A NON-LOCAL GURSON MODEL WITH TWO FRACTURE-MECHANISM ASSOCIATED LENGTH SCALES: SUPPORTED BY NUMERICAL ANALYSES AND EXPERIMENTS

Shuyue Wang[1]* and Jonas Faleskog[1]

[1]Department of Engineering Mechanics, KTH Royal Institute of Technology, Stockholm, Sweden
** Presenting Author email: shuyue@kth.se*

Abstract
An extension of Gurson's porous plasticity model capable of preventing pathological strain localization, and describing crack initiation and propagation under both shearing and tension is investigated. This paper separates the progression of shear failure and flat dimple rupture based on the assumption that these two failure mechanisms are governed by different characteristic length scales, a deviatoric and a dilatational length scale, respectively. A set of numerical analyses is presented which brings out the effects of these length scales on the development of e.g. cup-cone and slant fracture. Guided by the outcome of the numerical study, a set of tests has been designed and carried out for calibration of these length scales.

1. Introduction

A viable method to predict the initiation and propagation of cracks in ductile materials is using a Gurson model, which accounts for void nucleation, growth, and coalescence. A non-local treatment of suitable internal variables, involving one or several length scales, is preferable when numerically analysing failure processes based on damage constitutive models. In this way, a pathological dependence on the discretization of the numerical model and strain localization can be avoided.

In this study, an integral approach that utilizes two different length scales is applied, in which the integration is carried out in either that material (*Lagrangian* Ω_0) or the spatial (*Eulerian* Ω) configuration, respectively. The latter is motivated by the observation that ductile failure typically is preceded by finite deformation. To address ductile failure in the full range, low to high triaxial stress states, the Gurson model modified for shear failure is employed. A model for void nucleation is also included, which was observed to be a necessity to enable the development of cup-cone fracture in uniaxial tension. With this model, the progression of shear failure may be separated from the progression of flat dimple rupture, by assuming that the contribution to the evolution of the effective void volume fraction can be split into a deviatoric part in addition to the dilatational part. It is assumed that these failure mechanisms are governed by different characteristic length parameters, a deviatoric R_s and a dilatational length R_h, respectively.

2. Results

The influence on the failure of the two length parameters (R_s, R_h) and the choice of configuration for integration (Ω_0, Ω) is illustrated in three types of benchmark problems: 1) tensile geometries prone to flat dimple rupture, 2) shear type of geometries prone to shear failure, and 3) simple edge cracked beam failing by high constraint fracture. Physical material parameters describing the material properties are used aiming to correctly describe and validate the non-local Gurson model with experiment results. These benchmark problems constitute a set of discriminating tests, from which the two length parameters can be estimated for practical purposes. The numerical analyses are conducted by developing an explicit user-material subroutine in the finite element software Abaqus.

It is shown that the introduction of an additional deviatoric length parameter has a significant effect on the deformation to failure in shear-dominated geometries with strong plastic strain gradients, as well as on the appearance of the classic cup-cone failure and shear band formation leading to slant fracture in tension-dominated geometries. Below, a selection of results is presented and the parameters that are used in the figures include: L_e - element size, P - load, and δ - displacement. Fig.1 presents the geometry and load-deformation response of a shear-dominated geometry, modified Iosipescu specimen, with a strong plastic gradient. It is shown that the onset of failure is strongly related to the deviatoric length parameter R_s. Fig.2 presents failure modes for a round smooth bar loaded in uniaxial tension, where a smaller R_s facilitates the development of cup-cone fracture.

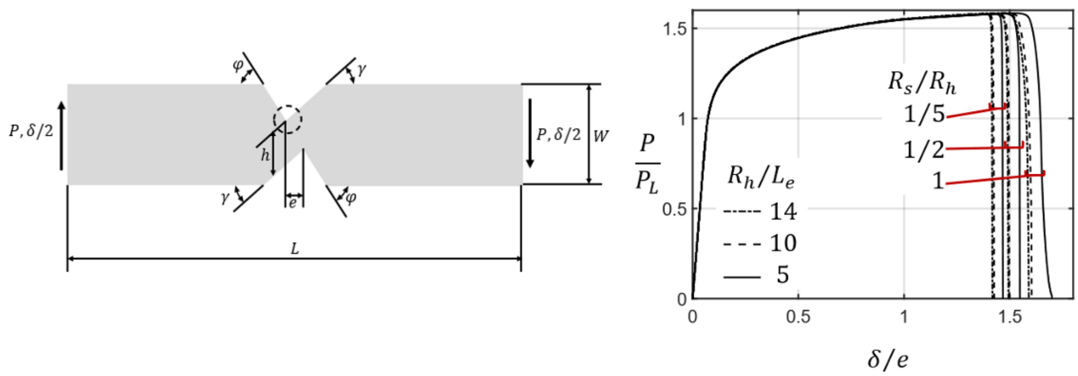

Fig.1 – Force-displacement response of the modified Iosipescu specimen.

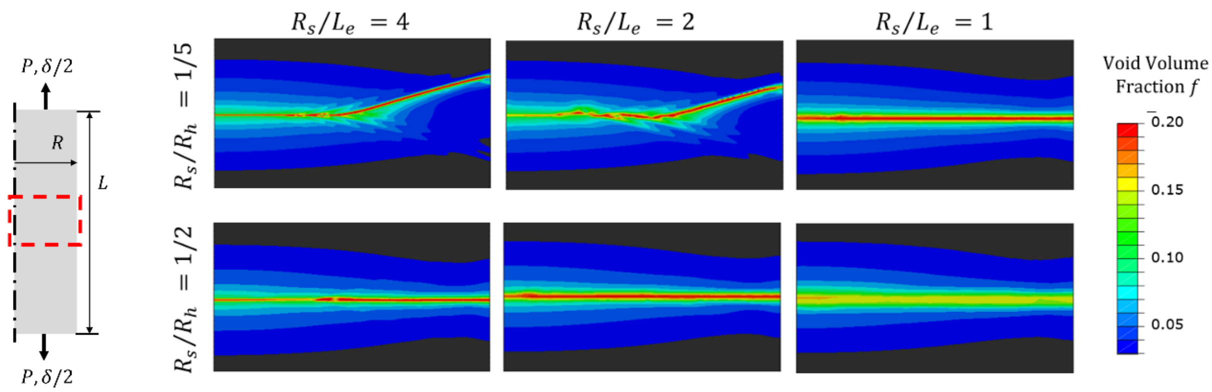

Fig.2 – Classic sup-cone failure modes in RSB plotted in the undeformed configuration. Iso-contours of the effective void volume fraction are shown and non-local integration is performed in Ω.

Experiments are carried out on test specimens similar to the numerically analysed benchmark problems on material A508 (a forged version of A533 pressure vessel steel). Model parameters are systematically estimated using experimental outcomes. The calibrated model is validated for a crack that completely grows through a compact-tension specimen splitting it into two halves. Such a test involves both high-constraint fracture at the early stages of crack propagation which terminates by slant fracture.

3. Conclusions

A non-local Gurson model with two length parameters, separating deviatoric and dilatational failure mechanisms, was investigated. An integral approach was employed on both Lagrangian and Eulerian configurations. The numerical investigation showed that separating these two failure mechanisms is essential and that integration on the Eulerian configuration is preferred. The deviatoric length combined with a suitable model for void nucleation affects the onset of failure in the shear-dominated geometries with strong plastic strain gradients, and the appearance of the classic cup-cone failure and shear band formation in tension-dominated geometries.

Acknowledgements

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