Micromechanical simulation of brittle and ductile fracture processes in metals to predict their fracture toughness

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ABSTRACT

The paper summarizes micromechanical modelling techniques to simulate the actual failure processes occurring at a crack tip in metallic materials. The aim of such simulations is to establish a relationship between microstructural properties of the material and its macroscopic crack growth resistance curves. For this purpose, a small scale yielding boundary layer concept is used, i.e. an increasing K-factor field is imposed as external load. By means of extensive finite element models, the three-dimensional microstructural details of the fracture process zone are discretized and analysed. Arrays of spherical voids or rigid inclusions are arranged around the crack tip to simulate ductile failure. In the ligaments between the forming voids and along the interface to the inclusions, cohesive elements are placed, which allow to capture cleavage. The deformation behavior of the material in-side the process zone is treated by J2-plasticity, whereas far away damage is included by the Gurson-Tvergaard-Needleman model.

This modelling strategy is applied to nodular cast iron (NCI) [1, 2] and ferritic steel [3] in the brittle, ductile and brittle-ductile transition region. The microstructure of NCI is characterized by spherical graphite particles of about 10 vol%, which can be simulated as voids [1]. In steel, carbides are represented by initial inclusions. When simulating ductile behavior, the plastic collapse between intervoid ligaments in front of the crack was identified as the dominating mechanism. With decreasing temperature, ferritic materials show a transition to brittle fracture. This is modelled by increasing the yield stress, whereas the cohesive strength is assumed to be temperature independent. With increasing ratio between yield stress and cohesive strength, the brittle failure of the cohesive elements becomes the dominating effect. Thus, a smooth transition from dimple fracture to cleavage can be adjusted in the simulations.

The simulation results are compared with experimental crack growth resistance curves from literature. Both for NCI and ferritic steel a good quantitative agreement of the J-Δa curves in the whole temperature range could be obtained with a minimum number of constitutive parameters. Moreover, the influence of microstructural parameters could be well predicted.

REFERENCES

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