ADMISSIBLE PRESSURE FOR FILLER OF SEALED SLEEVES USED TO REPAIR MAIN PIPELINES

V.I. MAKHNENKO, E.A. VELIKOIVANENKO, A.S. MILENIN, O.I. OLEJNIK, G.F. ROZYNKA and **N.I. PIVTORAK**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

Main variants of strengthening of thinning of pipeline walls by installing a sealed sleeve are considered. It is shown that the variant of the repair technology involving a sleeve structure with a liquid agent filling the gap between the pipe walls and sleeve requires a detailed substantiation, allowing for properties of the filler during polymerisation, as well as corresponding estimation of the load-carrying capacity of the welds.

Keywords: *repair of active pipelines, sealed sleeves, slot welds, volumetric changes during polymerisation*

In the last years, repair of extended corrosion defects on walls of active main pipelines, i.e. under the internal pressure of gas or oil, has been performed in Ukraine by using sealed sleeves of different designs, the main purpose of which is to partially unload the defective region of the pipeline wall, this being sufficient in a number of cases for changing characterisation of a defect from «inadmissible» to «admissible» [1].

For the linear part of a pipeline loaded mostly by the internal pressure, the efficiency of unloading of the defective pipe wall using a sleeve depends on many structural and technological factors providing a contact fit between the sleeve and pipe wall.

Figure 1 presents the known mechanical methods providing a good fit of the pipe walls and sleeve, which show a high labour intensiveness and complexity of the control means used to check their efficiency. This problem can be solved much simpler by using the appropriate filler for the gap between the pipe walls and sleeve. Sleeves of this type are more attractive, as they allow reliable and simple unloading of the defective pipe wall due to the controllable pressure in a liquid filler of the gap between the walls.

The scheme shown in Figure 2 demonstrates the principle of operation of a structure, which has certain advantages and peculiarities. The latter include the presence of circumferential welds *6*, which adjoin the gap containing the filler with pressure P_f, its maximal value being specified by the authors of patent [3] in a range of up to repair pressure P_{rep} in a pipe.

A crack-like slot forms in the adjoining zone at the presence of steel ring *2* (see Figure 2), which provides the required gap between the walls, i.e. circumferential welds *6* should be classed with the so-called slot joints, which are designed on the basis of fracture mechanics approaches for crack-containing bodies [4]. The limiting state for this type of the welded joints is usually specified based on a condition that the adjoining sharp cavity, i.e. crack, should be in the field of the stressed state, in which the conditions of its spontaneous growth are met. Worthy of attention among such sufficiently grounded conditions is a two-parameter criterion of tough-brittle fracture [4], which relates parameter of a purely brittle fracture at the crack apex, $K_r = K_I / K_{Ic}$ (where K_I is the stress intensity factor at the normal fracture crack apex, and K_{Ic} is the critical value of this indicator for a given material) to parameter of purely tough fracture for a given crack, $L_r = \sigma_{ref} / \sigma_y$ (where σ_{ref} is the reference stress that conditionally takes place at the apex of the given crack at the indicated value of loading and condition of ideal yield of the material with yield stress

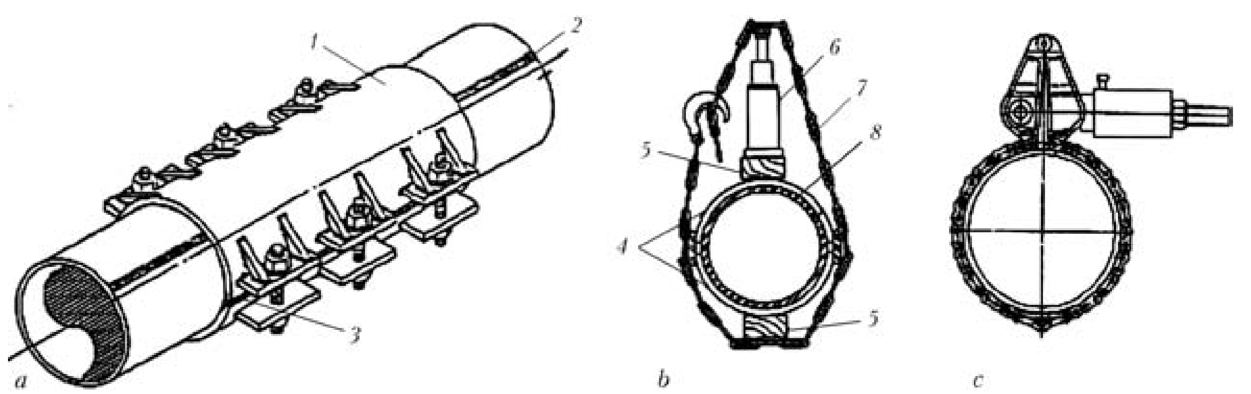

Figure 1. Schematics of mechanical methods providing fit of the sleeve to pipe wall [2]: *a* — bolted method; *b* — standard method; *c* — with chain pinch; *1* — repair sleeve; *2* — longitudinal weld; *3* — weld with full penetration and fusion with the substrate (two symmetric joints are used more frequently); *4* — sleeve halves with side supports; *5* — wood skid; *6* — hydraulic press; *7* — high-strength chain; *8* — pipeline being repaired

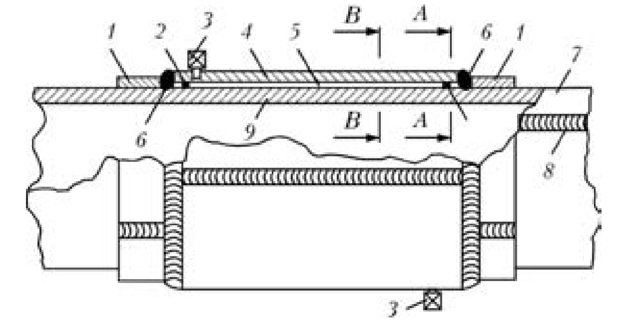

Figure 2. Schematic of the repair method using the sealed sleeve with filler [3]: *1* — technological rings; *2* — additional thin-walled ring; *3* — union; *4* — sleeve; *5* — filler; *6* — circumferential welds; *7* — pipeline; *8* — longitudinal weld; *9* — defective region

σ_y). According to [4], this criterion can be represented as follows:

$$K_r = f(L_r) \text{ at } L_r < L_r^{\max} \approx \frac{\sigma_y + \sigma_t}{2\sigma_y};$$
$$K_r = 0 \text{ at } L_r > L_r^{\max}, \qquad (1)$$

where $f(L_r)$ is the experimental function for the given material (Figure 3).

According to [4], curve $f(L_r)$ (see Figure 3) for structural steels at $L_r < L_r^{\max}$ can be adequately described by relationship

$$f(L_r) = (1 - 0.14L_r^2)[0.3 + 0.7 \exp(-0.65L_r^6)]. \qquad (2)$$

According to [4], values K_I and σ_{ref} for the slot-type welded joints (see Figure 2) can be conveniently computed by preliminarily conputing bending moment M and intersecting force Q acting in the zone of the welded joint per its unit length (along the circumference) and by using the following relationships [4]:

$$K_I = \frac{0.5369}{\sqrt{h}}\left(Q \cos\varphi + \frac{8M}{h}\right), \qquad (3)$$

$$\sigma_{ref} = \sqrt{\left(\frac{4M}{h^2} + \frac{Q\cos\varphi}{h}\right)^2 + 3\left(\frac{Q\sin\varphi}{h}\right)^2}, \qquad (4)$$

where h is the minimal size from the sharp cavity apex in the weld to a free surface (Figure 4). There are two such sizes h_1 and h_2. It is likely that size h_1 is more conservative:

$$h_1 = \delta_s \cos\varphi;\ \cos\varphi = (1 + \beta^2)^{-0.5};\ \beta = \frac{\delta_s + \Delta - \delta_{t.r}}{a}. \qquad (5)$$

Safety factor $n \geq 1$ is determined from the computed values of K_r and L_r by points nK_r and nL_r on dependence (2).

As follows from the above-said, the limiting state of tough-brittle fracture (spontaneous growth of the crack, i.e. sharp cavity, adjoining the circumferential weld) is determined by bending moment M and intersecting force Q, which depend on the internal pressure in the pipe, P_p, and in the filler, P_f, as well as by the geometric sizes of a section (see Figure 4), i.e. pipeline diameter D, thicknesses of the pipeline and sleeve, δ_p and δ_s, respectively, and those of technological rings $\delta_{t.r}$, sizes c, a, and b of the welded joint, inter-wall gap Δ, and corresponding characteristics K_{Ic}, σ_y and σ_t of the welded joint material in sections of minimal sizes h_1 and h_2.

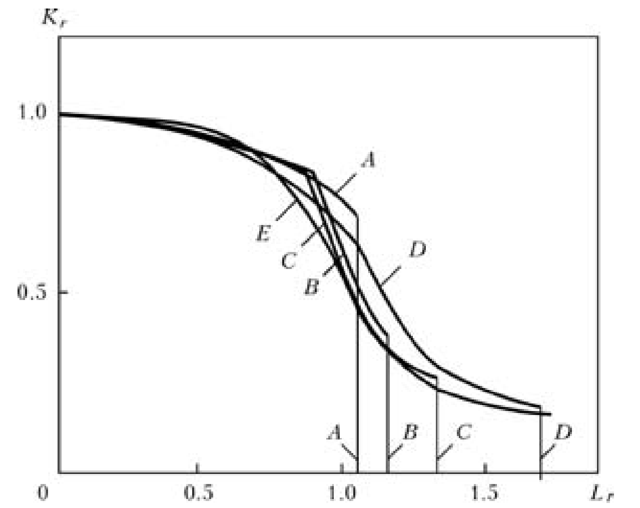

Figure 3. Diagram of limiting state $K_r = f(L_r)$ for different types of structural steels: *A* — high-strength steel EN408; *B* — pressure vessel steel A533B; *C* — manganese-containing low-carbon steel; *D* — austenitic steel; *E* — calculated curve plotted from dependence (2)

To generate the appropriate quantitative results, by using computer system «Weldpredictions» the E.O. Paton Electric Welding Institute developed a software to compute the stressed state for corresponding geometrical sizes and loads P_p and P_f by the finite element method. Moment M and intersecting force Q at the apex of the sharp cavity were computed from normal stresses σ_{zz} in section $z = z^*$ (see Figure 4) corresponding to the apex of the sharp cavity growing in direction h_1 or h_2.

Moment M can be represented in the form of difference $M = M_1 - M_2$, where

$$M_1 = \int_{-\frac{\delta_s}{2}}^{\frac{\delta_s}{2}} \sigma_{zz}\xi d\xi;\quad M_2 = \int_{-\frac{\delta_p + \Delta}{2}}^{\frac{\delta_p + \Delta}{2}} \sigma_{zz}\xi d\xi, \qquad (6)$$

for a variant of crack propagating in direction h_1, and respectively

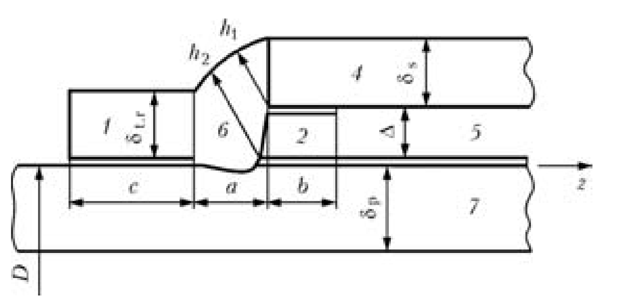

Figure 4. Schematic of section of circumferential weld *6* with designations of elements as given in Figure 2

$$M_1 = \int_{-\frac{\delta_s+\Delta}{2}}^{\frac{\delta_s+\Delta}{2}} \sigma_{zz}\xi d\xi; \quad M_2 = \int_{-\frac{\delta_p}{2}}^{\frac{\delta_p}{2}} \sigma_{zz}\xi d\xi \qquad (7)$$

for a variant of crack propagating in direction h_2.

Corresponding computation results for a pipeline of steel X70 at D = 1420 mm, δ_p = 20 mm and working pressure P_p = 7.5 MPa are given below for a sleeve 1400 mm long with thickness δ_s = 14 mm (a = 20 mm under repair pressure P_{rep} = 7.5 MPa, and a = 14 mm under $P_{rep} = 0.7P_p$ = 5.25 MPa).

Sizes of technological rings $\delta_{t.r}$ and c were assumed to be as follows: $\delta_{t.r} = \delta_s$, and c = 140 mm. Gap Δ was regulated by using additional rings *2* (see Figure 4) having width b = 30 mm.

Table 1. Computed values of bending moments M and intersecting forces Q at $P_{rep} = P_p$, a = 20 mm and σ_y = 440 MPa

P_p, MPa	P_f, MPa	n	K_I, MПa·mm$^{1/2}$	σ_{ref}, MPa	M, MPa·mm^2	Q, MPa·mm
Δ = 3 mm, h_1 = 13.845 mm						
7.5	2.0	58.35	7.6	1.9	91.6	0
7.5	2.5	8.35	53.4	13.4	640.5	0
7.5	3.0	4.49	99.2	24.8	1189.6	0
7.5	3.5	3.08	145.0	36.3	1738.8	0
7.5	4.0	2.34	190.8	47.7	2288.0	0
7.5	4.5	1.88	236.6	59.2	2837.2	0
7.5	5.0	1.58	282.3	70.7	3386.4	0
7.5	5.5	1.36	328.1	82.1	3935.5	0
7.5	6.0	1.19	373.9	93.6	4484.7	0
7.5	6.5	1.05	422.7	105.0	5033.9	20.9
7.5	7.0	0.94	473.4	116.5	5583.1	54.6
7.5	7.5	0.85	523.4	127.8	6125.6	88.2
0	7.5	0.62	719.0	162.0	7763.2	497.3
Δ = 12 mm, h_1 = 12 mm						
7.5	0.5	8.89	50.1	13.5	484.8	0
7.5	1.0	3.72	119.7	32.2	1159.1	0
7.5	1.5	2.78	160.0	43.0	1549.6	0
7.5	2.0	2.22	200.8	54.0	1944.1	0
7.5	2.5	1.84	241.6	64.9	2339.6	0
7.5	3.0	1.58	282.4	75.9	2735.2	0
7.5	3.5	1.38	323.4	86.9	3130.8	0.9
7.5	4.0	1.20	369.8	97.9	3526.4	36.4
7.5	4.5	1.07	416.1	108.9	3922.0	71.8
7.5	5.0	0.96	462.5	119.8	4317.6	107.3
7.5	5.5	0.88	508.8	130.8	4713.2	142.7
7.5	6.0	0.80	555.2	141.8	5108.8	178.1
7.5	6.5	0.74	601.5	152.8	5504.4	213.6
7.5	7.0	0.69	646.8	163.5	5890.6	248.8
7.5	7.5	0.65	690.4	173.8	6260.2	283.6
0	7.5	0.71	632.1	148.3	5342.4	518.9

Note. Here and in Tables 2–4: D = 1400 mm, δ_p = 20 mm, δ_s = 14 mm, b = 30 mm and c = 140 mm.

Tables 1–4 give the computation results on bending moments M and intersecting forces Q for different variants of input data and fracture in direction h_1 (see Figure 4). K_I, σ_{ref} and safety factor n at K_{Ic} = 1500 MPa·mm$^{1/2}$ [4] and σ_y = 360 and 440 MPa were computed on the basis of the M and Q values. It can be seen from these data that a change in yield stress from 440 to 360 MPa (for steels X70 and X60, respectively) at $P_{rep} = P_p$ = 7.5 MPa and $P_{rep} = 0.7P_p$ has no significant effect on the admissible pressure in the filler $[P_f]$ at safety factor $n \approx 2$.

The substantial effect is exerted by gap Δ. As it is increased from 3 to 12 mm, $[P_f]$ decreases from 4.3 to 2.3 MPa at $P_{rep} = P_p$ (Tables 1 and 2) and from 3.5 to 1.7 at MPa P_{rep} = 5.25 MPa (Tables 3 and 4).

Increase in pressure P_f above the said admissible value of $[P_f]$ is undesirable, as this causes a pronounced decrease in safety factor n.

A variant of fracture in direction h_2 (see Figure 4) was also considered. The corresponding results confirm the above assumption of a more conservative variant of fracture in direction h_1.

Therefore, it follows from the obtained computation results (see Tables 1–4) that, at the indicated sizes of the sealed sleeve [2] and conditions of filling of the inter-wall gap, it can be recommended that the pressure should be set based on a condition of maintaining integrity of the circumferential welds at a level of $[P_f]$ = 4.3–4.5 MPa at P_{rep} = 5.25–7.50 MPa and Δ = 3 mm. Increase of the Δ value to 12 mm causes a dramatic decrease of the admissible pressure in the filler to 1.7–2.3 MPa. As value D of the gap in many cases is within 3 mm and generated pressure P_f is not higher than 4 MPa, the structure of the repair sleeve under consideration for main pipelines with D = 1420 × 20 mm, made from steels X60 and X70, can ensure high unloading of the defective zone in the pipeline wall, naturally, providing that the set value of pressure of the liquid filler does not substantially changes after its polymerization. However, this important issue requires special consideration.

Worthy of attention at the given stage is providing the admissible value of pressure P_f for specific sizes of the pipeline and sleeve considered, as recommendations of the authors of study [2] on the upper limit at a level of P_{rep} are insufficiently substantiated. Consider what happens to pressure in the filler during solidification of the latter. It is well known that transformation from the liquid state to the solid one is accompanied by a change in the relative free volume, the weight of the matter remaining unchanged. On a condition of incompressibility of the liquid phase and at a coefficient of volumetric compression of the filler equal to

$$K_f = (1 - 2\nu_f)/E_f$$

(where E_f is the normal elasticity modulus of steel and solid filler, and ν_f is the Poisson ratio of the solid

Table 2. Computed values of bending moments M and intersecting forces Q at $P_{rep} = P_p$, a = 20 mm and σ_y = 360 MPa

P_p, MPa	P_f, MPa	n	K_I, MPa·mm$^{1/2}$	σ_{ref}, MPa	M, MPa·mm^2	Q, MPa·mm
Δ = 3 mm, h_1 = 13.845 mm						
7.5	2.0	56.62	7.8	2.0	94.0	0
7.5	2.5	8.28	53.6	13.4	642.9	0
7.5	3.0	4.47	99.4	24.9	1292.0	0
7.5	3.5	3.06	145.2	36.3	1741.2	0
7.5	4.0	2.32	191.0	47.8	1290.4	0
7.5	4.5	1.87	236.7	59.3	2839.6	0
7.5	5.0	1.57	282.7	70.7	3390.2	0
7.5	5.5	1.35	328.6	82.2	3940.8	0
7.5	6.0	1.19	374.5	93.7	4491.4	0
7.5	6.5	1.05	423.4	105.2	5042.1	20.8
7.5	7.0	0.94	472.3	116.2	5570.8	54.0
7.5	7.5	0.85	521.1	127.3	6099.8	87.1
0	7.5	0.64	690.7	155.3	7440.9	487.3
Δ = 12 mm, h_1 = 12 mm						
7.5	0.5	8.81	50.3	13.5	486.9	0
7.5	1.0	3.69	119.9	32.2	1161.3	0
7.5	1.5	2.76	160.2	43.1	1551.7	0
7.5	2.0	2.20	201.0	54.0	1946.3	0
7.5	2.5	1.83	241.8	65.0	2341.8	0
7.5	2.5	1.57	282.7	76.0	2737.3	0
7.5	3.0	1.37	323.7	87.0	3132.9	1.0
7.5	3.5	1.20	370.0	97.9	3528.5	36.5
7.5	4.0	1.06	416.4	108.9	3924.1	71.9
7.5	4.5	0.96	462.7	119.9	4319.7	107.4
7.5	5.0	0.87	509.2	130.9	4716.7	142.7
7.5	5.5	0.80	555.7	141.9	5113.9	178.1
7.5	6.0	0.74	599.5	152.3	5486.6	212.9
7.5	6.5	0.69	643.5	162.7	5860.5	247.6
7.5	7.0	0.65	685.6	172.6	6217.5	281.3
0	7.5	0.76	585.5	136.3	4911.8	505.4

filler), the relationship derived for the solid phase between the relative change of the volume in transformation from the liquid state to the solid one per unit weight will have the following form:

$$\frac{\Delta V}{V} = 3K_f(\sigma_{sol} - \sigma_{liq}) + \frac{\gamma_{sol} - \gamma_{liq}}{V}, \qquad (8)$$

where σ_{sol} and σ_{liq} are the pressures with an opposite sign in the solid and liquid phases, i.e. $\sigma_{liq} = -P_f$; and γ_{sol} and γ_{liq} are the volumes of the solid and liquid phases per unit weight.

The $(\gamma_{sol} - \gamma_{liq})/V$ value is a constant of a given environment (e.g. for epoxy it is approximately equal to −0.06 [5, etc.]).

If solidification occurs without violation of integrity of the filler and with conservation of bonds to the pipe and sleeve, then $\Delta V/V = 0$, and

Table 3. Computed values of bending moments M and intersecting forces Q at $P_{rep} = 0.7P_p$, a = 20 mm and σ_y = 440 MPa

P_p, MPa	P_s, MPa	n	K_I, MPa·mm$^{1/2}$	σ_{ref}, MPa	M, MPa·mm^2	Q, MPa·mm
Δ = 3 mm, h_1 = 13.7 mm						
5.25	1.50	18.99	23.5	5.9	276.9	0
5.25	1.75	9.35	47.7	12.0	562.0	0
5.25	2.00	6.20	71.8	18.1	847.2	0
5.25	2.25	4.64	96.0	24.2	1132.3	0
5.25	2.50	3.71	120.2	30.3	1417.5	0
5.25	2.75	3.09	144.4	36.3	1702.6	0
5.25	3.00	2.64	168.6	42.4	1987.8	0
5.25	3.25	2.31	192.8	48.5	2272.9	0
5.25	3.50	2.05	216.9	54.6	2558.1	0
5.25	3.75	1.85	241.1	60.7	2843.2	0
5.25	4.00	1.68	265.3	66.8	3128.4	0
5.25	4.25	1.53	290.4	72.9	3413.5	6.6
5.25	4.50	1.41	317.1	78.9	3698.7	23.6
5.25	4.75	1.30	343.7	85.0	3983.8	40.7
5.25	5.00	1.20	370.4	91.1	4269.0	57.8
5.25	5.25	1.12	397.1	97.2	4554.1	74.8
5.50	5.25	1.14	390.7	96.1	4502.2	61.3
5.75	5.25	1.17	382.7	94.6	4431.9	47.2
6.00	5.25	1.19	374.6	93.1	4360.6	33.0
6.25	5.25	1.22	366.5	91.6	4289.3	18.8
6.50	5.25	1.24	358.4	90.0	4217.9	4.6
6.75	5.25	1.27	351.6	88.5	4146.6	0
7.00	5.25	1.29	345.6	87.0	4075.3	0
7.25	5.25	1.31	339.5	85.5	4003.9	0
7.50	5.25	1.34	333.5	83.9	3932.6	0
0	5.25	0.82	541.9	123.4	5778.9	357.1
Δ = 12 mm, h_1 = 10.63 mm						
5.25	0.25	7.60	58.5	16.7	471.9	0
5.25	0.50	4.37	101.7	29.1	820.7	0
5.25	0.75	3.52	126.2	36.1	1018.4	0
5.25	1.00	2.95	150.8	43.1	1217.1	0
5.25	1.25	2.53	175.5	50.1	1416.1	0
5.25	1.50	2.22	200.2	57.2	1615.1	0
5.25	1.75	1.98	224.8	64.2	1814.2	0
5.25	2.00	1.78	249.5	71.3	2013.3	0
5.25	2.25	1.62	274.2	78.3	2212.3	0
5.25	2.50	1.48	300.0	85.4	2411.4	6.7
5.25	2.75	1.36	327.5	92.4	2610.4	23.8
5.25	3.00	1.25	354.9	99.5	2809.5	40.9
5.25	3.25	1.16	382.4	106.5	3008.6	58.1
5.25	3.50	1.09	409.9	113.6	3207.6	75.2
5.25	3.75	1.02	437.4	120.6	3406.7	92.3
5.25	4.00	0.96	464.9	127.7	3605.8	109.4
5.25	4.25	0.90	492.4	134.7	3804.8	126.6
5.25	4.50	0.86	519.9	141.7	4003.9	143.7
5.25	4.75	0.81	547.4	148.8	4202.9	160.8
5.25	5.00	0.77	574.9	155.8	4402.0	177.9
5.25	5.25	0.74	602.4	162.9	4601.1	195.0
5.50	5.25	0.74	604.3	163.8	4626.9	187.4
5.75	5.25	0.73	605.6	164.6	4648.3	179.2
6.00	5.25	0.73	606.9	165.3	4669.5	170.9
6.25	5.25	0.73	608.2	166.1	4690.7	162.7
6.50	5.25	0.73	609.4	166.8	4711.9	154.5
6.75	5.25	0.73	610.7	167.6	4733.1	146.2
7.00	5.25	0.73	612.0	168.3	4754.3	138.0
7.25	5.25	0.73	613.2	169.1	4775.5	129.8
7.50	5.25	0.72	614.5	169.8	4796.7	121.5
0	5.25	0.81	553.6	141.3	3991.2	357.7

$$\sigma_{sol} = \sigma_{liq} - \frac{1}{3K_f}\frac{\gamma_{sol} - \gamma_{liq}}{V}. \qquad (9)$$

As compression pressure σ_{liq} is a negative value, solidification at $(\gamma_{ols} - \gamma_{liq})/V < 0$ is accompanied by decrease of compression in the filler. The lower the K_f value in the solid filler, the more intensive is this decrease.

For example, for polyurethane that is widely used in Ukraine, the value of K_f is at a level of 0.002 MPa^{-1}, i.e. at $(\gamma_{sol} - \gamma_{liq})/V$ it is lower than −0.03. The condition of conservation of $\sigma_{sol} < 0$ requires that the

Table 4. Computed values of bending moments M and intersecting forces Q at $P_{rep} = 0.7P_p$, a = 20 mm and σ_y = 360 MPa

P_p, MPa	P_s, MPa	n	K_I, MPa·mm$^{1/2}$	σ_{ref}, MPa	M, MPa·mm^2	Q, MPa·mm
Δ = 3 mm, h_i = 13.7 mm						
5.25	1.50	18.90	23.5	5.9	276.9	0.0
5.25	1.75	9.31	47.7	12.0	562.0	0.0
5.25	2.00	6.18	71.8	18.1	847.2	0.0
5.25	2.25	4.62	96.0	24.2	1132.3	0.0
5.25	2.50	3.69	120.2	30.3	1417.5	0.0
5.25	2.75	3.07	144.4	36.3	1702.6	0.0
5.25	3.00	2.63	168.6	42.4	1987.8	0.0
5.25	3.25	2.30	192.8	48.5	2272.9	0.0
5.25	3.50	2.05	216.9	54.6	2558.1	0.0
5.25	3.75	1.84	241.1	60.7	2843.2	0.0
5.25	4.00	1.67	265.3	66.8	3128.4	0.0
5.25	4.25	1.53	290.4	72.9	3413.5	6.6
5.25	4.50	1.40	317.1	78.9	3698.7	23.6
5.25	4.75	1.29	343.7	85.0	3983.8	40.7
5.25	5.00	1.20	370.4	91.1	4269.0	57.8
5.25	5.25	1.12	397.1	97.2	4554.1	74.8
5.50	5.25	1.14	390.7	96.1	4502.2	61.3
5.75	5.25	1.16	382.7	94.6	4431.9	47.2
6.00	5.25	1.19	374.6	93.1	4360.6	33.0
6.25	5.25	1.21	366.5	91.6	4289.3	18.8
6.50	5.25	1.24	358.4	90.1	4218.8	4.5
6.75	5.25	1.26	351.8	88.5	4148.1	0.0
7.00	5.25	1.28	345.7	87.0	4076.8	0.0
7.25	5.25	1.31	339.8	85.5	4006.4	0.0
7.50	5.25	1.33	333.8	84.0	3935.8	0.0
0	5.25	0.83	536.8	122.2	5723.5	354.6
Δ = 12 mm, h_i = 10.63 mm						
5.25	0.25	7.56	58.5	16.7	471.9	0.0
5.25	0.50	4.35	101.7	29.1	820.7	0.0
5.25	0.75	3.50	126.2	36.1	1018.4	0.0
5.25	1.00	2.93	150.8	43.1	1217.1	0.0
5.25	1.25	2.52	175.5	50.1	1416.1	0.0
5.25	1.50	2.21	200.2	57.2	1615.1	0.0
5.25	1.75	1.97	224.8	64.2	1814.2	0.0
5.25	2.00	1.77	249.5	71.3	2013.3	0.0
5.25	2.25	1.61	274.2	78.3	2212.3	0.0
5.25	2.50	1.47	300.0	85.4	2411.4	6.7
5.25	2.75	1.35	327.5	92.4	2610.4	23.8
5.25	3.00	1.25	354.9	99.5	2809.5	40.9
5.25	3.25	1.16	382.4	106.5	3008.6	58.1
5.25	3.50	1.08	409.9	113.6	3207.6	75.2
5.25	3.75	1.01	437.4	120.6	3406.7	92.3
5.25	4.00	0.95	464.9	127.7	3605.8	109.4
5.25	4.25	0.90	492.4	134.7	3804.8	126.6
5.25	4.50	0.85	519.9	141.7	4003.9	143.7
5.25	4.75	0.81	547.4	148.8	4202.9	160.8
5.25	5.00	0.77	574.9	155.8	4402.0	177.9
5.25	5.25	0.74	602.4	162.9	4601.1	195.0
5.50	5.25	0.73	604.3	163.8	4626.9	187.4
5.75	5.25	0.73	605.6	164.6	4648.3	179.2
6.00	5.25	0.73	606.9	165.3	4669.5	170.9
6.25	5.25	0.73	608.2	166.1	4690.7	162.7
6.50	5.25	0.73	609.4	166.8	4711.9	154.5
6.75	5.25	0.72	610.7	167.6	4733.1	146.2
7.00	5.25	0.72	612.1	168.3	4755.1	137.9
7.25	5.25	0.72	613.4	169.1	4777.0	129.6
7.50	5.25	0.72	614.7	169.9	4798.2	121.4
0	5.25	0.83	536.0	136.5	3855.6	353.1

initial pressure in the filler, $P_f = -\sigma_{sol}$, be higher than $0.03/3\cdot0.002$ = 5 MPa, which, as follows from the above-said, is a limit of structural capabilities of the circumferential welds of the welded joints in the sleeves under consideration [3].

Moreover, it should be taken into account that providing the σ_{sol} value in the solidified filler at a zero level, the value of volumetric compression coefficient $K_f = (1 - 2\nu_f)/E_f$ being low, may lead to an insufficient unloading of the defective wall, i.e. it may affect the efficiency of operation of the sleeve, which will require an additional 2–3 MPa increase in P_f.

Therefore, the structure of the sleeve and its welds should withstand the inter-wall pressure at a level of that of the working gas in a pipe, which is quite realistic if the defect in the pipe wall under the sleeve for this or that reason becomes a through defect.

The extent of unloading of the defective region of a pipeline due to installing the sealed sleeve with the filler can be estimated by using the following approximating dependence:

$$\Delta P = -\sigma^f_{res} + \frac{P - P_{rep}}{1 + \frac{\delta_p}{\delta_s} + A_f}, \quad A_f = K_f \frac{E\delta_p\delta_f}{(D/2)^2}, \qquad (10)$$

where ΔP is part of working pressure P relieved due to the sealed sleeve with the filler in the gap between the walls of a pipe and sleeve, σ^f_{res} is the residual mean normal pressure in the solid filler, $K_f = (1 - 2\nu_f)/E_f$ is the coefficient of volumetric compression of the solid filler, and δ_f is the thickness of the filler.

In case of a purely mechanical contact of the pipe and sleeve, in (10) $\delta_f = 0$, $A_f = 0$ and, accordingly, $\sigma^f_{res} = 0$. At the same time, in (10) $\Delta P = \frac{P - P_{rep}}{\delta_s + \delta_p}\delta_s$ depends on $P - P_{rep}$, and it can be insufficient for efficient unloading of the defective region of the wall. Here it is the filler that provides wider possibilities. However, in this case the geometric sizes of the sleeve and welded joints should guarantee achievement of the corresponding value of σ^f_{res} in the solidified filler.

CONCLUSIONS

1. Structures of the sealed sleeves with fillers, as recommended in modern literature for repair of thinning defects in walls of main pipelines without interruption of their operation, are insufficiently substantiated in a number of cases, as welded joints cannot withstand the internal pressure of the liquid filler at a level of the working pressure of gas in a pipe.

2. When developing such structures, it is necessary to pay special attention to a change in properties of the filler taking place during its solidification from the stand point of providing the required pressure for efficient unloading of the defective region of the pipeline wall.

1. (2000) *Fitness-for-service*: Recommended practice 579. American Petroleum Institute.
2. (2006) *Updated pipeline repair manual*. Revision by Edison Welding Institute.
3. But, V.S., Marchuk, Ya.S., Podolyan, O.P. et al. *Method for repair of defective section of active pipeline*. Pat. 77931 Ukraine. Int. Cl. F 16 L 55/16, B 23 K 31/02. Publ. 15.01.2007.
4. Makhnenko, V.I. (2006) *Residual safe life of welded joints and assemblies in current structures*. Kiev: Naukova Dumka.
5. Zarelli, V., Skordos, A.A., Partridge, I.K. (2000) Investigation of cure induced shrinkage in unreinforced epoxy resin. *Plastics, Rubber and Composites Processing and Application*, **31**, 377–384.