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LOCALIZATION PROBLEM OF COUPLED DUCTILE FAILURE MODELS COMPARED TO UNCOUPLED ONES

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Abstract: *Comparison of accumulated damage field of coupled and uncoupled ductile damage models together with history of variables used in calibration process is presented in this paper. Using a non-linear damage accumulation in a local point of view, ductile failure criterion proposed by Xue is adopted and implemented into the Abaqus/Explicit via the user subroutine VUMAT for both types of models. Significant difference in localization between the coupled and uncoupled model is shown. The localization effect generally occurs when coupled models are used. One of the widespread practices to handle it is to use the non-local approach. In the other hand, we would not be able to predict a slant fracture without a certain degree of localization as shown in presented paper. Finally, the aluminum alloy 2024-T351 was examined.*

Keywords: Localization, Ductile, Failure, Damage, Explicit.

1. Introduction

The ductile fracture has been observed and less or more appropriate failure models have been developed since the second half of the last century. Several different approaches have been evolved, as the Continuum Damage Mechanics (CDM), porosity based models, decohering zone models, empirical models, void nucleation, growth and linkage models and forming limit diagrams.

The basics of CDM were laid by Kachanov (1958) in the sense of creep. Coupled ductile model represents model where the plasticity is influenced by damage process and vice versa. On the contrary, uncoupled ductile models do not couple the plastic flow with damage accumulation, so only the damage process is affected by plasticity. These models are empirical and can be also called as phenomenological.

2. Outline of Applied Approach

The non-linear damage accumulation in a local point of view is adopted for comparison purposes. Next presumption is using von Mises yield condition for the plastic flow and assuming the material to be isotropic.

Xue (2007) developed new ductile failure criterion based on CDM in his doctoral thesis. At first, it is necessary to identify the flow curve and then six material constants through various experimental tests.

Here follows short outline of criterion proposed by Xue (2007) which we adopted. Equation describing the stress-strain relationship of matrix material is:

$$\sigma_M = \sigma_{y0}\left(1+\frac{\bar{\varepsilon}_p}{\bar{\varepsilon}_k}\right)^n \tag{1}$$

where σ_M is the matrix stress, σ_{y0} is the initial yield stress, $\bar{\varepsilon}_p$ is the equivalent plastic strain, $\bar{\varepsilon}_k$ is the reference strain and n is the strain hardening exponent.

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The yield condition is given as:

$$\bar{\sigma} - w\sigma_M \leq 0 \tag{2}$$

where w is a weakening factor dependent on the damage parameter D through:

$$w = 1 - D^{\beta} \tag{3}$$

where β is a material constant. Then, the damage evolution law for complex loading paths can be written as:

$$D = \int_0^{\bar{\varepsilon}_f} m\left(\frac{\bar{\varepsilon}_p}{\bar{\varepsilon}_f}\right)^{m-1} \frac{\mathrm{d}\bar{\varepsilon}_p}{\bar{\varepsilon}_f} \tag{4}$$

where m is the damage exponent and $\bar{\varepsilon}_f$ is the fracture strain. The fracture depends on current stress state, thus, it is a function of pressure and Lode dependence:

$$\bar{\varepsilon}_f = \bar{\varepsilon}_{f0}\mu_p\mu_L \tag{5}$$

where $\bar{\varepsilon}_{f0}$ is the uniaxial tensile failure strain without confining pressure. Above functions of pressure and Lode dependence can be expressed through:

$$\mu_p = 1 - q\log\left(1 - \frac{p}{p_l}\right) \quad \text{and} \quad \mu_L = 1 + (1-\gamma)\left|\bar{\theta}\right| \tag{6}$$

where q is the shape parameter, p is the pressure, p_l is the limiting pressure governing the cut-off value, γ is the fracture strain ratio and $\bar{\theta}$ is the normalized Lode angle.

3. Material Data

The aluminum alloy 2024-T351 was used and ductile failure criterion proposed by Xue (2007) were taken over with following material constants, $\bar{\varepsilon}_{f0} = 0.8$, $p_l = 800\ \mathrm{MPa}$, $q = 1.5$, $\gamma = 0.4$, $m = 2$, $\beta = 2$ (Xue, 2007).

We also took over the flow curve of matrix material fitted from tensile tests of smooth cylindrical specimens with 9 mm diameters. Material constants defining the stress-strain relationship follows here, $\sigma_{y0} = 300\ \mathrm{MPa}$, $\bar{\varepsilon}_k = 0.00769$ and $n = 0.185$ (Xue, 2007).

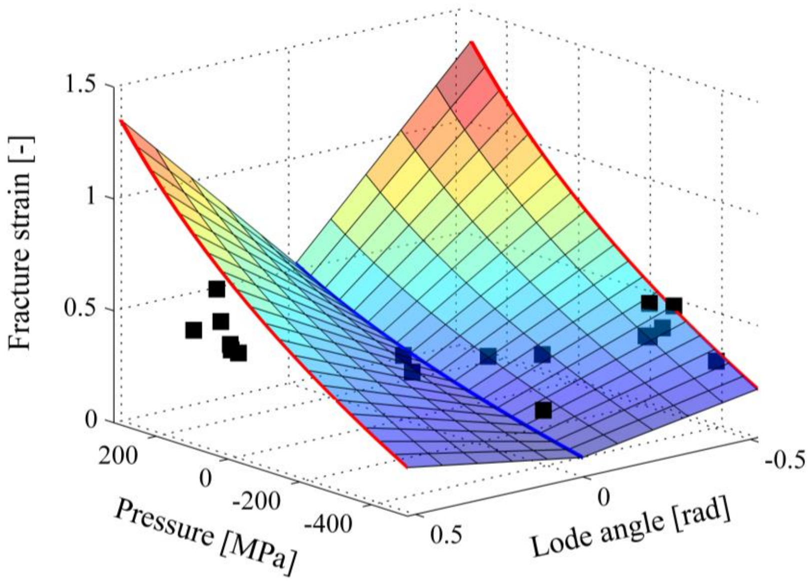

Fig. 1: Fracture envelope of criterion proposed by Xue (2007) for set of material constants taken over after Xue (2007).

The set of material constants listed above gives the fracture envelope shown in Fig. 1. Lou et al. (2013) reviewed experimental results of Bao and Wierzbicki (2004), Bai and Wierzbicki (2010) and Khan and Liu (2012). All these experimental results are placed in Fig. 1 as black squares. As one can see, the fracture strain of criterion proposed by Xue (2007) at axisymmetric compression is much higher than results reviewed by Lou et al. (2013).

4. Numerical Simulations

In this chapter, the numerical simulations of smooth and notched cylindrical specimens and double grooved specimen (Bao and Wierzbicki, 2004) are presented. First set of simulations was done using the criterion proposed by Xue (2007) and the second set for the same criterion but without weakening. The weakening factor was held unity in whole simulation, so the model was uncoupled.

Fields of damage parameter for coupled and uncoupled models immediately before and after the crack initiation are depicted in following Figs. 2-5.

In Fig. 6, the history of the pressure and the stress triaxiality is depicted because these variables influence the most the ductile fracture initiation and propagation.

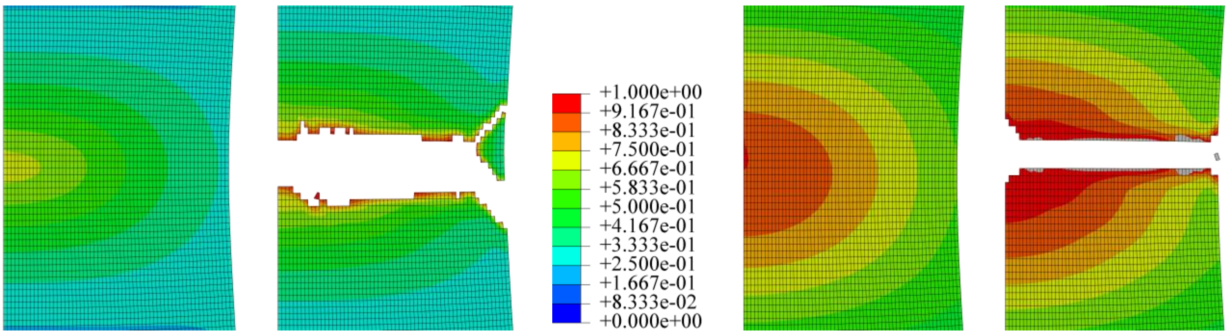

Fig. 2: Fields of damage parameter before and after initiation for smooth cylindrical specimen. At left due to coupled model and at right due to uncoupled one.

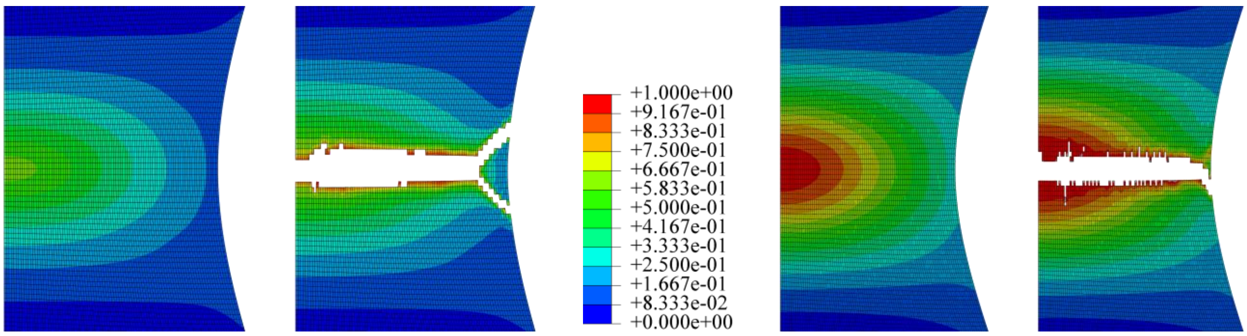

Fig. 3: Fields of damage parameter before and after initiation for notched cylindrical specimen with radius 12 mm. At left due to coupled model and at right due to uncoupled one.

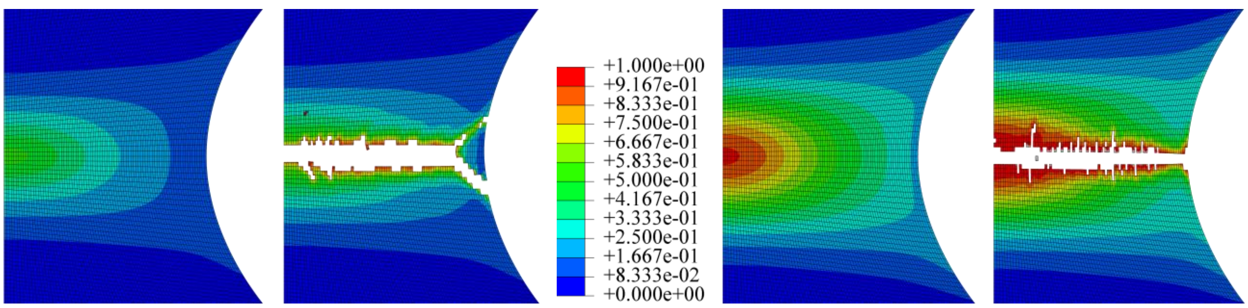

Fig. 4: Fields of damage parameter before and after initiation for notched cylindrical specimen with radius 4 mm. At left due to coupled model and at right due to uncoupled one.

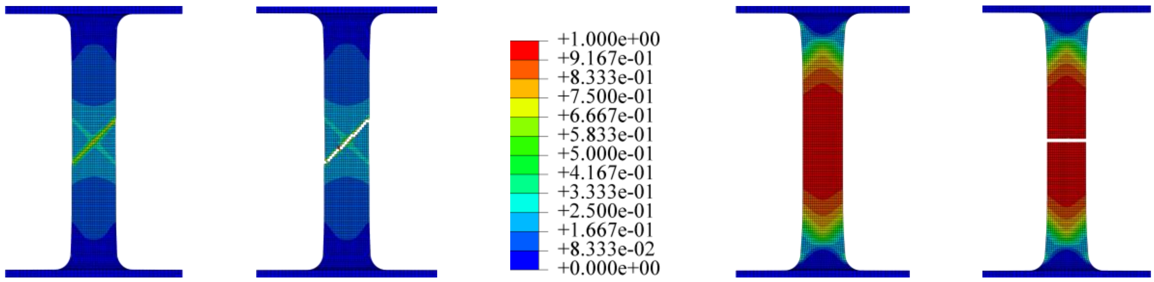

Fig. 5: Fields of damage parameter before and after initiation for double grooved specimen inducing plane strain. At left due to coupled model and at right due to uncoupled one.

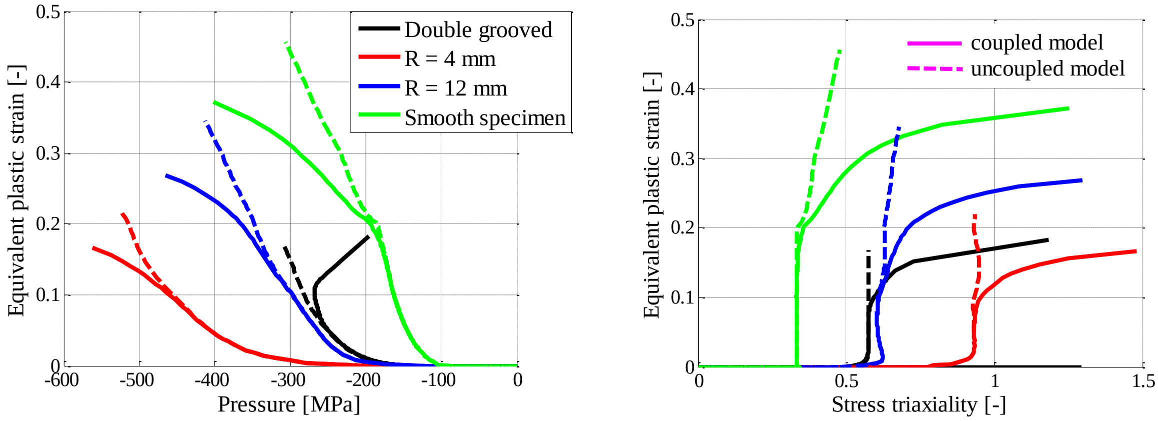

Fig. 6: History of the pressure and the stress triaxiality during straining.

5. Conclusions

Localization effect of coupled model in comparison to uncoupled one was presented. There is a strong localization in the case of coupled model due to coupling the fracture criterion with the flow rule. As shown, in the case of uncoupled model the localization effect did not occur. Therefore, such model is not able to predict the slant fracture, especially in the case of plane strain. It was also shown there is a significant difference in the loading history of the stress triaxiality between the coupled and uncoupled model. The coupled model shows considerable change in progress in the final part of the straining.

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