EXPERIMENTAL AND NUMERICAL INVESTIGATIONS ON CLEAVAGE FRACTURE

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Experiments and finite element analyses have been performed to investigate the influence of temperature, strain rate and specimen geometry on the cleavage fracture stress and on the transition temperatures. Double Edge Nodged Tension and Notched Axial Tension specimens of different steels have been analysed for different temperatures and cross head speeds.

INTRODUCTION

Notched specimens show pure cleavage fracture surfaces if fracture occured below or at general yield. The original Orowan criterion proposes that cleavage fracture is induced, when the maximum tensile stress below the notch root reaches a critical stress, the microscopic cleavage stress σ_f* (1). The usual procedure to determine σ_f* is shown schematically in figure 1. Tests on notched specimens give the fracture forces or displacements for each material, temperature and velocity. Uniaxial tension tests are necessary to get the stress strain curve for each case. Finite element analyses of the notched specimens are to be performed up to the given fracture force or displacement. A local stress analysis for that state leads to the distribution of the notch opening stress. Its maximum is the microscopic cleavage stress for the investigated material, temperature and velocity.

The aim of this work was to investigate the influence of temperature, strain rate

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and specimen geometry on the microscopic cleavage fracture stress. Another interesting item was to find out if there is a dependence of the initiation temperature for cleavage fracture T_i and the temperature for general yielding T_{gy} on the strain rate.

EXPERIMENTS AND FINITE ELEMENT CALCULATIONS

Experiments and finite element calcultions were carried out for different temperatures between 80 and 133 K, different cross head speeds and two different specimen types. The investigations were performed for three materials: a pressure vessel steel 22 NiMoCr 3 7, a controlled rolled steel FeE 460 and a low carbon steel C10. The specimen types were double edge notched tensile (DENT) and notched axial tension specimens (NAT). Both had notch radii ρ of 0.25mm. The NAT specimens had a notch depth t of 1.5mm, t for the DENT was 4mm.

The elastic plastic finite element calculations were carried out by the program Abaqus (2). For the NAT geometry a quarter of the specimen had to be analysed because of ist symmetry. Axisymmetric isoparametric elements with eight nodes and reduced integration were used. The DENT analyses were performed by modelling an eights of the specimens with three dimensional isoparametric elements with 20 nodes and reduced integration. In both cases the minimum element size was 0.1 mm.

RESULTS

Relevant temperatures concerning cleavage fracture are the transition temperatures T_i (initiation temperature) and T_{gy} (general yield temperature). Coming from higher temperatures Ti is the point for which cleavage fracture occurs at the whole fracture surface for the first time. T_{gy} is the lowest temperature for which net section yielding (general yield) is reached in the specimen. Figure 2 shows the influence of the strain rate on both transition temperatures T_i and T_{gy}. The tests were performed for the two steels FeE 460 and C10 using NAT specimens. The transition temperatures are shifted by the increasing cross head speeds due to the increasing yield strength. The transition temperatures of steel C10 are more sensible in terms of strain rate.

Some former studies i.e. (3) supposed the microscopic fracture stress to be temperature independent. Recent investigations concerning only one single material showed that it is not (4,5). In figure 3 the distribution of the notch opening stress σ_{yy} in the ligament of NAT specimen from the steel FeE 460 is to be seen. Keeping in mind that each maximum of these courses is the cleavage fracture stress for each temperature it becomes obvious that σ_f^* is temperature dependent.

Figure 4 shows the microscopic cleavage stress σ_f^* as a function of temperature for three different cross head speeds: 0.03, 3 and 400 mm/s. The specimen type was NAT, the material was FeE 460. From former investigations it is known that a small amount of local plasticity is necessary for cleavage fracture occurance. σ_f^* has to be above the yield strength σ_y (5). Due to the increasing yield strength with increasing strain rate σ_f^* increases, too. Again the temperature dependence of the microscopic cleavage stress is obvious for all three cross head speeds.

Beeing a material property the microscopic cleavage fracture stress σ_f^* is supposed to be geometry independent. In (6) the notch depth´ of DENT specimens were changed, while the notch radius remained constant. Analysing σ_f^* over a microstructural dependent distance Xc no influence of the geometrical change was found. In figure 5 the microscopic cleavage fracture as function of temperature is to be seen for NAT and DENT. Both had the same notch radius but different thickness and notch depth. The material was 22NiMoCr 3 7. Both test series were done with quasi static loading. Only the maximum stress values without any distance Xc were taken into account. There is a difference between the courses of maximum 20 %. The difference increases with increasing temperature. A geometry dependence can not be excluded.

CONCLUSION AND SUMMARY

The transition temperatures T_i and T_{gy} increase with increasing strain rate. Again the microscopic cleavage stress σ_f^* has been found to be temperature dependent. Also the strain rate is of great influence on σ_f^*. A higher strain rate yields a higher microscopic cleavage fracture stress.

Only a small number of tests with different specimen geometries for the same material and under the same conditions have been performed yet. There may be a geometry dependence which has to be checked by much more tests with different specimen geometries and materials.

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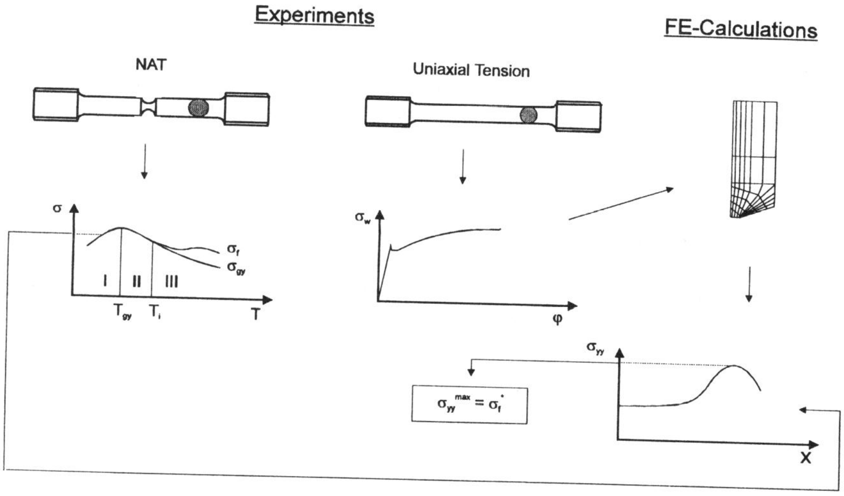

Figure 1. Determination of σ_f*

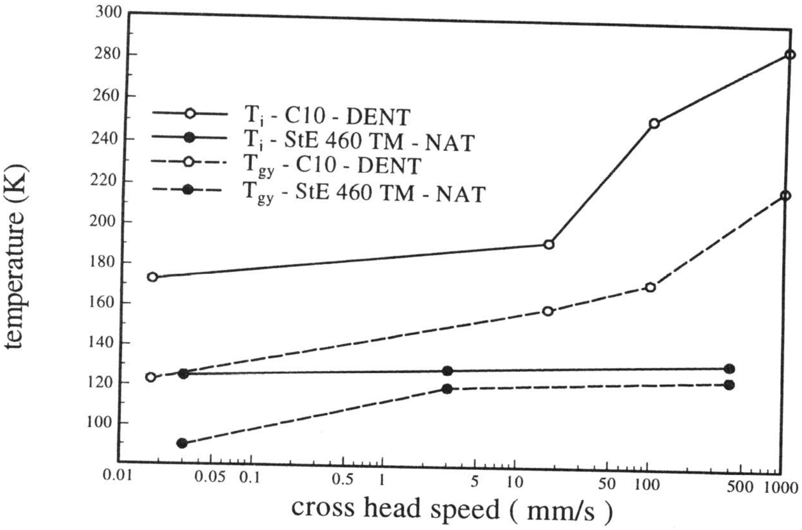

Figure 2. Influence of the stain rate on transition temperatures

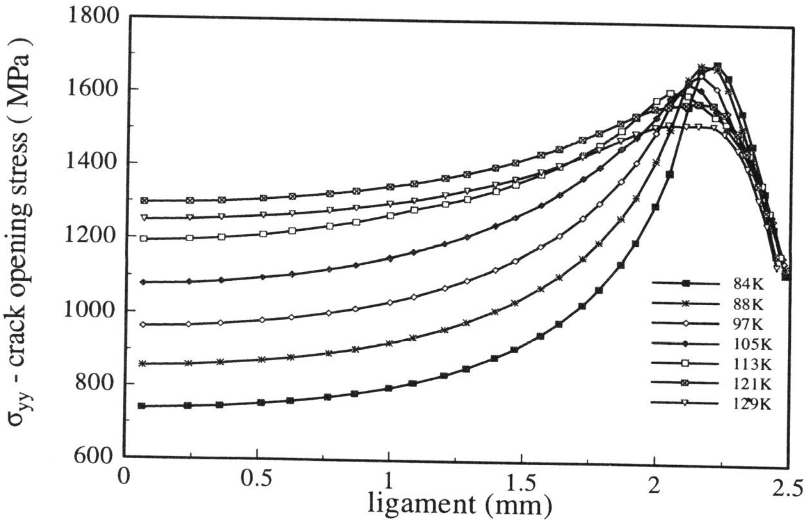

Figure 3. Distribution of σ_{yy} in the ligament

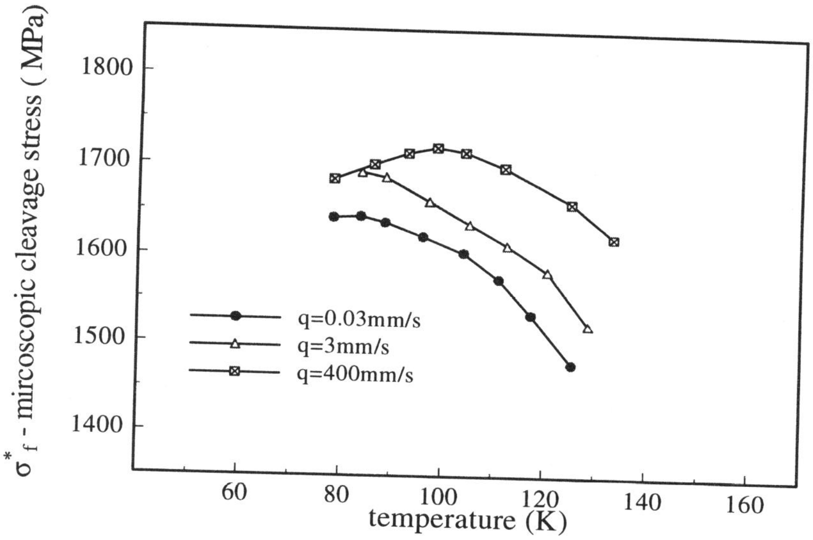

Figure 4. Influence of the strain rate on σ_f*

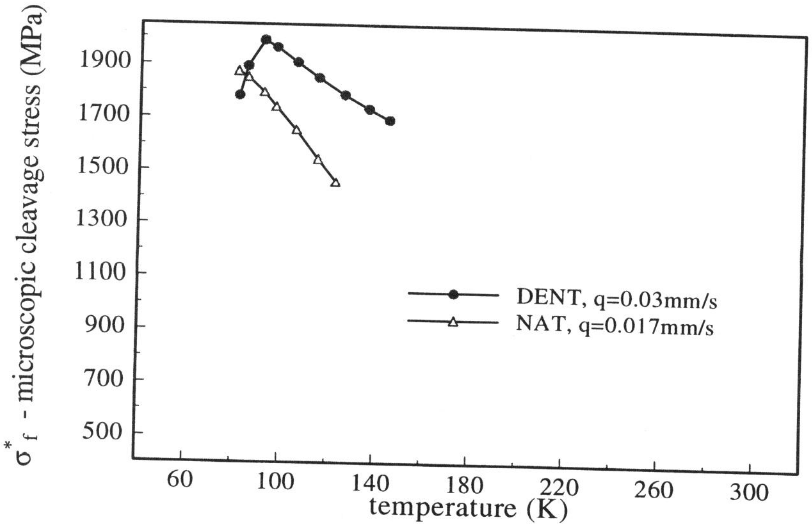

Figure 5. Influence of the specimen geometry on σ_f*