ANALYSES OF DUCTILE FRACTURE USING HUNNY THEORY

Vigneshwaran Radhakrishnan, and A. Amine Benzerga*

Texas A&M University, College Station, TX, USA
** Presenting Author email: benzerga@tamu.edu*

Abstract
We present a theory with a structure that enables analyses of ductile fracture under any type of loading. The theory builds on the standard concept of homogeneous yielding and further proceeds from the concept of unhomogeneous yielding on a (yield) system that depends on the spatial distribution of voids. Depending on the desired level of refinement in analysis, a given simulation employs one or more yield systems with the isotropic limit being reached for an infinite number. We illustrate the predictive capabilities of the theory by considering simulations of three-dimensional crack initiation and growth in a round notched bar, a shear specimen and a compression pin.

1. Introduction

Physics-based simulations of ductile fracture usually employ constitutive relations for porous material plasticity. The vast majority of formulations are based on homogeneous yield (HY) models, such as the Gurson or Rousselier formulations. To achieve complete degradation at the material point level, ad hoc formulations of void coalescence are introduced. Here, we introduce a theory which conceptualizes recent efforts in void coalescence modeling in the new notion of unhomogeneous yielding (UY). This is critical for expanding the range of applicability beyond tension-dominated loadings. Unhomogeneous yielding refers to plastic strain concentration in bands of dense void packing. In a program of loading, unhomogeneous yielding may occur in a single band. Hence, the theory is generally anisotropic. However, if the void distribution is statistically homogeneous then any orientation may be picked, dependent only on the stress state. Thus, an isotropic version of the theory is obtained in this limit. The theory qualitatively predicts failure under any type of loading. To obtain quantitative predictions, however, special emphasis is laid on the evolution laws of the internal parameters. Often, quantitative predictions demand that the anisotropic version be employed, which is named HUNnY. We also discuss the parallel between the isotropic version of HUNny theory and J_2 flow theory of damage-free plasticity and between the anisotropic HUNnY theory and crystal plasticity.

2. Results

Finite element analyses were carried out using three specimen geometries: a round notched bar, a top-hat shear specimen and a compression pin. In all calculations presented here (the first two specimens), the anisotropic theory is used with a single UY system. The internal parameters of the theory consist of the void volume fraction, f, the lengths and orientations of the void axes, and the void spacing ratio, S, defined as the void spacing normal to the band relative to the in-plane void spacing.

Figure 1 illustrates a typical simulation in a round notched bar. The material has isotropic hardening in the form of a power law with initial yield stress of 420 MPa and a power law exponent N=0.1. The initial internal state is characterized with f_0 = 0.01, w_0=1 (void aspect ratio) and S_0=1. The framework has the capability to sealessly describe degradation at the material point level (Gauss point zone painted black in Fig. 1), hence the complete loss of load bearing capacity at the structural level.

Figure 2 provides more details in simulating crack initiation and early growth in a "Top-Hat" specimen using a material with yield strength 390 MPa, N=0.16, f_0 = 0.0035, w_0=1.1 and S_0=2. Here, the phenomenology of failure is completely different from that in a notched bar. Plastic flow localizes in two thin regions on either side of the "hat". However, because the stress triaxiality is close to zero in the zone (except near the edges) porosity growth is minimal in the entire band. On the other hand, significant void rotation takes place in the severely sheared areas, as indicated by the arrows. Each arrow represents the current orientation of the void at that location. Shear-induced rotation is accompanied with void elongation in the rotated state and, depending on the initial void spacing, leads to coalescence by

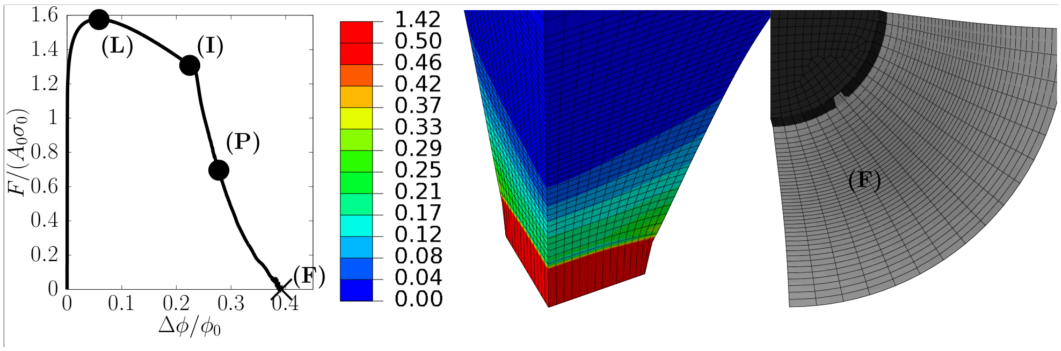

Fig.1 – Load vs. diameter reduction in round notched bar down to complete loss of load bearing capacity.

impingement with no significant increase in porosity. As a result, the ligament parameter reaches the critical value of 1, as shown in the corresponding contour.

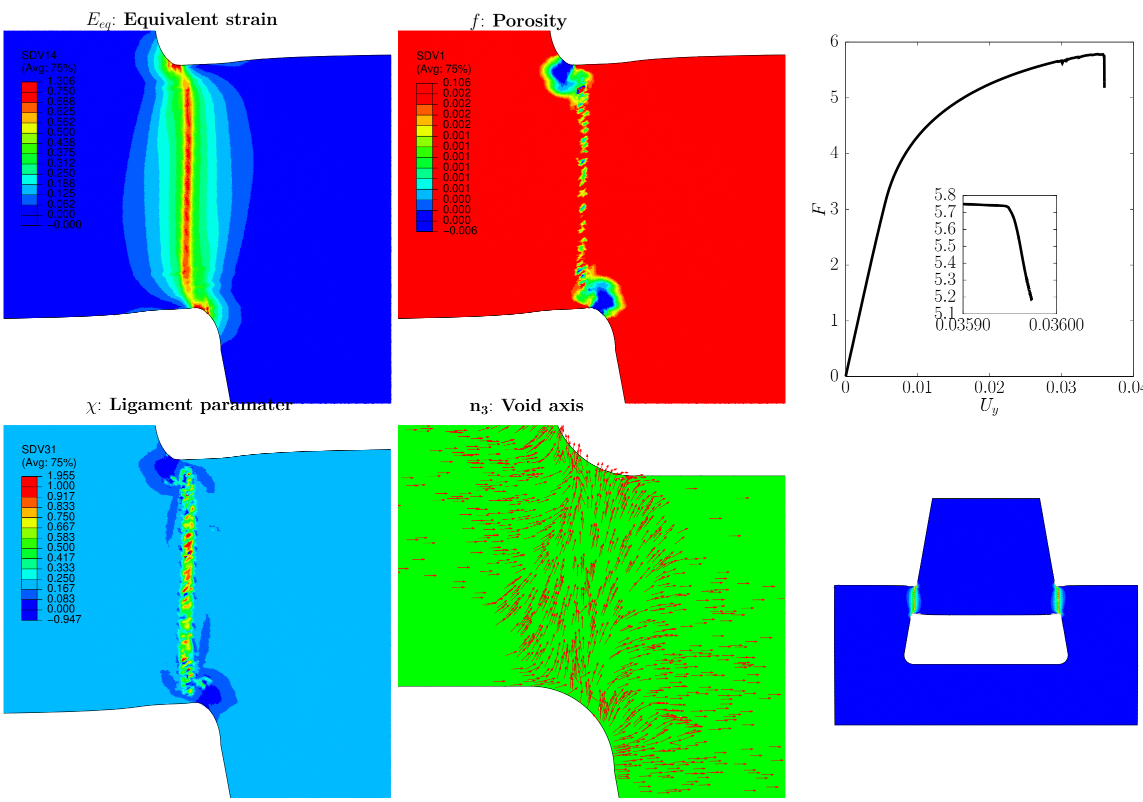

Fig.2 – Simulation of failure in “Top-Hat” specimen.

Conclusion

A unifying theory of ductile fracture is presented which has the capability to represent failure under both tension- and shear-dominated loadings. A formulation of the theory has been implemented in a commercial finite element code and its predictive capabilities illustrated.

Acknowledgements

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