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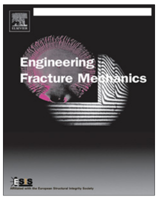

Further improvement of the Prometey model and Unified Curve method part 1. Improvement of the Prometey model

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ABSTRACT

The local approach to brittle fracture is able in principle to transfer fracture data from one type of specimens to another one for different test temperatures and different material conditions. However, in practice the capacity of existing models to perform transferability need to be improved. For this reason the probabilistic model of brittle fracture known as the Prometey model has been modified. The modified model (referred to as the Prometey-M model) has been used for analysis of the transferability of the experimental results on brittle fracture for smooth and notched cylindrical tensile specimens and cracked specimens from Reactor Pressure Vessel (RPV) steel in the initial and embrittled conditions. The Prometey-M model allows the calculation of the brittle fracture probability with the same model parameters for specimens of different types tested at different temperatures. Recommendations have been given for the parameter values of the Prometey-M model that may be taken the same for RPV steels in the initial and embrittled conditions.

1. Introduction

A pioneering work of the French scientists group [1] that is known as the Beremin model gave rise to intense development of local approach to brittle fracture modelling.

Local approach is known to allow the prediction of fracture properties on a macro-scale when using local fracture criterion and local fracture properties. It is assumed that the brittle fracture properties such as fracture toughness (for cracked specimen) or fracture stress (for specimen with a concentrator) may be predicted on the basis of local properties of fracture process in a grain of polycrystalline material. To take into account the stochastic nature of brittle fracture and calculate the brittle fracture probability the local approach uses the Weibull theory for non-homogeneous fields of stress and strain [1].

At first, the main task of local approach was to predict the temperature dependence of fracture toughness $K_{JC}(T)$ for BCC polycrystalline metals on the basis of the test results of tensile notched specimens tested in brittle regime over narrow temperature range [1].

Further development of local approach models was stimulated, to a great extent, by the needs of prediction of the $K_{JC}(T)$ curve for irradiated materials of reactor pressure vessels (RPV) on the basis of small-sized specimen testing. Embrittlement of RPV materials due to neutron irradiation and thermal aging is known to be estimated using data which are obtained from surveillance specimen programs. These surveillance specimens programs include irradiation and testing of small-sized specimens mainly.

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Nomenclature

σ_1	the maximum principal stress
σ_{eq}	the equivalent stress
σ_m	the mean component of stress tensor
$æ = \int d\varepsilon^p_{eq}$	the accumulated plastic strain
$d\varepsilon^p_{eq}$	the equivalent plastic strain increment
σ_Y	the yield stress
σ_{YS}	the temperature-dependent component of the yield stress
σ_{YG}	the temperature-independent component of the yield stress
S_C	the critical stress for microcrack propagation (the critical brittle fracture stress)
S_0	the stress to initiate the nucleus microcrack
$æ_d$	the plastic strain for which the dislocation cell substructure affecting microcrack propagation is formed
σ_d	the critical stress for microcrack nucleation
σ_{nuc}	the effective stress controlling microcrack nucleation
σ_{loc}	the maximum local normal stress at the tip of dislocation pile-up
$m_{T\varepsilon}$	the concentration coefficient for the local stress near the microcrack-nucleating particle
m_T	the temperature-dependent part of the concentration coefficient $m_{T\varepsilon}$
m_ε	the strain-dependent part of the concentration coefficient $m_{T\varepsilon}$
σ_{prop}	the effective stress controlling microcrack initiation and propagation
$\tilde{\sigma}_d$, σ_{d0} and η	the Weibull parameters for the probability of microcrack nucleation in unit cell
$\tilde{\sigma}_C$ and ξ	the Weibull parameters for the probability of microcrack propagation in unit cell
K_{JC}	fracture toughness
T	temperature
P_f	the brittle fracture probability of a unit cell
P_{nuc}	the probability of microcrack nucleation in a unit cell
P_{prop}	the probability of initiation and propagation of the nucleus microcrack in a unit cell
P^{sp}_f	the brittle fracture probability of a specimen
δ	delta function
A_0 and n	the strain hardening coefficients
C_1, C_2, A_d, m_0, b, h, g, λ	the coefficients in equations being material constants independent of temperature

Significant impact in development of local approach was given by the probabilistic model of brittle fracture known as the Prometey model [2–5] that aimed on prediction of the $K_{JC}(T)$ curve for irradiated RPV materials. It may be concluded that the Prometey model allowed one not only to solve this task but also to propose new engineering method for the $K_{JC}(T)$ curve prediction. This method named the Unified Curve method was included in Russian Standards of the JSC “Concern Rosenergoatom”.

An advantage of the Prometey model over other models is explained to a great extent by using a new local cleavage fracture criterion proposed in [6–8]. This criterion takes into account not only stress that controls the start and propagation of cleavage microcracks as in paper [1] but also plastic deformation affecting cleavage microcrack nucleation. It may be noted that the connection of cleavage microcrack nucleation with plastic deformation seems to be quite clear from the physical point of view. Nevertheless, when formulating the local cleavage fracture criterion this connection was explicitly used only near twenty years ago, first of all, in investigations devoted to the Prometey model [6–8] and in the works of Chen [9,10]. Now this consideration is widely used in other models, for example, [11–15].

The introduction of plastic deformation into the local criterion of cleavage fracture allows the $K_{JC}(T)$ curve to be adequately predicted and many factors to be taken into consideration. In particular, the Prometey model allowed one to describe the experimental results such as the nonmonotonic effect of plastic prestrain on K_{JC} [16], the warm pre-stressing effect [17], the shallow crack effect on K_{JC} [4,18], and the ductile tearing effect on $K_{JC}(T)$ curve [19]. Radiation embrittlement by various mechanisms has been also modeled [4,5,16].

At the same time, in spite of considerable advancement of the local approach [1,2–5,20], there are still two principal problems in its application. One of them may be designated as the transferability problem or, in other worlds, as the consistency of data for specimens of different type (precracked specimens, notched cylindrical specimens and smooth cylindrical specimens). This problem is connected with a possibility of the prediction of brittle fracture for specimens of different types with the same parameters of a model. Two other tasks may be also attributed to the transferability problem. They are the prediction of fracture characteristics for a given material at test temperatures different from test temperature of the model parameter calibration, and the prediction of fracture characteristics for various conditions of a material (initial, irradiated, aged, etc.).

The transferability problem seems to be caused by inaccurate or ungrounded dependences used for internal model parameters in one or other model. Let us give some examples.

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