NUMERICAL ROUND ROBIN ON MICROMECHANICAL MODELS

W. Brocks[1],

Continuing former activities on "Local Approaches“, ESIS TC8 started a numerical round robin on the application of "Micromechanical Models" for describing fracture phenomena in ferritic steels, both ductile tearing and cleavage. The paper reports the results of Phase I, i.e. the numerical analyses of a standard smooth and a notched tensile specimen to identify critical damage parameters for ductile tearing at room temperature and for cleavage at $-196^{o}C$, respectively. The round robin will continue with numerical simulations of fracture mechanics tests.

INTRODUCTION

"Local approaches" and "micromechanical models" of fracture have found increasing interest since some years. Their general advantage, compared with classical fracture mechanics, is that, in principle, the parameters are only material and not geometry dependent. The identification and determination of the "micromechanical" parameters require a hybrid methodology of combined testing and numerical simulation [1]. Different from classical fracture mechanics, this procedure is not subject to any size requirements for the specimens as long as the same fracture phenomena occur. The fracture process for most of the structural steels under monotonic loading may take place either by the formation of microcracks and their extension with little global plastic deformation ("brittle" or cleavage fracture), or by the nucleation, growth, and coalescence of microvoids with significant plastic deformation (ductile rupture). Modern constitutive models for both failure phenomena exist, in particular

---

[1] GKSS Research Centre, Max-Planck-Str.,, D-21502 Geesthacht

- the BEREMIN model [2] based on a critical fracture stress concept together with the "weakest link" assumption and WEIBULL statistics [3], and
- the GURSON-TVERGAARD-NEEDLEMAN (GTN) model [4, 5] based on the RICE and TRACEY void growth law [6].

TASK

ESIS TC8, Numerical Methods, started a numerical round robin in October 1993 on the application of "Micromechanical Models" for describing fracture phenomena in metals, both ductile tearing and cleavage. The task included the numerical analyses of

- Task A: a standard smooth tensile specimen of total length $60mm$ and diameter $d_0 = 6mm$, to identify critical damage parameters for ductile tearing at room temperature (RT), and
- Task B: a notched tensile specimen of total length $75mm$, gross section diameter $D_0 = 10mm$, net (minimum) section diameter $d_0 = 5mm$ with a semi-circular circumferential notch of radius $R = 2mm$, to identify critical parameters for cleavage at -196^oC..

Tests on respective specimens made of the ferritic steel with the German destination 22 Ni Mo Cr 3 7 have been performed at SIEMENS/KWU Erlangen to provide the experimental data. No restrictions were imposed on the participants with respect to the "micromechanical" model they would prefer to use for describing ductile tearing, in order to encourage as many participants as possible to join the round robin. The application of the GTN model [4, 5] and the BEREMIN model for cleavage fracture [2] was recommended, nevertheless.

CONTRIBUTIONS

By the end of 1994, there were 14 contributions to the round robin from 12 European countries. Not all of them provided results for both tasks. The simulation of ductile damage requires a special routine which is not yet available in all commercial codes. Thus, there are only ten full solutions for task A and eleven for task B, respectively. Eight participants applied the GTN model for task A. One participant gave an additional solution for the ROUSSELIER model [12]. and another had chosen the RICE and TRACEY [8] void growth model. Eight participants applied one of the major commercial general purpose FE programs, the rest had less widespread, internal or self-developed codes.

RESULTS

Table 1 summarizes the basic results, i.e. the parameters of the "micromechanical" models which have been determined by fitting the numerical simulations to the experimental records, especially the void volume fractions of the GTN model for coalescence and final failure, f_c and f_f, respectively, for task A and the WEIBULL parameters of the BEREMIN model, m and σ_u, for task B. Further details may be found in the report [8]

Task A: Ductile Failure of a Smooth Tensile Bar

The critical void volume fraction at coalescence, f_c, should be determined by fitting the numerical results to the experimental records of load, F, vs. reduction of diameter, Δd, in the necking cross section at the break-point of final rapid decrease of load. The F vs elongation, ΔL, and reduction of diameter, Δd, curves of all participants in comparison with the experimental data are plotted in Figure 1 respectively The agreement within the different solutions and with the experimental data is, in general, satisfactory. Maximum load varies between 16522*N* and 17067*N* with an average value of 16726*N*, For comparison, the maximum loads in the two experiments were 17063*N* and 16730*N*. The variations in the displacements between the different solutions is much higher. The various F vs Δd curves lie much closer together than the F vs ΔL curves, as long as no relevant damage occurs.

The critical values of void volume fraction, f_C, which vary between 0.005 and 0.035, Table 1, depend on the individual fitting strategy of the numerical simulation. As the two experiments differed with respect to Δd at fracture the f_C values naturally differ according to whether an average or the highest value was fitted.

Task B: Cleavage Fracture of Notched Tensile Bars

The WEIBULL parameters, σ_u and m, were to be determined by an elastic-plastic FE analysis and calculations of the WEIBULL stresses at final fracture of the five tested specimens. The FE calculation yields one key curve of the deformation behaviour of the notched tensile bars. Figure 2 shows all the contributed data of F vs ΔL and F vs Δd curves. With two exceptions, they coincide very well. It was left to the participants whether they used the force, F, or the reduction of diameter, Δd, to correlate the load steps of their numerical analyses with the respective test results at fracture. Table 1 summarizes the results for m and σ_u. Two clusters of values have been obtained for m depending on the identifying parameter of fracture. If the reduction of diameter is taken, m is about 2.5 times higher than in the cases where the fracture load was chosen. As m is a measure of the scatter, this result means that the scatter of the loads at fracture is higher than the scatter of the deformations at fracture. The variation in σ_u is much less for Δd as identifying parameter. The predictions of the failure probability at a prescribed elongation of $0.14 mm$ range from 57% to 100% though the corresponding Δd lies between $0.084 mm$ and $0.087 mm$.

TABLE 1: Critical parameters for the GTN and the BEREMIN model

	specimen type A			specimen type B		
participant	f_c [-]	f_c [-]	K [-]	id. param.	m [-]	σ_u [MPa]
01	-	-	-	F	13.1	1920
02	-	-	-	-	30.0	1763
03	0.014	0.200	3.2	-	-	-
04	0.015	0.179	4.0	Δd	42.8	1784
05	-	-	-	-	-	-
06	0.035	0.193	4.0	Δd	42.2	1812
07	0.033	0.150	5.4	F Δd	16.8 42.3	1846 1805
08	0.020	0.054	15.0	F	16.7	1924
09	0.016	0.179	4.0	F	10.5	2132
10	0.005	0.170	4.0	F Δd	24.2 41.4	1694 1810
11	(0.023)	-	-	Δd	33.0	1810
12	0.015	0.178	4.0	F Δd	16.7 42.8	1879 1809
13	0.010	0.174	4.0	F	16.6	1800
14	-	-	-	-	-	-

CONCLUSIONS

The "determination" of the material parameters depended more on the identification strategy than on the FE code. A generally accepted assent about the respective procedures has to be found and, finally, to be fixed in recommendations.

Problems of mesh dependence of results due to localization of damage and questions of the choices of characteristic material lengths and volumes did not yet arise, they will gain significance in the next phase when tests on fracture mechanics specimens are to be simulated. Again, this is not only a question to numerics but to physics as well.

The experiences of the round robin also suggest the application of improved techniques in materials testing. For instance, the reduction of diameter should always be measured together with the necking radius in future tensile tests. Methods of examining and measuring damage on the micro scale might help to improve the mechanical models and to validate the numerical procedures.

REFERENCES

[1] MUDRY, F. and DI FANT, M.: "A round robin on the measurement of local criteria", IRSID Report RI 93.334, September 1993.

[2] BEREMIN, F.M. Metallurgical Transactions A, Vol. 14A (1983), 2277-2287.

[3] WEIBULL, W., "A statistical theory of the strength of materials", Ingeniørsvetenskapakademiens, Nandlinger No. 151, 1939.

[4] GURSON, A. L., J. Engng. Materials and Technology 99 (1977), 2-15.

[5] TVERGAARD, V. and NEEDLEMAN, A., Acta Metall. 32 (1984), 157-169.

[6] RICE, J.R. and TRACEY, D.M., J. Mech. Phys. Solids 17, (1969), 201-217.

[7] ROUSSELIER, G.,, Nuclear Engineering and Design 105 (1987), 97-111.

[8] Brocks, W.: „Numerical round robin on micrmechanical models“ Report IWM T 8/95, Freiburg, March 1995.

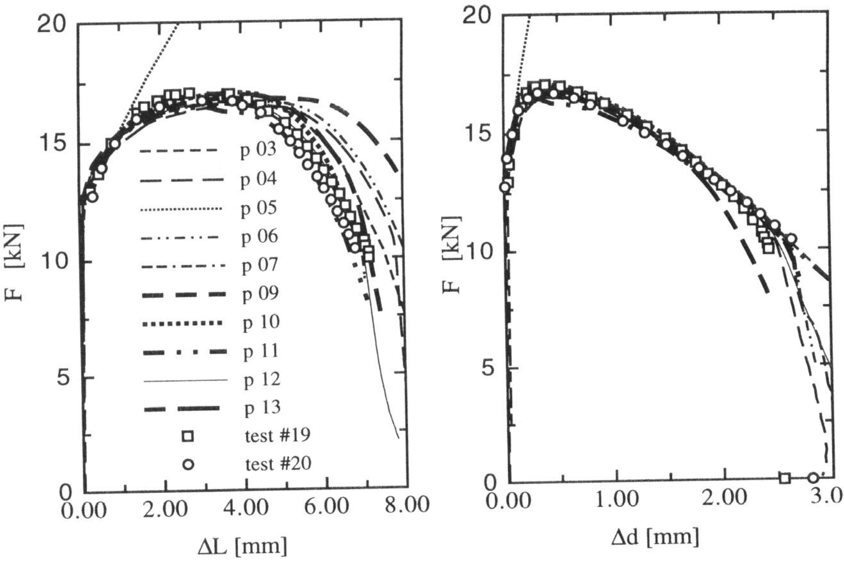

Figure 1: Task A, smooth tensile bar at 20 °C

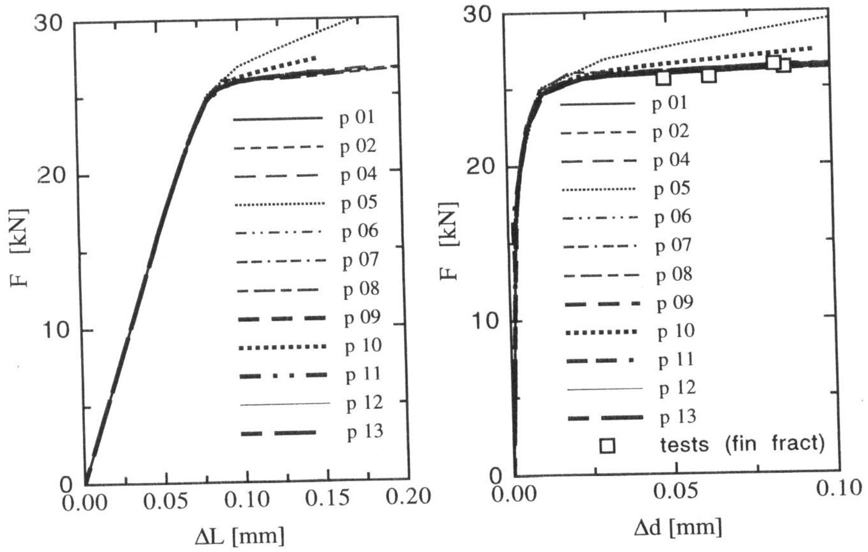

Figure 2: Task B, notched tensile bar at -196 °C