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EVALUATION OF FRACTURE TOUGHNESS FROM SMALL SPECIMENS

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ABSTRACT

The modified Gurson model is used to determine micromechanical toughness parameters of a weld material from the irradiation surveillance of a Reactor Pressure Vessel (RPV) mainly based on available results of instrumented Charpy tests. These parameters were used to numerically simulate static and dynamic fracture mechanics tests for the determination of J-resistance curves. The results were confirmed by means of experiments with irradiated specimens of the original material. The initiation values of the J-R curves converted into fracture toughness values K_{Ic} allowed a conservative adjustment of the ASME reference toughness curve for the weld material.

1. INTRODUCTION

The application of the modified Gurson model [1,2] for the determination of the ductile fracture resistance of irradiated weld material from results of a static tensile test was reported earlier in [3,4]. Here this method is applied for the determination of the fracture toughness of the weld material of a RPV from results of instrumented Charpy tests supported by additional results from tensile and fracture mechanics specimens.

Elastic-plastic finite element analyses are employed to determine the critical volume fraction of voids from a comparison of the numerical results with the experimental test record of an instrumented Charpy test.

In order to verify that the numerical models are capable of describing the complex loading and support situation of the specimen including sliding and friction at the anvils precracked and sidegrooved Charpy-type specimens (SENB) of an unirradiated weld material were tested and simulated with a plane strain model. The crack extension is calculated by evaluating the length of the damage zone on the ligament which does no longer carry load. Figure 1 shows the calculated and measured load vs. displacement curve of one SENB-specimen. Considering the complexity of the gliding processes at the anvils and the inhomogenity of the multi-layer weld material the agreement between the numerical and experimental result is satisfactory.

Another problem is the correct consideration of the strain-rate dependency of the stress-strain curves for strains up to failure by a visco-plastic material model in combination with the Gurson model, and the appropriate determination of the material parameters by static and dynamic tests.

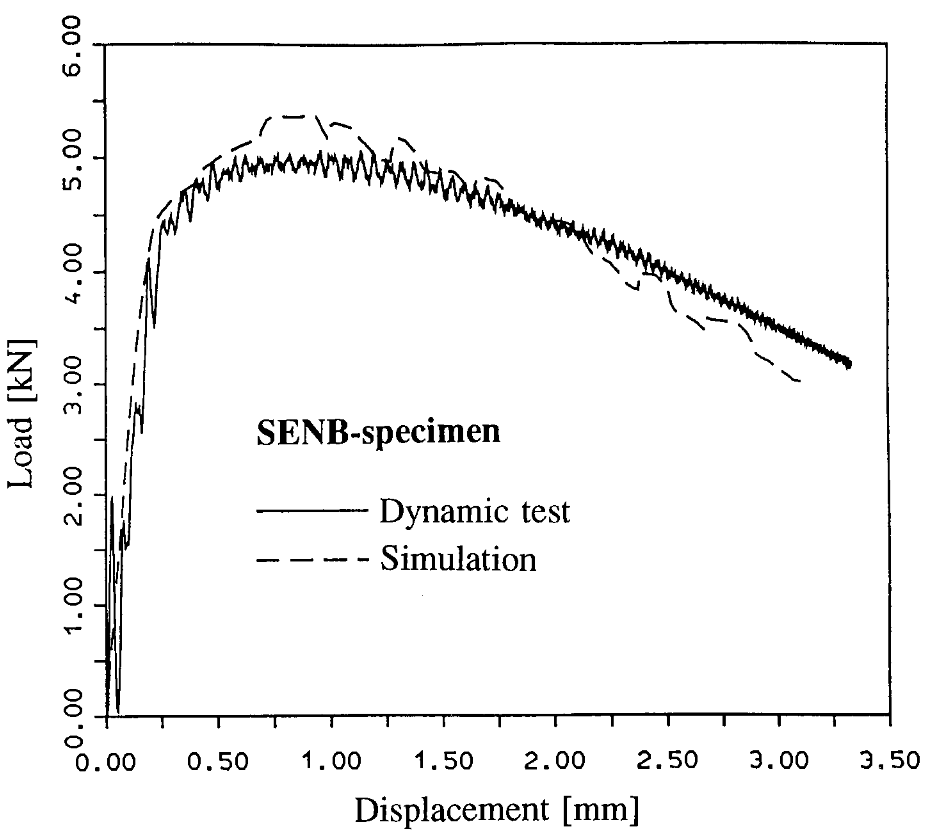

Figure 1. Measured and calculated load-displacement curves of a SENB-specimen (unirradiated)

Figure 2 shows the measured and calculated load vs. diameter change curves of smooth tensile specimens for static and dynamic loadings. The numerical results - taking into account the temperature elevation in the necking part - demonstrate an adequate modelling of the rate-dependency of the stress-strain curve.

More results of this preliminary study with unirradiated weld material may be found in [5,6]. In the following, the determination of the micromechanical toughness parameters of the irradiated RPV material from a sub-sized tension bar test and directly from the record of a Charpy test will be presented. Such results are used to calculate static and dynamic J_R- curves, the initiation values of which are then converted into plane strain fracture toughness values allowing a conservative adjustment of the ASME-reference curve for the RPV-safety evaluation.

2. EVALUATION OF THE IRRADIATED RPV WELD MATERIAL

The Charpy energies of the irradiated weld material for different temperatures are shown in figure 3. One test at T=100 °C in the upper transition regime was selected for the evaluation and is marked.

In addition, a static tension test with a sub-sized smooth round bar (diameter 2.6 mm) was performed by SIEMENS also at T=100 °C. From this test the static stress-strain curve was determined and, by fitting the sudden load drop in the load vs. diameter-change curve, also the critical volume fraction of voids was calculated. A combined plane strain - plane stress model

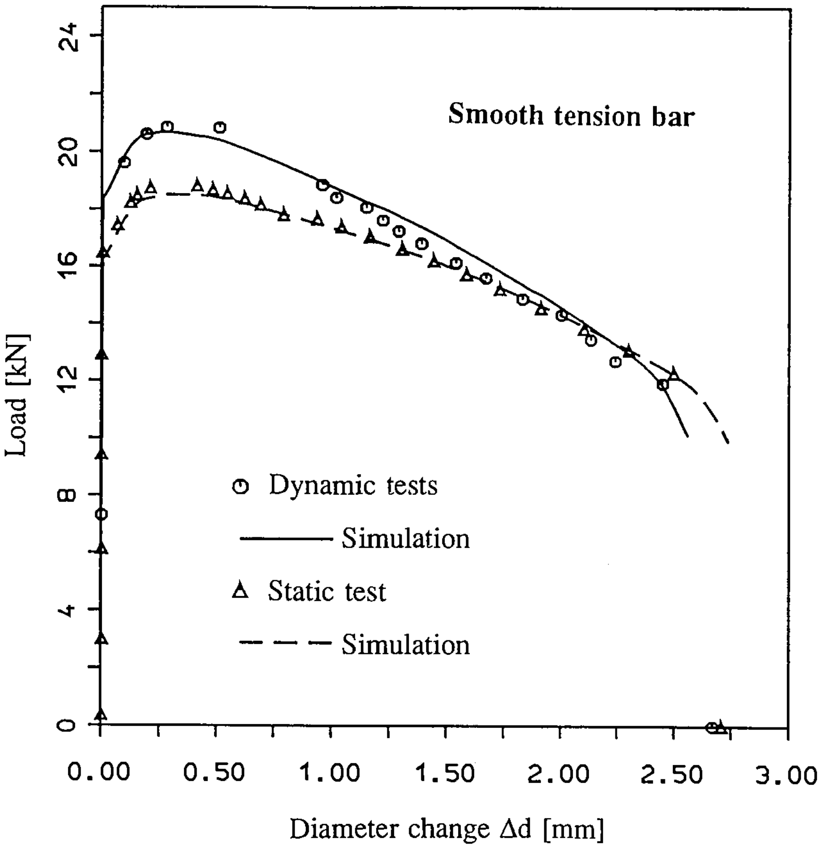

Figure 2. Load vs. diameter change curves of smooth tensile specimens (unirradiated)

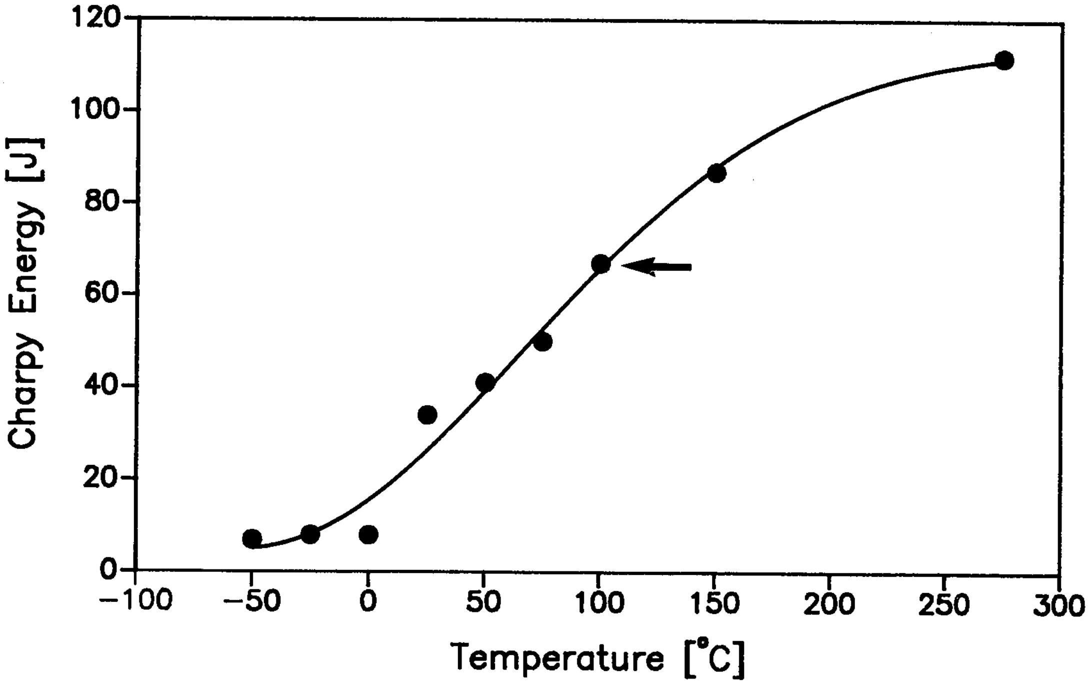

Figure 3. Impact energy vs. temperature curve of the irradiated RPV weld material

with stress-strain curve and micromechanical parameters as determined from the static tension test was then used for the simulation of the Charpy test. The strain rate sensitivity of the material was obtained by fitting the calculated loads in the Charpy test to the measured loads up to initiation prior to maximum load.

The same set of micromechanical parameters was then used to calculate the behaviour of a CT20 compact specimen and, hence, to predict a static J resistance curve. This static R-curve in figure 4 was further supported by dynamic tests with SENB specimens fabricated (in compound technique) and tested in a 300 J pendulum by SIEMENS. One test was simulated numerically; the resulting dynamic J_R-curve - as expected from previous studies the dynamic curve lies well above the static one - is also given in figure 4. Three additional specimens were tested with reduced impact energy (below 10 J) and the ductile crack growth was measured on the fracture surfaces. This experimental three-specimen resistance curve is also in good agreement with the calculated curve.

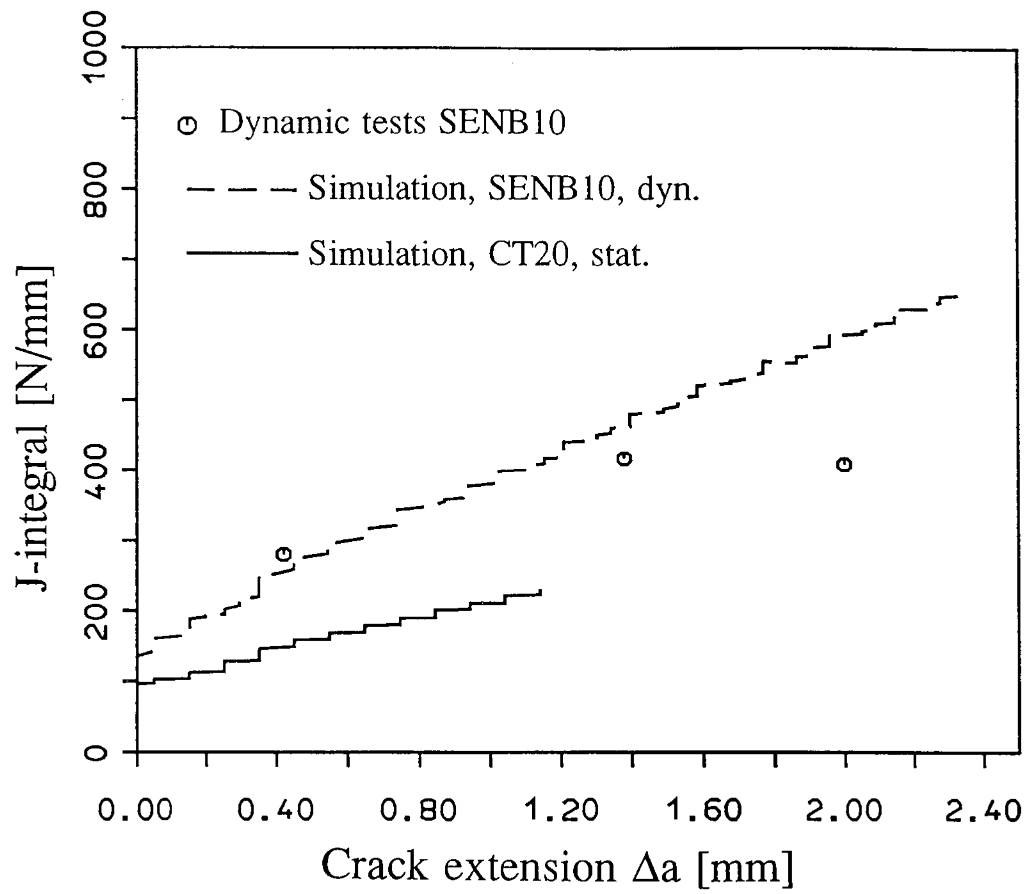

Figure 4. Static and dynamic J resistance curves of the irradiated RPV material

The initiation values of the static and dynamic resistance curves were formally converted into K_{Ji}-values. Since the chosen Charpy test marks the onset of the upper shelf, the results obtained at 100°C are used to adjust the ASME-K_{Ic}-curve. Thus, a reference temperature of 56°C is determined, see figure 5. In the adjusted position the ASME-K_{Ic}-curve is a conservative envelope of the K_{Ic}-curve of the irradiated weld material.

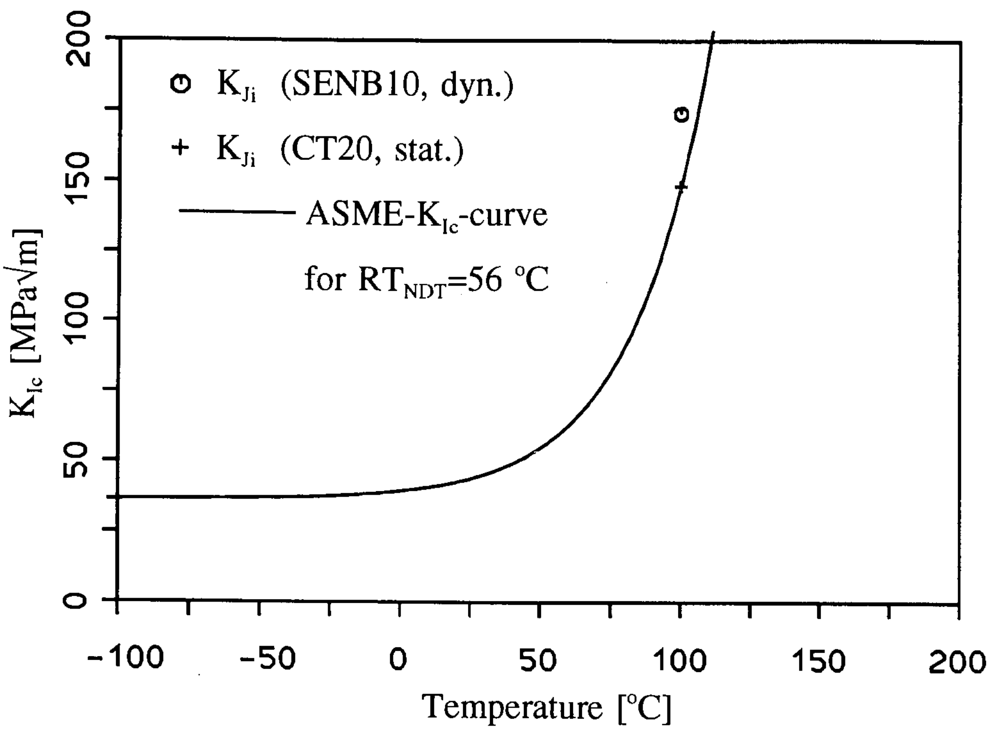

Figure 5. K_{Ji}-values converted from the static and dynamic J_i-values for T=100 °C and the adjusted ASME-K_{Ic}-curve with reference temperature RT_{NDT}=56°C

3. CONCLUSIONS

Different specimen geometries and loading rates were used to study the applicability of a strain-rate dependent Gurson model to the analysis of the deformation and fracture behaviour of an unirradiated weld material. The results prove that the material parameters relevant for the micromechanical model can be determined likewise from the simulations of a static or a dynamic tension or from a Charpy-V impact test. The material parameters for the model are sufficiently independent of strain rate. Both static and dynamic J_R-curves can be well predicted using the micromechanical model.

Following the validation program an irradiated weld material was evaluated by testing and modelling smooth tension and Charpy-type specimens. The material parameters for the simulations were abstracted from tension and Charpy-V tests. With these parameters it was possible to calculate the behaviour of CT and SENB specimens and, hence, to deduce static and dynamic crack resistance curves. Furthermore, an ASME-reference curve was adjusted based on the fracture toughness determined at T=100°C to approximate the K_{Ic}(T)-curve of the irradiated weld material.

4. REFERENCES

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