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DYNAMIC TOUGHNESS OF FRACTURE AND A COLD RESISTANCE OF WELD JOINTS

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Résumé: La méthode proposée consiste à déterminer la valeur limite de la ténacité dynamique K_{IA}^{min} et la vitesse de propagation maximum de fissures fragiles V_{br}^{max} dans un essai standard. On montre la possibilité à partir des valeurs de K_{IC} et V_{br} et de la connaissance de la distribution statistique des indices fractographiques de la surface de fracture fragile. La conclusion est que les critères K_{IA}^{min} et V_{br}^{max} peuvent être efficacement utilisés pour estimer la résistance à froid des joints soudés.

ABSTRACT

The proposed method seeks to determine the limiting value of the dynamic fracture toughness K_{IA}^{min} and maximum rate of the brittle crack propagation V_{br}^{max} in standard specimen testing. There is shown the possibility to estimate them using K_{IC} and V_{br} values and character knowledge of statistical distribution of the fractographical indices of the brittle fracture surface. The conclusion is that the K_{IA}^{min} and V_{br}^{max} criteria can be effectively used in estimation of the weld joint cold resistance.

THE CONTENT OF THE WORK

The main assessment criterion of steels cold resistance and their weld joints in dynamic loading is specific fracture energy a_C^A of a specimen with a crack (according to [1] and All-Union Standard 9454-78) and also K_{IC}^A and K_{IC}^B ; using the concentrators of U and V type the criteria are KCU, KCV, KCU_{0.7}, KCV_{0.7}, and also KCU_p and KCV_p. Lowering the specimen test temperature at the same values of stored energy during a shock loading results in decrease of material resistance to the brittle crack propagation and hence leads to increase of its propagation rate. The stress intensity factors K_{IC}^A and K_{IC}^B are the criteria of fracture toughness that determine the cracking resistance of the material at the moment the crack is starting to move during a dynamic (shock) loading of a specimen, and therefore they cannot be used in analyzing the limit values of dynamic fracture toughness when a brittle crack is propagating in materials.

In this paper there is considered a method to determine the limit values of dynamic fracture toughness K_{IA}^p and V_{br}^p using the strain diagram and the data of the fractographic indices of the specimen brittle fracture surface. The application of K_{IA}^p and V_{br}^p to estimation of the weld joints cold resistance for metalwork units and Northern machinery is substantiated by the authors.

Within the framework of the linear fracture mechanics model for a crack with normal breaking-off the authors [2] of this article have work-

ed out the method to determine the critical factor of stress intensity K_{IA} by relation to crack propagation rate and test temperature. The method is based on the estimation of the work expended on a brittle crack propagation using an oscillography procedure to record a fracture process in terms of coordinates "force-time" (fig.1) and can be applied to the shock loading of any type if a fracture process oscillography is available.

Fig.1. The typical oscillogram of the specimen fracture process: Ω_{0r} , Ω_p - areas corresponding to the works of crack origination and propagation; t_1, t_2 (Ω_{br}) - area corresponding to the energy (A_{br}) expended on the brittle crack propagation.

A rapid decrease of a fracture load at sections 1 and 2 (fig.1) is caused by the brittle crack movement; and the area underneath the curve at this section characterizes the work A_{br} expended on the crack progress and can be estimated by the formula [3]:

$$A_{br} = \left\{ V_0 - \frac{L}{l_{red}} \cdot \frac{q}{F} \left[\int_0^{t_1} P(t) dt - \frac{1}{2} \int_{t_1}^{t_2} P(t) dt \right] \right\} \int_{t_1}^{t_2} P(t) dt \quad (1)$$

where L - distance from the pendulum axis to collision point; l_{red} - reduced pendulum length; q - gravity; F - necessary force for horizontal pendulum equilibration that is applied to the pendulum face at L -distance from its axis; t_1 - start of a brittle crack movement; t_2 - a brittle crack stop. Complexity of A_{br} determination consists in reaching the high accuracy in estimating the oscillogram area Ω_{br} (fig.1) corresponding to the brittle crack propagation. Computer science application is the most effective in this case.

The K_{IA} value is determined by the relation $K_{IA}^2 = EG_{IA} / (1-\mu^2)$ [2]; where E - elastic modulus; μ - Poisson factor; G_{IA} - energy release intensity during a crack propagation of a break-off type that is equal to the ultimate work necessary to form a brittle crack of a unit area i.e. $G_{IA} = A_{br} / F_{br}$. The brittle crack area, F_{br} , with clear boundaries for low-alloyed steels and their weld joints, and the brittle crack length, l_{br} , are measured after the specimen destruction. The mean rate ($\bar{v}_{br}$) of the brittle crack propagation can be estimated on the basis of crack propagation time, equal to $t_2 - t_1$, and the length l_{br} [2].

Within the framework of the given model there is established a relation between K_{IA} and $\bar{V}_{br}$. (rate of brittle crack propagation), fig.2. The obtained relationship can be written down as a function $\bar{K}_{IA} = A/\bar{V}_{br}$, where A and B are constants. Consequently, as the propagation rate of a brittle crack increases the dynamic factor of stress intensity decreases. To reach the precise values of A and B one should refine the limit values of K_{IA}^p and V_{br}^p , representing the functions $K_{IA}^p = f_1(l_{br})$ and $V_{br}^p = f_2(l_{br})$.

The energy release intensity during the crack propagation of a break-off type G_{IA} , equal to the ultimate work, that is necessary to form a brittle crack of a unit area, is based on the supposition that A_{br} is equally distributed over the whole fracture surface (F_{br}), i.e. it is assumed that energy intensity of the separate sections of brittle fracture surface is the same. As a result of this assumption the dynamic factor of stress intensity and propagation rate of a brittle crack are averaged values ($\bar{K}_{IA}$ and $\bar{V}_{br}$), i.e. they are constant from the start moment till the stop of the of the brittle crack in the specimen, while the surface of a brittle fracture of the standard specimens are made up of several sections: the sections of starting to move and stop, and of rapid, steady and slow propagation of brittle crack [4] (fig.3).

Fig.2. Dependence of the mean values of critical factors of stress intensity $\bar{K}_{IA}$ during the dynamic propagation of the brittle crack on its movement rate: x, • - steel 20HFMΦ if concentrators are along and across the roll; ■ - steel 20.

The statistical analysis of the fractograms of the brittle fracture surface shows that dimensions (length and area) of the spall facets change towards the crack propagation direction and depend on the state of material brittleness, i.e. the propagation rate of a brittle crack. At the first stage of the crack propagation the spall facets dimensions increase, then they are stabilized and finally they start to decrease gradually. On the basis of this conclusion one can consider the brittle fracture surface made up from different sections (Table).

The increase of spall facets dimensions is caused by material resistance decrease to brittle fracture, and the propagation rate of a brittle crack is proportional to growth of spall facets dimensions. Hence, to determine the limit values of K_{IA}^p and V_{br}^p during a brittle crack propagation one can use $\bar{K}_{IA}$ and $\bar{V}_{br}$ as initial characteristics represented in the form of relationships $\bar{K}_{IA} = f(l_{br})$ and $\bar{V}_{br} = f^1(l_{br})$, and the statistical distribution of the fractographic indices of the section surface of brittle fracture towards brittle crack propagation.

Direction of the crack evolution

Fig.3. The scheme of the crack evolution in specimens.

It's valid to consider that its rate increases till l_{br1} , and is constant between l_{br1} and l_{br2} . Starting from l_{br1} up to l_{br} it decreases and can be written as function $V_{br}^p = f_2(l_{br})$, i.e. the character of function change V_{br}^p corresponds to the character of change of the fracture fractographic indices towards the crack propagation.

From the constancy of energy expended on the brittle fracture of a breaking-off type and on the basis of areas equality restricted by functions $\bar{V}_{br} = f^1(l_{br})$ and $V_{br}^p = f_2(l_{br})$, $\bar{K}_{IA} = f(l_{br})$ and $K_{IA}^p = f_1(l_{br})$ one can obtain the following formulae for $V_{br}^{\max}$ and $K_{IA}^{\min}$:

$$V_{br}^{\max} = \frac{1}{l_{br}^{st}} \left[\bar{V}_{br} \cdot l_{br} - \int_0^{l_{br1}} f_2(l_{br}) dl_{br} - \int_{l_{br2}}^{l_{br}} f_2(l_{br}) dl_{br} \right] \quad (3)$$

$$K_{IA}^{\min} = \frac{1}{l_{br}^{st}} \left[\bar{K}_{IA} l_{br} - \int_0^{l_{br1}} f_1(l_{br}) dl_{br} - \int_{l_{br2}}^{l_{br}} f_1(l_{br}) dl_{br} \right] \quad (4)$$

To estimate $V_{br}^{\max}$ and $K_{IA}^{\min}$ it is necessary to find the integral values in (3,4) by the character of change of fractographic indices of fracture surface, and in particular by the change of statistic distribution of the area or the length of the spall facets towards the brittle crack propagation.

The results of v_{br}^{max} and K_{IA}^{min} estimation show that in load testing of the standard specimens with V-shaped notch made from the low-alloy steel (C - 0,19%, Si - 0,35%, Mn - 1,0%, Cr - 0,3%, Ni - 1,0%, Mo - 0,22%, V - 0,11%, $\sigma_{0,2} = 471$ MPa, $\sigma_b = 647$ MPa, $KCV_{20} = 720$ KJ/m²) at -40°C $v_{br}^{max} = 660,78$ m/s and $K_{IA}^{min} = 35,2$ Mn/m^{3/2}, while $\bar{v}_{br} = 546,1$ m/s and $\bar{K}_{IA} = 44,6$ Mn/s m^{3/2}.

Table 1. Change of fractographic indices of fracture under test temperature lowering.

Fracture indices	Test temperature, °C		
	0°	-20°	-40°
elongation zone, $\bar{l}_b$	13	10	5
mean length of fracture brittle zone, $\bar{l}_{br}$, mm	5,33	6,64	7,45
mean distance Δl from the top of the notch to the section of stable crack propagation, mm	2,7	2,5	2,25
mean length of the section (l_{br}^{st}) brittle crack propagation, mm	1,5	2,0	2,5

The complex analysis of KCU_p , KCV_p - dependences on temperature and the ultimate values of v_{br}^p and K_{IA}^p determined by the P-t or P-V diagrams of the test and by the change of the distribution character of fractographic indices of a brittle fracture surface of the standard specimens makes it possible to analyze the cold resistance of weld joints of metalwork units and Northern machinery. These criteria are the most sensitive to test temperature lowering and change of weld technology under the low climatic temperatures.

The control of the structure and mechanic properties of a weld and the stress-strain state of the weld joints as well by optimization of the technologic processes parameters can result in production of the cold resistance joints and improvement of operational strength of the weld structures designed to operate under the North extreme conditions.

On the basis of developed criteria requirements to cold resistance of steels and their weld joints the standard documents on optimization of the weld technology of steels for classes C 44/29, C 46/33, C 52/40, C 60/45, C 70/60 have been worked out by the authors.

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