CRACK INITIATION AND -GROWTH IN CASE OF CHARPY SPECIMEN

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The purpose of the present paper is to evaluate J_i-values using Charpy-V-notch specimen. In order to do this, a deflection value related to crack initiation must be determined. This is done in slow bending experiments which are interrupted after a predefined deflection value. An examination of these bended specimen results in a correlation between plastic bending and notch opening. Cracks appear in the notch ground if specimen bending exceeds a critical value - this value is used to determine the crack initiation work U_i and J_i which are directly interrelated. These investigations are performeded for several notch radii and temperature. Applying this procedure to Charpy-impact-tests would allow to determine J_i from Charpy-impact-tests.

INTRODUCTION

It is the aim of this paper to evaluate J_i-values by means of Charpy-V-notch specimen. Crack initiation was especially considered in order to eliminate specimen size dependancy. According to the standard DVM 002 (1) for the determination of J_i, crack initiation was defined as the point, where further deflection does not result in a further growing of the stretch-zone resp. in a further deformation of the notch ground. Basing on this definition of initiation, J_i-values have been determined by means of Charpy specimen in the upper shelf region. Additional to the standard ISO-V-specimen we used as well specimen with a radius Ro = 0.1 mm and specimen with eroded slit (Ro = 0.04 mm).

EXPERIMENTAL PROCEDURE

The reactor pressure vessel steel 22 NiMoCr 37 in the quenched and tempered condition (2) has been used for the present investigation. The position of the specimen within the block was perpendicular to the rolling direction. Three-point-bending tests were performed by means of a computerized

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servo-hydraulic testing machine. Tests were stopped after a previously defined amount of deflection. The crosshead velocity was 0.05 m/s. Bending tests have been done at different temperatures between -160°C and +200°C. The testing device agrees with the standards for Charpy-V-notch impact test (1),(2).

The bent specimen were cut. The inserted halves of the specimen were ground and polished. Photographs of the notch base were taken by means of a stereo microscope, and shown in an 50-fold magnification.

EVALUATION OF R = R(f) AND R_i

The amount of plastic deflection f was optically measured after unloading. Up to a deflection of approx. 3 mm the notch ground can still be described by a circle with the radius of R. R = R(f) has been fitted by linear regression curves:

$$(V-notch; Ro = 0.25mm) \quad f_p = -1.0644mm + 4.4104 \cdot R \qquad (1)$$

$$(V-notch; Ro = 0.1mm) \quad f_p = -0.3340mm + 4.2509 \cdot R \qquad (2)$$

In case of eroded specimen we chose a section at 0,04 mm distance from the notch ground (Fig.1). The width of the notch was measured at a distance of 0,3 mm from this point. This place is very close to the point, where the actual notch radius begins. X indicates half the width of the notch and corresponds approx. to the notch radius. The X(f)-values obtained at different temperatures, are fitted by a regression line

$$(eroded \quad slit; Ro = 0.04mm) \quad f_p = -0.137mm + 5.38 \cdot X \qquad (3)$$

The determination of the critical notch radius R_i is based on the assumption that the notch ground is no longer deformed after crack initiation has taken place. The critical notch radius R_i which is typical for crack initiation, was calculated on this assumption by a numerical method. All cracks and bays which have been found in the 135°-segment of the notch were measured as parts of a straight line of the length b_j. The length of the original 135°-segment of the circular notch is diminished by the sum of the crack and bay segments b_j. The critical notch radius R_i, belonging to the new and smaller segment is calculated by means of equation

$$R_i = R(f) - \frac{\sum_i b_i}{117.8} \qquad (4)$$

This procedure was not applicable for specimen with large deflections, as here the notch base is no longer circular, as in case of the eroded specimen. In these cases the cracks were closed according to a more difficult graphical method: Transparent paper is placed over the 50-fold magnified photograph of the ground section. The outline of the notch is drawn on this paper up to the

first crack border. The final point is moved to the opposite crack border and the crack, thus, is graphically closed. In order to reconstruct the uncracked notch ground the segments are fitted applying the condition that the slope at the connection points is steady. After that, the drawing of the outline is continued. The reconstruction, thus obtained, shows the contour of the notch base in the state of crack initiation. The critical radius R_i is obtained by fitting notch patterns with known radii against this reconstruction. The critical COD-value in case of a crack corresponds to the difference $2(R_i\text{-}R_o)$ for a V-notch which should be described by critical notch opening displacement which is given in Fig.2 as a function of temperature.

EVALUATION OF J_i-VALUES

The critical plastic deflection f_i for each testing temperature was calculated by means of the regression lines (equ. 1 and 2 and 3)) and the critical notch radii R_i. The crack initiation work $U_i = U(f_i)$ was taken from the individual load-deflection-diagrams of each specimen. J_i has been calculated using the equation

$$J_i = \frac{U_i \cdot K}{B \cdot (W - a)} \tag{5}$$

where K = 1.46 holds in case of the notch radius Ro = 0.25 mm according to Aurich (4). K = 2 is typical in case of an ideal crack. The value K = 1.78 respectively K = 1.91 has been found by interpolation for the notch radius R_o = 0.1 respectively R_o = 0.04mm. The remaining cross-section of the notched specimen is B· (w-a) = 80 mm^2. The corresponding Ji-values as a function of temperature are given in Fig. 3.

DISCUSSION OF THE RESULTS

Discussion of the results has to take into consideration the limited accuracy of the evaluation methods and the material inherant scattering of the J_i-values. Determination of R and R_i by means of the above mentioned methods is found to be influenced by the person doing the measurement. Therefore, the fitting procedure has been repeated by 8 persons. We found an error of 2% for R and a rather more important error of 15% for R_i in case of V-notches. In order to reduce this rather large error, R_i can be determined by means of slightly grinding off, repeating measurement and taking the average. The error for the J_i-value determined by means of four R_i-measurements (notch radius 0.1 resp. 0.25mm) ranges at abt. 30%.

The opening of the eroded notch can be measured more exactly, therefore, the eroded specimen give far more exact results. The scattering of the J_i-values is smaller as well. There is no temperature dependance of the $2(R_i - R_o)$- and J_i-values within the accuracy of measurement.

Our measuring results have been compared with those of Eisele (5). The material used by Eisele possessed higher contents of C, whereas the contents of

Ni was smaller. The mechanical properties of the material shows equal ductility A_5 and Z, whereas the R_m - and R_{el}-values of our material are abt. 50 N/mm^2 higher. In case of our material the steep decrease of Charpy-V-notch energy and lateral expansion in the upper shelf region correspond approximately. The J_i-values and the critical notch opening $2(X_i\text{-}X_o)$ are nearly equal in the upper shelf region (Tab. 1). The slightly higher J_i-values of our measurements may be explained by the higher R_{el}- and R_m values increasing the initiation work.

LITERATURE

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Tab. 1: comparison of the results

	Ro			100 C		200 C	
				average	stand. div.	average	stand. div.
present investigation	0,25mm	2(Ri-Ro)	[mm]	0,1	0,03	0,15	0,05
		Ji	[N/mm]	88	23	96	18
	0,1mm	2(Ri-Ro)	[mm]	0,21	0,05	0,1	0,02
		Ji	[N/mm]	151	15	80	7
	0,04mm	2(Xi-Xo)	[mm]	0,1	0,02	0,1	0,03
		Ji	[N/mm]	81	4	108	18
Eisele /5/ (T = 110 C)	fatigue crack	COTDi*	[mm]	0,13	0,01		
		Ji**	[N/mm]	83	14		

* metallographic method (4 values)
** DVM 002 (7 values

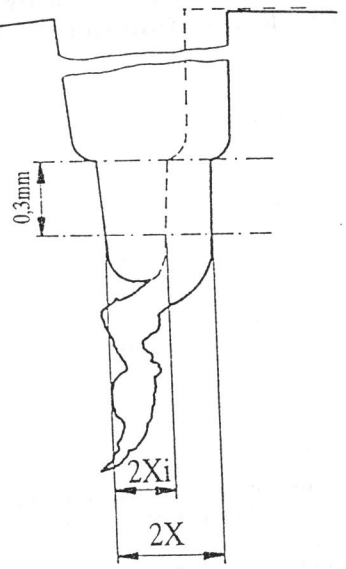

Fig.1: measurement 2X and 2Xi for eroded specimen

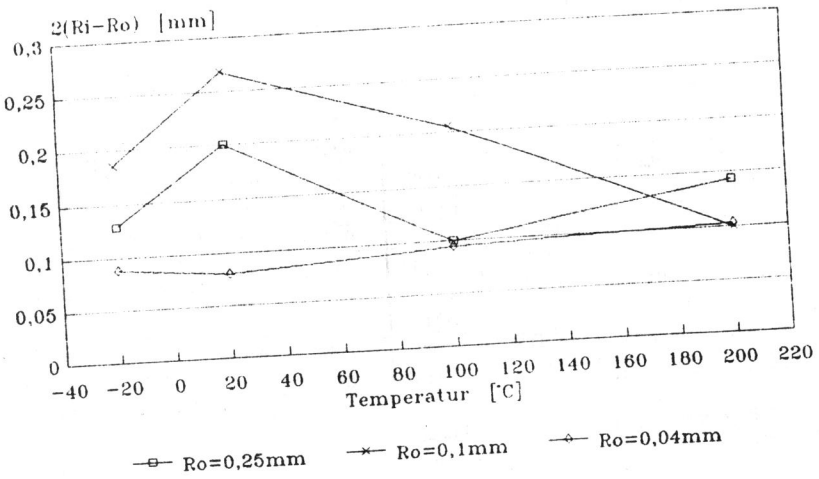

Fig.2: critical notch opening displacement 2(Ri-Ro) as function of temperature

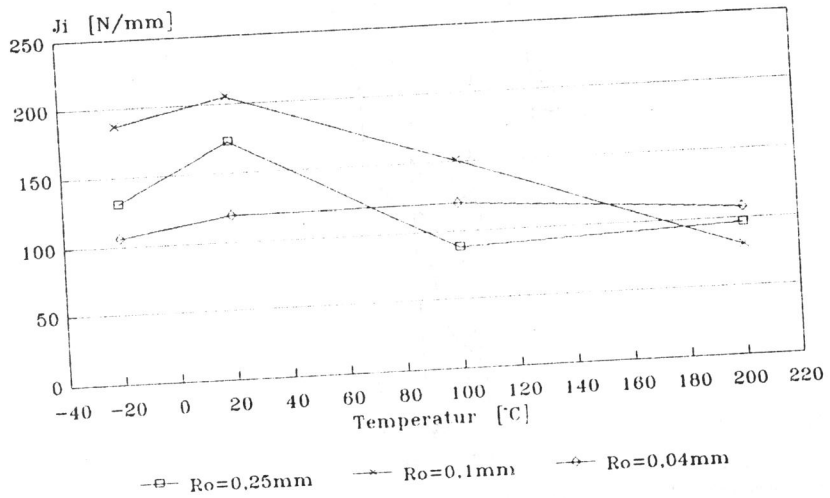

Fig.3: Ji as function of temperature