INVESTIGATING THE EFFECTS OF GEOMETRICAL PARAMETERS ON FRACTURE RESPONSE OF THE NOTCHED SMALL PUNCH TEST

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1. Introduction

The non-destructive techniques have the great advantage to evaluate the material properties in-situ, in particular the small punch test shows to be very attractive and promising as it relies on a small, but representative material volume of the component in-service and it has been successfully applied in other research fields. Therefore, the aim of this study is a numerical investigation of the effects of geometrical parameters of a predefined notch on fracture characteristics of small punch testing specimens. Taking the experimental research of notched specimens published by Turba et.al, finite element based study of small punch fracture specimens made of P91 steel, have been modeled in ABAQUS. Then, using this model as a departure point, geometrical parameters of the predefined notch (such as notch radius, placement, depth) have been varied and the effects of such geometrical changes on fracture response of the specimen is investigated numerically.

2. Theoretical Background

Theoretical framework is based on the thermo-mechanical finite strain coupled plasticity and continuum damage mechanics models. Cleavage failure in metallic materials is modled with the deterministic model by Ritchie-Knott-Rice [3], relies on a critical stress over the critical distance principle whereas whereas the ductile fracture is characterized by using the Gurson porous plasticity to model dilatational yielding and ductile rupture.([5], [2], and [1]. This model devises a hydrostatic stress dependent yield potential derived using homogenization over void-rigid plastic matrix and limit analysis

$$
\begin{aligned}
\phi^p &= \left[\frac{\overline{\overline{\sigma}}_{eq}}{\sigma_y}\right]^2 + 2q_1 f^* \cosh\left(\frac{q_2}{2\sigma_y}\mathrm{tr}\left[\overline{\overline{\sigma}}\right]\right) - \left[1+\left[q_1 f^*\right]^2\right] = 0. \\
\overline{\overline{\sigma}}_{eq} &= \sqrt{\frac{3}{2}\left[\mathrm{dev}\overline{\overline{\sigma}} : \mathrm{dev}\overline{\overline{\sigma}}\right]}
\end{aligned}
\tag{1}
$$

where f is the void volume fraction that evolves with plastic strains, σ_y is the current yield stress of material and $\overline{\overline{\sigma}}$ is the so-called *effective stress* [4]. Note that the proposed coupling with continuum damage mechanics formalism introduces dev $\left[\overline{\overline{\sigma}}\right]$ as the deviatoric part of the effective stress tensor at rotationally neutralized configuration in the yield potential ϕ^p, onto which both void-growth and micro-crack driven damage mechanisms are reflected in order to account for softening effects of ductile and brittle failure phenomena.

3. Numerical Analysis of Small Punch Test

Small Punch Testing is a recently developed mechanical testing method that allows the mechanical, fracture and creep characterization of tiny specimens. Axisymmetric finite elements with reduced integration and enhanced hourglassing controls (CAX4R) has been used. Small punch experiment has been modelled for 22° and -196C. The set of material parameters used to predict P91 behavior have been listed in the following table.

Table 1: Gurson-Tvergaard-Needleman model parameters for P91.

f_N	s_N	ε_N	q_1	q_2	$q_3 = 1/f_U$	f_0	k_w
0.005	0.1	0.03	1.5	1.0	2.25	0.0055	3.0

3.1. Effects of specimen geometry on fracture response of SPT

The geometrical parameters of the small punch experiment such as puncher radius and notch depth (Figure-**??**) have been varied and the effects of such geometrical changes on fracture response of the specimen is investigated numerically. The effects of the puncher radius on the fracture response of SPT, is investigated using various the puncher radius of the loading with the values of 2.25mm, 2.5mm and 2.75mm, respectively. The results of analyses are presented in Figure 1. As one can notice that reducing the puncher radius a too small

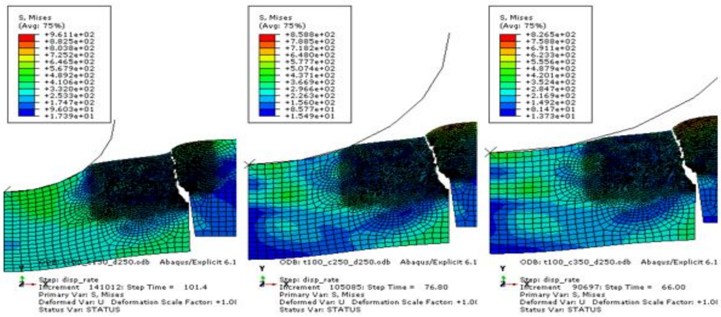

Figure 1: (a) Numerical prediction of effects of the puncher radius with 2.25mm, 2.5mm and 2.275mm on the notched specimen

value, more stress concentration occurs near by the underneath of the puncher region and also failure of the specimen is dominated by shear due to punching effect. Depth of the crack is one of the most important fracture parameter that causes the damage and fracture in the materials. Therefore, to investigate the effect of crack depth on the fracture response of the small punch test, three different crack depths, with length of of 0.44mm, 0.49mm, and 0.54mm, are used in numerical simulation. As the crack depth increases along the direction of the thickness of the specimen material becomes weaker and is much likely prone to damage and fracture. At the lower temperature $-196°$C for all crack lengths the material behaves completely brittle.

4. Conclusions

In the enclosed work, a coupled continuum damage mechanics and porous plasticity model on local scale has been presented. Constitutive modelling and small punch experiments have been performed for P91 steel. It has been found out that the proposed model precisely and conveniently predicts crack patterns within a relatively wide temperature range from 22°C to $-196°$C.

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