Contribution to the Study of Slow Crack Growth Conditions in Thermomechanically Treated Ultrahigh Strength Steels

L. Hyspecká [x)], M. Tvrdý [x)], K. Mazanec [+x)]
x) Research Instute of Vítkovice Steelworks, Ostrava
+) University of Mining and Metallurgy, Ostrava, Czechosl.

Introduction

In view of the increasing use of ultrahigh strength steels, attempts are being made to improve our knowledge of their mechanical metallurgy characteristics. Particularly atractive are their fracture toughness values at various test temperatures and, generally, the conditions of stable (slow) crack growth (SCG).

One of the most promising ways of improving the strength properties of structural steels proved to be their high-temperature thermomechanical treatment (HTMT). The objects of this paper are to compare the fracture toughness values after HTMT and after conventional heat treatment (CT) of structural steels with strengths ranging from 150 up to 230kgf/mm^2, and to discuss the significance of their K_{Ic} and SCG characteristics.

Experimental details

The K_{Ic} values were obtained on single edge notch specimens by three-point bending. The experimental technique, conforming to the ASTM Specification /1/, was further modified for the study of SCG, in that the time recording of crack opening displacement, based on the output from clip strain gauge /1/, was used to represent the time dependence of the crack increment /2/. Simultaneously the technique was developed for detecting and analysing the stress waves emitted during SCG /3,4/. The fracture toughness testing at room and cryogenic temperatures was carried out at a loading rate of $\dot{K} \cong 500$ kgf/ /$mm^{3/2}$/min. The chemical composition of the steels studied is shown in Table I.

Table I - Chemical Composition of steels studied

Steel	%C	%Mn	%Si	%P	%S	%Cr	%Ni	%Mo
A	0.25--0.48	1.10--1.28	1.10--1.40	0.013--0.020	0.012--0.018	1.00--1.20	0.90--1.20	0.23--0.30
B	0.33	1.05	1.34	0.015	0.014	1.20	1.10	0.24

All these steels, produced commercially, were further treated by both HTMT and CT, in plates 16 mm thick. The tempering temperature was in both cases 200°C /5/. The mechanical properties of steel B are listed in Table II.

Table II - Mechanical properties of steel B

Treatment	$\sigma_{0,2}$ kgf/mm^2	σ_{UTS} kgf/mm^2	Elong. %	C_v(+20°C) kgfm/cm^2	K_{Ic} (+20°C) kgf/$mm^{3/2}$
HTMT	168	198	10,0	5,0	325
CT	145	170	8,5	4,8	272

Experimental Results and Discussion

The effect of the tensile strength on the plane strain fracture toughness of steel A (at 20°C) is shown in Fig. 1, where each point represents the average of at least ten measurements. As evident from this diagram, the relationship $K_{Ic} - \sigma_{UTS}$ of HTMT material is shifted towards higher values by 80 kgf/$mm^{3/2}$. These results confirm quite unambigously the beneficial effect of HTMT, not only on the tensile properties, but also on the K_{Ic} values. This effect can be explained primarily by the marked refinement of the martensitic structure /4/.

The effect of the test temperature on the K_{Ic} values of steel B, after CT and after HTMT, is plotted in Fig.2. Irrespective of the test temperature, the K_{Ic} values for

HTMT material are considerably higher than those for CT material. The conditions of SCG are also different for each of these treatments. The extent of SCG before the point of instability is mostly larger in HTMT than in CT material. The records of stress waves emitted during SCG in HTMT steel B were analysed in detail /6/. Both curves of time record of the acceleration amplitudes of stress wave emissions (SWE) and of crack increments (Δa) were processed to yield a relationship between the sum of acceleration amplitudes of SWE (Σg) and Δa /4/. The curves obtained this way are linear, and their slopes are proportional to the K_{Ic} value /3/. Such results are very interesting; it could be deduced from Fig. 3 that, for any given value of Δa, the higher value of (Σg) always corresponds to the higher test temperature, and/or that for any given level of (Σg), the crack increment is the smaller, the higher the test temperature.

In Fig. 4, the crack velocity during SCG is plotted against the crack increment (Δa) in HTMT steel B for two test temperatures. The resultant SCG velocity values should be considered as only apparent, since the SCG process is in reality discontinous and consists of large numbers of elementary burst processes /2/. In Fig. 4, the crack velocity at a test temperature of -78°C (at K_{Ic} = = 215 kgf/$mm^{3/2}$), and for a given crack increment of Δa = 0,3 mm, is 60 % higher than that at room temperature (at K_{Ic} = 325 kgf/$mm^{3/2}$); when Δa is increased to 1.1 mm, the rise in the crack velocity at -78°C, as against room temperature, is 75 %.

At both of these test temperatures, the crack velocity gradually increases with the crack length. This increase was observed consistently right up to the point of instability, which occurs after an amount of SCG which varies with the test temperature, i.e. the crack increment attained when the point of instability is reached is much smaller at a low test temperature (-78°C). The technique of measuring the crack increment by the summation of SWE amplitudes (defect growth evaluation) could be therefore applicable only in cases when the basic relationship between Σg and Δa for a given steel is known.

Conclusions

The paper demonstrates the beneficial effect of thermomechanical treatment on the fracture toughness over a wide range of test temperatures and strength levels. It further presents the relationships between the crack increment and the sum of SWE acceleration amplitudes, as well as the dependence of the crack velocity on the crack increment.

References

1/ W.F.Brown: Review of developments in plane strain fracture toughness testing, ASTM-STP-463,(1970), 216.

2/ J.Crha,M.Tvrdý, L.Hyspecká,K.Mazanec: Kovové materiály 8, (1970), 588.

3/ W.W.Gerberich,C.E.Hartbower: Inter.Jnl.of Fracture Mech., 3, (1967), 185.

4/ L.Hyspecká,K.Mazanec: JISI, 205, (1967), 1261.

5/ L.Hyspecká,K.Mazanec: Mém.scient.R.de Métal., 68, (1971), 305.

6/ H.L.Dunegan, A.T.Green: Mater.Research and Standards, 11, (1971), No 3, 21.

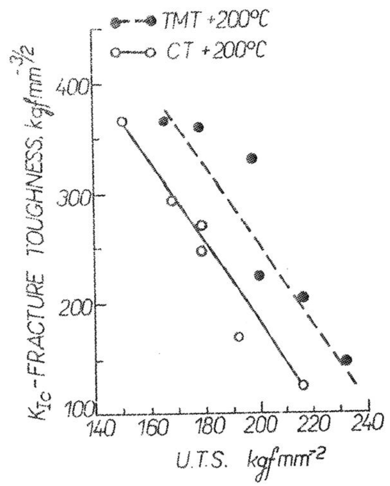

FIG.1.

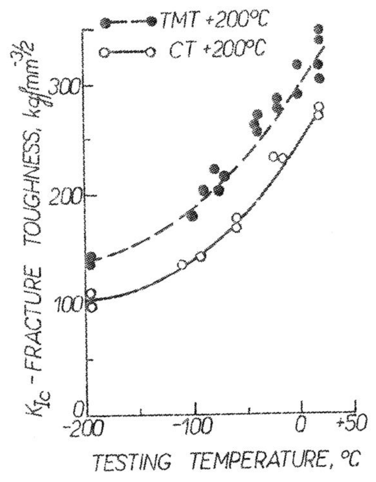

FIG.2.

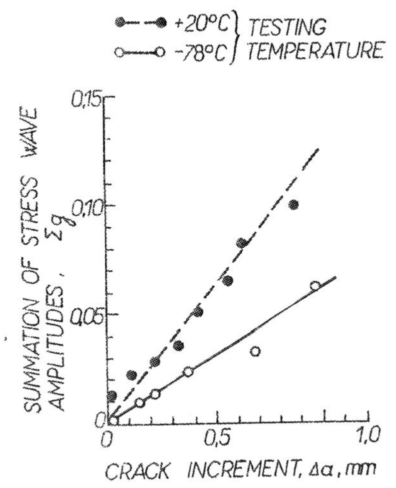

FIG.3.

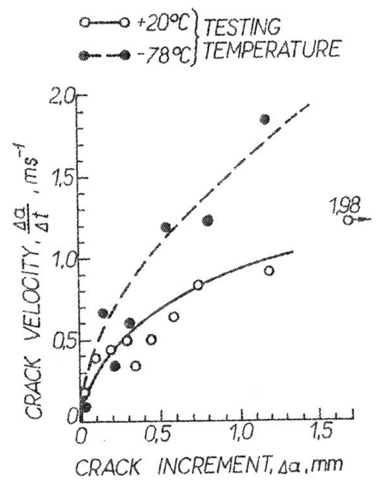

FIG.4.