THE EFFECT OF INTERCRYSTALLINE DECOHESION ON FRACTURE TOUGHNESS OF ULTRA-HIGH STRENGTH STEELS

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A structural interpretation of the reversed Hall-Petch relation for the fracture toughness K_{IC} in the case of Cr-Ni-Mo UHS LA steel is presented. The process of intercrystalline decohesion is considered as the most significant for both the crack branching and reduction of the equivalent K-factor in the initial stage of fracture. The reversed relation seems to be associated with a critical ratio between both the plastic-zone and grain sizes, the ratio being roughly equal to one.

INTRODUCTION

In the last years, much attention has been devoted to the relation between structural and mechanical characteristics of metallic materials. E.g., close correlations between the fracture toughness K_{IC} , impact Charpy notch toughness (CVN) and the average grain size <u>d</u> in the sense of the well known Hall-Petch relation were found. In several cases, however, reversed relationships between K_{IC} and <u>d</u> were also reported, e.g. Ritchie et al /1/, Pacyna and Mazur /2/. This discrepancy can be explained by the existence of the structural parameter comparable with the grain size and the cleavage stress criterium, respectively (Zeman et al. /3/). In the case of heterogeneous martensite structure of UHS LA steels, however, the interpretation of the structural parameter is diffi-

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cult and it is not usually used in connection with austenite grain size. This statement also holds for the UHS LA steel ČSN 41 6341 (comparable with AISI 4340 steels), used in our investigations.

EXPERIMENTAL RESULTS

The test samples were annealed, oil quenched from different austenitization temperatures $T_A \in \langle 840, 1100 \rangle$ °C and tempered at 180 °C. The fracture toughness K_{IC} was measured within the temperature range of $T \in \langle -190, 20 \rangle$ °C using the standard procedure. The increase of T_A resulted particularly in

i) an increase in the average grain size $d \in \langle 8, 90 \rangle$ µm,

ii) crack branching caused by the enhanced intercrystalline decohesion in the initial fracture stage.

The K_{IC} vs. T dependence could be exactly expressed in the form

$$K_{IC} = A \exp\{T/B\} \quad \text{.........................(1)}$$

In eq. (1) $A = 23.9$ MPa $m^{1/2}$; $B = 396.3$K for $T_A = 840$ °C and $A = 32.6$ MPa, $B = 421.9$ K for $T_A = 1100$ °C, respectively. The K_{IC} vs. d dependence (at room temperature) corresponded to the reversed Hall-Petch relation

$$K_{IC} = K_{I0} + k_c . d^{1/2} \quad \text{.........................(2)}$$

In eq. (2) $K_{I0} = 42$ MPa.$m^{1/2}$ and $k_c = 2330$ MPa.

DISCUSSION

An increase in K_{IC} with the coarsening of austenite grains in AISI steels was observed by many authors, e.g. Lee et al /4/, Tsan Lin et al /5/. To the present, inconsistent explanations of this phenomenon were based on some parallel favourable changes of various structural characteristics, e.g. distribution of both residual austenite and carbide, chemical heterogeneity, etc. The most probable explanation in the case of the investigated steel follows from the reduction of the crack driving force induced by crack branching. The intergranular crack extension in the initial stage can be described as a random process in analogy with the Bernoulli problem. Pokluda et al. /6/ have shown that the average value of the deflection angle $\bar{\alpha}$ between the plains of both the primary crack and the branched one depends on the ratio $q = w/d$ (w - plastic zone size at the moment of fracture). If $q < q_c \approx 2$ (e.g., $d \gtrsim 2w$), a drastic increase in $\bar{\alpha}$, with the decreasing q, takes place. The corresponding reduction in the equivalent stress intensity factor K_{EQ} results in an increased K_{IC} value. This is in agreement with a recent work by Armstrong /7/,where, as the critical value, $q_c \approx 1$ is proposed.

Thus, if the ratio w/d approaches 1, the reversed Hall--Petch relationship is to be expected generally.

SYMBOLS USED

A,B = constants in equation (1)/MPa $m^{1/2}$ /, /K/

d = average austenite grain size /m/

K_{IC} = stress intensity factor for direct crack /MPa . $m^{1/2}$/

K_{EQ} = equivalent K_I factor for branched crack /MPa . $m^{1/2}$/

K_{IO}, k_c = constants in equation (2) /MPa $m^{1/2}$/, /MPa/

T = testing temperature /K/

T_A = austenitization temperature (^oC)

w = plastic zone size at the moment of fracture /m/

$\bar{\alpha}$ = average deflection angle of branched crack /rad/

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