Обґрунтовано критеріальні значення глибини потенційних тріщиноподібних дефектів профільних елементів стріли буртоукладника. Використана концепція «опірності конструкційного елемента росту тріщини», яка характеризується швидкістю зміни коефіцієнта інтенсивності напружень у вершині тріщини. Враховано результати експериментальних досліджень тріщиностійкості матеріалу в різних середовищах. Сформульовано інженерні рекомендації щодо прогнозування розвитку тріщиноподібних дефектів

Ключові слова: стріла буртоукладника, профільний елемент, тріщиноподібний дефект, опірність росту тріщини

Обоснованы критериальные значения глубины потенциальных трещинообразных дефектов профильных элементов стрелы буртоукладчика. Использована концепция «сопротивляемости конструкционного элемента росту трещины», которая характеризуется скоростью изменения коэффициента интенсивности напряжений в вершине трещин. Учтены результаты экспериментальных исследований трещиностойкости материала в различных средах. Сформулированы инженерные рекомендации по прогнозированию развития трещинообразных дефектов

Ключевые слова: стрела буртоукладчика, профильный элемент, трещинообразный дефект, сопротивляемость росту трещины

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PREDICTION OF THE PROPAGATION OF CRACK-LIKE DEFECTS IN PROFILE ELEMENTS OF THE BOOM OF STACK DISCHARGE CONVEYOR

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1. Introduction

Nowadays, the problem of providing for reliability and security of functioning of engineering long-operating structures is absolutely relevant in many countries of Europe and throughout the world [1]. This is explained by the fact that the planned resource of many technological complexes and engineering constructions is gradually being exhausted and more and more damage of diverse nature is revealed in their elements [2]. As it is known, designing structural elements with regard to the influence of operational loads is carried out on the basis of approaches of mechanics of continuous environment. However, each structural element contains certain defects that are formed both at the stage of its production and at the stage of its operation [1]. In this connection, to provide a reliable and no-failure operation of the equipment and facilities, it is necessary to develop quantitative approaches to evaluating the degree of danger of the detected crack-like defects. There appears a need for the methods of express-analysis, which, on the basis of the results of non-destructive control or information about the condition of the surface of material, could assess a particular defect and determine residual resource of a structural element or a structure in general [3, 4].

With an increase in production power, the influence of various factors on the operational characteristics of structural elements and the probability of adverse consequences of manifestation of such influence (breakdowns, accidents, etc.) rises. The results of technical diagnosis of technological equipment [1, 2] indicate that in structural elements the number of so-called non-traditional damages, which are impossible to predict using regulations and documents, is increasing. They appear as a result of long operation of equipment or various deviations of parameters of operational modes from their calculated values. Such damage is mostly of corrosive-mechanical nature and is formed primarily in the areas of high concentration of stresses caused by special features of design or by the technology of manufacturing the parts [4].

2. Literature review and problem statement

Residual strength and residual durability of engineering structures are significantly influenced by corrosion and corrosive-mechanical defects that occur on the surfaces of their elements. Therefore, an important factor in providing for the efficiency of production equipment and facilities is monitoring the formation and development of defects of the specified type and an analyzing the probability of further operation of such systems. Despite quite different physical nature of origin of a wide range of defects, it can be argued that simultaneous localization of physical-mechanical and physical-chemical processes of destruction of materials is characteristic for most of them. Therefore, corrosive-mechanical damage and destruction of material can be assessed on the basis of the common methodological approach. Scientific tools for analyzing the damage are the mechanics of destruction of materials and structures. It studies regularities of origin and development of crack-like non-homogeneity and defects of structure of material under conditions of influence of cyclic loads [2]. Methods of mechanics of destruction in combination with non-destructive methods of objects monitoring are used for prediction of cracks development given the shape and dimensions of defects.

Paper [5] presents an analysis of corrosive-cyclic crack resistance of steel shapes of art. 3 of a boom straightedge of 45×45×45 mm of the stack discharge conveyor BUM-65M2B3K. But these studies do not contain any assessment of residual durability of structural elements. For such assessment, it is necessary to apply analytic ratios for SIF (stress intensity factor) K_I and for their rate of changes dK_I/da in the slab, by which the examined steel shapes of the stack discharge conveyor are simulated.

Article [3] considers 6 cases of potentially possible crack-like defects. For each of them, the boundary values of load cycles, after which the destruction of material occurs, were calculated by the defined SIF value K_I.

Based on experimental research, presented in [6], it is possible to determine criterial values a_{fc} of characteristic crack dimensions, that is, the value, at achieving or exceeding of which ($a \geq a_{fc}$), the spontaneous propagation of cracks, leading to fragile destruction of the studied object, becomes possible.

Along with the definition of critical depth of a crack, it is necessary to consider an analytical base for evaluation of durability of structural elements with crack-like defects by the indicator of «resistance of a structure element to crack propagation» [7], which is a characteristic of rate of changes of SIF K_I near the top of a crack with the length a in the process of its growth. The concept of «resistance of a structure element to cracks propagation» and its suitability for engineering needs is presented in paper [8]. It is considered to be an effective tool for assessing reliability of a structural element that contains crack-like defects [9].

The study of structural integrity of engineering components is directly related to studying the process of damage of material. This takes into account operational conditions of the structure with existing defects and the impact of these defects on stress-deformed state, temperature and neutron-magnetic field [10]. For setting the safety level of operation of a structure in a particular case, it is possible to be guided by different methods, but first of all, it is necessary to answer the following questions [11]: how can a destruction process be controlled with the available equipment? In which part of the structure does the damage appear? Which methods can detect it?

It should be noted that concepts of reliability of constructions can be based on the principles of mechanics of destruction. Reliability of elements depends on the following basic parameters: geometry, location and distribution of defects, stressed-strained state under different operating conditions, and crack propagation at different stages of objects operation [12].

At present, the research into crack formation has reached high level. The final outcomes of these studies are recommendations for the complete destruction of a structural element [13]. Using a combination of different methods of mathematical modeling, approaches of mechanics of destruction and up-to-date software, it is mainly possible to receive the answer to the question when it is necessary to inspect or replace a particular object of research [14].

However these statements do not always reliably assess the situation at the top of a crack, because there is a certain probability of an abrupt jump in the studied criterial parameters [15]. One can also state that despite the fact that the negative impact of those or other factors was demonstrated considering different forms of structures, the problem of specifying the pre-destruction zone remains [16]. This applies to the research into changes in shape of crack-like defects, at which the acceleration of the progress of structures destruction is observed [17].

Thus, the concept of «resistance of a structure element to crack propagation» may be used as a separate invariant parameter of mechanics of destruction, although for a specific actual structural element this parameter depends on geometry of cracks, while the stress intensity factor (or other parameters of mechanics of destruction) depend on the type of structural elements, load conditions and geometrical parameters of crack-like defects. Therefore, «resistance of a structure element to cracks propagation» may be considered as an important supplement to the results of an analysis of the risk of destruction of structure elements.

However, for the estimation of the pre-destruction zone in order to prevent the emergency-dangerous cases, which are observed at a sudden increase in the dimensions of defects to critical values, the indicator of crack propagation sensitivity is very important [1]. It is essential, with the use of above mentioned directions of research into crack formation in material, to develop engineering recommendations for improving monitoring of technical condition of the boom of stack discharge conveyor during its long-term operation. The solution of this problem is considered below.

3. The aim and tasks of the study

The aim of present research is the development of engineering recommendations as for predicting crack propagation in steel shapes by means of an analysis of the defined criterion and characteristic values of the length of crack-like defects, based on experimental data, obtained for different systems «material-environment», as well as on the basis of theoretical calculations.

To achieve the set goal, the following tasks were to be solved in the work:

1. Taking into account the known results of mechanics of destruction of materials and structures, analytical dependences of SIF K_I and derivative dK_I/da on the dimensionless parameter a/t were established (a, t are the characteristic dimensions of a crack and a slab) for the model cases of crack-like defects:

– tension of a slab with a central longitudinal crack;
– tension of a slab with external edge crack;
– tension of a slab with two external edge cracks;
– tension of a slab with half-elliptical edge crack;
– tension of a slab with quarter-elliptical angular crack;
– tension of a slab with internal elliptical central crack.

2. Based on the analysis of dependences $K_I(a/t)$ and $dK_I(a/t)/da$, theoretical values of depths of cracks, which precede the destruction of profile elements of the boom of stack discharge conveyor, were established.

3. Criterial values of crack depth in profile elements of the boom of the stack discharge conveyor were determined on the basis of results of experimental studies of behavior of systems «material-environment».

4. Materials and methods of studying the frame of the stack discharge conveyor

Special steel shape of art. 3 of straightedge 45×45×5 mm of the frame of the operated stack discharge conveyor BUM-65M2B3-K and non-operated steel of the same brand were studied. Critical value of depth of the crack-like defect was determined through analysis of relations for SIF with regard to geometric parameters of defects of different shapes. Having taken the derivative of SIF with respect to the crack depth and having reduced the obtained expression to the function of dimensionless value a/t, we received the scheme for determining the crack depth, which can precede the destruction of the structure.

All in all, six model cases of crack-like defects were considered.

Scheme I. Tension of a slab with a central longitudinal crack (Fig. 1). To determine SIF, we use dependence [18]:

$$K_I=\frac{1-0.025\left(\frac{a}{t}\right)^2+0.06\left(\frac{a}{t}\right)^4}{\sqrt{\cos\left(\frac{\pi a}{2t}\right)}}\sigma\sqrt{\pi a}. \tag{1}$$

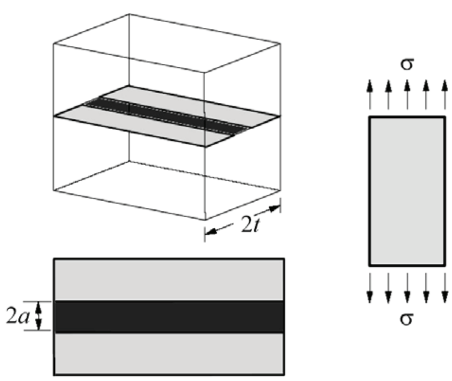

Fig. 1. Loaded slab with a central longitudinal crack: 2t – the width of slab; 2a – the length of slab; σ – applied force

The rate of change in SIF in this case takes the form:

$$\frac{dK_I}{da}=\frac{0.24\frac{a^3}{t^4}-0.05\frac{a}{t^2}}{\sqrt{\cos\left(\frac{\pi a}{2t}\right)}}\sigma\sqrt{\pi a}+\frac{1-0.025\left(\frac{a}{t}\right)^2+0.06\left(\frac{a}{t}\right)^4}{2\sqrt{a}\sqrt{\cos\left(\frac{\pi a}{2t}\right)}}\sigma\sqrt{\pi}+$$

$$+\frac{1-0.025\left(\frac{a}{t}\right)^2+0.06\left(\frac{a}{t}\right)^4}{4t\sqrt{\cos\left(\frac{\pi a}{2t}\right)}}\sigma\pi\sqrt{\pi a}\tan\left(\frac{\pi a}{2t}\right). \tag{2}$$

Scheme II. Tension of a slab with an exterior edge crack (Fig. 2). To determine SIF, we will use ratio [19]:

$$K_I=Y\sigma\sqrt{a}, \tag{3}$$

where

$$Y=1.99-0.41\left(\frac{a}{t}\right)+18.7\left(\frac{a}{t}\right)^2-38.48\left(\frac{a}{t}\right)^3+53,85\left(\frac{a}{t}\right)^4.$$

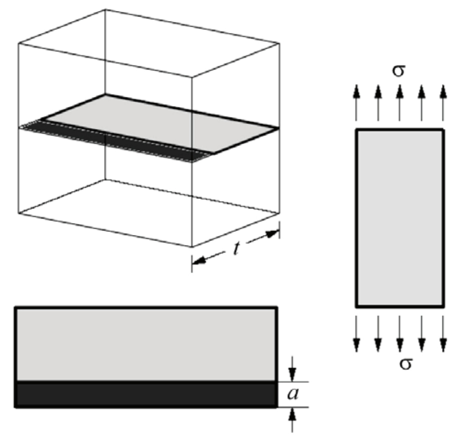

Fig. 2. Loaded slab with external edge crack: t – width of the slab; a – length of the crack; σ – applied force

We calculate rate of change in SIF as

$$\frac{dK_I}{da}=\frac{dY}{da}\sigma\sqrt{a}+\frac{1}{2}Y\sigma\frac{1}{\sqrt{a}}, \tag{4}$$

where

$$\frac{dY}{da}=-0.41\frac{1}{t}+37.4\frac{a}{t^2}-115.44\frac{a^2}{t^3}+215.4\frac{a^3}{t^4}.$$

Scheme III. Tension of the slab with two external edge cracks (Fig. 3). To determine SIF, we use ratio (3) [18], where

$$Y=\frac{1.122-0.561\left(\frac{a}{t}\right)-0.015\left(\frac{a}{t}\right)^2+0.091\left(\frac{a}{t}\right)^3}{\sqrt{1-\frac{a}{t}}}.$$

The rate of change in SIF in this case is calculated by formula (4), where

$$\frac{dY}{da}=\frac{-0.561\frac{1}{t}-0.03\frac{a}{t^2}+0.273\frac{a^2}{t^3}}{\sqrt{1-\frac{a}{t}}}+$$

$$+\frac{1.122-0.561\left(\frac{a}{t}\right)-0.015\left(\frac{a}{t}\right)^2+0.091\left(\frac{a}{t}\right)^3}{2t\left(1-\frac{a}{t}\right)^{\frac{3}{2}}}.$$

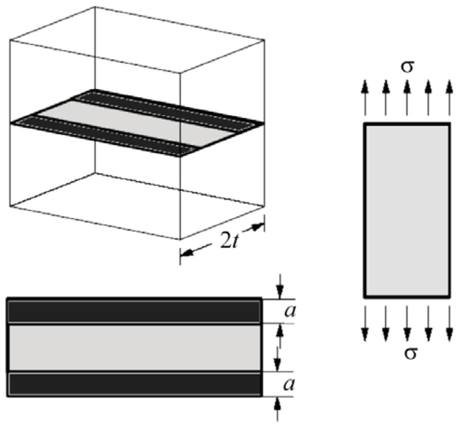

Fig. 3. Loaded slab with two external edge cracks: 2t — width of the slab; a — length of crack; σ — applied force

Scheme IV. Tension of a slab with a half-elliptical edge crack (Fig. 4). To determine SIF, we use ratio [20]

$$K_I = \sigma F \sqrt{\pi a}, \tag{5}$$

where

$$F = \frac{M_1 + M_2\left(\frac{a}{t}\right)^2 + M_3\left(\frac{a}{t}\right)^4}{\sqrt{Q}} F_w; \quad F_w = \sqrt{\frac{1}{\cos\left(\frac{\pi c}{2W}\sqrt{\frac{a}{t}}\right)}};$$

$$Q = 1 + 1.464\left(\frac{a}{c}\right)^{1.65};$$

$$M_1 = 1.13 - 0.09\left(\frac{a}{c}\right); \quad M_2 = -0.54 + \frac{0.89}{0.2 + \frac{a}{c}};$$

$$M_3 = 0.5 - \frac{1}{0.65 + \frac{a}{c}} + 14\left(1 - \frac{a}{c}\right)^{24}; \quad K_{Ia} = K_0;$$

$$K_{Ic} = K_0\left(1.1 + 0.35\left(\frac{a}{t}\right)^2\right)\sqrt{\frac{a}{c}}.$$

The rate of change is SIF in this case is calculated as follows:

$$\frac{dK_I}{da} = \sigma \frac{dF}{da}\sqrt{\pi a} + \frac{1}{2}\sigma F \sqrt{\frac{\pi}{a}}, \tag{6}$$

where

$$\frac{dF}{da} = \frac{\frac{dM_1}{da} + \frac{dM_2}{da}\left(\frac{a}{t}\right)^2 + 2M_2\frac{a}{t^2} + \frac{dM_3}{da}\left(\frac{a}{t}\right)^4 + 4M_3\frac{a^3}{t^4}}{\sqrt{Q}} F_w -$$

$$- \frac{\frac{1}{2}\left[M_1 + M_2\left(\frac{a}{t}\right)^2 + M_3\left(\frac{a}{t}\right)^4\right]\frac{dQ}{da}}{Q\sqrt{Q}} F_w +$$

$$+ \frac{M_1 + M_2\left(\frac{a}{t}\right)^2 + M_3\left(\frac{a}{t}\right)^4}{\sqrt{Q}} \frac{dF_w}{da};$$

$$\frac{dF_w}{da} = \pi c \sin\left(\frac{\pi c}{2W}\sqrt{\frac{a}{t}}\right)\left[8Wt\cos\left(\frac{\pi c}{2W}\sqrt{\frac{a}{t}}\right)^2 \sqrt{\frac{a}{t}}\sqrt{\frac{1}{\cos\left(\frac{\pi c}{2W}\sqrt{\frac{a}{t}}\right)}}\right]^{-1};$$

$$\frac{dQ}{da} = 2.4156\frac{a^{0.65}}{c^{1.65}};$$

$$\frac{dM_1}{da} = -0.09\frac{1}{c}; \quad \frac{dM_2}{da} = -\frac{0.89}{c\left(0.2 + \frac{a}{c}\right)^2};$$

$$\frac{dM_3}{da} = \frac{1}{c\left(0.65 + \frac{a}{c}\right)^2} - 336\frac{1}{c}\left(1 - \frac{a}{c}\right)^{23}.$$

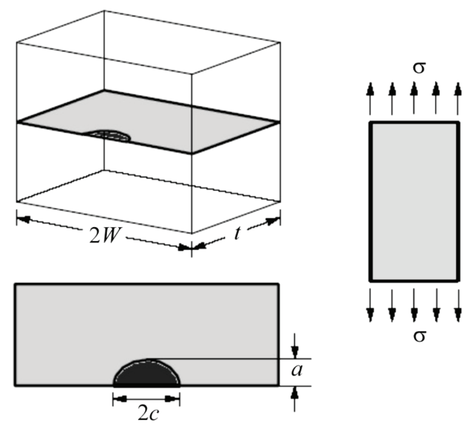

Fig. 4. Loaded slab with half-elliptical edge crack: 2W — length of the plate; t — its width; a — length of crack; 2c — its width; σ — applied force

Scheme V. Tension of a plate with quarter-elliptical corner crack; (Fig. 5). To determine SIF, we use ratio [20]:

$$K_{Ia} = K_\varphi(\varphi = \pi/2), \tag{7}$$

where

$$K_\varphi = \sigma F\sqrt{\frac{\pi a}{Q}}; \quad F = \left[M_1 + M_2\left(\frac{a}{t}\right)^2 + M_3\left(\frac{a}{t}\right)^4\right] g_1 g_2 f_\varphi;$$

$$f_\varphi = \left[\left(\frac{a}{c}\right)^2 \cos^2\varphi + \sin^2\varphi\right]^{\frac{1}{4}};$$

$$M_1 = 1.08 - 0.03\frac{a}{c}; \quad M_2 = -0.44 + \frac{1.06}{0.3 + a/c};$$

$$M_3 = -0.5 + 0.25\frac{a}{c} + 14.8\left(1 - \frac{a}{c}\right)^{15}; \quad Q = 1 + 1.464\left(\frac{a}{c}\right)^{1.65};$$

$$g_1 = 1 + \left[0.08 + 0.4\left(\frac{a}{t}\right)^2\right](1 - \sin\varphi)^3;$$

$$g_2 = 1 + \left[0.08 + 0.15\left(\frac{a}{t}\right)^2\right](1 - \cos\varphi)^3.$$

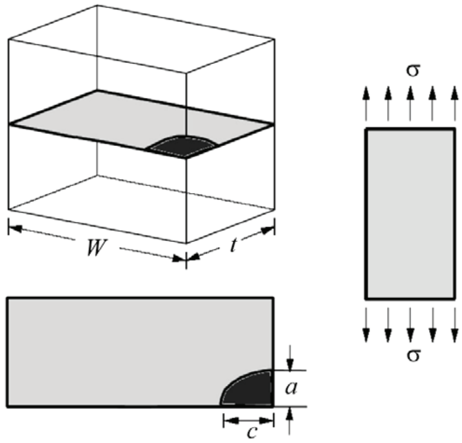

Fig. 5. Loaded slab with quarter-elliptical angular crack: W – length of the slab; t – its width; a – length of the crack; c – its width; σ – applied forces

Rate of change in SIF is calculated by the formula

$$\frac{dK_{Ia}}{da}=\frac{dK_{\varphi}}{da}(\varphi=\pi/2), \tag{8}$$

where

$$\frac{dK_{\varphi}}{da}=\sigma\cdot\sqrt{\pi}\cdot\frac{Q\cdot\left(2\frac{dF}{da}\cdot a+F\right)-\frac{dQ}{da}\cdot F\cdot a}{2Q\cdot\sqrt{a\cdot Q}},$$

in this case,

$$\frac{dF}{da}=\left[\begin{array}{l}\frac{dM_1}{da}+\frac{dM_2}{da}\left(\frac{a}{t}\right)^2+\frac{2}{t}M_2\left(\frac{a}{t}\right)+\\+\frac{dM_3}{da}\left(\frac{a}{t}\right)^4+\frac{4}{t}M_3\left(\frac{a}{t}\right)^3\end{array}\right]g_1g_2f_{\varphi}+$$

$$+\left[M_1+M_2\left(\frac{a}{t}\right)^2+M_3\left(\frac{a}{t}\right)^4\right]\frac{dg_1}{da}g_2f_{\varphi}+$$

$$+\left[M_1+M_2\left(\frac{a}{t}\right)^2+M_3\left(\frac{a}{t}\right)^4\right]g_1\frac{dg_2}{da}f_{\varphi}+$$

$$+\left[M_1+M_2\left(\frac{a}{t}\right)^2+M_3\left(\frac{a}{t}\right)^4\right]g_1g_2\frac{df_{\varphi}}{da};$$

$$\frac{df_{\varphi}}{da}=\frac{a\cos^2\varphi}{2c^2\left[\left(\frac{a}{c}\right)^2\cos^2\varphi+\sin^2\varphi\right]^{\frac{3}{4}}};$$

$$\frac{dM_1}{da}=-\frac{0.03}{c};\quad \frac{dM_2}{da}=-\frac{1.06}{c\left(0.3+\frac{a}{c}\right)^2};$$

$$\frac{dM_3}{da}=\frac{0.25}{c}-\frac{222}{c}\left(1-\frac{a}{c}\right)^{14};\quad \frac{dQ}{da}=2.4156\frac{1}{c}\left(\frac{a}{c}\right)^{0.65};$$

$$\frac{dg_1}{da}=-\frac{0.8a(\sin\varphi-1)^3}{t^2};\quad \frac{dg_2}{da}=\frac{0.3a(1-\cos\varphi)^3}{t^2}.$$

Scheme VI. Tension of a slab with internal elliptical central crack (Fig. 6). To determine SIF, we use ratio [20]:

$$K_{Ia}=FF_w\sigma\sqrt{\pi a}, \tag{9}$$

in this case,

$$F=\frac{M_1+M_2\left(\frac{a}{t}\right)^2+M_3\left(\frac{a}{t}\right)^4}{\sqrt{Q}};\quad F_w=\sqrt{\frac{1}{\cos\left(\frac{\pi c}{2W}\sqrt{\frac{a}{t}}\right)}},$$

where

$$Q=1+1.464\left(\frac{a}{c}\right)^{1.65};$$

$$M_1=1;\quad M_2=\frac{0.05}{0.11+\left(\frac{a}{c}\right)^{\frac{3}{2}}};\quad M_3=\frac{0.29}{0.23+\left(\frac{a}{c}\right)^{\frac{3}{2}}}.$$

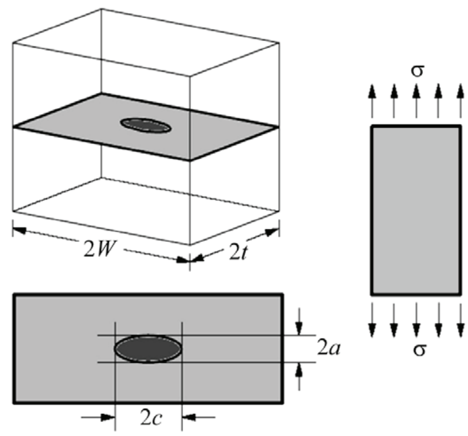

Fig. 6. Loaded slab with internal elliptical central crack: 2W – length of the slab; 2t – its width; 2a – length of the crack; 2c – its width; σ – applied force

The rate of changes in SIF is calculated as

$$\frac{dK_{Ia}}{da}=\frac{dF}{da}F_w\sigma\sqrt{\pi a}+F\frac{dF_w}{da}\sigma\sqrt{\pi a}+\frac{1}{2}FF_w\sigma\sqrt{\frac{\pi}{a}}, \tag{10}$$

where

$$\frac{dF}{da}=\frac{\left[\frac{dM_1}{da}+\frac{dM_2}{da}\left(\frac{a}{t}\right)^2+2M_2\frac{a}{t^2}+\frac{dM_3}{da}\left(\frac{a}{t}\right)^4+4M_3\frac{a^3}{t^4}\right]Q}{Q\sqrt{Q}}-$$

$$-\frac{\frac{1}{2}\left[M_1+M_2\left(\frac{a}{t}\right)^2+M_3\left(\frac{a}{t}\right)^4\right]\frac{dQ}{da}}{Q\sqrt{Q}};$$

$$\frac{dF_w}{da}=\pi c\sin\left(\frac{\pi c\sqrt{\frac{a}{t}}}{2W}\right)\left[8Wt\cos\left(\frac{\pi c\sqrt{\frac{a}{t}}}{2W}\right)^2\sqrt{\frac{a}{t}}\sqrt{\frac{1}{\cos\left(\frac{\pi c\sqrt{\frac{a}{t}}}{2W}\right)}}\right]^{-1},$$

in this case,

$$\frac{dQ}{da}=2.4156\frac{a^{0.65}}{c^{1.65}};\quad \frac{dM_1}{da}=0;$$

$$\frac{dM_2}{da}=-\frac{0.075\sqrt{a}}{c^{\frac{3}{2}}\left(0.11+\left(\frac{a}{c}\right)^{\frac{3}{2}}\right)^2};\quad \frac{dM_3}{da}=-\frac{0.435\sqrt{a}}{c^{\frac{3}{2}}\left(0.23+\left(\frac{a}{c}\right)^{\frac{3}{2}}\right)^2}.$$

The expressions of derivatives with respect to typical dimensions of a crack a will be used for building dependences of the specified derivatives of dimensionless magnitudes a/t taking into account the ratio

$$(\sqrt{t}/\sigma)\cdot(dK_I/da)=F(a/t), \tag{11}$$

where t is the dimension of a structural element in direction of crack propagation; σ is the applied force, a is the depth of the crack, which is a variable magnitude y compared to dimension t, which is constant. For further consideration of the results of work we will introduce variable parameter $(a/t)^*$, which characterizes effective dimension of defect.

We will note, that characteristic feature of studied dependences is that in their graphs a certain value of parameter $(a/t)^*$ is well manifested, starting with which there is an abrupt increase in stress intensity factor K_I. This value of $(a/t)^*$ is accepted for characteristic evaluation of strength and reliability of elements of structures with crack-like defects.

5. Results of research into criterial depths of crack-like defects of profile structures of the boom of stack discharge conveyor

For the determination of characteristic values of length of the crack in the examined elements of structures, we will use the previously created experimental base [5] and analytical ratio in the form of the Paris power law type [21]:

$$da/dN=C\cdot(\Delta K)^n, \tag{12}$$

where C and n are the constants that characterize the system «material – environment». The following constants, as well as the boundary values of SIF for different systems «material – environment» are given in Table 1.

All experimental points for each specific system «material – environment» were plotted on one coordinate plane with the use of methods, described in paper [2], for determining criterial depths of crack-like defects. In this way we obtained 4 arrays of points for describing the process of cracks propagation in operated and non-operated material without taking account the influence of corrosive factors. Based on these results, 4 equations of type (12) were constructed, by which the criterial values of SIF were defined (Table 1).

These values form the basis for determining the critical values of SIF ΔK_{fc} for each examined system «material – environment», which, in their turn, were used for finding critical lengths of crack-like defects in profile elements of structures using the schemes, considered above.

Table 1

Power laws of the rate of crack propagation for systems «material – environment» and criterial values of SIF

System «material – environment»	Paris power law for correspondent system	Values ΔK_{fc}, МПа$\sqrt{м}$
New – Air	$da/dN=3.96\cdot10^{-11}(\Delta K)^{2.06}$	44.834
Operated – Air	$da/dN=7.3\cdot10^{-11}(\Delta K)^{1.92}$	43.022
New – Corrosion	$da/dN=1.7\cdot10^{-21}(\Delta K)^{9.43}$	28.853
Operated – Corrosion	$da/dN=2.06\cdot10^{-10}(\Delta K)^{2.21}$	22.089

Along with these values, obtained by processing experimental data, the value of a* corresponding to characteristic magnitude $(a/t)^*$ was calculated using procedure [22], based on the use of analytical relations for derivatives of SIF. We will note that in the course of studying processes of crack-like defects propagation in the straightedge of the boom of stack discharge conveyor that has dimensions of $45\times45\times5$ mm we took into account that the most vulnerable parameter to crack development is the wall thickness of the straightedge (5 mm), so all results of calculations are shown for the case when a crack propagates perpendicularly to the longitudinal axis of the straightedge along the cross-section cut of a shelf.

For each case we found characteristic values of $(a/t)^*$, according to which we determined the calculated depth of crack a*, which with large probability may be considered to precede the destruction of a structure, and therefore, along with the value of a_{fc}, it may be used as criterial depth of a crack during planned or unplanned monitoring the operated structure.

Fig. 7 represents the graphs of determining a^* for all model cases under consideration. Thus, according to the algorithm, proposed in [22], we draw two tangent lines from the derived SIF on the graph of the function. On each graph there is a certain value of defect dimension $(a/t)^*$, starting from which the rate of change in SIF increases dramatically. The value of parameter $(a/t)^*$ was defined by the following numerical procedure. Current values of $dK_I/da=F(a/t)$ were computed at the step $a/t=0{,}01$ F (t/a). In this case, three characteristic points, with arguments $(a/t)_1$, $(a/t)_2$, $(a/t)_3$ were established. After this, tangent lines to the graphic dependence were drawn in the points with arguments $0.5[(a/t)_1+(a/t)_2]$ and $0.5[(a/t)_2+(a/t)_3]$. By the coordinates of intersection points of these tangent lines we will find the characteristic value of the ratio $(a/t)^*$ (Fig. 7).

We may argue that characteristic value $(a/t)^*$ of 0.35760 is dangerous for scheme I; 0.38497 – for scheme II; 0.48637 – for scheme III. Regarding schemes IV–VI, by the results, presented in article [3], we can assert that the most unfavorable for operations are the following forms of crack-like defects: for scheme IV – $a/c=0.15$; for schemes V and VI – $a/c=0.10$. For the obtained values of dimensionless parameters $(a/t)^*$ and a/c, it is necessary to carry out monitoring of technical condition of profile structures for obtaining the values of dimensionless parameters $(a/t)^*$ and a/c.

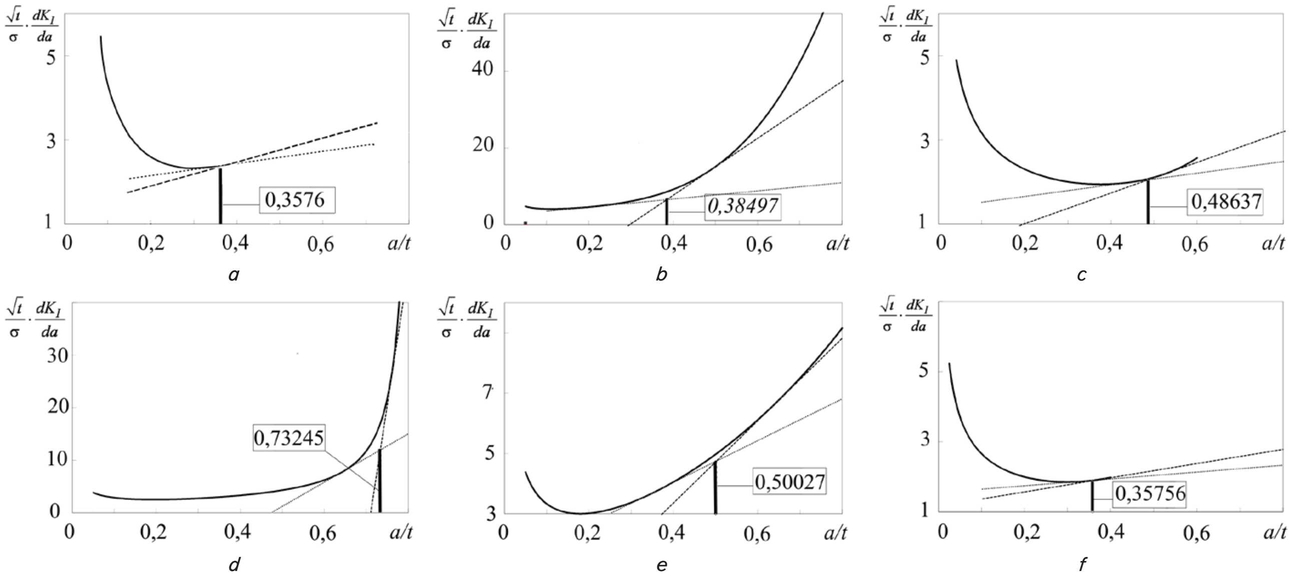

Fig. 7. Determining characteristic values (a/t)* for the cases of propagation of crack-like defects at the tension of slab: *a* — with a central longitudinal crack; *b* — with external edge crack; *c* — with two external edge cracks; *d* — with a half-elliptical edge crack; *e* — with a quarter-elliptical angular crack; *f* — with an internal elliptical central crack

6. Discussion of the results of research into improving the monitoring of profile structures

The next step of diagnosis of technical condition of the profile structure will be obtaining the values of critical crack depth for the studied cases and comparing them with the found characteristic values. The lesser of these two values for engineering calculations may be considered preceding the potential danger of operating the structure, and therefore proves the need for intensified control over the given object.

Table 2 presents the calculated values of a_{fc}, obtained with the use of ratios (1), (3), (5), (7), (9) and power laws (Table 1) for each of the examined system «material – environment». It should be noted that the value of a* depends on geometry of the structural element, method of loading, shape, and location of a crack-like defect, and the value of a_{fc} depends on the same factors and also on material and its testing conditions. Therefore, during consideration of specific structural elements, made of specified material and operated under certain conditions (that is, for a particular system «material – environment»), the value of parameter a* may formally be lower or higher than the critical dimension of defect a_{fc}.

From the results, presented in Table 2, it is obvious that corrosive environment significantly affects the dimensions of the critical crack depth, however, the intensified control over the object of research must be started at achieving a* in all cases, except for IV, and this is especially true for the system «metal – corrosive environment». As we can see from the obtained results, only in case IV it is advisable to do with a classic approach for monitoring the condition of a constructive element.

It should be noted that every single case of crack propagation requires tracking the process with respect to crack depth, because having compared some values of parameter a* with correspondent values of this parameter for the most dangerous system «operated material – corrosive environment», it is possible to conclude that there is no strictly defined dependence of the level of danger of operating the structures on the specified parameter (Fig. 8), therefore, to substantiate engineering recommendations, it is necessary to monitor each system and every defect only according to the scheme which is characteristic for it.

Table 2

Characteristic and criterial values of crack depth in the considered systems «material — environment» for the straightedge 45×45×5 mm of frame of stack discharge conveyor with defects of different shapes

System «material-environment»	a*, mm	a_{fc}, mm
Case I		
New – Air	1.79	2.455
Operated – Air		2.455
New – Corrosion		2.4
Operated – Corrosion		2.34
Case II		
New – Air	1.92	2.9
Operated – Air		2.85
New – Corrosion		2.4
Operated – Corrosion		2.07
Case III		
New – Air	2.43	2.435
Operated – Air		2.43
New – Corrosion		2.35
Operated – Corrosion		2.24
Case IV		
New – Air	3.66	3.35
Operated – Air		3.32
New – Corrosion		2.93
Operated – Corrosion		2.59
Case V		
New – Air	2.50	3.62
Operated – Air		3.56
New – Corrosion		2.94
Operated – Corrosion		2.52
Case VI		
New – Air	1.79	2.15
Operated – Air		2.135
New – Corrosion		1.995
Operated – Corrosion		1.865

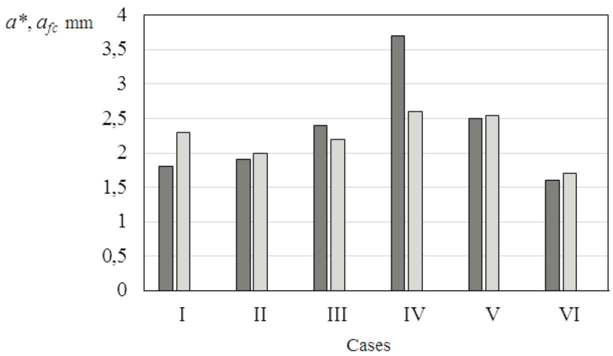

Fig. 8. Comparison of characteristic values of a (on gray background) and criterial values of a_{fc} for system «operated material – corrosive environment»

7. Conclusions

1. Based on the results of experimental research, we defined the criterial values of SIF for steel of art. 3, of which the straightedge of the boom of the stack discharge conveyor 45×45×5 mm was manufactured. By the analytical ratios of SIF, we calculated the criteria of value a* based on research into derivative of SIF, and characteristic values of a_{fc}, which are based on direct research into SIF, the length of crack-like defects that may appear in a profile structure.

2. Engineering recommendations for monitoring this object with crack-like defects of different shapes were substantiated. The values of crack-like defects, at which it is necessary to carry out further monitoring of the technical condition of structural elements of the boom of stack discharge conveyor, were defined.

3. It was found that each case of the crack propagation requires separate research, because the endurance of a structure depends considerably on geometric and physical-mechanical parameters of the system. We confirmed the possibility of assessing the technical state of the elements of the boom of stack discharge conveyor, based on systematic express-analysis of material in corrosive environments, as well as monitoring the depth of crack-like defects.

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THE USE OF CONTACT HEAT GENERATORS OF THE NEW GENERATION FOR HEAT PRODUCTION

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Обґрунтовано необхідність пошуку нових підходів для підвищення енергетичної ефективності та екологічної чистоти тепловиробництва в системах теплопостачання. Розглянуто переваги високоефективних компактних і недорогих контактних теплогенераторів різних типів для теплопостачання великих міст і промислових районів. Запропоновано використання теплогенератора контактного типу нового покоління, що дозволяє вирішити комплекс проблем щодо якісного спалювання палива і теплообміну

Ключові слова: контактний теплогенератор, теплова енергія, теплозабезпечення великих міст і промислових районів, тепловиробництво

Обоснована необходимость поиска новых подходов для повышения энергетической эффективности и экологической чистоты теплопроизводства в системах теплоснабжения. Рассмотрены преимущества высокоэффективных компактных и недорогих контактных теплогенераторов разных типов для теплоснабжения крупных городов и промышленных районов. Предложено использование теплогенератора контактного типа нового поколения, позволяющего решить комплекс проблем по качественному сжиганию топлива и теплообмену

Ключевые слова: контактный теплогенератор, тепловая энергия и теплообеспечение больших городов и промышленных районов, теплопроизводство

1. Introduction

The advantages of the centralized heat supply in large cities and large industrial centers by the indicators of energy effectiveness and the possibilities of attaining high level of ecological safety are well-known [1]. At the same time, the development of decentralized heat-power engineering has gained wide scope and scale over recent decades. And there are objective reasons to this: in the large cities and industrial regions the old centralized systems of heat supply are not only morally and physically obsolete and worn-out, but simultaneously, in this case, they gave rise to ecological problems of atmospheric pollution, they require serious capital expenditures for maintaining their operational mode. In addition, the density of buildings in the cities increases and this further complicates the process of quality heat supply. The process of designing new city blocks for new industrial, social and everyday-activity centers is also complicated.