Failure Prediction for a Perforated Guide under Tearing Considering Triaxiality

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1. Introduction

For reliable prediction of the behavior of automobile parts during crash events, accurate knowledge of material properties, in particular those pertaining to the post-necking region, is of paramount importance. This requires a flexible damage model as well as a means for obtaining strains on a highly local level.

The recently developed generalized incremental stress state-dependent damage model (GISSMO) is a promising tool as it is capable of overcoming the problem of mesh-dependence. However, as the derivation of its parameters relies heavily on the accuracy of the load-displacement (FD) curve, digital image correlation (DIC) is chosen to obtain accurate local true stress-strain data.

In this study, these two tools are employed to derive true stress-strain data and, based on them, GISSMO parameters. Validation is conducted by applying these parameters to a perforated strap with two elongated holes, where the rim of the upper hole is loaded in upward direction by a pin.

2. Test setup and strain measurement by DIC

All tests were performed with a standard universal testing machine (UTM). The DP980 specimens, used to obtain stress-strain curves for six stress states, represented by the stress triaxiality η (mean-to-equivalent stress ratio), are shown in Fig. 1. Local strains were measured by digital image correlation (DIC). To do so, a high-contrast speckled pattern was sprayed onto the specimen surface, which was recorded during the test by a high-speed, high-resolution stereo camera (Fig.2). Local strains are then derived from the change in the pattern using software GOM ARAMIS [1]. Thus-derived FD curves are shown in Fig.3.

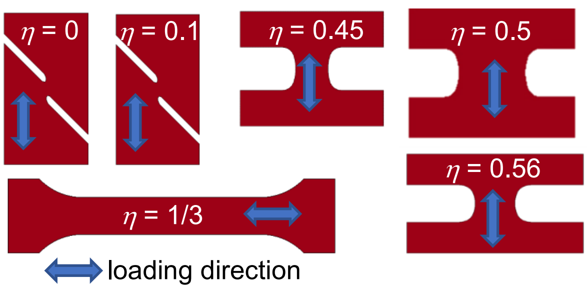

Fig.1 Specimens (active region): shear0 (η = 0), shear25 (0.1), uniaxial tension (1/3), notch9 (0.45), notch16 (0.5), notch5 (0.56)

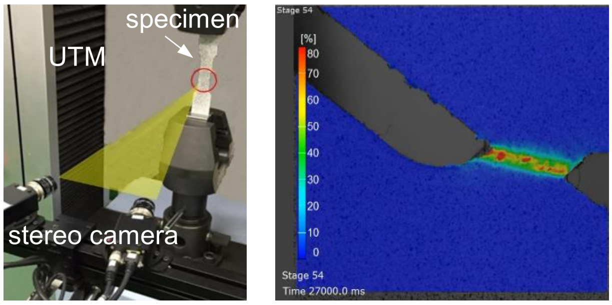

Fig.2 DIC setup (left); GOM ARAMIS image of strain distribution during shear test (right)

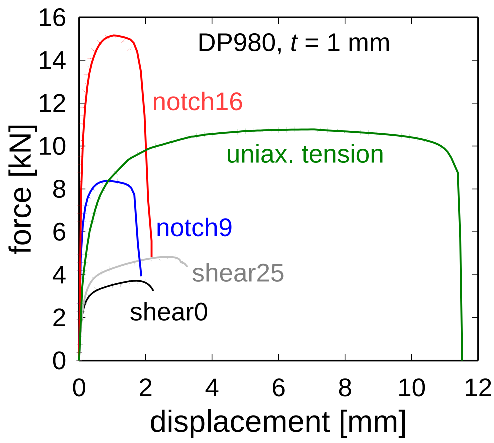

Fig.3 Experimental (dotted lines) vs. FD curves obtained with optimized parameters (solid)

3. Damage model

The GISSMO, a pragmatic, phenomenological damage model, was developed to facilitate transfer of pre-damage from forming to crash analysis, where coarser meshing is essential [2]. The equivalent strains at the onset of necking, ε_u, and at fracture, ε_f, are taken as η-dependent weight functions in the calculation of forming intensity F and damage parameter D

$$F = \int_0^{\varepsilon_p} \frac{m}{\varepsilon_u(\eta)} F^{1-1/m} d\varepsilon_p \quad (1)$$

$$D = \int_0^{\varepsilon_p} \frac{m}{\varepsilon_f(\eta)} D^{1-1/m} d\varepsilon_p \quad (2)$$

where ε is the equivalent strain; m and f are, together with ε_u, and ε_f, GISSMO parameters that need to be found by optimization. F and D start accumulating with positive plastic strain increments $d\varepsilon_p$ and thus with the onset of plasticity. Once F reaches unity, D_c is set to the current D value, upon which the stress tensor $\boldsymbol{\sigma}$ is degraded to $\boldsymbol{\sigma}^*$ according to

$$\boldsymbol{\sigma}^* = \boldsymbol{\sigma}\left[1-\left(\frac{D-D_c}{1-D_c}\right)^f\right] \quad \text{for } D \geq D_c \qquad (3)$$

and the material fails when D = 1. The problem of mesh-dependence is tackled by a mesh regularization function that serves to scale numerical post-necking material behavior.

4. Optimized damage parameters

Damage parameters are found by setting up FE models (geometrically equal to Fig.1; 4-node shell elements with element size e = 2 mm) and applying them to LS-Opt with ε_u, ε_f, m and f being the parameters to be optimized by minimizing the area between experimental and numerical FD curves.

Final values are shown in Fig.4 along with the mesh regularization curve; for m and f we arrive at 0.102 and 3.86, respectively.

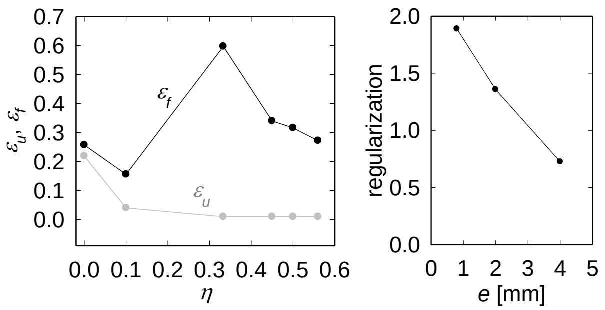

Fig.4 η-dependence of ε_u and ε_f and regularization

5. Validation Strap

A strap with two elongated holes is loaded by clamping its lower part and sticking a quasi-rigid pin through the upper hole, which then moves upwards (Fig.5). The external load-displacement responses from experiment and finite element analyses (FE) with and without damage are compared in Fig.6. We can see from Fig.6 that close to the point where tearing sets in both numerical models give results similar to the experiment, although the maximum load is somewhat underestimated. However, afterwards the curves deviate significantly due to the neglect of damage; while the 'no damage' curve rises, the 'GISSMO' curve approaches zero, which is in accordance with the experiment. Further, strain values are compared in the region subject to high tearing short before fracture (Fig.5). Here, the neglect of damage leads to a high overestimation of the strains in the failure region, while the strain obtained with the GISSMO is close to the one observed in the actual test.

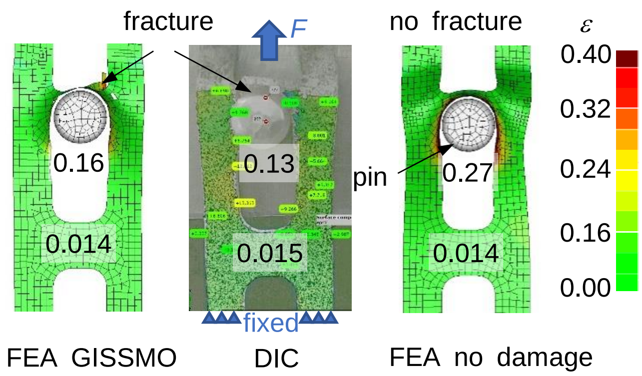

Fig.5 Strain distribution short before fracture

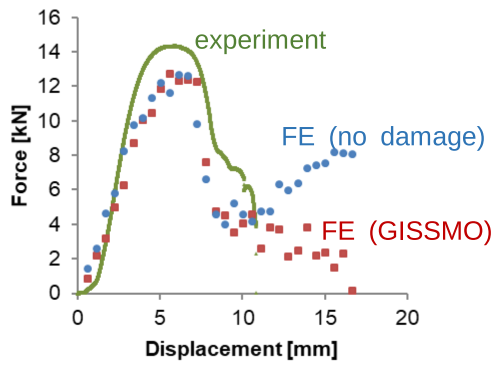

Fig.6 Comparison of experimental with numerical FD curves

The underestimation of the maximum load may be due to the assumption of shell elements (instead of solid ones) and the neglect of in-plane anisotropy, inevitable in metal sheets. Nevertheless, the validation shows that using the GISSMO we can accurately predict the failure in structures under even complex loading conditions.

References

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[2.] F. Neukamm et al., Considering damage history in crashworthiness simulations, *7th Eur. LS-DYNA Conf.* (2009).