawback constricts the application scope and does not enable to realize the internal hydrofracturing. An additional point is that its low axial stiffness does not allow its mounting in an upward well and at depth of more than 20 m. Thus, under conditions of extended wells and interval hydrofracturing it is reasonable to employ rigid-body sealers and sealing elements made of elastomers. They are less sensitive to mechanical effects and more adaptable to variable conditions of interaction with well surface. However interaction of elastomers with host rocks in wells has not got thorough investigation yet. All the above complicates selection of an elastomer material considering mining and geological environment and a high risk for sealer jamming after hydrofracturing.

2. Laboratory tests of the elastomer specimen
The test bench was designed and manufactured to test elastomer sealers on axial compression and stability (Figure 1). The test bench consists of frame 10, collet clamp 2, sliding carriage 3, balance wheel 4 with screw 5. Sealer case end 1 is rigidly locked by collet clamp 2, the other end is dressed with running-fit sleeve 7. Dynamometer 6 is mounted between sleeve 7 and screw 5. Elastic elements 8 of a sealer are mounted on case 1 and loaded by axial compression through sleeve 7 by screw 5 and balance wheel 4 in its rotation. Ball 9 centralizes force transmitted from screw 5 to sleeve 7. Diameter of elastic element 8 is changed by means of clock-type indicator 11 at three points: in center, and on ends of the element.

Table 1 reports test data on polyurethane specimen with Shore hardness of 40 units. Figure 2 demonstrates basic dimensions of the test specimen made of elastomer and its loading scheme. The
left end of the specimen supports on a plain washer and the right end supports on a conical washer. Loading was cancelled after the test specimen lost stability.

![Figure 1. Test bench scheme.](image1)

**Table 1.** Tests of the elastomer specimen.

| Plunger stroke, mm | Specimen length, mm | External diameter \( d_{\text{ext}} \), mm | Increment \( \Delta d \), mm | Dynamometer readings, kg |
|--------------------|---------------------|------------------------------------------|------------------------|------------------------|
|                    |                     | left end | center | right end | left end | center | right end | left end | center | right end | left end | center | right end | left end | center | right end | left end | center | right end | left end | center | right end |
| 0                  | 60                  | 31.5    | 31.7   | 31.5      | —        | —      | —        | 180      |        |           |        |        |           |        |        |           |        |        |           |        |        |           |
| 4                  | 56                  | 32.5    | 33.4   | 33.1      | 1        | 1.7    | 1.6      | 550      |        |           |        |        |           |        |        |           |        |        |           |        |        |           |
| 8                  | 52                  | 34.1    | 34.8   | 35.8      | 2.6      | 3.1    | 4.3      | 950      |        |           |        |        |           |        |        |           |        |        |           |        |        |           |
| 12                 | 48                  | 34.6    | 34.5   | 43.3      | 3.1      | 3.1    | 12.8     | 1000     |        |           |        |        |           |        |        |           |        |        |           |        |        |           |
| 16                 | 44                  |         |        | Stability loss |         |        |           | 1020     |        |           |        |        |           |        |        |           |        |        |           |

![Figure 2. Scheme of elastomer specimen of 40 units in Shore hardness.](image2)

**Figure 2.** Scheme of elastomer specimen of 40 units in Shore hardness.

![Figure 3. Relationship of the elastomer specimen diameter variations \( d_{\text{ext}} \) at three points versus plunger stroke: 1—left end; 2—central section; 3—right end](image3)

**Figure 3.** Relationship of the elastomer specimen diameter variations \( d_{\text{ext}} \) at three points versus plunger stroke: 1—left end; 2—central section; 3—right end
It is obvious from Table 1, the largest increment of diameter in the middle section amounts to \( \Delta d = 3.1 \) mm. Thereto, the right-side end of the specimen supporting on conical washer increased in diameter by \( \Delta d = 12.8 \) mm.

The experimental evidence was used to plot relationships, one of which illustrates variation in specimen diameter at three points along length under axial compression (Figure 3). Similar tests were conducted on 15 other elastomer specimens with wide-range variations in geometric parameters and stiffness properties in Shore hardness scale.

Abundant database enabled to make the following conclusions:

— stability of an elastomer specimen depends on ratio \( K = L / D \leq 2 \), where \( L \) is specimen length; \( D, d \) is external and internal diameters of the specimen. The less it is, the higher stability of the specimen under axial compression is;

— application of conical washer on the sealer ends is not reasonable, as this enhances probability to “jam” a sealer in a well;

— to apply axial compression exceeding the calculated stability of the specimen to this specimen is not admissible. After stability loss the specimen loses symmetrical shape and fails to bear uniformly against well walls.

Next, the research concerned evaluation of the effect of axial elastomer specimen compression on hermetic tightening of a well section under the supplied fluid pressure.

In [6] the calculation of hermetic tightening between packer body and a well wall is made under simplified assumption running as: a ring-shaped space is filled with an incompressible mass of a sealing element, like a fluid. However, it is found in laboratory tests that the filling of a ring-shaped gap with a sealing material is not sufficient for the hermetic level needed to realize hydrofracturing. After the axial compression and contact with a well wall the sealing element requires additional pressing to gain its density value, corresponding to the maximum pressure of the fluid supplied to the area of hydrofracturing. Otherwise, the working fluid can affect the sealing element and compress it along its external diameter and initiate leaking from the sealed section. This statement is verified by tests executed at the test bench in Figure 4.

Hole 2, imitating a well, is made in organic glass block 1. The fluid was supplied by pump 5 through fitting 4 to blind side of hole 2. The body of sealer 6 is inserted from the opposite side; sealer 6 contains elastic-springing element 7 made of polyurethane of 40–60 u. Shore hardness. Axial compression of element 7 was realized by means of screw 9 and dynamic sleeve 8.

The input data are: hole diameter in organic glass \( D_{\text{hole}} = 50 \) mm; external diameter of the elastic element \( d_{\text{ext}} = 43 \) mm; length of the element \( L = 154 \) mm; the maximum compression stroke up to stability loss is 40 mm; maximum diameter of the increment \( \Delta d \) after compression—from 6.8 to 7.2 mm (two last parameters were established at the test bench in Figure 1). The fluid (3% emulsion) was supplied by hand pump 5.

![Figure 4](image-url)
Test sequence:
—screwing screw 9 into screw section of sealer 6 through sleeve 8 provides compression of sealing element 7 up to contact of its external diameter with walls of hole 2.
—pump 5 supplies the fluid through fitting 4 into hermetized area.
—successive screw motion stroke is 5 mm (compression of the test specimen is held up to stability loss).
—ring-shaped inserts made based on epoxy resin were used to vary diameter of the hole $D_{\text{hole}}$ in organic glass to size of 48 and 46 mm.

The test bench results cited in Table 2 indicate that the sealing element after axial compression up to stability loss ($< 40$ mm) is pressed to walls of a conditional well, but pressurization failure is initiated at pressure of 7.5 MPa. Axial compression exceeding critical stability ($> 40$ mm) does not increase hermetization level. The highest hermetization level is observed in test no. 3 where axial compression of the sealing element by 35 mm led to pressure higher than 18 MPa. Further increase in pressure was constrained by strength of the body made of organic glass.

Table 2. Experimental results.

| $D_{\text{hole}}$, mm | Parameter          | Shore hardness 60A |
|----------------------|--------------------|---------------------|
| 50                   | $P_{\text{max}}$, MPa | 0.3 1.5 4.8 5.2 6.2 7.5 7.5 7.5 |
| Screw stroke, mm     | 15 20 25 30 35 40 45 45 |
| 48                   | $P_{\text{max}}$, MPa | 1.5 5.1 6.8 8.0 9.0 12.0 — — |
| Screw stroke, mm     | 15 20 25 30 35 40 — — |
| 46                   | $P_{\text{max}}$, MPa | 5.0 8.2 12.0 14.0 18.0 — — — |
| Screw stroke, mm     | 15 20 25 30 35 — — — |

The above sequence was followed in tests on sealing specimens Nos. 2–5. Parameters of the test specimens are, mm: No. 2 — $D_{\text{ext}} \times d_{\text{int}} \times l = 30 \times 15 \times 60$; No. 3 — $D_{\text{ext}} \times d_{\text{int}} \times l = 30 \times 15 \times 30$; No. 4 — $D_{\text{ext}} \times d_{\text{int}} \times l = 40 \times 15 \times 160$; No. 5 — $D_{\text{ext}} \times d_{\text{int}} \times l = 70 \times 40 \times 170$.

3. Conclusions
A series of test on different length and external-diameter sealing elements at the test bench revealed that the maximum hermetical tightening in a well is feasible under the following conditions: axial compression (linear value) should not exceed critical stability value; the initial ring-shaped gap between internal diameter of a well and external diameter of a sealing element should be by 5–8% less than the maximum increment of diameter increase under the free axial compression. Given that axial compression of the sealing element exceeds stability limit, in most cases the sealing element used to be jammed in the well, viz., loss of the sealer without improved hermetic tightness.

The efficient sealing elements should be of high elasticity stability along with high-level stiffness. Soft high-elasticity specimens of less than 40A hardness tend to leak to all irregularities of a well and to produce high level of hermetic tightness at the well section at their application point, but because of their insufficient elasticity they remain in the compressed state after axial loading is cancelled. This imperfection can lead to loss of such sealing elements.

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