SOME RESULTS OF THE NUMERICAL ROUND-ROBIN ON LOCAL CRITERIA

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Fifteen different laboratories have modelled numerically the same experiment on a notched tensile bar. Comparisons of their results are given as well for measured parameters like the load and the displacement as for more local parameters computed from the stress and strain distribution. The aim of this exercise is an estimation of the errors made when the local criteria for fracture are measured.

INTRODUCTION

The EGF task-group on elastic plastic mechanics has launched a round-robin on the local criteria. This round-robin includes an experimental part and a numerical one. The first one is not finished. The second part is well advanced and 15 participants have completed the calculations and have sent a complete set of results.

These calculations include the numerical simulation of a notched tensile test. This test is used to measure the parameters of the local criteria. The object of this short note is to give preliminary results on the comparison of the different results.

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PROBLEM DEFINITION

The geometry and boundary conditions used are given in figure n° 1. the document which defines the exercise (1) gives also some indications on the maximum size allowed for the elements. It recommends to use standard isoparametric 8 nodes elements with reduced integration, but this was not obligatory. The stress-strain curve of the material is described in details. It is a typical hardening curve for a low alloyed steel. All other parameters such as : computer code, algorithm used, exact meshing etc..., are left free.

The only specific point required is the necessity to include some large strain formulations such as the updated lagrangian calculation : the plastic strains at fracture in this kind of specimen are actually very large.

RESULTS GIVEN

Fifteen participants gave a complete set of results. These results include :
- the load,
- the current diameter fo the minimum section, i.e., displacement of node 2, at the tip of the notch (see Figure 1),
- the maximum principal stress, the stress triaxiality and the plastic stran in the center of the specimen,
- the evaluation of the local criterion for ductile fracture in the center of the specimen (2),
- the evaluation of the local criterion for cleavage (3).

Moreover, they gave the isovalues of the plastic strain, hydrostatic stress, maximum principal stress and their distribution along the axis of the specimen and in the minimum section.

GLOBAL EVOLUTION OF THE DIFFERENT PARAMETERS

For the first steps of loading, the specimen behaves elastically. Then, plasticity begins at the root of the notch. At this moment, the tensile stress and the tensile strain are a maximum at the tip of the notch. However, for a rather small increase of the remote imposed displacement, the plastic zone reaches the axis of the specimen : the whole minimum section becomes plastic. Afterwards, the plastic zone increases upward. A stress redistribution takes place and the maximum of the tensile stress shifts from the root of the notch towards the axis of the specimen. In this location, the stress triaxiality is very high. That is why ductile fracture and cleavage fracture occur in the center of the specimen for this kind of smooth notches. All participants found the same kind of behaviour.

COMPARISONS OF THE DIFFERENT RESULTS

Global Parameters

During the experiments on the notched tensile bars, the load and the minimum diameter of the specimens are continuously recorded. The experimental result is mainly a curve relating these two parameters plus the point at which fracture occurs.

Because of the similarity with a conventional tensile test, we define a mean stress $\bar{\sigma}$ as the load divided by the current area of the minimum section and a mean strain by :

$\bar{\varepsilon} = 2\ \mathrm{Ln}(\emptyset_0/\emptyset)$ where $\emptyset_0$ is the initial diameter of the minimum section and $\emptyset$ is its current value ($\emptyset_0$ = 10 mm).

The numerically predicted loading curves are given in Figure 2. Node 2 is the one at the tip of the notch. Up to a 0.22 mm shrinkage of the minimum radius (i.e. $\bar{\varepsilon} \approx$ 8,8%), all the calculations agree very well. Beyond this point, corresponding roughly to the maximum of the load, the scatter increases. If the "hump" on curve N° 11, at 0.37 mm is removed, the error is 2% on the load for a given shrinkage of the diameter. This is comparable to an experimental scatter in a real experiment. A precise inspection of the figure shows that, besides curve N° 11 and the lower curve (N° 14), two curves are on the upper side of the scatter band (N° 15 and 12). For the remaining 11 calculations, the agreement is excellent till the end (better than 1% on the load for a given displacement).

Plotting the displacements of the node at the tip of the notch as a function of the imposed displacement on top of the model shown that the scatter is larger. For a given imposed displacement, the shrinkage of the miminum diameter is predicted with a 8% scatter. In the calculations, as in the experiments, the shrinkage of the minimum diameter is a better measure of the deformation of the specimens.

Local parameters. Local criteria use local values of the stresses and strains. It is therefore important to know if the local stresses and strains are comparable.

For example, the computed stress triaxiality in the center of the specimen exhibits a rather large scatter. The result from the participant number 6 is significantly lower and should be removed. The others are still scattered. Once again results of curves, N° 15, 12, 1 and 14 behave in a different manner. Removing it, the scatter becomes much smaller (triaxiality = hydrostatic stress/von Mises equivalent stress ≈ 1.38 ± 0.02). However, even including the former results, the scatter is large but still reasonable (± 6%) given the long procedure required for such a computation.

The scatter on the plastic strain (von Mises equivalent cumulated plastic strain) (see Figure 3) is also reasonable and all participants except participant number 12 have a very similar behaviour. For example, for $\bar{\varepsilon}$ = 25%, the predicted strain in the center element is 16.1% ± 0.8%. It is still not so large a scatter given the complexity of the numerical procedure to get this value.

Local criteria for fracture. Removing curve number 6, the maximum principal stress is computed with a ± 2,5% accuracy which is actually very good for 14 participants!

The scatter on the local criteria for a given mean strain is a direct consequence of the error already given on the local values of the stresses and strains. Especially, the stress triaxiality has a very strong influence on the ductile damage parameter. This damage parameter $(R/Ro)_c$ is computed from the plastic von Mises strain and the stress triaxiality ratio (3,4).

Therefore, the ± 6% error on the stress-triaxiality induces a ± 10% error on the computed ductile damage. More specifically, if the measured mean strain at fracture is 25%, the ductile damage is

$Ln\ (R/Ro)_c = 0{,}34 \pm 0.06$ or $(R/Ro)_c = 1.41 \pm 0.08$; (for $\bar{\varepsilon}$= 8%; $Ln\ (R/Ro)_c = 0.09 \pm 0.01$).

If the results N° 11, 14, 15, 12 are removed, the scatter is significantly reduced.

For the cleavage damage, once the corrections for the errors on the unit volume V_0 are made because of an ambiguous notation in the definition of the exercice, the Weibull stress, for a mean strain of 25% is computed as :

$\sigma_w = \bar{\sigma} \times (1.91 \pm 0.07)$. (For $\bar{\varepsilon}$ = 8%, it will be a multiplicative factor of 1.88 ± 0.05). This Weibull stress is computed from the distribution of the maximum principal stress in the plastic zone. It is simply related to the probability of failure (see Ref. 2). Once again, the scatter can be reduced if the results giving different loading curves are removed.

CONCLUSIONS

All the participants gave very similar results as far as the global behaviour of the specimen is concerned. The scatter on the local values of the mechanical parameters is rather small and can be correlated with slight differences on the loading curve. The local criteria, for a given experimental result at fracture of 25% average strain and 1290 MPa average stress will be, depending on the numerical results used :

$(R/Ro)_c = 1.41 \pm 0.08$

$\sigma_w = 2460 \pm 90$ MPa

This scatter, depending on the numerical procedure used, is of the same order of magnitude than the experimental scatter. A better standardisation of the numerical procedure would lead to a narrowed band.

ACKNOWLEDGEMENTS

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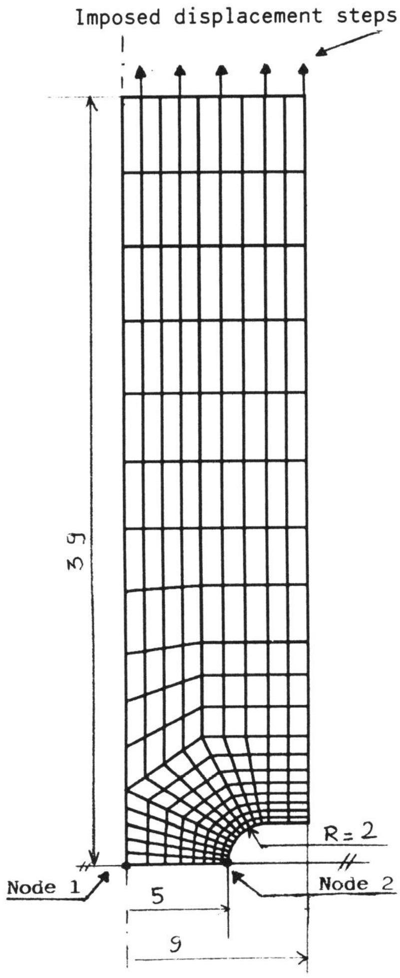

Figure 1 Geometry and loading of the modelized specimen. The minimum diameter is 10mm and the notch radius is 2mm

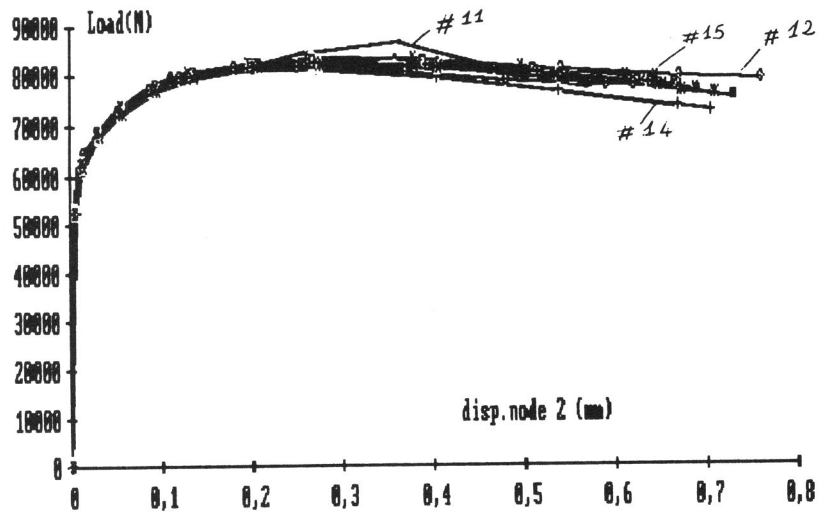

Figure 2 Computed load displacement curve

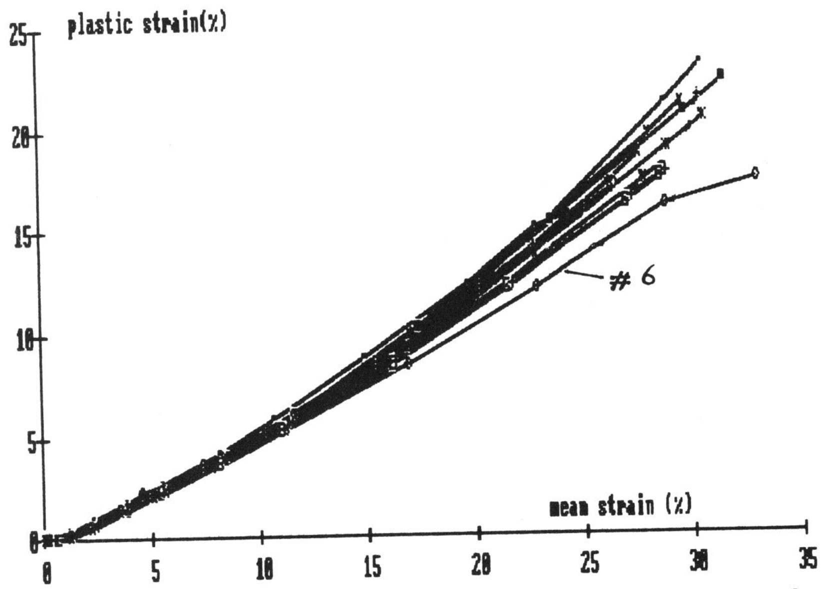

Figure 3 Equivalent von Mises plastic strain in the center of the specimen