ON LOCALIZATION OF PLASTIC WORK AT VOIDS AND INCLUSIONS IN DUCTILE FRACTURE

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SUMMARY

Metallographical studies have revealed that the features of ductility of two-phase alloys (temperatures below 50% melting) which consist of a matrix subdivided by grain boundaries, and of hard inclusions, include: (1) formation and growth of voids around inclusions and/or at grain boundaries in slip bands; and (2) formation of intense shear bands between inclusions. The two processes are strongly coupled. Holes nucleate around inclusions, in order to relieve stress, but they are blunted as a result of intense local plastic flow of the matrix. The growth of holes is initially a stable process, but at a certain stage it may destabilize, resulting in a quick coalescence of voids. It is believed that the ductility is influenced by the shape, size, and distribution of the inclusions, by the three-dimensionality of the stress-state, and by the temperature.

To better understand and quantify this phenomenon, a systematic model study has been initiated by the authors. The considered models include hard inclusions, a matrix which can undergo large plastic strains, and grain boundaries which are regarded as inextensible but very flexible. Attention is focused on the mechanism of generation of voids at inclusions, their growth, and in particular, the localization of intense plastic work around voids and inclusions within the metallic matrix of the corresponding alloy. In certain loading regimes (e.g. those pertaining to low cycle fatigue) the intense localized plastic work results in localized temperature rises which in turn enhance the plastic flow. In the model, this phenomenon is accounted for by allowing the yield limit and the hardening parameter in the constitutive relation for the matrix to be a decreasing function of temperature: actual experimental data are used in the quantitative illustrative examples, where a J_2 work-hardening yield criterion is employed. The local temperature increase is calculated from the plastic work. Results are obtained for two-dimensional models, i.e. plane strain cases. Numerical calculations are made for "unit cells" which are supposed to represent "magnified" continuum particles. Since in most continuum theories the deformation is regarded to be "locally homogeneous", it is reasonable to characterize the *macroscopic* material inelasticity by intense inhomogeneity of *micro*-deformations. The locally homogeneous deformation implies that the unit cell is subjected at its boundary to uniform displacements. Calculations are performed for this model. It is shown that the formation, the growth, and the coalescence of voids, and the formation and growth of slip bands, are all very highly coupled phenomena. The role of the localization of plastic work in constitutive relations for ductile fracture in low cycle fatigue is explored.

Since large plastic deformations are essentially incompressible, a numerical formulation is developed, which accounts for this directly. Furthermore, an efficient iterative scheme is used, which allows relatively large incremental loading steps with good accuracies.