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INFLUENCE OF PRECRACKING AND GRAIN SIZE ON FRACTURE TOUGHNESS OF STRUCTURAL STEELS

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During the precracking by fatigue of specimens for fracture mechanics tests the plastic zone size in fatigue must be carefully controlled [1], [2]. It is possible to produce precracks for testing structural steels at 77 K which conform to this condition [3].

The work described in this paper demonstrates the variation of fracture toughness of a steel St 52-3 with 0.13% C, 0.2% Si, 1.19% MN, 0.017% P and 0.018% S when the above mentioned condition is not observed. The results of two test series with plastic zones during precracking by fatigue of $0.5 \cdot 10^3$ μm and 160 μm respectively are shown in Figure 1 in which fracture toughness and yield point are presented as functions of temperature. Calculating the plastic zone by J. R. Rice [4], these values decrease for a quarter, but this could not change the following considerations. The fracture toughness of specimens with a plastic zone of $10.5 \cdot 10^3$ μm increase from 47.4 $MPa \cdot m^{1/2}$ at 77 K to 104.4 $MPa \cdot m^{1/2}$ at 233 K and then decrease to 85.4 $MPa \cdot m^{1/2}$ at room temperature. In these specimens the length of the plastic zone at fracture was never more than four times the zone at fatigue. The transition temperature following the ASTM thickness criterion was found at 137 K, the transition temperature at which the force-displacement-curve was no longer linear at 173 K.

A reduction of the plastic zone during fatigue to 160 μm shifts the fracture-toughness-curve to lower values with the exception of room temperature where the deviation is very small. From a value of 24.3 $MPa \cdot m^{1/2}$ at 77 K fracture toughness increase with rising temperature to 75.9 $MPa \cdot m^{1/2}$ at 193 K above which the rate of increase becomes smaller. The condition for precracking is satisfied above 113 K. Verification of the fracture toughness at 77 K of a specimen with a plastic zone length of 100 μm yields the same value. The deviation of K_{Ic}- and K_c-values owing to different conditions of precracking can be shown as the relative increase of K_{Ic} and K_c as a function of the length of plastic zone during fatigue (Figure 2). The filled circles show the values measured at 77 K, the reference value for the calculation of K_{Ic} being 24.3 $MPa \cdot m^{1/2}$. The relative deviation grows slowly at first and quicker above 300 μm. Above 1.10^3 μm the gradient becomes less and the deviation reaches 88% at a length of plastic zone of 1.10^4 μm. The arrows indicate, for the formula given in the figure, the allowable length of plastic zone during precracking at the particular temperature. At test temperatures of 153 K and 173 K the deviation of K_c rises steeply up to 16% above the allowable length of the plastic zone. Afterwards the curve is linear with a slight gradient. At 193, 213, and 233 K the gradient of the K_c-deviation against plastic zone length is slight from the beginning. As the figure shows, the recommendations for precracking by fatigue are reasonable and should be followed.

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The curves in Figure 3 show the deviation of K_C-values as functions of temperature and of the length of the plastic zone during precracking. The deviation is 85% at 77 K and a length of plastic zone of 8.10^3 μm and drops to 25% at 153 K. The deviation remains nearly constant up to 183 K. At higher temperatures the curve falls steeply and touches the abscissa at 233 K. With decreasing length of the plastic zone the curve is shifted to lower values of K_C-deviations and to lower temperatures. The deviation is about zero at a length of 160 μm.

The reason for the deviation of fracture toughness is the compression residual stresses in the ligament near the crack tip calculated by J. R. Rice [4] and measured by G. Hellwig [5], the value of which is influenced by length of the plastic zone during fatigue. If the stress during fatigue is great there may be branching of the crack and/or blunting of the crack tip. Blunting is found at the maximum of the load during fatigue by tensile stresses. When reducing the stress afterwards to 50% of the maximum load the sides of the crack should touch each other following the measurements of W. Elbert [7]. Therefore after the complete relieving of the load the yield point of the metal should be exceeded at the crack tip. Consequently the crack is sharpened after every stress cycle and no blunting occurs. C. Laird [8] has put forward a model for branching of cracks during fatigue. From our results and measurements of K. H. Schwalbe [9], branching occurs at high K_f-values and secondary cracks were found on the surface of the specimen which lie under about 45° to the original crack. The lower stresses on these cracks, which are not perpendicular to the main stress but subject to the mutual influence of the stress at the crack tip, are probably responsible for the increase of fracture toughness besides the influence of the residual stresses.

Having estimated the deviation of measured toughness values by precracking, in the following we will give some results of investigations on the influence of grain size on fracture toughness of a structural steel St 37-3 with 0.08% C, 0.17% Si, 0.45% Mn, 0.019% P and 0.017% S as supplement to a previous report [10].

Specimens were prepared with grain sizes of 25 μm and 96 μm by thermal treatment (see Table 1). The shape of the specimens was single-edge-notch-tensile (SENT) and compact tension (CT). The latter were used at temperatures below 153 K.

In Figure 4 fracture toughness is shown against temperature for specimens with coarse grains (crosses), and with fine grains (circles). At low temperature the fracture toughness of these fine- and coarse-grained-steels are falling together. Up to higher temperatures the fracture toughness of the fine-grained-steel is increasing much more than one of the coarse-grained-steel. The transition temperature relating to the ASTM-thickness-criterion is marked with I, the transition temperature above which the force-displacement-curve was no longer linear with II and the start of macroscopic stable crack growth with III. Taking the scatter of experimental data into account, the results show that at low temperatures and small plastic zones at the crack tip the fracture toughness is independent of grain size. With growing plastic deformation fracture toughness of fine grained steels increase as from transition temperature I of the fine grained steel. The difference shown in an earlier report [10] was the result of an excessively large plastic zone during precracking. By reducing the size the transition temperatures were shifted to lower temperatures. At 193 K fracture toughness is about 31.6 $MPa \cdot m^{1/2}$ higher for the fine grain, which means that unstable crack growth would be found at 70% higher load at the same crack length.

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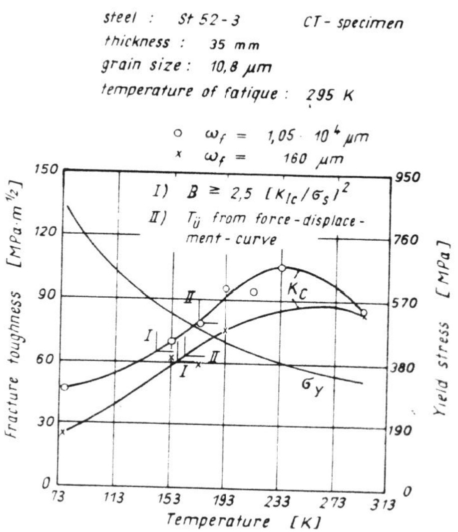

Figure 1 Fracture Toughness and Yield Stress of a Steel St 52-3 as a Function of Temperature

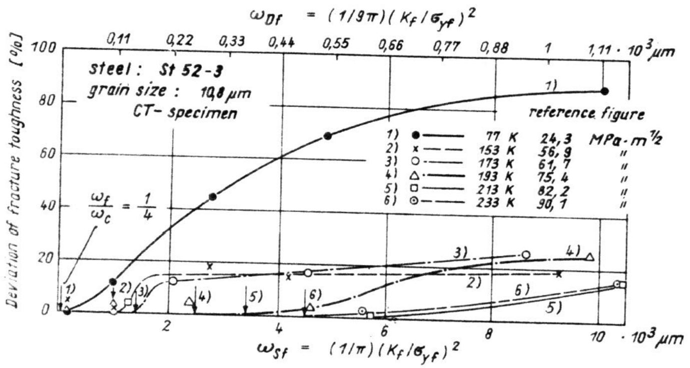

Figure 2 Deviation of Fracture Toughness as a Function of the Size of Plastic Zone During Fatigue as Different Temperatures

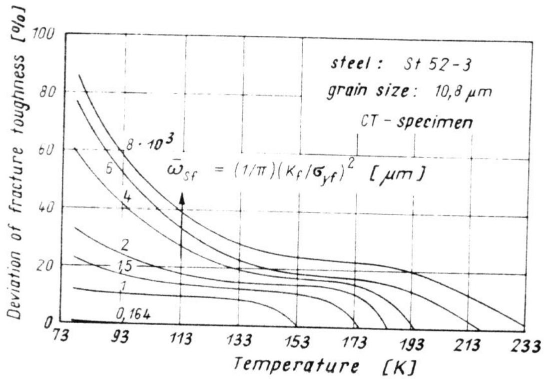

Figure 3 Deviation of Fracture Toughness as a Function of Temperature for Different Sizes of Plastic Zones During Fatigue

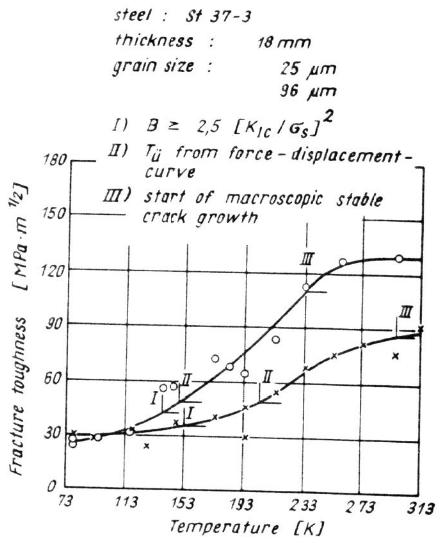

Figure 4 Fracture Toughness as a Function of Temperature for a Steel St 37-3 in Two Grain Sizes

Table 1 Heat Treatment of Steel St 37-3

Heat Treatment	Grain Size µm
15 h / 1473 K / furnace +0,5 h / 973 K / air	96
15 h / 1473 K / furnace +0,5 h / 1193 K / air +0,5 h / 1193 K / air +0,5 h / 973 K / air	25