Crack Growth Resistance of Steel of the Main Circulating Pipeline of Nuclear Power Plant Cooling Contour

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Keywords: cyclic elasto-plastic fracture diagram, crack growth resistance, main circulating pipeline, nuclear power plant.

Abstract. The results of experimental research of crack growth resistance characteristics and hardness of 08X18H12T steel in an initial condition and after 100 thousand hours operation in the conditions of the 1st contour of the main circulating pipeline of the New-Voronezh nuclear power plant are presented.

Introduction

The purpose of the present work is the experimental definition of crack growth resistance characteristics for 08X18H12T steel in an initial condition and after an operating time (100 thousand hours) in the conditions of the 1st contour of the main circulating pipeline of the New-Voronezh nuclear power plant (the block № 1). The problem of studying of influence of anisotropy and an operating time at characteristics of crack growth resistance for 08X18H12T steel was considered.

Crack growth in a pipe of the main circulating pipeline of the nuclear power plant can occur in the various directions; therefore the knowledge of characteristics of crack growth resistance, received as a result of tests of specimens with various orientations of the direction of a crack front development (CFD) is important. Such data should allow more accurate definition of the sizes of critical defects depending on their orientation.

Analysis of Experimental Data

Tests on cyclic crack growth resistance of standard compact specimens with the thickness of 20 mm at tension were performed at frequency of 20 Hz, asymmetry of a cycle 0,1 at a room temperature. Test results are shown in the form of the diagram "Stress intensity factor (SIF) - crack growth rate" on Fig. 1.

The fatigue crack growth diagram for it only at SIF value $\sim 55\ \mathrm{MPa}\sqrt{\mathrm{m}}$ is crossed with the fatigue crack growth diagram for specimens with CFD in an axial direction, i.e. there is an insignificant reduction of a crack growth rate. The fatigue crack growth diagram for specimens made of 08X18H12T steel after 100 thousand hours of operation has a similar character (Fig. 1). However it is necessary to notice, that difference of crack growth rates on a part of the diagram with SIF values, smaller than 25 $\mathrm{MPa}\sqrt{\mathrm{m}}$ has more obvious character, and at SIF values of 20 $\mathrm{MPa}\sqrt{\mathrm{m}}$ the intensive growth of a crack for specimens with CFD occurs in an axial direction, and at SIF values of 30 $\mathrm{MPa}\sqrt{\mathrm{m}}$ diagrams are crossed. On the top part of the diagram crack growth rate for specimens with CFD in an axial direction exceeds crack growth rate for specimens with CFD in a circumferential direction, but this difference of rates is not so expressed on the bottom part. It means that crack growth rate in a material after 100 thousand hours of operation at small SIF values reacts to a direction of crack growth more strongly, than at higher values.

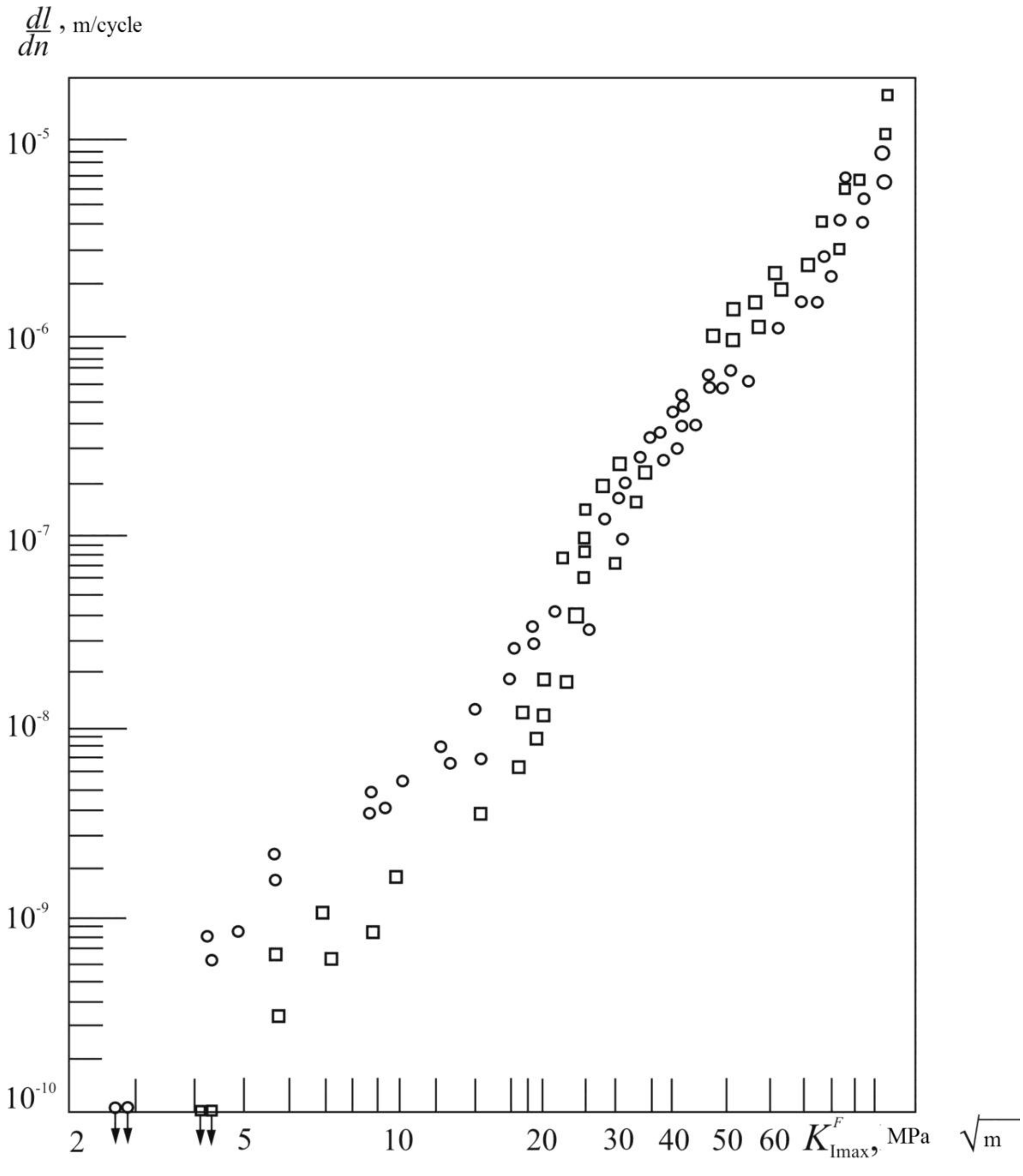

Fig. 1 - Experimental diagram «SIF - growth rate of a fatigue crack» for 08X18H12T steel after 100 thousand hours of operation time for specimens with CFD in a direction: ○ - circumferential, □ - axial

SIF values also react to anisotropy. At small crack growth rate specimens with CFD in an axial direction have SIF values bigger than specimens with CFD in a circumferential direction. At the crack growth rates a close to limiting, position varies, i.e. already specimens with CFD in a circumferential direction have higher SIF values. It is necessary to notice, that definition of limiting value of SIF for this specimen party is complicated by that deviation CFD from the horizontal is possible. Such deviation sometimes did not give possibility to consider the conducted test correct, and results of such tests were not considered at processing of test results. SIF values for 08X18H12T steel after 100 thousand hours of operation in the conditions of the nuclear power plant have the same character of increase, but at low crack growth rates a SIF of such material is most sensitive to anisotropy. So threshold values of SIF for specimens with CFD in axial and circumferential directions differ by 31,9 %, whereas the limiting value of SIF differ only by 2,9 %. It is observed in reduction of influence of anisotropy on SIF with growth of their absolute values. It would be visible in Fig. 2, that the fatigue crack growth diagram for an investigated steel in connection with an operation time has changed.

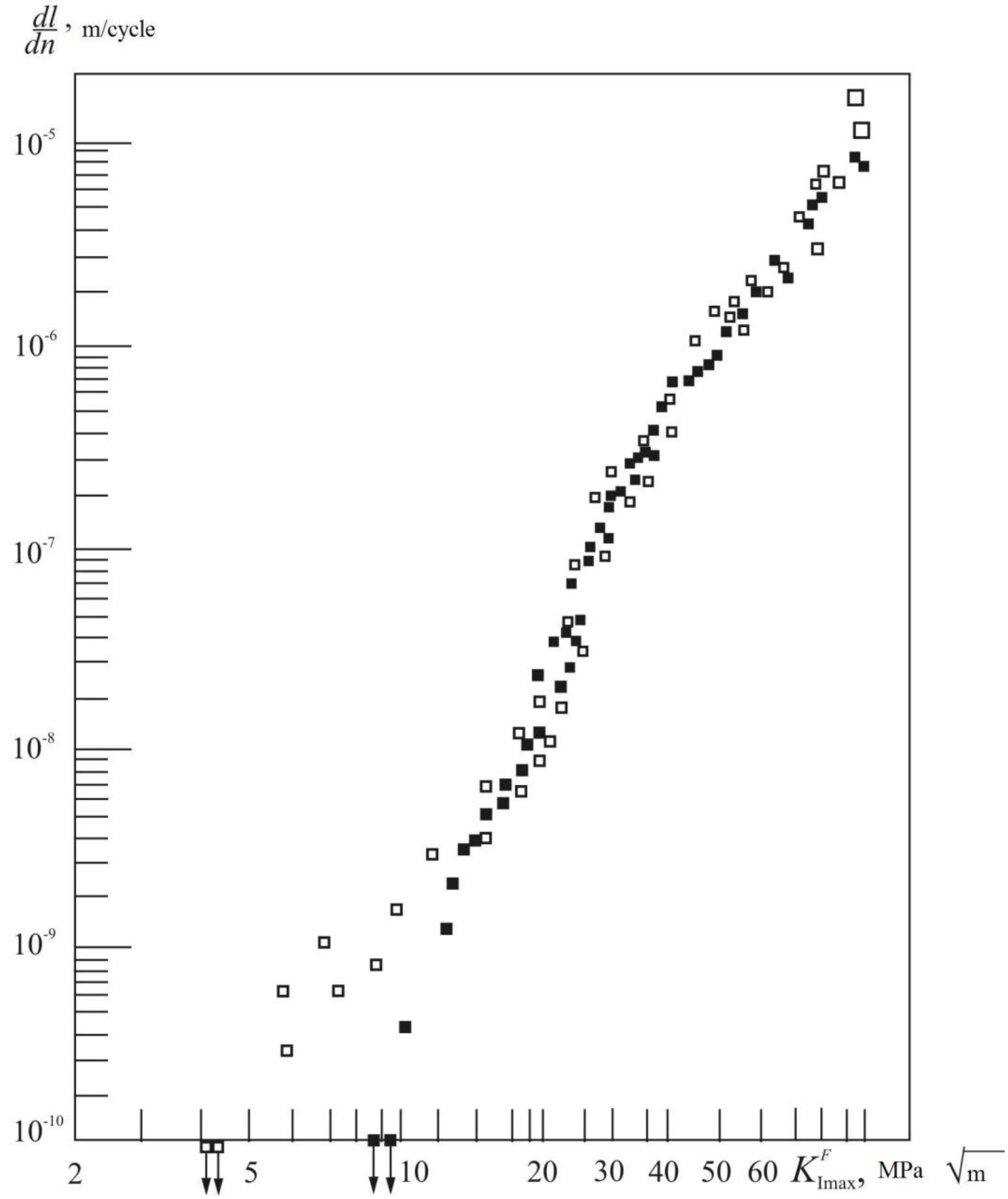

Fig. 2 - Experimental diagram «SIF - growth rate of a fatigue crack» for 08X18H12T steel depending on an operation time with CFD in an axial direction: ■ - an initial condition, □ - after 100 thousand hours of operation

It is necessary to notice that at development of cracks both in circumferential and in axial directions it is possible to allocate three parts on the fatigue crack growth diagram, two of which are sensitive to an operation time, and one - not reacting to operational influence. So in the field of small growth rates of a crack, less than $2 \cdot 10^{-8}$ m/cycle, the metal after long operation has growth rate of a crack above than metal in a delivery condition has. Thus for specimens with CFD in a circumferential direction this excess has absolute value more, than for specimens with CFD in an axial direction. The part of the diagram with growth rates of a crack from $2 \cdot 10^{-8}$ m/cycle to $2 \cdot 10^{-6}$ m/cycle represents merge of areas of dispersion of diagrams of the tested specimens both in a delivery condition, and after operation. The third part of diagrams at growth rate of a crack more than $2 \cdot 10^{-6}$ m/cycle also visually shows excess of growth rate of a crack for a material after operation in comparison with growth rate of a crack for an initial material. It is necessary to tell that the limiting crack growth rate has the greatest value in specimens with CFD in the axial direction made of a material after operation (see Fig. 1 and 2, Tab. 1), i.e. limiting value of crack growth rate for specimens with CFD in a circumferential direction has increased on 41,9 %, and for specimens with CFD in an axial direction - on 46,5 %.

The big influence was rendered by operational influences on SIF values in threshold and close to threshold areas. So threshold SIF values for specimens with CFD in a circumferential direction have decreased on 64,2 %, and for specimens with FCD in an axial direction - on 52,6 %. With increase of numerical values of SIF the influence of operational factors decreases, and limiting values of SIF K_{fc}^{F} decrease only on 6,3 % for specimens with CFD in a circumferential direction, and on 1,9 % for specimens with CFD in an axial direction.

The influence of operational factors affects the plastic properties of the investigated steel. Schedules of dependence SIF from the area damaged by a crack are usual kinetic curves of fatigue crack growth; influence of anisotropy here is not found out almost.

According to the developed approach [1-5] whole process of elasto-plastic deformation and destruction are described by means of the cyclic elasto-plastic fracture diagram for a specimen with a crack. This diagram is built in SIF coordinates K_I^F and absolute φ or relative ψ contraction.

Cyclic elasto-plastic fracture diagram for 08X18H12T steel built by results of the lead tests on cyclic crack growth resistance of compact specimens and of measurement of the specimen's contraction in a zone of development of a fatigue crack, postponing the contraction of specimen an axis of abscises, and the SIF value $K_{I\,max}^{F}$ corresponding it and calculated under the formulae

$$K_{I\,max}^{F} = \frac{P_{\max}}{t_0 \sqrt{B}} \omega_F^{1/2} Y(\omega_F), \tag{1}$$

$$Y(\omega_F) = 29{,}6 - 185{,}5(\omega_F) + 655{,}7(\omega_F)^2 - 1017(\omega_F)^3 + 638{,}9(\omega_F)^4. \tag{2}$$

in view of the offered amendment on plasticity on an axis of ordinates. This diagram resulted on Fig. 3 confirms the fragile process of 08X18H12T steel due to the influence of operational factors, and decrease of limiting value of contraction for specimens with CFD in a circumferential direction is 12,8 %, and for specimens with CFD in an axial direction is 19,5 %.

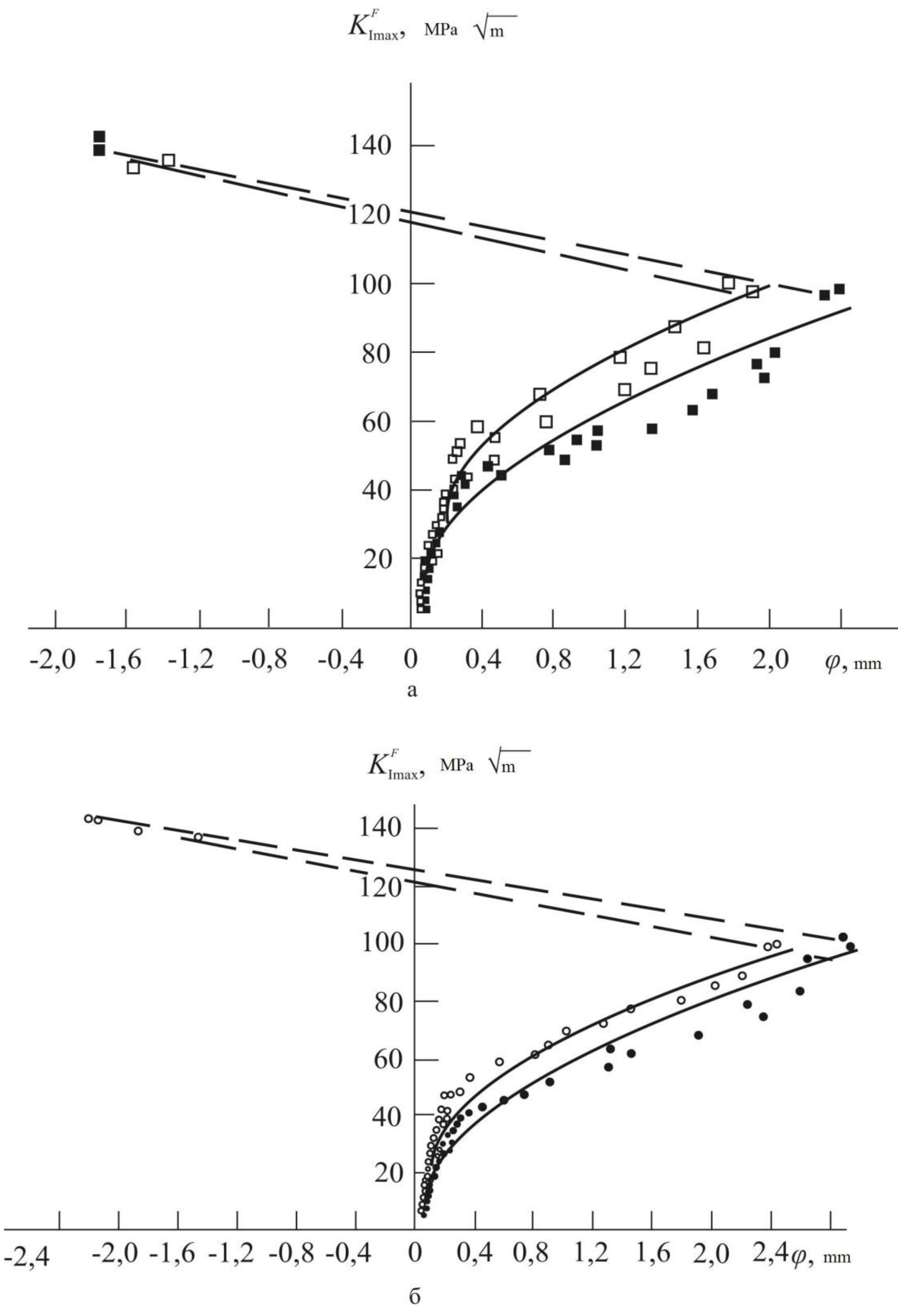

Fig. 3. - Diagram $K^F_{Imax} - \varphi$ for specimens of 08X18H12T steel depending on an operation time with CFD in a direction: • - circumferential, ■ - axial in an initial condition (*a*) and ○ - circumferential, □ - axial after an operational operating time (*b*)

Parameters of the Eq. (1), (2) are $P_{\max}$ (is the maximum load of a cycle); t_0, B (are the sizes of a dangerous section of the specimen); function (Eq. 2) $Y\left(\frac{l}{B}\,\frac{t_\varphi}{t_0}\right) = Y\left(\frac{F_l}{F_0}\right) = Y(\omega_F)$ considers not only geometry of the specimen and its scheme of loading but also integrally the size of plastic strain in dangerous cross-section; F_0 (is the nominal (before deformation) area of dangerous cross-section of the specimen); F_l (is the area damaged by a crack with a length l and defined with the account of the plastic deformation of cross-section).

Influence of operation factor A_{op} was defined as the relation of value of parameter for a material after operation to value of the given parameter for a material in an initial condition (Tab. 1).

Tab. 1 - Influence of an operation time on characteristics of crack growth resistance 08X18H12T steel

Parameter	Direction of a CFD	Material's condition		Operation factor A_{op}
		initial	after 100 thousand hours of operation	
K_{th}^F, MPa $\sqrt{m}$	circumferential	8,04	2,88	0,36
	axial	8,92	4,23	0,47
K_{fc}^F, MPa $\sqrt{m}$	circumferential	106,0	100,2	0,94
	axial	99,2	97,3	0,98
υ, m/cycle at ≈10 MPa $\sqrt{m}$	circumferential	$6{,}8\cdot10^{-10}$	$5\cdot10^{-9}$	7,35
	axial	$4{,}2\cdot10^{-10}$	$2{,}6\cdot10^{-9}$	6,19
υ, m/cycle at $K_{I\max}^F$ ≈35 MPa $\sqrt{m}$	circumferential	$3{,}4\cdot10^{-7}$	$2{,}8\cdot10^{-7}$	0,82
	axial	$3\cdot10^{-7}$	$2{,}6\cdot10^{-7}$	0,87
υ_c, m/cycle	circumferential	$3{,}6\cdot10^{-6}$	$6{,}2\cdot10^{-6}$	1,72
	axial	$6{,}95\cdot10^{-6}$	$1{,}3\cdot10^{-5}$	1,72
φ_f, mm	circumferential	0,28	0,21	0,75
	axial	0,275	0,205	0,75
φ_c, mm	circumferential	2,81	2,44	0,87
	axial	2,26	1,82	0,81
φ_s, mm	circumferential	-2,20	-1,61	0,73
	осевое	-1,77	-1,51	0,85
	axial	58,24	66,75	1,15

Summary

It is possible to make following conclusions basing on the experimental data analysed above.

1. The experimental research of cyclic crack growth resistance and laws of growth of fatigue cracks for compact specimens from 08X18H12T steel, cut out from pipes of 1-st contour of the New-Voronezh nuclear power plant in an initial condition and after 100 thousand hours of operation is conducted.

2. It is shown that after 100 thousand hours of operation time:

a) limiting SIF values K_{fc}^{F} decrease only by ~2 - 6 % (see Tab. 1). It allows to draw a preliminary conclusion, that bearing ability of the investigated pipes by criterion of crack growth resistance is not yet reached, therefore it is expedient to put and solve the problem on prolongation of their term of operation (with the additional analysis of change and other characteristics of service properties of the steel);

b) growth rate of fatigue macrocracks in an average part of the fatigue crack growth diagram (at values SIF from ~18 till 50-55 MPa$\sqrt{\text{m}}$) practically has not changed in comparison with crack growth rate in an initial material;

c) threshold values SIF K_{th} have decreased on ~50-60 % (see Tab. 1, Fig. 1). It is accompanied by corresponding increase in growth rate of especially small cracks (see Tab. 1), that is connected with fragile processes of steel during long operation. Results of tests have confirmed, that the characteristic of plasticity - residual contraction of cross-section of the tested specimens has decreased on ~12 - 20 % (see Tab. 1).

It means that for prolongation of operation term of pipes from 08X18H12T steel working in the 1-st contour of the nuclear power plants, it is necessary to take special measures on detection and elimination of especially small initial cracks. This question demands additional research for finding-out of conditions of transition of small cracks in greater which could represent real danger.

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