CALCULATION AND CONTROL OF THE TECHNICAL STATE OF ELEMENTS AND STRUCTURES WITH CRACKS

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ABSTRACT

One of the most effective ways to lower the risk of unexpected failures is the operation of the equipment and structures according to their technical state. In the paper considered the author presents the system of predicting brittle and quasi-brittle failure (stage of structure design) and calculation of ultimate strains, which is necessary for timely diagnostics of the technical state of structure elements with cracks.

KEYWORDS

Failure, cracks, energy, probability, detection, ultimate strain.

RELIABILITY OF STRUCTURES WITH CRACKS

Statistical analysis of full-scale tests of pipes and pressure vessels, as well as analysis of mechanical properties of steels showed a considerable probability dependence of structure reliability evaluation on the test temperature (Duffy et al., 1972; Hahn et al.,1972; Aprosimov et al.,1985).Technical state of structures with cracks can be evaluated according to structure reliability which, in its turn, is connected with the arrangement of non-destructive testing methods.Due to technical advantages of non-destructive testing methods it becomes possible to predict structure failure. In literature (Klyuiev, 1991) the information on the prospects of the detection of different defects and development of non-destructive testing systems are presented.

Truth and reliability of non-destructive testing (NT) of a structure depend on technical characteristics of a device and physiological possibilities of an operator. On the basis of the analysis of experimental results and other investigations (Grebennik,1981) the model of the probability of defect detection depending on the type of information, size of a visible part of a defect and time τ of information processing has been developed:

$$P = 1 - \exp(-\alpha\tau)$$

where P - probability of defect detection; α - constant which is proportional to the visible part of the defect having the 2ℓ size.

For the different NT methods probability of detecting defect with 2ℓ length:

visual inspection	$P = 1-0,12^{\ell/12}$
capillary	$P = 1-\exp(-0,22\cdot 2\ell)$
ultrasonic	$P = 1-\exp(-0,18\cdot 2\ell)^2$
radiography	$P = 1-\exp(-0,62\cdot 2\ell)$

Probability of defect detection will determine the initial technical state of the structure with a defect or a crack. Then one can determine the range of critical stress intensity factor (SIF) where the upper limit of SIF corresponds to minimal sizes of cracks which cannot be detected by NT

$$K_{IB} = 0,51(\sigma_B + \sigma_T)\sqrt{\pi\ell/(1+3,22\,\ell^2/Dt)} ,$$

where σ_T, σ_B are limits of yield and strength of the material; D, t are diameter and thickness of the pipeline wall.

The lower limit of SIF values is determined by the operating stress in the pipeline wall at the same crack sizes:

$$K_{IH} = \sigma^{p}_{\theta c}\sqrt{\pi\ell}$$

where $\sigma^{p}_{\theta c}$ is the allowable stress.

Calculation results show that the required reliability level of the pipeline made of the 16Г2САФ steel, equal to 0,998, can be provided to 200°K only with the use of ultrasonic and radiography methods (Fig.1)

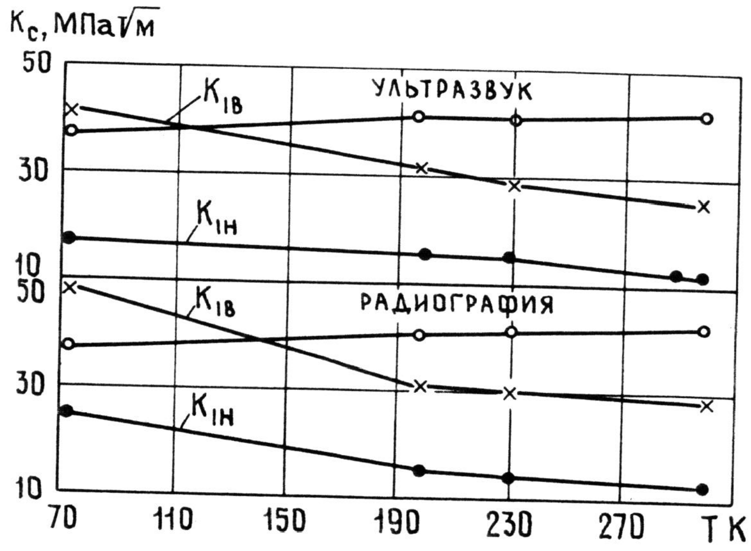

Fig.1.Failure viscosity of steel 16Г2САФ and the range of allowable values of SIF.

EVALUATION OF THE MATERIAL STATE IN THE PRE-FAILURE ZONE

To choose the required minimum safety factors or to determine the geometry of a structure element according to the limiting states of material and taking into account the possible formation and growth of a crack, it is necessary to have the precise parameters for checking the situation. In the first paragraph the way to select the necessary NT methods is presented. Change of the crack length in the process of structure operation gives rise to some requirements for inspection intervals.

In practice formation and growth of a crack are observed in almost inaccessible parts of a structure and it is very difficult to disassemble and examine power details and units. That is why the problem of the development of the built-in diagnostic systems for checking the evolution of the structure technical state during all the period of its service is of current concern nowadays.

Deformations calculated by the method developed by the author (Noyev et al.,1984) can be used as parameters for checking technical state of material in the zones of risk.

At quasi-brittle failure of metals stresses at the top of a crack or a notch are equal to or are slightly higher than yield strength σ_T. Then, at known ε at some distance from the concentrator and specific energy ω it becomes possible to evaluate the ultimate strains in the zones of interest.

Measurements of energy consumption for deformation and failure are performed by simultaneous measurements of work expended for tension in different sections of a sample with the known stress concentrator using the special measurement unit.

Separate measurement of the shift of notch or crack edges makes it possible to determine specific work by planimetry of the curves "load-shift" of the notch edge.

Specific energy ω at the top of a notch is sensitive to stress concentration at the notch radia $R \leqslant 0,25$ mm (Fig.2).

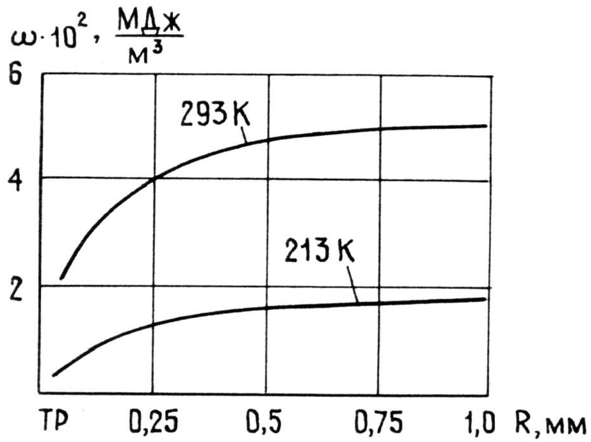

Fig.2.Change of the specific energy at the different radius of the concentrator top (steel 20) at different testing temperature.

It characterizes integral properties of the material in the zone of intensive localization of plastic flow.

Effective response of specific strain energy (ultimate power-intensity of material) to stress concentration and temperature allows to calculate strain limiting values for different particular configurations of parts. According to the definition:

$$\omega = \sigma_{пр} \quad \varepsilon_{пр}$$

Ultimate stresses $\sigma_{пр}$ are constant and known for elastic $\sigma_{пр} = \sigma_{пц}$ or plastic loading $\sigma_{пр} = \sigma_{т}$ or $\sigma_{пр} = S_{к}$. Then
$$\frac{\omega_1}{\varepsilon_1} = \frac{\omega_2}{\varepsilon_2} = \frac{\omega_3}{\varepsilon_3} = \dots = const$$

This equality is satisfied for different thickness and along the length of samples. However,analysis of stress and strains in the zone of the top of a notch or a crack is of the most particular interest. Separate measurements of the shift of notch edges allow to find out the dependence of the specific energy of the strain along the sample length and calculate the ultimate strain for the zone subjected to intensive plastic deformation. To do this it is enough to have ω -values in the zone of elastic deformation.

Assuming $\sigma = \sigma_{т}$ one can determine the ultimate strain of steel at the notch boundary which can be considered as lower estimate of the ultimate strain $\varepsilon^{н}_{пр}$

$$\varepsilon^{н}_{пр} = \frac{\omega_{пр} \cdot \varepsilon_{т}}{\omega_{т}} .$$

At static loading it is necessary to know maximum strains leading to metal breakdown. The influence of a concentrator, temperature, strain speed and other factor, which reduce deformation is characterized qualitatively by the decrease of plastic deformation level at which breakdown occurs.

To evaluate this level, the upper estimate of deformation $\varepsilon^{в}_{пр}$ is introduced, which is determined by ω at the known breaking stress and sample geometry. The upper estimate $\varepsilon^{в}_{пр}$ is calculated, as $\varepsilon^{н}_{пр}$, for a particular stress concentrator and is considered as a generalized characteristics of metal at pre-failure stage.

Deformations at which plastic flow of material in the zone of the concentrator top results in disturbance or failure are found by:

$$\varepsilon^{в}_{пр} = \frac{\omega}{S_{к}}$$

where $S_{к} = \sigma_{т} + E_{т} (\varepsilon^{в}_{пр} - \varepsilon^{н}_{пр})$ - breaking stress.

Ultimate strains of steels studied at quasi-brittle failure (%).

Steel quality	Test temperature °K	Radius of rounding of the notch top R =1mm $\varepsilon^{н}_{пр}$	R =1mm $\varepsilon^{в}_{пр}$	R=0,25mm $\varepsilon^{н}_{пр}$	R=0,25mm $\varepsilon^{в}_{пр}$	Crack $\varepsilon^{н}_{пр}$	Crack $\varepsilon^{в}_{пр}$
1	2	3	4	5	6	7	8
Steel 20	293	9,0	19,7	6,6	15,2	6,0	10,5
	213	7,2	14,3	6,0	11,8	2,4	2,80
Steel 10X2ГМ	293	7,0	24,1	6,7	17,4	5,7	12,0
	213	6,0	21,2	5,6	14,3	2,5	5,20
Steel Y8	293	5,0	13,8	2,7	5,60	1,3	1,49
	213	3,5	8,70	2,1	2,78	0,6	0,67

CONCLUSION

Decrease of metal specific quantity of structures and maintenance of sufficient reliability are provided due to the calculation of technical state of a structure with a crack and periodic testing by non-destructive methods. SIF-values at operation loads are determined with the prescribed probability of detecting defects of particular dimensions.

Having known values of specific energy of strain and failure, which are obtained at tension of samples with notches, it is possible to determine ultimate strains of two levels.The first one characterized loss of the elastic qualities of the material in the risk section of a structure element. The second level characterizes disturbance and failure of the material. The obtained values of the unit strain do not exceed the elongation values.

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