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NUMERICAL ASPECTS OF A REMESHING STRATEGY TOWARDS THREE-DIMENSIONAL DUCTILE DAMAGE SIMULATIONS

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ABSTRACT

A proper modelling and understanding of ductile damage and fracture gives us the capability to predict the behavior of metals and alloys in extreme loading cases. Fracture is the final stage of this behavior and a three dimensional modelling provides us with a comprehensive tool to predict it in a realistic manner. Here we focus on three different aspects of numerical modelling: (i) element technology, (ii) remeshing issues and (iii) 3D crack insertion. Each aspect is developed and evaluated independently and finally the combination of them is used for the modelling of large deformation three dimensional crack initiation and propagation.

KEYWORDS:

Three dimensional ductile damage, Bubble enrichment, History transfer, consistent recovery

1. INTRODUCTION

Damage and fracture in metals has been an important subject of research especially during recent years. From a practical point of view our understanding is reaching a level which allows one to make quantitative predictions of ductile damage and fracture initiation in industrially relevant materials and applications. A next step is to also predict crack propagation by three dimensional modelling. This is necessary especially when the fracture surface is to be predicted. For instance because it determines the quality of a product, the required components to reach this goal have been an area of research in recent years and are briefly reviewed below.

2. ELEMENT TECHNOLOGY

One important practical aspect of 3D finite element modelling of material deformation is the geometrical discretization. From a meshing point of view it is more favorable to use tetrahedral elements than hexagonal elements. The drawback of using such elements is the numerical problems that they show in constrained conditions, notably locking effects when the material is (nearly) incompressible as in large-strain plasticity of metals. We have developed an element to deal with (nearly) incompressible large strain elasto-plasticity coupled with nonlocal damage.

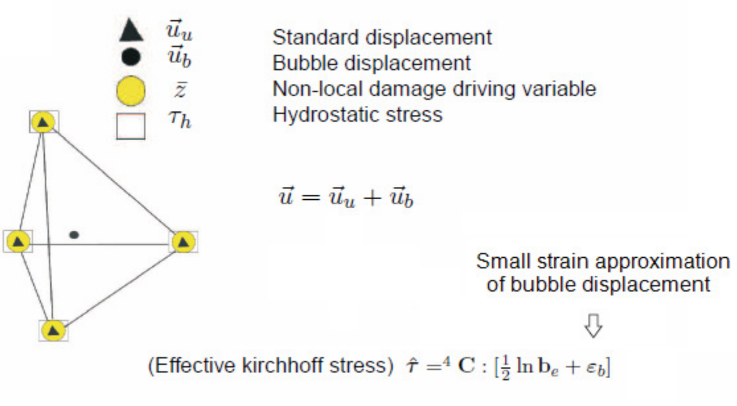

FIGURE 1. THE DEVELOPED ELEMENT AND BUBBLE ENRICHMENT IS HIGHLIGHTED.

The element is based on a bubble-enriched low-order mixed finite element formulation tailored to a finite strain elasto-plasticity model which is coupled with non-local damage similar to [1]. In addition to the standard displacement $\vec{u}_u$ and non-local damage driving variable ($\bar{z}$), the effective hydrostatic Kirchhoff stress (τ_h) and a bubble displacement ($\vec{u}_b$) are introduced as discretised fields –see Figure 1.

The kinematical variable $(\bar{z})$ shown in Figure 1 is obtained from solving a non-local equation together with equilibrium in a fully coupled way [1]:

$$\bar{z} - \ell^2 \nabla^2 \bar{z} = z \tag{1}$$

In equation (1) ℓ is a material dependent length parameter, commonly denoted as internal or intrinsic length scale and z is the local value of the damage driving variable which depends on both plastic strain and stress triaxiality as follows:

$$\dot{z} = \left\langle 1 + A \frac{\tau_h}{\tau_{eq}} \right\rangle \varepsilon_p^B \dot{\varepsilon}_p \tag{2}$$

with A and B material constants, τ_h and τ_{eq} hydrostatic and equivalent stress respectively.

3. TRANSFER OPERATOR

The next important step towards stable crack propagation simulations is a consistent remeshing technique. A crucial ingredient is the transfer of history variables from one mesh to another. The work done by Mediavilla [2] is taken as a basis here and it is further developed to incorporate the newly added element features and to make it more stable and consistent. The bubble-enriched mixed formulation which we use (see the previous section) necessitates a way to reconstruct the bubble displacement in the new mesh. This is important since it has a significant impact on the resulting hydrostatic stress field and consequently on the global forces in the system. We use a global smoothing technique in order to transfer a carefully selected, minimum set of history variables, among which the hydrostatic stress obtained excluding bubble influence, and then recover all other history variables and equilibrium in a zero load increment. The bubble displacement on the new mesh is also computed in this zero load increment.

In order to test the robustness of the adopted strategy, a simulation of a tensile test is done until a certain amount of displacement. Then the simulation is stopped and the history variables are transferred. The same mesh is used here since the transferring is to be validated. Figure 2 shows the damage distribution before and after the transfer operation. Hardly any difference is observed and we can thus conclude that the transfer has been accurate.

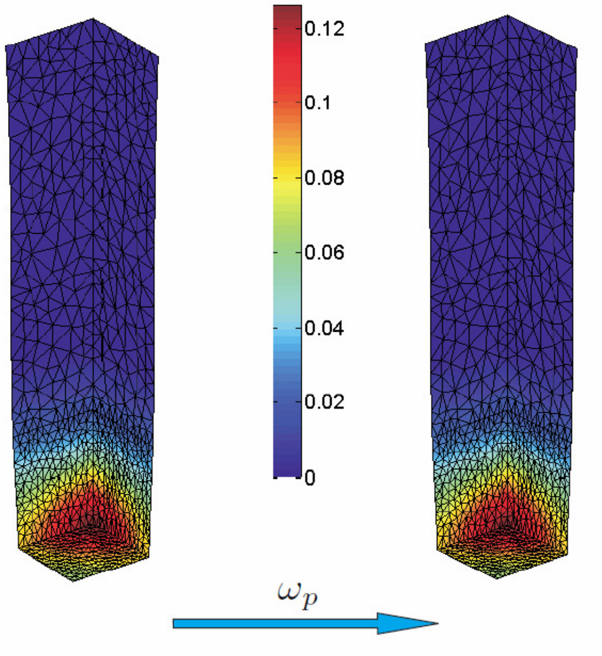

FIGURE 2. DAMAGE DIRSTIRBUTION BEFORE (LEFT) AND AFTER (RIGHT) TRANSFER.

Another example which is used in order to show the performance of the developed remeshing and transfer algorithm is the double notched specimen test proposed by Brokken et al. [4]. This test shows a less homogenous stress distribution and a high degree of constraint, which may trigger locking effects. The hydrostatic stress distribution before and after remeshing and transfer is plotted in Figure 3, again showing a good correspondence.

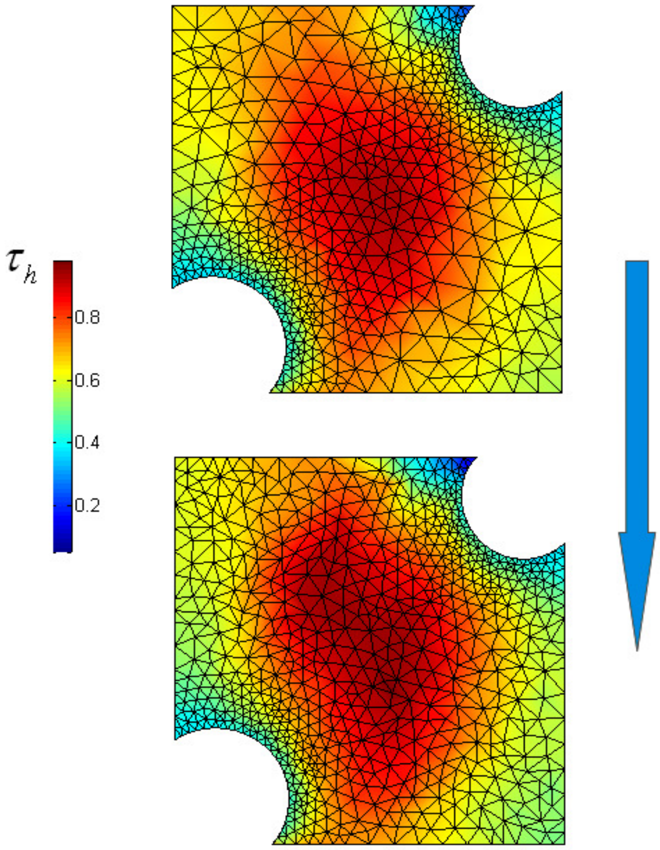

FIGURE 3. MESH REFINEMENT IN DOUBLE NOTCH SPECIMEN AND HYDROSTATIC STRESS PLOT.

4. 3D CRACK INSERTION

A final requirement is a robust algorithm for crack initiation and propagation. The methodology used is that when the damage reaches a critical value, a crack is inserted into the geometry. Geometry and boundary are updated and data from the old mesh is transferred to the new mesh. This process is repeated until the final fracture of the material. A first result is illustrated in Fig. 4. It shows a cube containing an initial crack at one of its edges and which is vertically loaded in tension. Crack growth is driven by the growth of damage throughout the simulation. The computed damage field in each increment is used to predict the evolution of the crack surface, which is then included in the geometrical description of the problem and fed into a remesher. However, the algorithms developed are not yet sufficiently robust to be applied routinely in large-scale forming analysis and, in particular, do not yet take into account the geometry changes which may result from large plastic strains [3].

5. CONCLUSIONS

A new and computationally efficient tetrahedral finite element has been developed in order to deal with plasticity induced finite element locking. A transfer technique capable of transferring element history variables from one mesh to another is in place. This transfer operator is being used to develop a robust 3D crack initiation and propagation algorithm for large deformation elasto-plastic non-local damage material behavior.

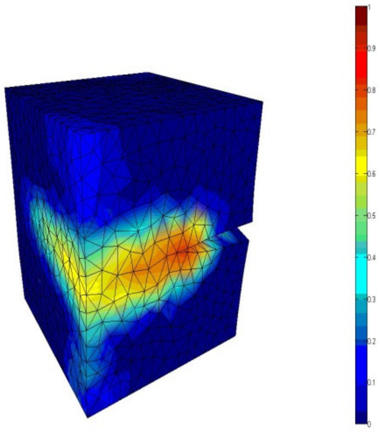

FIGURE 3. NON-LOCAL DAMAGE DRIVEN CRACK GROWTH IN A SMALL STRAIN ELASTICITY-BASED DAMAGE ANALYSIS.

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REFERENCES

[1] J. Mediavilla, R.H.J. Peerlings, M.G.D. Geers, A nonlocal triaxiality-dependent ductile damage model for finite strain plasticity, *Computer Methods in Applied Mechanics and Engineering*, 2006, **195**, 4617-4634

[2] J. Mediavilla, R.H.J. Peerlings, M.G.D. Geers, A robust and consistent remeshing-transfer operator for ductile fracture simulations, *Computers & Structures*, 2006, **84**, 604-623.

[3] R. H. J. Peerlings, H. R. Javani, J. Mediavilla, M.G.D. Geers, Modelling of damage initiation and propagation in metal forming, *Computers International Journal of Material Forming*, 2008, **1**, 1123-1126.

[4] D. Brokken, W. A. M. Brekelmans, F. P. T. Baaijens, Numerical modelling of the metal blanking process, j*ournal of Materials Processing Technology*, 1998, 83, 192-199

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