AN YUGOSLAV HSLA STEEL USER'S EXPERIENCE FOR ELASTIC-PLASTIC FRACTURE TOUGHNESS

V. Ćulafić*, M. Anđelić**

The elastic-plastic fracture toughness parameter, J_{Ic}, has been determined for HSLA steel which has Yugoslav Standard designation JUS Č.4732. Specimens were available in one prescribed heat treatment. Tests were carried out in accordance with ASTM Standard E 813-87 utilizing single-specimen computer interactive test procedure.

INTRODUCTION

The use of elastic-plastic fracture mechanics for the predictions of the fracture of flawed structures has been shown to be a useful tool for design and material selection. The purpose of this investigation was to determine the effect of one heat treatment regime on the J_{Ic} parameter for one HSLA steel.

TEST PROCEDURE

The material used for the test program was a high strength low alloy steel (HSLA) which has Yugoslav Standard designation JUS Č.4732. This steel was 20 minutes quenched in oil at 840°C and 1 hour air tempered at 650°C. The chemical composition for this material is presented in Table 1, and the mechanical properties for prescribed heat treatment are shown in Table 2. The 25 mm thick specimens used were of compact type (1TCT) with starter notches in the T-L orientation as defined by ASTM E 399 (1). Specimens were fatigue precracked to initial crack lengths a_o=0.6W=30 mm, where W is specimen width. For the final 0.64 mm of fatigue precrack extension, the ratio of stress intensity factor range to Young's modulus was $(\Delta K/E) = 26/2\times10^{-5} = 0.004\ mm^{1/2}$ which was less than $0.005\ mm^{1/2}$. In order to meet crack straightness, 10% side grooves were made. The J_R curve tests were conducted at room temperature in accordance with ASTM E 1152-87 (2).

The results reported here utilized INSTRON-1333 servo-hydraulic test machine with PC-HP9000/300 computer for calculation and storing data. Typical load history is shown in Fig. 1.

* Faculty of Mechanical Engineering, University of Crna Gora, Podgorica, Yugoslavia
** Institute of Metallurgy, Nikšić, Yugoslavia

Table 1 Chemical composition of HSLA steel Č.4732 (wt %)

C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Nb
0.05	0.30	0.62	0.011	0.004	0.88	0.72	0.185	0.105	0.041

Table 2 Tensile properties of HSLA steel Č.4732

Heat treatment	Yield strength $R_{p0.2}$ (MPa)	Tensile strength R_m (MPa)	Elongation % in 50 mm	Reduction of Area (%)
Q&T	782	886	27	73

ANALYSIS OF THE RESULTS

To get J_R curves for presented load histories J-integral was calculated according to the expression (2):

$$J_{(i)} = \frac{(K_i)^2(1-\nu^2)}{E} + J_{pl(i)} \tag{1}$$

where stress intensity factor, K_i, is

$$K_{(i)} = [P_i/(BB_N W)^{1/2}]f(a_i/W) \tag{2}$$

and plastic component of J is:

$$J_{pl(i)} = \left[J_{pl(i-1)} + \left(\frac{\eta_i}{b_i}\right)\frac{A_{pl(i)} - A_{pl(i-1)}}{B_N}\right]\left[1 - \frac{\gamma_i}{b_i}(a_i - a_{i-1})\right] \tag{3}$$

In Eq.3, for CT specimens, $\eta = 2 + (0.522)b_i/W$, $\gamma = 1 + (0.76)b_i/W$, W -specimen width, b_i -instantaneous length of remaining ligament, B_N -minimum specimen thickness, a_i -instantaneous crack length and $A_{pl(i)} - A_{pl(i-1)}$ is the increment of plastic area under the load versus load-line displacement record between lines of constant displacement at points i-1 and i.

Crack lengths are determined using unloading compliance method (2). The resulting J_R curve is shown in Fig.2. After testing, specimens were heat tinted at 300°C for 10 minutes to mark crack extension broken open at liquid nitrogen temperature. Original crack size, a_o, and the final physical crack size, a_p, were measured at nine equally spaced points across the crack front using the average of the two surface measurements as a single point. Calculated average values of a_o and a_p satisfied all accuracy requirements of crack length measurements.

To establish a crack initiation measurement point under dominant slow-stable crack growth (3), a power law curve fitting procedure is used. First, blunting line was determined using equation $J = 2\sigma_Y \Delta a = 1668\ \Delta a$, where effective yield strength is $\sigma_Y = (\sigma_{YS}+\sigma_{TS})/2 = (782+886)/2 = 834$ MPa, and after that 0.15 mm and 1.5 mm exclusion lines and 0.2 mm offset line parallel to blunting line were drawn as shown in Fig.2.

Using a method of least squares on the qualified data regression line of the form $J = C_1(\Delta a)^{C2} = 397(\Delta a)^{0.524}$ was found and in the intersection with offset line provisional J_{Ic}, J_Q=223 kJ/m^2 determined. As requirements B, $b_o > 25\, J_Q/\sigma_Y$ = 6.68 mm and $\sigma_Y > (dJ/da)_{\Delta a_Q=0.32mm}$ = 352 MPa were satisfied, J_Q is valid as a measure of fracture toughness J_{Ic} for tested material.

CONCLUSIONS

Conducted tests show complexity of the problem of determination fracture toughness parameter J_{Ic}, but when a computer interactive single-specimen test method is once overcome it becomes routine. In the same time this method is very convenient for analysis of material variability and capable for testing a range of environments and temperatures.

REFERENCES

(1) ASTM Standard E 399-78A, *Test Method for Plane-Strain Fracture Toughness of Metallic Materials*, Annual Book of ASTM Standards, Part 10, 1987, pp.540-561, Philadelphia.

(2) ASTM E1152-87, *Standard Test Method for Determining J_R Curves*, Annual Book of ASTM Standards, Part 10, 1987, pp.800-810, Philadelphia.

(3) ASTM E 813-87, *Standard Test Method for J_{Ic}, A Measure of Fracture Toughness*, Annual book of ASTM Standards, Part 10, 1987, pp.686-700, Philadelphia.

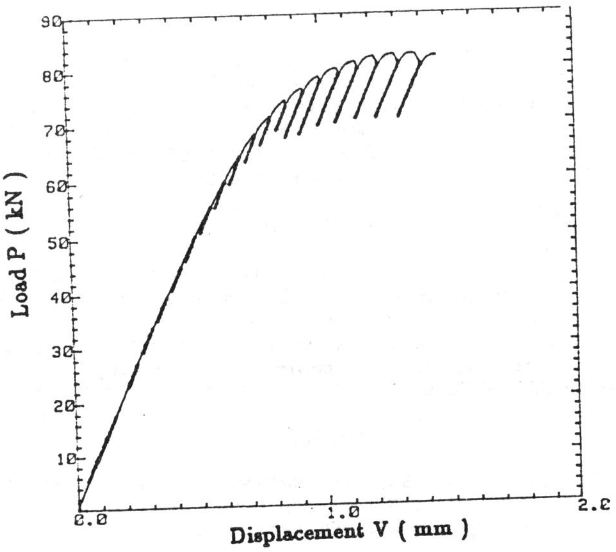

Figure 1 Load-displacement history for specimen ID-2.

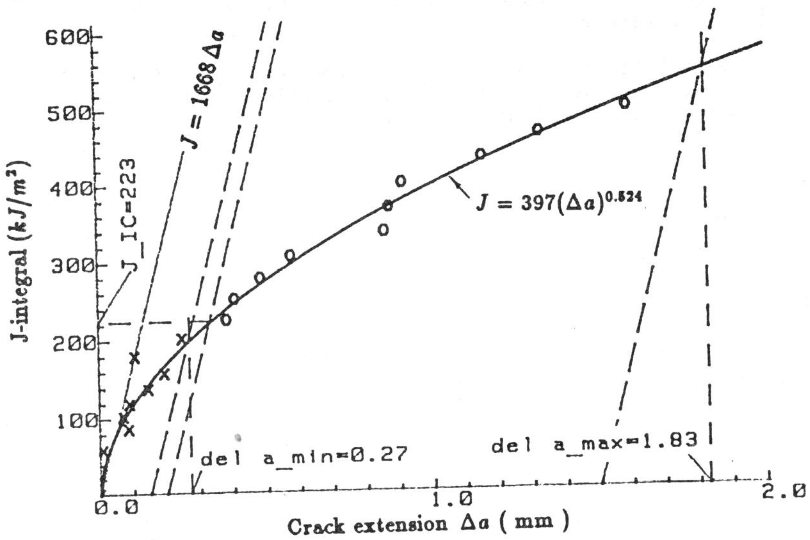

Figure 2 Procedure of J_{Ic} determination from J_R curve for specimen ID-2.