RESULTS AND ANALYSIS OF LOCAL CRITERIA EXPERIMENTS IN THE SCOPE OF ESIS ROUND ROBIN

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The Laboratory for Fracture Mechanics at the Faculty of Technology and Metallurgy, University of Belgrade, has been included in Round Robin, organized by ESIS TC1 Subcommittee on Local Approach, lead by Prof Mudry. The experimental procedure, that differed slightly from the prescribed procedure is described. The changes in notch profile had been followed not only by measurement of contraction, but also by use of the image on a profile projection. Additionally, the surface roughness was measured in the notch root. The analysis of fractured surfaces has been performed in order to get a closer insight into the fracture mechanism, that is different at different testing temperatures (100°C and - 196°C).

INTRODUCTION

Since classical criteria for determining K_{Ic} and J_{Ic} are not reliable in more complex cases, such as large scale yielding, asymmetrical or anisothermal loading conditions and a complex stress state of the components of large structure, the local approach is more frequently applied (1). It represents a combination of calculations of local stress and strain in the most stressed parts of the structure and mechanical parameters, characterizing physical damage mechanisms. These were the reasons for ESIS to organize a comprehensive Round Robin experiment. This paper describes the experimental part performed by the Laboratory for Fracture Mechanics at the Faculty of Technology and Metallurgy, University of Belgrade. Due to the complexity of the experiment, some original technical solutions were necessary, as well as highly precise measuring equipment, defined in (2).

EXPERIMENT

In order to carry out the experiment under the conditions of ductile and cleavage fractures, the specimens were tested at temperatures of 100°C and - 196 °C. The material, specimens design, conditions of testing, instructions for computing the results and the technical consulting were provided by the organizer of this project.

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The process of machining and testing. The specimens were made according to Figure 1, showing that the dimensions are with high tolerances and with high quality of surfaces. In order to meet such high demands, the assistance of some specialized firms was asked. Apart from special types of mechanical machining, such as grinding with a profiled grind and polishing, special care was applied to dimension and roughness control of specimens. The control of roughness and the profile of the notch was carried out using Taylor-Hobson equipment. Three different notch radii R where used in order to check the influence of triaxiality. Table 1 and 3 show initial dimensions of specimens measured by this method.

Notched Tensile Bars - Ductile Fracture. As it was mentioned this experiment was carried out at temperature range 100°C ± 1°C, in order to meet the conditions of ductile fracture. Test was carried out in cross head control at a speed of 0.5 mm/min, with co-axial conditions fulfilled. The following equipment was used: Electro-mechanical Testing Machine Schenck Trebel RM 100 - 100 kN, Temperature Chamber Brabender, Material Testing Computer HP 300, X-Y Recorder HP 7090 A and Diametral Extensometer Instron A 1439-1014, Figure 2. During testing load and diametral strain were recorded by X-Y recorder. At the same time, the computer acquisition was made.

TABLE 1 - Initial dimensions of the specimens - ductile

Specimen No	Theoretical notch radius R_t mm	Actual notch radius R_s mm	Outer diameter D mm	Diameter min section Φ_0 mm	Roughnes R_a μm
E	10	9.956	17.82	9.962	1.261
F	10	9.989	17.80	9.959	1.275
A	4	3.983	17.75	9.930	1.371
D	4	4.116	17.78	9.932	0.631
B	2	2.057	17.84	9.941	0.367
C	2	2.102	17.76	9.977	0.410

Results of the experiment. On the basis of recorded diagram, and digital acquisition, the values of load and diametral strain P_f and Φ_F were chosen, corresponding to the unstable crack growth. The data enabled calculation of the mean stress σ_F:

$$\sigma_F = \frac{4\ P_F}{\pi\ \Phi_F} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

and the mean ductility at rupture ε_F:

$$\varepsilon_F = 2\ ln\left(\frac{\Phi_0}{\Phi_F}\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

which made possible to reach critical cavity growth R/R_0 on the basis of the diagram $log\ (R/R_0)$ - ε_F (2). The summary of these results is given on Table 2.

TABLE 2 - Experimental results in the conditions of ductile fracture

SPECIMEN No.	ACTUAL NOTCH RADIUS R_s (mm)	VALUES AT FRACTURE INITIATION				CRITICAL CAVITY RATIO $\frac{R}{R_0}$
		DIAMETER Φ_F (mm)	LOAD P_F (N)	MEAN DUCTILITY ε_F	MEAN STRESS σ_F (MPa)	
E	9.956	7.622	51 450	0.535	1 128	3.503
F	9.989	7.615	51 150	0.537	1 123	3.524
A	3.983	8.295	63 350	0.360	1 172	3.670
D	4.116	8.277	64 400	0.364	1 197	3.766
B	2.057	8.615	74 800	0.286	1 283	2.800
C	2.102					

TABLE 3 - Initial dimensions of the specimens - cleavage

Specimen No	Theoretical notch radius R_t (mm)	Actual notch radius R_s (mm)	Outer diameter D (mm)	Diameter min section Φ_0 (mm)	Roughnes R_a (μm)
29 E	10	9.901	17.75	9.936	
29 F	10	9.929	17.78	9.936	1.733
29 L	10	9.907	17.80	9.944	0.836
29 C	4	4.066	17.70	9.955	1.094
29 G	4	3.985	17.76	9.974	
29 K	4	4.020	17.82	9.954	1.229
29 A	2	2.001	17.88	10.003	0.983
29 B	2	2.027	17.78	10.004	0.587
29 M	2	2.051	17.80	9.984	0.504

Notched Tensile Bars - Cleavage Fracture. This experiment was carried out at - 196 °C which meets the conditions of cleavage fracture. The temperature was obtained in liquid nitrogen. Thus, meeting the requirements of co-axiality during the tests, as well as safe and reliable work on the test, was ensured with a minimum use of liquid nitrogen. Since the maximum load during the experiment sometimes exceeded 100 kN testing was done using the frame RM 400 - 400 kN. The test was performed under cross head displacement control at the speed of 0.5 mm/min. Since no extensometer for measuring of diametral strain at such low temperature was available, we followed the load as the function of displacement. The analogous record of this test enabled to check its regularity.

Results of the experiment. The value of maximum load was memorized during tests, of which the mean stress σ_F was calculated by eq. (1). Since we had no possibility of measuring diametral strain, and

having also in mind that the elastic deformations are negligible in case of cleavage fracture, diameter of the fracture surface was measured both in transverse and short transverse direction. Table 4 shows that differences between the two diameters (T and ST) are not

TABLE 4 - Experimental results for the cleavage fracture

SPECIMEN No.	DIRECTION	REAL NOTCH RADIUS R_s (mm)	DIAMETER MINIMUM SECTION ϕ_0 (mm)	DIAMETER AT FRACTURE ϕ_F (mm)	LOAD P_F (N)	MEAN DUCTILITY AT RUPTURE ε_F	MEAN STRESS σ_F (MPa)	WEIBULL STRESS σ_w (MPa)
29 E	T	9.901	9.936	9.49	90 750	0.09185	1 283	2 483
	M			9.485		0.09291	1 284	
	ST			9.48		0.09396	1 286	
29 F	T	9.929	9.936	9.91	88 200	0.00524	1 143	2 038
	M			9.895		0.00827	1 147	
	ST			9.88		0.01134	1 150	
29 L	T	9.907	9.944	9.56	90 600	0.07876	1 262	2 446
	M			9.55		0.08086	1 265	
	ST			9.54		0.08295	1 267	
29 C	T	4.066						
	M							
	ST							
29 G	T	3.985	9.974	9.84	101 200	0.02705	1 331	2 531
	M			9.835		0.02807	1 332	
	ST			9.83		0.02908	1 333	
29 K	T	4.020	9.954	9.86	100 900	0.01898	1 321	2 448
	M			9.855		0.01999	1 323	
	ST			9.85		0.02101	1 324	
29 A	T	2.001	10.003	9.94	113 250	0.01264	1 459	2 586
	M			9.935		0.01364	1 461	
	ST			9.93		0.01465	1 462	
29 B	T	2.027	10.004	9.89	113 750	0.02292	1 481	2 713
	M			9.88		0.02494	1 484	
	ST			9.87		0.02697	1 487	
29 M	T	2.051	9.984	9.87	111 100	0.02297	1 452	2 656
	M			9.865		0.02398	1 453	
	ST			9.86		0.02499	1 455	

significant. Anyhow, since they are within a measuring accuracy, they should be taken with reserve. Since it was necessary to measure minimal diameter in the area of fracture, measurements were made on the Profile Projector Mitutoyo PV-500 magnified 10 and 40 times. On basis of radii measured in this way, mean ductility at rupture ε_F was calculated according to eq. (2). From a diagram, showing the dependence of σ_w/σ_F on ε_F for different radii of notch, (2), Weibull stress was obtained. Results are given in Table 4.

CONCLUSION

Since the results of Round Robin experiment presented here are only a part of ESIS project, their evaluation will be made after the comparing and collecting all other results. In future we have idea to continue the local approach method in case of welded structure testing. This method is expensive, but if one has such problems as cracking in spherical welded pressure vessel it will pay of.

ACKNOWLEDGMENTS

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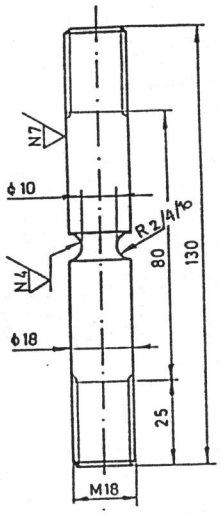

Fig. 1 Specimen design

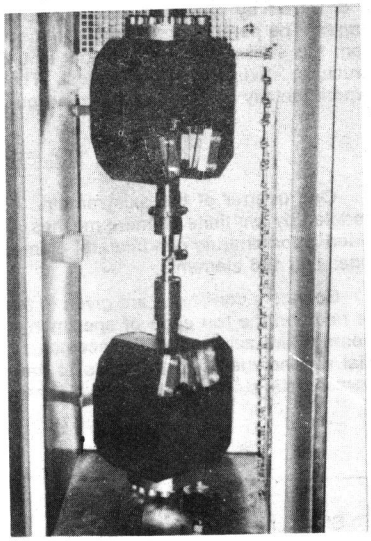

Fig. 2 Testing equipment