THE KEY PROBLEMS OF LOCAL APPROACH TO CLEAVAGE FRACTURE

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The theoretical basis of Local approach to cleavage fracture of metal and alloys are given. Three main problems of Local approach to fracture are considered, namely: (i) intensity of micro-crack nucleation within "process zone" and its influence on fracture probability; (ii) theoretical and experimental assessments of the value of threshold stress; (iii) "multi-barrier" effect at micro-crack growth in polycrystalline metal.

Introduction

The Local approach (LA) to fracture has been considerably developed over the past two decades, not only to provide a better understanding of the fracture behaviour of materials, in particular the failure micromechanisms, but also to deal with loading conditions which cannot easily be handled with the conventional global fracture mechanics. However, recent findings have demonstrated limitation of both the predictive capabilities and fundamental assumptions of conventional versions of LA to fracture. The main reason of the problems lies in empirical nature of existing versions of LA to cleavage fracture because all of them are based on empirical Weibull distribution which was obtained for very brittle materials, such as ceramics, so, it can't account for specific features of cleavage fracture of metal. This appears, specifically, in the fact that Weibull distribution parameters, m and σ_u, aren't material's constants but depend on the temperature, notch radius and plastic strain value.

Multi-scale version of LA was developed in [1,3]. Unlike the conventional one, this version doesn't use empirical Weibull distribution. Fracture probability is estimated by the analysis of the crack nuclei (CN) formation and unstable propagation in polycrystalline aggregate. In this approach a hierarchy of structural levels of stresses acting on the CN (macro-stresses and stochastic micro- and submicro-stresses) is accounted. The crack growth is considered as instability of it nucleus inside of the grain with further overcoming of boundaries of randomly oriented grains by grain-size crack.

This report **is aimed** at employment of such multi-scale version of LA as the theoretical basis of analysis of three key problems of LA to cleavage fracture, namely: (*i*) intensity of microcrack nucleation and its influence on fracture probability; (*ii*) theoretical and experimental assessment of the value of threshold stress; (*iii*) stochastic analysis of "multi-barrier" effect at microcrack growth in polycrystalline metal

Crack nuclei formation

Specific feature of cleavage fracture of metals and alloys is that: (*i*) CN are formed as a result of plastic flow; (*ii*) only "fresh" CN, which have became unstable at the moment of nucleation, may be the cause of a global fracture [4, 5]. The latter isn't accounted in conventional models of LA. They assumed that microcracks remain "active" over the entire loading history. It is, specifically, one of the reasons for the dependence of Weibull parameters on temperature and strain rate. Therefore, only number of cracks arising at given certain value of plastic strain should be accounted. In other words, one should know the intensity of CN generation in a volume unit ρ. Within the framework of the multi-scale model it is shown that ρ depends nonmonotonically on the plastic strain value.

Threshold stress

Conventional version of LA, uses, as a rule, two-parameter Weibull distribution, i.e. the value threshold stress σ_{th} is assumed to be zero. For steels, the value of σ_{th} is sufficiently great and may reach $\sigma_{th} = (0{,}4-0{,}6)\sigma_f$, where σ_f is local fracture stress, so, neglect of σ_{th} gives rise to significant (several times) error in estimation of Weibull modulus *m*, As a result, certain attempts were made in some works to estimate σ_{th} using the value of yield stress σ_Y. However, this contradicts to physical essence of threshold stress of cleavage fracture. From the multi-scale point of view, the difference between the critical value of minimal stress of microcrack instability, $\xi_c^{\mathbf{min}}$, and the value of threshold stress, σ_{th}, is predetermined by the value of stress fluctuations:

$$\sigma_{th} = \xi_c^{\mathbf{min}} / (1 + t I_{\xi_{11}}) \qquad (1)$$

where $I_{\xi_{11}}$ is the coefficient of variation of micro-stresses ($I_{\xi_{11}} \approx 0{,}13$); t is the realization probability tolerance ($t \approx 3$); $\xi_c^{\min}$ is specified by the grain sizes in "tail" region of density distribution [2].

Simulation findings have enabled to express the value of σ_{th} via *macroscopic* stress R_{MC}:

$$\sigma_{th} = \alpha R_{MC} \qquad (2)$$

where α is coefficient (for structural steels $\alpha \approx 0{,}8 - 0{,}9$); R_{MC} is brittle strength of metal. It value is determined as the minimum fracture stress over the "ductile-to-brittle transition" temperature range. If for steel this range lies below the temperature of liquid nitrogen, so the value of R_{MC} may be determined by the results of tests of notched cylindrical specimens with notch radius 2 mm.

"Multi-barriers" effect

Ascertainment of critical event of microcrack growth, which governs possibility of global fracture, is one of the urgent and unsolved problems. Within the framework of multi-scale model, mechanism of microcrack in non-homogeneous medium, which consists of *randomly* oriented grains separated by boundaries as energy barriers is offered. Stochastic nature of micro-stresses acting inside of the grain is accounted. Computer simulation findings have shown that for typical structural steels the average value of macro-stresses, at which the CN become unstable, exceeds critical level required for overcoming of grain boundaries. On the whole, it is exhibited that multi-scale models of fracture are theoretical basis for the further improvement of conventional version of LA. Moreover, this gives new field of application of LA related to prediction of the influence of metallurgical factors on the shape of temperature dependence of fracture toughness, scatter limits of K_{JC}, scale effect value, etc.

References

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