RESULTS AND NUMERICAL ANALYSIS OF LOCAL CRITERIA ROUND ROBIN

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Results and numerical analysis of local approach to cleavage and ductile fracture of ASTM A508 steel are presented in the paper. The results of the numerical simulation, presented in the paper are obtained by the computer program published in (1). Through the numerical analysis of the results, a new criterion of cleavage fracture is derived. It is based on the relation of plastic to total deformation energy of a loaded structure. A brief comparison with the results of statistical cleavage criterion shows a reasonable agreement.

INTRODUCTION

Local approach to fracture combines the computation of local stresses and strains in most loaded parts of a structure, mechanical parameters and characteristics of physical damage mechanisms. It attempts to join metallurgical and mechanical analysis through the direct relation between mechanical parameters of damage and fracture micro mechanics (1).

The structure is axisymmetrical notched tensile bar, made from ASTM A508 steel. It is analyzed by means of an elasto-plastic finite element calculation of 12 tensile test stages. The parameters of damage model of cleavage and ductile fracture are evaluated from the stress and strain history in unit volumes, characteristic for the material micro structure, during the tensile test. The dimensions of unit volumes are determined experimentally and are taken into account in the finite element mesh design.

NUMERICAL ANALYSIS

One quarter of the axisymmetric notched tensile bar - specimen of A508 steel, is modeled by two finite element meshes: the first one consisted of 331 nodes and 96 eight-noded isoparametric quadrilateral elements (shown in Fig.1) and the second one of 584 nodes and 196 elements.

Boundary conditions are given in the form of known axial displacements, imposed to the nods on the top edge of specimen. Additional boundary conditions, according to the geometry are zero radial displacements of the nods at the axial symmetry axis and zero axial displacements of the nods at the radial symmetry axis of the specimen. Twelve characteristic steps of the tensile test are chosen for the simulation.

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Calculations of relevant displacement, strain and stress fields in the specimen, through the given steps of the tensile test are performed by personal computer programme published in (1) and modified accordingly.

The problem is analysed according to the instructions given by Mudry (2). Two different meshes were used in order to investigate the mesh influence on the results. As it can be seen from the tables 1 to 3, this influence is rather small. Comparing the results obtained here and presented by Mudry (2), one can notice generally that the displacements, strains and stresses are cca. 10% lower here while the load is cca. 8% higher. We believe that the reason for this is due to the large geometry changes, which were not taken into account here.

RESULTS OF THE SIMULATION

The finite element calculations were performed for the mechanical characteristics at the room temperature. The values of local approach parameters, V_o = (0,1 mm)^3 and m = 22 are assumed for the evaluation of Weibull stress (3).

Results for load F vs. u_r are shown in Fig. 2 for both meshes. As it can be seen there is almost no diference between them. This surprising result needs further clarification in future work.

TABLE 1 - Specimen load and radial notch tip displacement, calculated by FEM for imposed elongation, in various steps of tensile test.

Measured values		Calculated values			
Tensile test	Axial displac.	Notch tip dis.		Load	
Step N°	w_z [mm]	$- u_r$ [mm] *		F [kN] *	
1	0.050	4.34	4.01	52.8	53.0
2	0.065	12.0	11.5	60.3	63.3
3	0.085	28.2	2706	69.6	69.9
4	0.110	51.3	51.0	74.6	74.9
5	0.145	86.4	84.5	79.6	79.7
6	0.180	123	120	82.4	82.7
7	0.235	180	177	85.2	85.6
8	0.290	240	239	86.2	86.4
9	0.380	341	340	87.0	87.6
10	0.465	446	450	86.3	86.4
11	0.545	546	555	82.3	84.4
12	0.567	587	582	80.7	80.9

* Results for the rude mesh

TABLE 2 - Stresses and strains in the center of the specimen, calculated by FEM in various steps of tensile test.

Step N°	ε_p	ε_p *	σ_m/σ_{eq}	σ_I [MPa]	σ_{zz} [MPa]
1	0.000	0.000	1.13	474.9	474.9
2	0.000	0.000	1.06	681.4	681.3
3	0.001	0.000	1.03	877.3	877.3
4	0.005	0.005	1.31	1000.1	1000.1
5	0.012	0.012	1.31	1102.9	1102.8
6	0.019	0.019	1.31	1166.6	1166.5
7	0.031	0.032	1.27	1228.1	1228.0
8	0.045	0.043	1.26	1287.2	1287.1
9	0.069	0.067	1.28	1365.0	1365.0
10	0.102	0.097	1.27	1407.4	1407.2
11	0.138	0.138	1.37	1446.0	1445.6
12	0.165	0.157	1.31	1498.3	1497.9

* Results for the rude mesh

The Weibull stress value σ_W, increases linearly with the equivalent plastic strain ε_p at the notch tip, after reaching the constant load in the minimal cross section (Fig.3). That implies that until the plastic zone propagates over the specimen, the cleavage fracture probability P* should increase according to the physical postulates of the model (3). If micro cracks are created as soon as plasticity begins and there are no cracks out of the plastic zone and all plastic deformation energy vanishes into the damage, then P* can be expressed as the relation of the plastic deformation energy E_{PD} to total deformation energy E_D of the structure:

$$P^* = E_{PD}/E_D \qquad (1)$$

Plastic deformation energy $E_{PD,i}$ of the "i-th" finite element in the plastic zone, can be arbitrary treated as an accurate measure of the intensity of cleavage process , unless the whole element volume ΔV_i is captured by plastic deformation and all $E_{PD,i}$ is invested in nucleation and growth of micro cracks. Mathematical expression for $E_{PD,i}$ exhibits the influence of local stress and plastic strain tensor components to the cleavage process as:

$$E_{PD,i} = 1/2\ \Sigma_{PZ} \{ \Sigma_j \Sigma_k \sigma_{jk} \varepsilon_{p,,jk} \} \Delta V^*_i \qquad (2)$$

The complete investment of total deformation energy E_D in the damage of the structure is then a measure for the certain complete fracture. E_D can be expressed as:

$$E_D = 1/2\ \Sigma_i \{ \{ \Sigma_j \Sigma_k \sigma_{jk} \varepsilon_{jk} \} \Delta V^*_i \} \qquad (3)$$

where j and k are direction indexes, $\Delta V^*_i = 2\ \Delta V_i$ considers the whole specimen and Σ_i is the summation over all finite elements of the mesh.

The material parameter σ_u = 2027.2 MPa is determined as a value corresponding to P* = 1- e^{-1} (3). The cavity growth rate at the notch tip is in the reasonable agreement with critical value $(R/R_0)_c$ = 1.2 derived by Mudry (2), for specimens of A508 steel, with transversally oriented notches.

Figure 4 shows the dependance of the probability of cleavage fracture P* of Weibull stress.

TABLE 3 - Stresses and strains at the tip of the specimen's notch, calculated by FEM in various steps of tensile test.

Step N°	ε_p	ε_p *	σ_m/σ_{eq}	σ_I [MPa]	σ_{zz} [MPa]
1	0.007	0.011	0.75	722.0	711.9
2	0.015	0.024	0.72	755.1	745.6
3	0.028	0.042	0.67	804.0	794.3
4	0.044	0.066	0.65	852.0	841.4
5	0.070	0.100	0.66	899.1	887.6
6	0.097	0.135	0.64	932.8	919.9
7	0.143	0.195	0.64	966.3	950.8
8	0.183	0.253	0.62	983.9	966.1
9	0.255	0.331	0.62	1022.1	1002.9
10	0.324	0.427	0.59	996.5	973.9
11	0.390	0.504	0.57	1061.8	1039.2
12	0.413	0.495	0.56	1056.5	1030.6

* Results for the rude mesh

TABLE 4 - Weibull stress, ductile fracture cavity growth rate at the notch tip and in the center of the specimen and probability of cleavage fracture calculated by eq.1

Step N°	σ_w [MPa]	R/R_0 (1) at the notch tip	R/R_0 (2) in the center	P* (eq.1)
1	1167.57	1.006	1.000	4.1
2	1313.61	1.013	1.000	11.8
3	1464.45	1.023	1.001	29.1
4	1593.73	1.035	1.011	48.2
5	1732.67	1.056	1.023	57.1
6	1828.62	1.077	1.039	69.0
7	1926.49	1.113	1.062	78.0
8	2007.47	1.145	1.089	84.6
9	2093.26	1.204	1.141	91.9
10	2162.96	1.262	1.212	95.1
11	2178.12	1.317	1.307	97.2
12	2241.76	1.340	1.380	97.9

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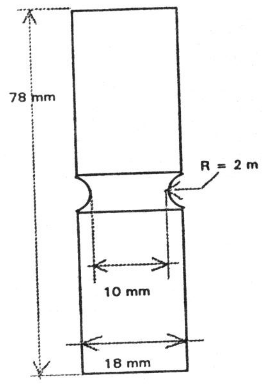
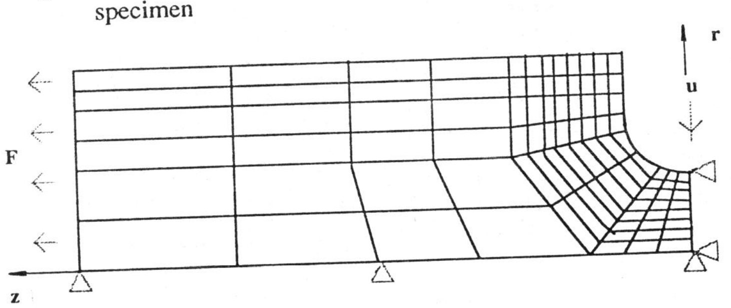


Fig.1 : Finite element mesh of one quarter of the axisymmetric notched specimen



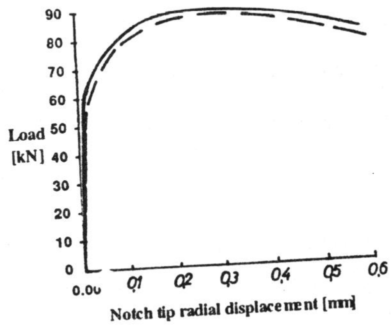


Fig.2 : Spacemen load versus radial displacement of the notch tip calculated by FEM.

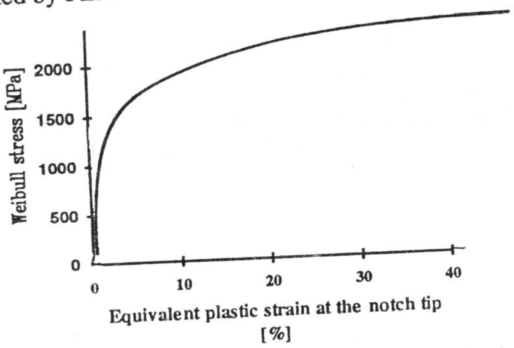


Fig.3 : Weibull stress versus equivalent plastic strain at the notch tip.

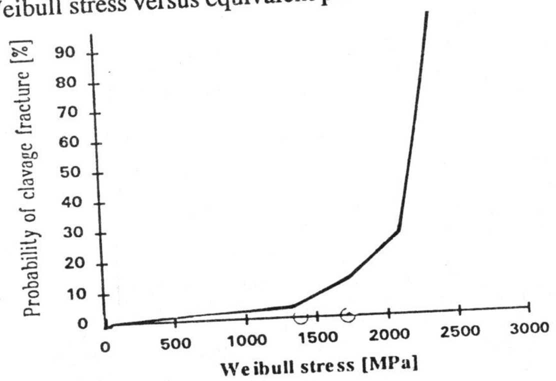


Fig.4 Probability of cleavage fracture versus Weibull stress.