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SIMULATION OF CRACK INITIATION AND PROPAGATION IN HETEROGENOUS MATERIALS WITH A NON-LOCAL DAMAGE MODEL

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Summary. *This work presents a recently developed non-local formulation of a damage model for ductile damage at locally large deformations and its successful application to the simulation of crack initiation and propagation in heterogeneous microstructures.*

1 INTRODUCTION

The numerical analysis of ductile damage and failure in engineering materials and metal matrix composites is often based on a micromechanical description of the damage and failure process (Gurson[1], Needleman and Tveergard[2], Tveergard and Needleman[3]). In heterogeneous metal matrix composites, ductile crack extension occurs only in the ductile metallic phase, whereas cracks of rigid inclusions and decohesion is not necessarily experimentally observed. The failure process in the metal phase consists of the nucleation of voids resulting from rigid second-phase inclusions, the growth and coalescence of voids up to final failure and macroscopically observable crack growth.

Numerical studies in the context of Finite Element simulations of the damage and failure behaviour of metal matrix materials demonstrates that the application of local damage models to such problems and the numerical simulation of the initiation and propagation of localized damage zones is not generally reliable and strongly mesh-dependent (e.g. Klingbeil and Brocks[4], Mishnaevsky[5]). The numerical problems concern the global load-displacement response as well as the onset, size and orientation of localized damage zones and crack growth in the metal matrix material and thus to the reliability of the obtained results.

The picture below (Fig.1) shows three different mesh topologies (A,B,C) for an artificial metal matrix composite with hard spherical inclusions (geometry and fe-mesh shown in the 1st row) using plain-strain bi-linear four node elements (1st row) and the results of crack growth simulation using the local Gurson model under external tensile load (2nd row).

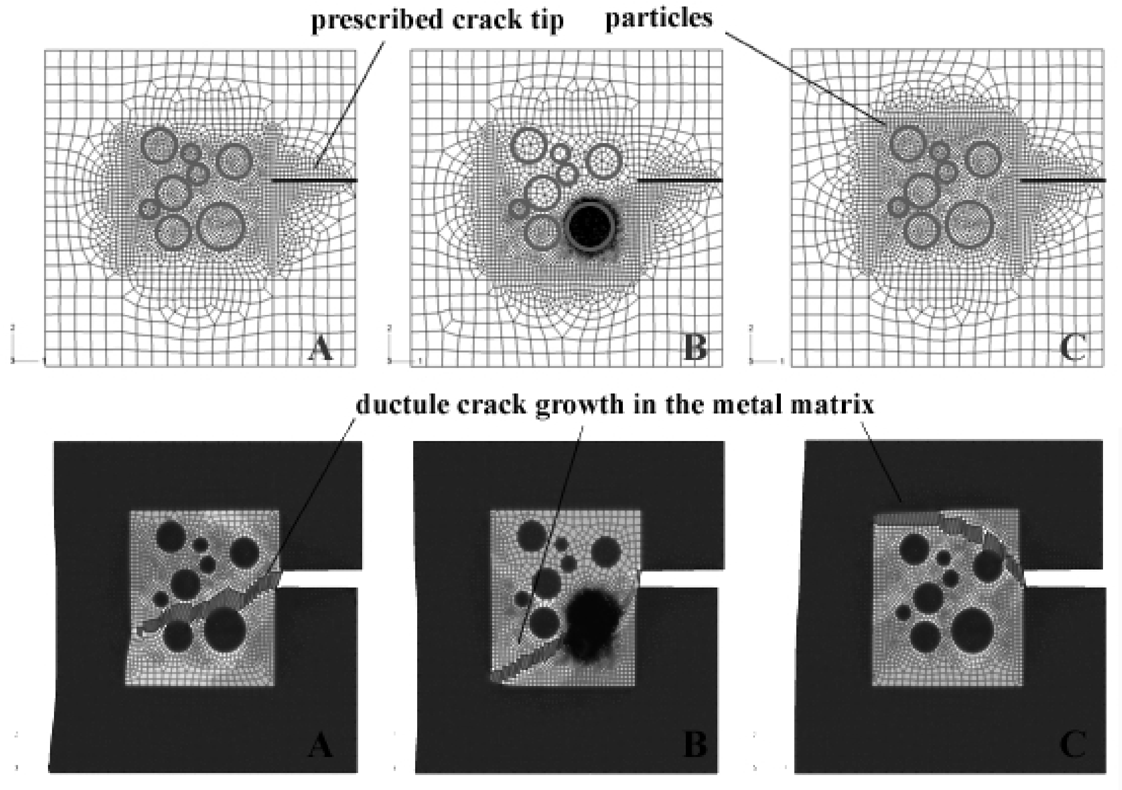

Figure 1: Crack growth simulation in a MMC (Aluminium matrix and stiff particles) with the local damage model from Gurson with three different FE-meshes (A,B,C)

The result demonstrates clearly the strong mesh-dependence of the results due to the different element size and orientation that causes three different predictions of the crack growth in the metal matrix.

2 SIMULATION OF CRACK PROPAGATION WITH A NON-LOCAL DAMAGE MODEL

One possible way to overcome these problems with is the application of so-called non-local damage models. In particular, these are based on the introduction of a gradient type evolution equation of the damage variable regarding the spatial distribution of damage and thus the incorporation of a material length scale (Feucht[6], Ramaswamy and Aravas[7], Reusch et al.[8,9]).

This work will present a recently developed non-local formulation of a damage model for ductile damage at locally large deformations (Reusch et al.[8,9]) and its successful application to the Finite Element simulation of crack initiation and propagation in heterogeneous microstructures.

Figure 2 demonstrates the regularization of the solution obtained with help of the non-local damage model using the finite element method for the crack growth prediction in microstructures. Using again two different meshes mesh (A,B) with slightly different mesh topology for the discretization of the geometry of an artificial MMC microstructure, the simulation predicts two different crack growth pathes in the ductile matrix material using the standard local Gurson model (1st row, mesh A and B). Applying the non-local formulation to the fracture simulation helps to obtain mesh-independent and unique predictions of the localized damage zone in the microstructure (2nd row, mesh A and B).

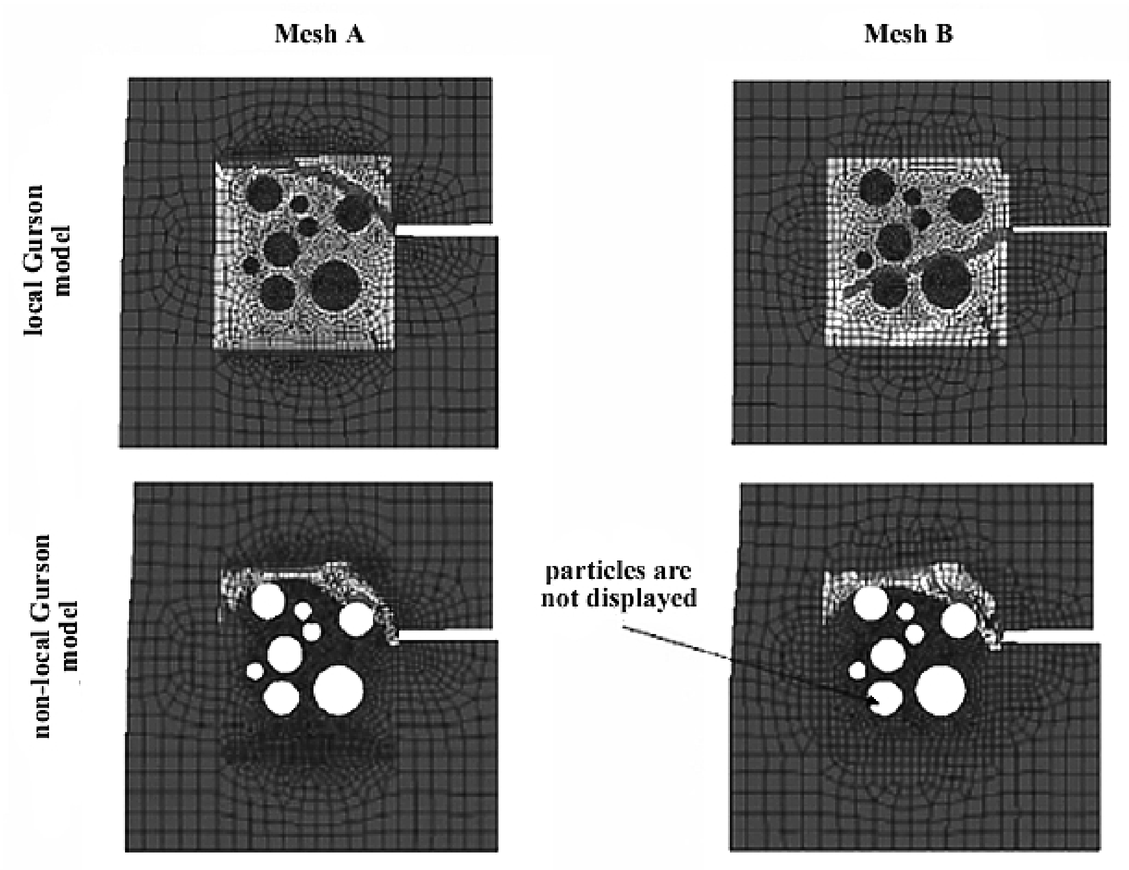

Figure 2: Crack growth simulation in a MMC (Aluminium matrix and stiff particles) with the local (1st row) and the non-local damage model (2nd row) with two different meshes (A,B)

Such a non-local formulation of a damage model exhibits a multifield problem, which needs a closer look on the formulation of possible criteria for the preservation of the wellposedness of the underlying constitutive equations and thus the stability of the deformation process (Benallal and Tvergaard[10], Liebe et al.[11], Reusch[12]). The development and application of a criterion for loss of ellipticity (Reusch[12]) is presented and accounts for the regularization of the solution obtained by the non-local damage model. Furthermore the regularizing effects of the non-locality of the damage evolution are investigated and its effect on the stability of the numerical solution is presented compared to results obtained with standard damage modelling techniques.

3 CONCLUSIONS

The results document quantitatively the effect of the delocalization of the model damage process and the minimization of mesh-dependence on the characteristic dimension of the damage process zone and the global structural response with help of the non-local damage model.

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