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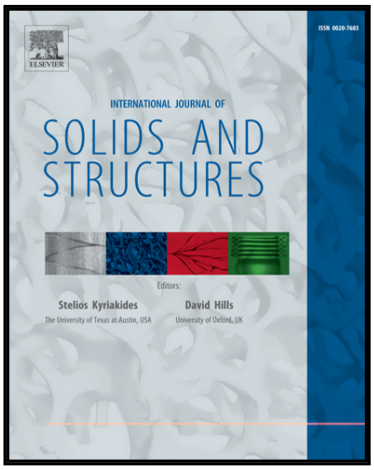


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# Influence of loading path on ductile fracture of tensile specimens made from aluminium alloys

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**Abstract**

Experimental data and numerical simulations of smooth and notched tensile tests on four different aluminium alloys are used to investigate the effect of loading path on ductile fracture. Micromechanical studies are undertaken by the use of axisymmetric unit cells. Stress triaxiality is extracted from the critical element in numerical simulations of smooth tensile tests and used as input in the subsequent unit cell simulations. The stress triaxiality evolution of the unit cell is prescribed as either i) strain-averaged values or ii) continuous functions of equivalent strain in order to examine possible effects of loading path on ductile fracture properties. Results from these simulations clearly demonstrate the importance of non-proportional loading paths on the predicted ductility of the aluminium alloys used in this investigation. The micromechanical model is finally used to estimate initial porosity values such that coalescence strain values obtained from simulations of the smooth tensile specimens are recaptured in the unit cell simulations. Both the conventional $J_2$ flow theory and the Gurson-Tvergaard porous plasticity model are used in simulations of smooth and notched tensile specimens, and the numerical results are compared with experimental data. Simulation results for the smooth tensile specimens conform to experiments for both descriptions of plastic flow. Simulations of notched tensile specimens with the $J_2$ model are shown to overestimate the tensile stress. This deficiency is not remedied by the inherent softening behaviour of the Gurson-Tvergaard model. However, the Gurson-Tvergaard model is seen to predict the ductility quite well for smooth and notched specimens of all aluminium alloys examined in this paper.

*Keywords:* Ductile fracture; Non-proportional loading; Aluminium alloys; Micromechanics; Unit cell modelling; Gurson-Tvergaard model

## 1. Introduction

Material ductility is often decisive for practical applications, such as energy absorbing structures, where structural components are deformed extensively leading to large plastic deformations. However, the material should not be severely damaged or fracture during these deformation processes, which must be accounted for in the design phase of such structures. Predictive descriptions of ductile failure are of utmost importance in this regard.

Ductile fracture of metal alloys has been subject to many studies over the past decades and is known to occur by nucleation, growth and coalescence of voids. The voids either pre-exist within the material (Toda et al., 2014) or nucleate at material inclusions due to decohesion of the matrix-particle interface or particle cracking (Maire et al., 2011). Proper modelling of the ductile damage process on the structural level requires consideration of the underlying mechanisms on a microscopic level. Damage models and associated failure criteria have been proposed (see e.g. Cockcroft and Latham (1968); Johnson and Cook (1985)) throughout the vast literature on ductile failure. Another approach is to use constitutive models that somehow reflect the microstructural evolution during plastic deformation. A widely used and reputable model was proposed by Gurson (1977) and later modified by Tvergaard (1981), the latter being referred to as the Gurson-Tvergaard (GT) model.

Micromechanical finite element models are fre-

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