CRITERIA FOR CRACK INITIATION IN ELASTIC PLASTIC MATERIALS UNDER DIFFERENT LOADING RATES

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Crack initiation is determined by different methods for ferritic and austenitic material under different loading rates up to $\dot{K} = 10^7$ MPa$\sqrt{m}$/s. A new method using near tip strain gauges and the process of crack initiation is described. Multiple specimen methods are used for very high loading rates. A critical value J_i ist determined. Partial unloading method and a modified key curve method is used for the determination of J_i by means of crack resistance curves and the stretched zone width (SZW). The results are compared with J_{Ic}-values according to ASTM E813/89. It is shown that it is possible to determine realistic J-values for crack initiation by means of the near tip strain gauge and the SZW-method.

INTRODUCTION

For elastic-plastic material behaviour the J-integral is a parameter which characterizes the crack driving force. Critical values can be determined by measuring the force and the crack opening displacement. The critical value J_{Ic} acc. to ASTM E813/89 is not a material property; in many cases it can not be transferred to components because J_R-curves and J_{Ic}-values depend on the stress and deformation. Efforts are made to determine a material parameter J_i for crack initiation. However, the definition of crack initiation is not even clear. Regarding the models for the development of a crack by damaging the material through void growth and coalescence it is not easy to determine a distinct point for crack initiation in the case of ductile material behaviour. Combined with a crack resistance curve the measurement of the width of the stretched zone (SZW) on the fracture surface is used to obtain the J_i-value and a more practical approach determines J_i at a distinct crack growth (eg. 0.1 mm). To investigate crack initiation for quasistatic and dynamic loading, tests with compact tension specimens were carried out with specimens made of different ferritic steels (A508 Cl.3 resp. 20 MnMoNi 5 5 with an upper shelf Charpy energy of 200 J and

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15 NiCuMoNb 5 with an upper shelf Charpy energy of about 50 J) and of an austenitic steel (X6 CrNi 18 11). 20 % side grooved compact tension specimens of 25 mm thickness (CT25), Figure 1, and CT10-specimens without side grooves (15 NiCuMoNb 5) were tested at ambient temperature. The load was measured via strain gauges on the upper and lower surface of the dynamically loaded CT-specimens (Kussmaul et al. (1)). The crack opening displacement was measured optically using round marks to get a rotation correction (Kussmaul et al. (2)). The J-integral and J_{Ic} was calculated according to ASTM E813/89 for quasisatic and dynamic case. Partial unloading method was used for quasistatic tests, a modified key curve method was used to obtain quasistatic and dynamic crack resistance curves. For the detection of crack initiation on both surfaces of the CT-specimens strain gauges were attached in the region of the near field of the crack tip (Figure 1). High-speed photography has been used to investigate the crack growth. Tests with fatigue precracked Charpy specimens were performed on a Split Hopkinson Pressure Bar (SHPB). Critical J-integral values for the SHPB-tests were determined by means of high speed photography and 3d- and 2d-finite element-calculations.

DETERMINATION OF CRACK INITIATION

Specimens made of 20 MnMoNi 5 5 were loaded quasistatically up to different values of load line displacement. Figure 2 shows the scanning electron microscope (SEM) picture of the fracture surface near the crack front for a specimen which was loaded up to a J-value of 88 N/mm. Secondary cracks can be seen in the stretched zone. These small cracks are growing in different directions. Only a few cracks can be found in the same plane as the fatigue precrack. Taking any observed crack growth as indicator, yields very small J_i-values. However, these small scattered cracks should be regarded only as material damage and not as crack growth. By increasing the load of the CT-specimen the small cracks are growing along the crack front. Some cracks coalesce to a bigger one. Figure 3 shows a SEM micrograph of the crack tip area for a specimen loaded up to a J-value of 217 N/mm. The crack has spread in a stable manner over the specimen thickness. This stable crack growth leads to an unloading of the material near the crack tip in the process zone. The width of the streched zone is growing up to this point, see Figure 2 and 3. For the definition of a "technical" crack initiation the coalescence of small cracks to one big crack over the whole ligament width can be used. To record this crack initiation three strain gauges were attached to the surface of a CT-specimen. The direction of the principal stress resp. the angle of this direction to the plane of the fatigue precrack was calculated and plotted in Figure 4. With the onset of plastic deformation the angle increases from 30° to about 45°. The growing of the secondary cracks diminish the slope of this increase. When global stable crack growth occurs, the center of plastic deformation moves towards the ligament and the angle of the principal stress direction decreases. The decrease of this angle at the onset of crack initiation can be measured with one strain gauge attached perpendicular to the crack growth direction. Figure 5 shows the typical signal of such a strain gauge for ferritic steels in quasistatic case. This method detecting crack initiation has also been used in dynamic case. Crack initiation and crack growth can be observed on the surface of the 20 % side groved

CT-specimens. High-speed photography with an IMACON 790 camera showed a good agreement to the near tip strain gauge method.

Two different loading situations were used on the SHPB: dynamic tensile pulse loading of a single edge cracked specimen (SECT) and dynamic loading of a Three-Point-Bend specimen. In both cases a multiple specimen method was used. The above explained criterion for crack initiation of using a fully connected area of stable crack growth over the total thickness of the ligament yields comparable, geometry independent J_i-values. For tests with non-side-grooved specimens the definition has to be modified. In this case only the inner part of the specimen is important, because only there is the assumption of plain strain fullfilled. Specimens with at least 10 % side grooves show a homogeneous behaviour over the whole thickness of the specimen.

For the austenitic steel X6 CrNi 18 11 the signal of the near tip strain gauges shows a smooth decrease without significant drop. This is due to differences in crack propagation, shown in Figure 6 . In the ferritic material a sharp crack tip is formed after blunting and coalescence of the small cracks over the specimen thickness. This stage could not be observed for the austenite. It seems that blunting turns into material separation gradually. Further blunting occurs during material separation. However, by derivating this signal a point of decreasing strain rate can be found which determines an adequate value for crack initiation. Figure 7 shows critical J-values for the steel 20 MnMoNi 5 5 determined by different methods over the rate of change of the stress intensity factor calculated according to Draft 4-BS 7448-Part 3. J_{Ic} increases from ~400 N/mm for quasistatic loading up to ~620 N/mm for $\dot{K} = 10^6$ MPa$\sqrt{m}$/s. Using the Streched Zone Width (SZW) as a value which is not increasing after stable crack growth over the whole thickness of the specimen, J_i can be determined by means of the crack-resistance-curve. These values are lower than half of that one determined according to the standard. The results of the near tip strain gauge method shows lower J_i-values of ~180 N/mm for quasistatic loading and ~330 N/mm for $\dot{K} = 10^6$ MPa$\sqrt{m}$/s. One reason for this difference can be the neglection of the small stable crack growth and the secondary cracks by determining the SZW. However, for ferritic steels the near tip strain gauge method and the SZW-method cause to more conservative and realistic values because of taking into account measured parameters on the specimen itself. For the austenitic material determination of SZW and the interpretation of the strain gauge signal is more difficult. Figure 8 shows a comparison of J_i-values for different materials determined with the near tip strain gauge method. For the austenitic steel and the ferritic steel with high toughness loading rate increases J_i-values. Due to the shift in the ductile-brittle transition temperature the values for the low-toughness steel are lower at high loading rates.

REFERENCES

(1) Kussmaul, K. et al., Inst.Phys.Conf.Ser. No 102 (1989), pp157-164

(2) Kussmaul, K. et al., Determination of crack initiation ..., to be published in Nucl.Eng.Des.

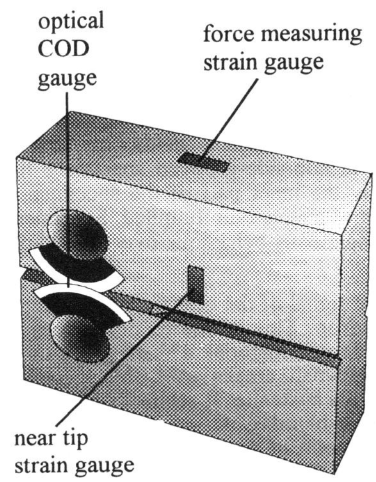

Figure 1: CT-specimen

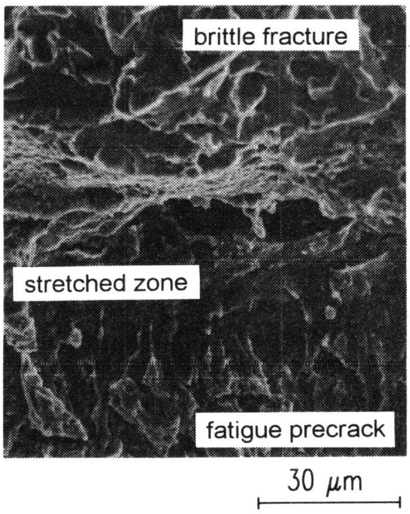

Figure 2: SEM-micrograph (specimen loaded up to J = 88 N/mm

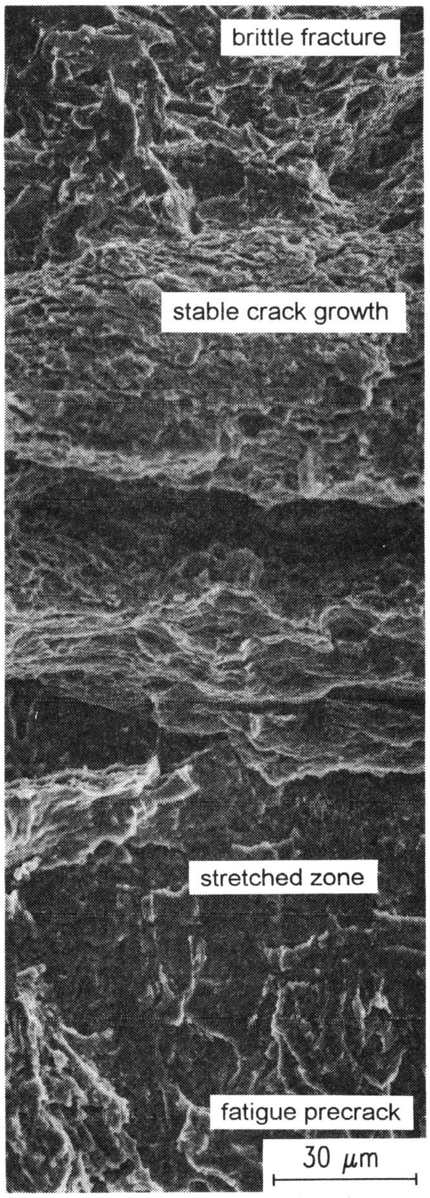

Figure 3: SEM-micrograph (specimen loaded up to J = 217 N/mm

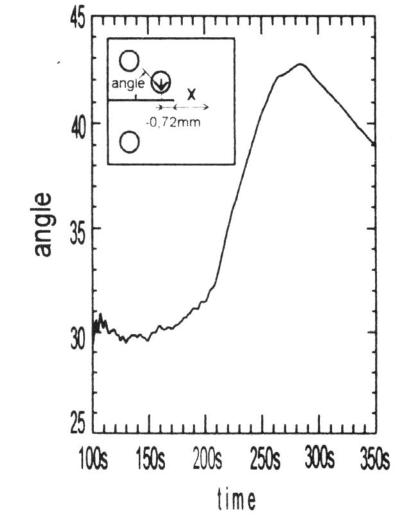

Figure 4: direction of principal stress

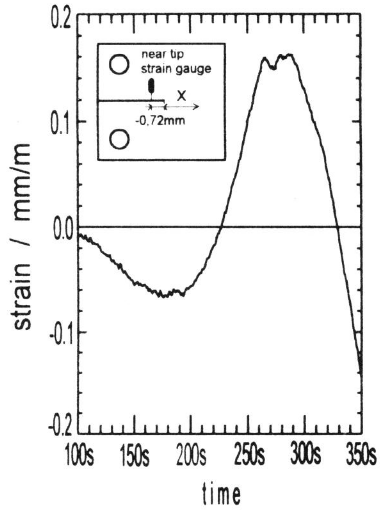

Figure 5: strain near crack tip

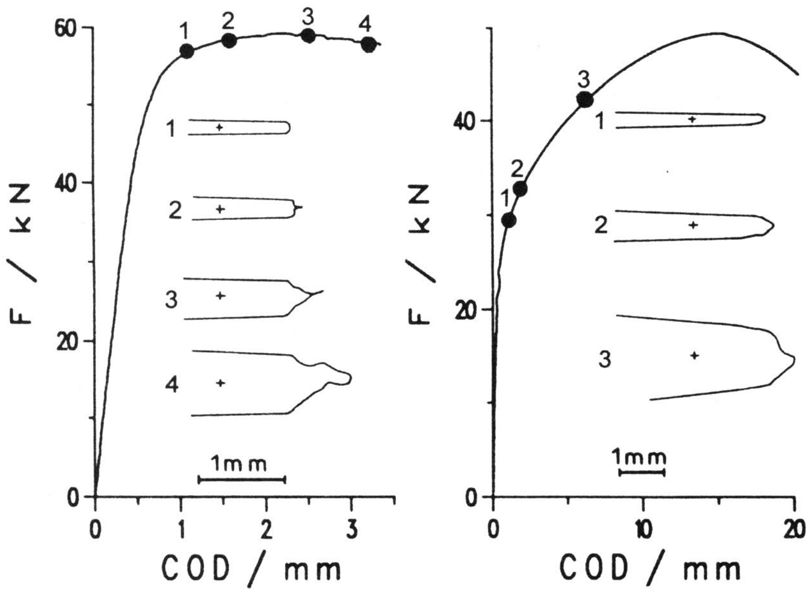

Figure 6: different crack forms: 20 MnMoNi 5 5 (left) and X6 CrNi 18 11 (right)

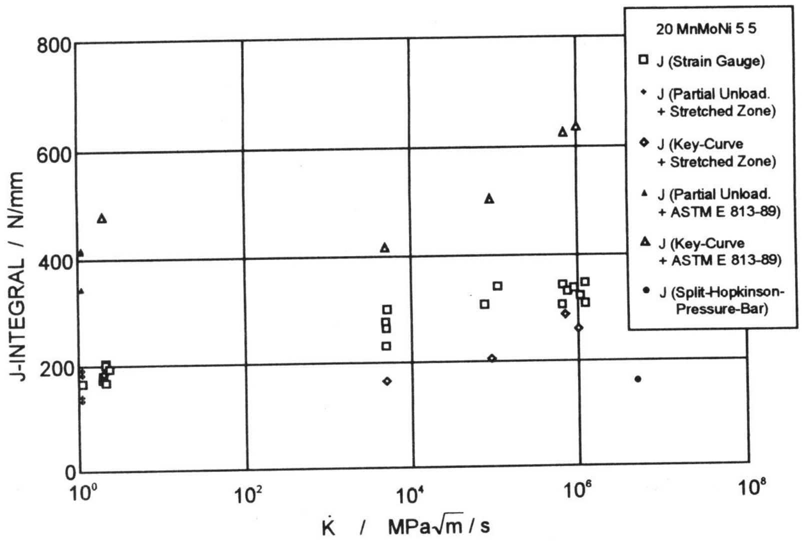

Figure 7: Critical J-values for 20 MnMoNi 5 5 obtained with different methods

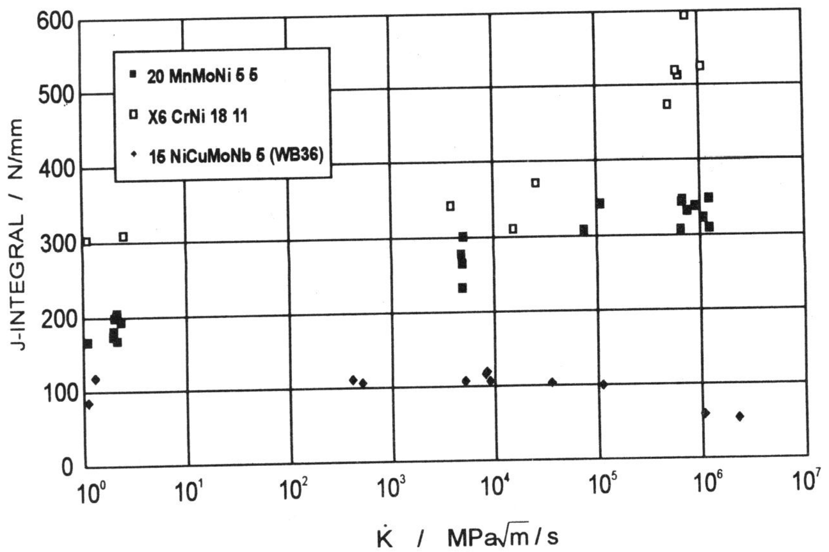

Figure 8: J_i-values determined by means of near tip strain gauges