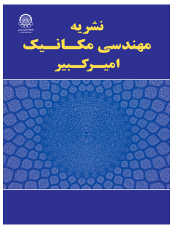

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Numerical Simulation of Elastoplastic Behavior and Damage Evolution at Various Stress Triaxiality

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ABSTRACT: The theory of continuum damage mechanics with a phenomenological approach is able to simulate phenomena such as soft strain, local necking of materials, and their failure. Stress triaxiality is defined as the stress state in a material that strongly affects the ductile failure phenomena. In this study, two damage models, Ganjiani and Bonora, are chosen to simulate and compare the elastoplastic behavior as well as damage evolution of some metals. These damage models are sensitive to the stress triaxiality. In order to validate the capability of the models in structural response, the proposed model has been implemented into user-defined subroutines VUMAT in the finite element program ABAQUS/Explicit. For this purpose, the explicit stress integration algorithms of the model have been explained. The model has been validated by comparing the predicted results with experimental data. The simulations are performed for steel 1045, aluminum 2024-T351, and steel HY130. The details of the integration algorithm in the framework of the explicit scheme are presented. Also, the model is developed in the large strain deformation. For the determination of the constants in the models, the stress-strain, the damage-strain, and the fracture strain-triaxiality curves are used. The predicted curves of load-displacement from simulation have good agreement with corresponding experimental data.

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1. INTRODUCTION

Continuum Damage Mechanics (CDM) as a phenomenological approach is widely used in a coupled or uncoupled scheme to join the (visco) plasticity theory to simulate well the strain softening, damage localization, and fracture phenomena in materials, [for example [1, 2-4]. Experimental evidence has shown the key factor of stress triaxiality, which replies the mean stress, on fracture strain. Besides that, the stress triaxiality has been found to be not the single factor to affect the ductile damage evolution, especially under shear loading conditions. In order to consider the effect of shear loading on the ductile fracture, another key factor as the Lode angle parameter was proposed. This parameter is actually related to the third deviatoric stress invariant J_3. Many ductile fracture models have been proposed in the literature, which used the definition of damage to predict fracture strain [4-10]. The original Gurson–Tvergaard–Needleman (GTN) model [11, 12] predicts no damage change with strain under zero stress triaxiality except when voids are nucleated. On the other hand, this model has limitations which ignore the fracture mechanism due to shear. Therefore, many authors attempt to modify the limitations of this model.

In this study, two damage models, Ganjiani and Bonora, are chosen to simulate and compare the elastoplastic behavior as well as damage evolution of some metals. The simulations are performed for steel 1045, aluminum 2024-T351, and steel HY130. The details of the integration algorithm in the framework of the explicit scheme are presented.

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2. METHODOLOGY

The stress triaxiality η is defined as $\eta = \sigma_m / \sigma_{eq}$ where $\sigma_m = \text{trace}(\boldsymbol{\sigma})/3$ is the mean stress.

2.1. Ganjiani model

The model of Ganjiani can be presented as follows:

$$D = \frac{1}{c_d}\operatorname{arctanh}\left\{\frac{1}{EK_d}\left[1+c_\eta \ln\left(\frac{1+\eta}{1+\eta_{ref}}\right)\right]^2\left[R(\varepsilon^p_{eq})\right]^2 - \frac{Y_0}{K_d}\right\} \quad (1)$$

where $\bar{\varepsilon}^p$ is the equivalent plastic and the parameters E, K_d, c_η and c_θ are material constants and the superscript "ref" refers to the reference test which is used to identify the parameters involved in the model. $R(\varepsilon^p_{eq})$ is the plastic hardening which is selected as $K\left[\varepsilon_0+\varepsilon^p\right]^n$.

2.2. Bonora model

The model of Bonora can be presented as follows:

$$D = D_{cr}\left\{1-\left[1-R_\eta^{1-\gamma}\frac{\ln(R_\eta^{\gamma}\varepsilon^p / \varepsilon_{th})}{\ln(\varepsilon_{funi} / \varepsilon_{th})}\right]^\alpha\right\} \quad (2)$$

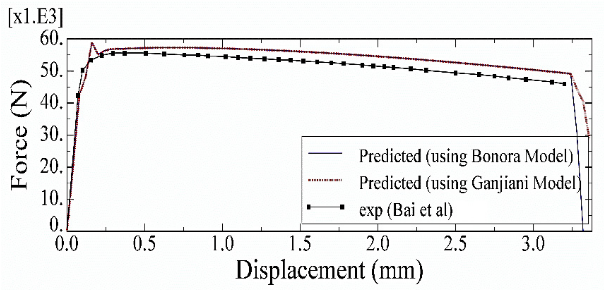

Fig. 1. The comparison of force-displacement between simulation and the result of Ref. [34] for steel 1045.

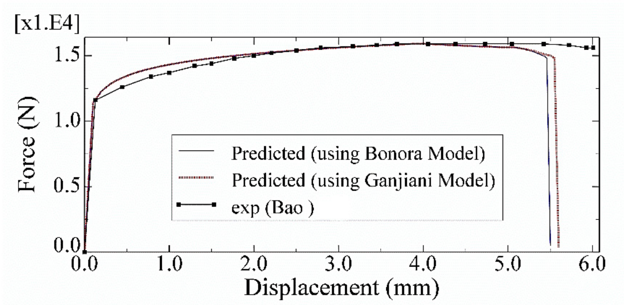

Fig. 2. The comparison of force-displacement between simulation and the result of Ref. [44] for aluminum 2024-T351

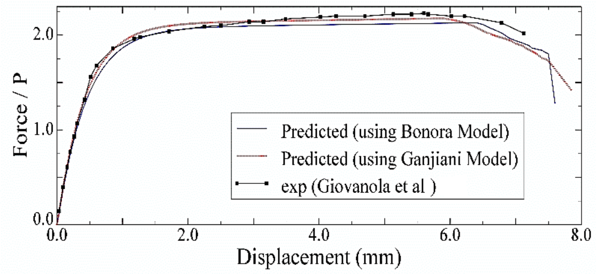

Fig. 3. The comparison of force-displacement between simulation and the result of Ref. [52] for steel HY130.

In which The $R_\eta = \frac{2}{3}(1+v)+3(1-2v)\eta^2$ is the function that accounts for stress triaxiality effects. S_0, γ, α, β are constants. ε_{th} is thresholds strain and ε_{funi} is the fracture strain at the uniaxial tension test.

3. RESULTS AND DISCUSSION

The simulations are performed for steel 1045, aluminum 2024-T351, and steel HY130. The material properties are calibrated. The tension test is simulated for steel 1045 and aluminum 2024-T351, and the three-point bending test is simulated for steel HY130. The force-displacement of these simulations is presented in Figs. 1 to 3.

The finite element analysis is carried out to show the capability of the model at a structural scale. As indicated in these figures, the predicted results have good agreement

4. CONCLUSIONS

In this paper, a fracture model has been presented in the framework of Continuum Damage Mechanics. Two damage models, Ganjiani and Bonora, are chosen to simulate. The simulations are performed for steel 1045, aluminum 2024-T351, and steel HY130. The details of the integration algorithm in the framework of the explicit scheme are presented. The cures of load-displacement from simulation have good agreement with corresponding experiment ones

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