tike (“Engineering - From Theory to Practice”: materials of International Scientific and Technical Conference).No17-1, p.p. 75-79.
5. Razumov M.S., Gladyshkin A.O., Zinovkin A.A., Pykhtin A.I., Sidorova M.A. (2015) Determination the geometric characteristics of complex profile connections. *Fundamental'nye issledovaniya*. No4. p.p. 130-134.
6. Razumov M.S., Gladyshkin A.O., Kassikhin V.N, Pykhtin A.I., Skripkina E.V. (2014) Stress calculation of moment transmitting roll with profile on the base of Reuleaux triangle. *Metallurgical and Mining Industry*. No 3, p.p. 50-54.
7. Barbot’ko A.I., Ponkratov P.A., Razumov M.S. A method of processing of profile shaft by sides with equal width: 2463129. Russian Federation No201 1110843/02, Appl. 22.03.2011 Publ. 10.10.2012g

Factors determining the intensity of loading of long operated gas pipelines under complex mining and geological conditions

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According to the existing standards, the ultimate bearing capacity of pipes is calculated using the dependences, which are based on the momentless theory of shells and allow determining of the maximum pressure or available thickness of a wall considering the mechanical properties of metal, the initial sizes of pipe and uniform stress distribution in a wall.

As the basic equation for evaluation of the bearing property of pipelines, the following formula is used:

$$p_{int} = \frac{2\sigma_{ul}S_0}{D_0} \quad (1)$$

where p_{pr} – boundary value of internal pressure; σ_{ul} - ultimate resistance of pipes material; S_0 , D_0 - initial value of wall thickness and pipe diameter respectively.

Relative simplicity of dependence (1) was conducted to its wide spread occurrence. At the same time, the results of actual tests of the pipes internal pressure obtained by a number of researches [1, 6] testify to serious difference between calculated and actual parameters of pipes defect (Table 1). Among the provided data, it can be seen that the difference between calculated and experimental values of pipes strength reaches 25%. At that, we can observe the calculated values, which are both lower and higher than the experimental ones. From our standpoint, such difference is a consequence of imperfection of calculating formula (1). In this dependence, the stress influence on resistance of deformation material and change of the pipes sizes till the time of maximum pressure value reaching is not considered. When pipe strength evaluation, it is also wrong to characterize the resistance of deformation material by the stress value corresponding to limit uniform deformation at uniaxial extension.

Table 1. Calculation and actual parameters of pipes failure

Pipe diameter, mm	Wall thickness, mm	Steel grade	σ_{ul}, MPa	Calculating value p_{cpr}, MPa	Experimental value p_{epr}, MPa	Ratio p_{cpr}/p_{epr}	Sourse
720	8	19Mn	515	11.5	10.9	1.05	[4]
720	8	19Mn	578	12.8	11.3	1.14	[4]
720	8	19Mn	582	13.0	11.9	1.09	[4]
720	8	14CrMnSi	520	11.5	15.5	0.74	[4]
720	8	14CrMnSi	560	12.5	16.5	0.76	[4]
529	8	MK	594	16.7	14.0	1.09	[4]
529	6.8	MK	530	13.7	12.8	1.07	[1]
529	6.6	MK	530	13.5	12.3	1.10	[1]
529	6.7	MK	530	13.5	13.0	1.04	[1]
273	6.3	St3	505	23.5	22.8	1.03	[1]
273	6.5	St 3	505	23.5	22.8	1.03	[1]
273	6.5	St 3	505	24.2	24.5	0.99	[1]
325	8.2	20	490	24.9	24.2	1.03	[1]
325	7.8	20	490	23.5	23.1	1.02	[1]
325	8.6	20	490	26.1	26.8	0.97	[1]
325	8.6	20	490	26.1	26.0	1.01	[1]

For correction of these shortcomings of the existing calculation of strengths, first of all, we will consider the phenomenon of plastic hardness in the pipes loaded with internal pressure.

Generally, when loading of pipes by internal pressure, two cases related to loss of plastic hardness are possible:

In process of pipes deformation by internal pressure, there comes the moment when further increase of stress is carried out due to increase in diameter and reduction of a wall thickness without growth and even at reduction of pressure *p*.

By analogy, when pipe uniaxial extension with neck forming, there comes the moment when resultant loading F, which is in the area I, reaches the maximum value.

The condition of these moments emergence can be characterized by the equations:

$$\frac{dp}{d\varepsilon_i} = 0, \quad (2)$$

$$\frac{dF}{d\varepsilon_i} = 0, \quad (3)$$

where ε_i – intensity of logarithmic deformations.

Let us consider the pipe loaded with the internal pressure and axial force, but under condition that

$$0 \le \sigma_{lon} = \sigma_2 \le \sigma_{cir} = \sigma_1, \quad (4)$$

where σ_{lon}, σ_{cir}- longitudinal and circular stress in a pipe wall respectively.

Let us introduce designation:

$$\frac{\sigma_2}{\sigma_1} = K_\sigma \qquad (5)$$

Let us write down the load condition

$$p = \frac{\sigma_1 S}{R}, \qquad (6)$$

$$F = \sigma_1 S I, \qquad (7)$$

where R_0, S_0, I_0 – thickness, radius and unit length respectively.

Let us express the dependence between the current values R, S, I and the main deformations ε_1, ε_2 and ε_3 as follows:

$$\left.\begin{aligned} \varepsilon_1 &= \ln\frac{R}{R_0}; R = R_0 e^{\varepsilon_1};\\ \varepsilon_2 &= \ln\frac{I}{I_0}; I = I_0 e^{\varepsilon_2}\\ \varepsilon_3 &= \ln\frac{S}{S_0}; S = S_0 e^{\varepsilon_3}; \end{aligned}\right\} \qquad (8)$$

where R_0, S_0, I_0 - initial values of geometrical parameters; e - basis of Napierian logarithms.

After substitution of (8) into (6) and (7), we obtain

$$p = \sigma_1 \frac{S_0}{R_0} e^{(\varepsilon_3-\varepsilon_1)}, \qquad (9)$$

$$F = \sigma_1 I_0 S_0 e^{(\varepsilon_2-\varepsilon_3)}, \qquad (10)$$

As we know, the intensity of stress for two-axial stress state is the equal to

$$\sigma_i = \sqrt{\sigma_1^2 - \varrho_1\varrho_2 + \sigma_2^2}, \qquad (11)$$

From here, considering (4), we obtain

$$\sigma_1 = \frac{\sigma_i}{\sqrt{1-K_\sigma+K_\sigma^2}}, \qquad (12)$$

Introducing (9), (10) and (12) in (2) and (3), and having carried out differentiation, we obtain:

$$\frac{dp}{d\varepsilon_i} = \frac{S_0}{R_0}\frac{1}{\sqrt{1-K_\sigma+K_\sigma^2}}\left[\frac{d\sigma_i}{d\varepsilon_i}e^{(\varepsilon_3-\varepsilon_1)} + \sigma_i e^{(\varepsilon_3-\varepsilon_1)}\left(\frac{d\varepsilon_3}{d\varepsilon_i} - \frac{d\varepsilon_3}{d\varepsilon_i}\right)\right] = 0, \qquad (13)$$

$$\frac{dp}{d\varepsilon_i} = \frac{S_0 I_0}{\sqrt{1-K_\sigma+K_\sigma^2}}\left[\frac{d\sigma_i}{d\varepsilon_i}e^{(\varepsilon_2-\varepsilon_3)} + \sigma_i e^{(\varepsilon_2-\varepsilon_3)}\left(\frac{d\varepsilon_2}{d\varepsilon_i} - \frac{d\varepsilon_2}{d\varepsilon_i}\right)\right] = 0, \qquad (14)$$

Expressions (13) and (14) can be reduced:

$$\frac{d\varrho_i}{d\varepsilon_i} = \sigma_i \frac{d\varepsilon_1}{d\varepsilon_i} - \frac{d\varepsilon_3}{d\varepsilon_i}, \qquad (15)$$

$$\frac{d\varrho_i}{d\varepsilon_i} = -\sigma_i \frac{d\varepsilon_2}{d\varepsilon_i} - \frac{d\varepsilon_3}{d\varepsilon_i}, \qquad (16)$$

Using the equation of plasticity [6], we can obtain

$$\left.\begin{aligned} \frac{d\varrho_1}{d\varepsilon_i} &= \frac{\sigma_1-\sigma_2/2}{\sigma_i};\\ \frac{d\varrho_2}{d\varepsilon_i} &= \frac{\sigma_2-\sigma_1/2}{\sigma_i};\\ \frac{d\varrho_3}{d\varepsilon_i} &= \frac{\sigma_1+\sigma_2/2}{2\sigma_i}. \end{aligned}\right\} \qquad (17)$$

After substitution of (17) into (15) and (16) considering (12), we obtain

$$\frac{d\varrho_i}{d\varepsilon_i} = \frac{3}{2}\frac{\sigma_i}{\sqrt{1-K_\sigma+K_\sigma}} \quad \text{for } p_{max}, \qquad (18)$$

$$\frac{d\varrho_i}{d\varepsilon_i} = \frac{(2-K_\sigma)\sigma_i}{\sqrt{1-K_\sigma+K_\sigma}} \quad \text{for } F_{max}. \qquad (19)$$

Let us use the widespread dependence of approximation $\sigma_i(\varepsilon_i)$ in the theory of plasticity in the form of

$$\sigma_i = A(\varepsilon_i)^m. \qquad (20)$$

According to [7]

$$A = \sigma_{ul} e^m m^{-m}, \qquad (21)$$

$$m = \varepsilon_p. \qquad (22)$$

Where ε_p – uniform logarithmic deformation at uniaxial extension.

Let us write down the known expressions for deformations intensity at μ = 0.5, in this case, the conditions of volume constancy and of components proportionality of stress deviators and deformations will be of the form

$$\varepsilon_i = \frac{\sqrt{2}}{3}\sqrt{(\varepsilon_1-\varepsilon_2)^2+(\varepsilon_2-\varepsilon_3)^2+(\varepsilon_3-\varepsilon_1)^2} \quad (23)$$

$$\varepsilon_1+\varepsilon_2+\varepsilon_3=0 \quad (24)$$

$$\frac{\varepsilon_1-\varepsilon_2}{\sigma_1-\sigma_2}=\frac{\varepsilon_2-\varepsilon_3}{\sigma_2-\sigma_3}=\frac{\varepsilon_3-\varepsilon_1}{\sigma_3-\sigma_1} \quad (25)$$

For two-axial stress condition, having obtained $\sigma_1 = K_\sigma \sigma_2$ from (4) and having solved (23), (24) and (25) together, we obtain

$$\varepsilon_i = \frac{2\varepsilon_1}{2-K_\sigma}\sqrt{1-K_\sigma+K_\sigma^2} \quad (26)$$

Having substituted (20) into (18) and (19) considering (22), after transformations we obtain expression for determination of deformations intensity critical values, which corr nd the moment of maximum pressure ching (ε_{icr}) and the moment of neck formation (ε_{in}):

$$\varepsilon_{i\,cr} = \frac{2}{3}\varepsilon_p\sqrt{1-K_\sigma+K_\sigma^2} \quad (27)$$

$$\varepsilon_{i\,n} = \frac{2}{2-K_\sigma}\varepsilon_p\sqrt{1-K_\sigma+K_\sigma^2} \quad (28)$$

Using (26), let us express the critical value of deformations intensity through the corresponding values of circular deformation $\varepsilon_{1\,cr}$ and ε_{1n}:

$$\varepsilon_{1cr} = \frac{2-K_\sigma}{3}\varepsilon_p \quad (29)$$

$$\varepsilon_{1n} = \varepsilon_p \quad (30)$$

According to entrance criteria, $\varepsilon_{i\,cr}$ *and* ε_{1cr} characterize the pipe strength (p_{max}), and criteria $\varepsilon_{i\,n}$ and ε_{1n} - material strength (F_{max}). For the convenience, let us call them as criteria of loss of plastic hardness of pipe and material respectively.

However, it should be noted that expressions (27-30) are not original. In different variants (for separate values of K_σ, as well as in general cases), they were obtained earlier.

For convenient analysis of obtained expressions, let us show them in the form of diagram (Fig. 1).

Actually, having considered the essence of these criteria, it can be noted that first of all, they both depend on the deformation resistance change nature with the increase in deformation (strengthening module).As it is known, the letter may be essential even for materials with equal values of uniform deformation ε_p. In another words, materials with equal value of ε_p may have different ratios of yield point to time resistance σ_{ul}.

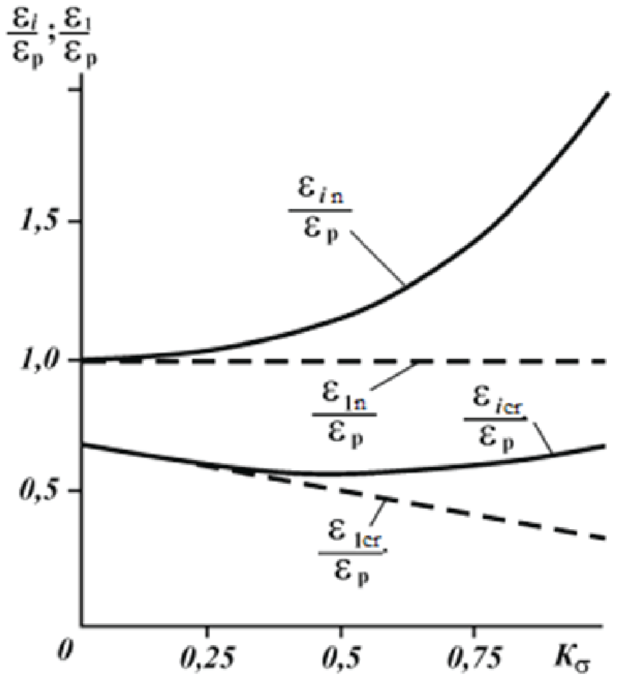

Figure 1. The curves of critical values dependences of intensive deformation on coefficient, which characterises the metal loaded state

As we can see, application to such materials of deformation, according to considered criteria of plastic hardness, cannot be identical.

In the paper [4], it is noted about observation of a condition (30) during hydrostatic extrusion of sheet metal through the circular hole. Influence of power characteristics together with deformation on plastic hardness of material was also noticed in practice of metal treatment under pressure. In particular in papers [2], it is pointed out that deformation ability of material when pressing and drawing depends both on ε_p and σ_T/σ_{ul}.

It can be seen that the plastic hardness of a pipe in the entire investigated range of change of K_σ is lost at much smaller deformations, than the neck is formed. Thus, all the considered criteria are defined only by material plasticity and coefficient K_σ and do not depend on strength characteristics. Value $\varepsilon_{1n}$is independent of K_σ.

Referenses

1. Karpenko G.V. *Prochnost' stali v korozionnoy srede*.[Steel strength in the corrosion medium]. Moscow, Mashgiz, 1963. 188 p.
2. Pokhmurs'kiy V.I. *Koroziyno mekhanichne ruynuvannya zvarnikh konstruktsiy*. [Corrosion mechanical destruction of welded constructions]. Kyiv, Naukova dumka, 1990. 347p.
3. Pokhmurs'kiy V.I. *Korrozionnaya ustalost' metalov*.[Corrosion fatigue of metals]. Moscow, Metalurgiya, 1985. 207 p.
4. Krizhanivs'kiy Ye.I. (2012) Features corro-

sion-fatigue fracture of the weld joints of long operated pipelines. *Fiziko–khimichna mekhanika materialiv.* No 9, p.p. 653 – 661
5. Tarayevs'kiy O.S. (2012) The impact of characteristics of pipelines operating for deformation resistance of welded joints. *Journal of Donbass State Engineering Academy*. No3 (28), p.p.264-268
6. Tarayevs'kiy O.S. (2012) Forecasting of the residual life of circular welded joints of long operated main gas pipelines. *Nadiynist instrumentu ta optimizatsiya tehnologichnih system*. No31, p.p.46-53
7. Tarayevs'kiy O.S. (2012) The impact of uneven gas consumption on corrosion-fatigue properties of welded joints of pipelines. *Scientific Bulletin Ivano-Frankivsk National Technical University of Oil and Gas*. No2 (32) p.p.66-74.
8. Tarayevs'kiy O.S. (2013) Evaluation of strength of capacity of circular welded joints of pipes with corrosion defects. *Problemi naftogazovoyi promislovosti*. No3, p.p.45-50.