BRITTLE DISTRUCTION. DISCUSSION

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ON PREDICTING COLD BRITTLENESS OF STEELS UNDER THE EFFECT OF STRESS CONCENTRATORS

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Structural steels widely used in basic engineering and the building industry belong to the class of materials susceptible to embrittlement at low climatic temperatures, especially in the presence of stress concentrators, which is known as cold brittleness. It is assumed that the cold brittleness is mainly caused by the considerable dependence of the yield limit of iron, or, rather, of its body-centered cubic modification commonly used as a base of structural steels, on temperature. The growth of the yield limit with a decrease in temperature is indeed considerable but, unfortunately, not the only factor affecting cold brittleness. The point is that with the growth of the yield limit the embrittlement characterizes the loaded part of the structure with a stress concentrator, i.e., the material-structure combination, rather than the steel itself. This kind of embrittlement should rather be called structural cold embrittlement of the metal in contrast to the purely physical embrittlement caused by the nature of the material, its structure, and the behavior of the forces of interatomic interaction.

For this reason, the toughness, as a measure of the resistance of the materials to embrittlement, is commonly evaluated in special tests of notched specimens or specimens with a crack. The values of the toughness parameters obtained in such tests (the specific work of fracture $KCV$, the fracture toughness $KIC$, etc.) bear information on the actual level of the parameter under the test temperature only. They are not related with the "margin of toughness" that characterizes the material from the standpoint of the state of the tough-brittle transformation at a temperature of cold brittleness $T_c$ determined by tests in a range limited by the brittleness temperature in correspondence with a chosen criterion. This means that the toughness characteristics accepted in today's engineering do not possess any possibility of prediction and are applicable only for determining the toughness level under the conditions under which the material is tested.

At the same time, an analytical prediction of the temperature of structural cold brittleness, i.e., the temperature $T_c$ at which a material with a given concentrator undergoes fracture at a rated stress below the yield limit $\sigma_y$, presents a purely scientific and a practical interest.

However, this possibility is hard to realize today, not only due to the methodological problems related with the choice of the appropriate toughness characteristic, but also the absence of a clear understanding of the physical nature of the used toughness parameters.

The aim of this work consists in using modern concepts on the physical nature of fracture in steel for choosing a system for estimating the toughness of the metal that would allow us to characterize the tested materials in accordance with the level of their toughness and predict the conditions under which the toughness will be lost, i.e., the conditions of the transformation into a brittle state without resorting to tests of specimens with notches (cracks) in the temperature zone of embrittlement.

It would be logical to begin with analyzing from this standpoint the possibility of traditional standard toughness parameters $KCV$, $KIC$, and $GIC$. It should be noted that if the curves of the temperature dependences of these parameters turn out to be rectilinear or at least monotonic with a decrease in temperature, they would be applicable for solution of the problem. It would be enough to conduct a series of tests with notches in a range limited by the brittleness temperature in correspondence with a chosen criterion. This means that the toughness characteristics accepted in today's engineering do not possess any possibility of prediction and are applicable only for determining the toughness level under the conditions under which the material is tested.

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Beginning with the third number the editorial board has opened this section to meet the decision of a conference devoted to problems of brittle fracture and prevention of emergencies conducted on April 24, 1996 in the Ministry of Science and Engineering Policy of the Russian Federation. The notation in the present paper is suggested by the author.

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ture energy is an integral parameter of strength and ductility of a material and includes realization of the specific features in the region of local ductility near the concentrator. This multifactor phenomenon at the tip of the concentrator with an uninterpreted pattern of microscopic deformation and fracture processes cannot have a simple quantitative expression in terms of such toughness parameters as \( K_{VC} \), \( K_{IC} \), and \( G_{IC} \). Therefore, we cannot hope to solve the problem of predicting the conditions of the loss of toughness on the basis of these characteristics.

However, if we proceed from the physical micromechanism of the initiation of fracture on known elements of the structure of the metal in the process of plastic deformation in the zone of a stress concentrator, we can arrive at a representation of a quantitative measure of the margin of toughness that would reflect integrally and explicitly the effect of the force and deformation factors simultaneously with the parameters of the degree of localization of the stress field near the concentrator \([1 - 3]\).

The suggested method for predicting the cold brittleness of steels \([3]\) is based on the definition of a dimensionless parameter of the margin of toughness \( K_{MT} = K_T / K_T^* \), where \( K_T = R_{ms} / \sigma_{0.2} \) \([4]\) is the toughness coefficient at the test temperature \( (R_{ms} \) is the resistance to microspalling, i.e., the minimum value of the brittle strength of the steel in the temperature range of the tough-brittle transformation for a smooth unnotched specimen \([1, 4]\)), \( K_T^* = j \alpha_n \sigma_z \) is the critical toughness coefficient at the temperature of cold brittleness \( T_c \) of the metal, at which a specimen with a given concentrator breaks under a rated (mean) stress \( \sigma_z^* = \sigma_{0.2}^*, \sigma_{0.2} \) and \( \sigma_{0.2}^* \) are the yield limits of the steel at the operating temperature and at \( T_c \), respectively; \( j \) and \( \alpha_n \) are parameters of the stress concentrator; \( j = \sigma_z / \alpha_n \) \([5]\) is the rigidity of the stress state \( (\sigma_z \) is the principal local stress at the site of fracture, \( \sigma_z \) is the stress intensity); \( \alpha_n \) is the coefficient of concentration of elastic stresses \([6]\); \( n \) is the Hollowmon parameter of strain toughening (in the equation \( \sigma_z = A \varepsilon^n \)). In \([2]\) \( K_T^* \) is calculated using the hypothesis that the rigidity of the stress state at the temperature of cold brittleness is not high, i.e., \( j \approx 1.15 \). This is explained by the fact that at \( T = T_c \) the zone of ductility near the concentrator is narrow and therefore the source of the initiation of fracture is positioned close to the extreme fiber at the tip of the notch, where the metal is in a plain stress state.

Then the critical coefficient of toughness \( K_T^* \) under the condition \( \sigma_z^* = \sigma_{0.2}^* \) is

\[
K_T^* = 1.15 \sigma_{0.2}^*, \tag{1}
\]

and the coefficient of the margin of toughness at the operating temperature is

\[
K_{MT} = \frac{K_T}{1.15 \sigma_{0.2}^*}. \tag{2}
\]

The physical meaning of \( K_{MT} \) is quite simple and clear, namely, it shows what fraction in the total coefficient of toughness of the metal \( K_T \) is "absorbed" by the available concentrator at the operating temperature. If the "absorbed" toughness \( K_T^* \) is equal to \( K_T \) the "metal-concentrator" system is in a brittle state, i.e., the temperature of cold brittleness is attained when \( K_{MT} = 1 \) and \( \sigma_{0.2} = \sigma_{0.2}^* \) (see Fig. 1). At \( T > T_c \) the parameter \( K_{MT} > 1 \) and has the meaning of the coefficient of the margin of toughness with respect to the dangerous toughness level \( K_T^* \) possessed by the metal at the moment of cold brittleness at temperature \( T_c \). It can be seen that the dimensionless parameter \( K_{MT} \) has a meaning close to that of the coefficient of the margin of safety and in this connection can be of interest to a designer as a toughness parameter for designing the brittle strength of an article.

It follows from the definition of \( K_{MT} \) as the \( K_T / K_T^* \) ratio and with allowance for the fact that \( K_T = R_{ms} / \sigma_{0.2} \) and \( K_T^* = R_{ms} / \sigma_{0.2}^* \) (at \( T = T_c \)) that

\[
K_{MT} = \frac{R_{ms} \sigma_{0.2}^*}{\sigma_{0.2} R_{ms} / \sigma_{0.2}} = \frac{\sigma_{0.2}^*}{\sigma_{0.2}}. \tag{3}
\]

This means that the quantity \( K_{MT} \) bears information on how much the yield limit \( \sigma_{0.2} \) of the metal can increase due to the fall of the temperature to the point \( T_c \) relative to \( \sigma_{0.2} \) at the operating temperature \( T \) without the danger of being em-