EFFECT OF TEMPERING TREATMENT ON FRACTURE TOUGHNESS OF 0.4 C STEEL

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J_R and δ_R curves of 0.4 C quenched and tempered steel have been obtained using Charpy-sized, %20 side-grooved specimens with LT orientation.

J_i values are found not to be dependent on the yield strength. Resistance to crack initiation and stable crack growth characterized with δ_i and $d\delta/da$ and dJ/da respectively are found to vary with the yield strength. These variations are empirically related to the carbide spacing.

INTRODUCTION

The ductile fracture of medium and high carbon steels containing a significant volume fraction of carbide particles follows a dual scale process of void nucleation and coalescence: Large voids formed at nonmetallic inclusions subsequently link through the formation of finer secondary voids at carbide particles (Stone and Cox (1), Curry and Pratt (2).

The object of this study was to examine the effect of carbide particle spacing on the crack initiation and propagation behaviors of quenched and tempered 0.4 C steel.

EXPERIMENTAL PROCEDURE

The chemical composition of the steel used in this study is given in Table 1. All specimens were normalised at 870°C. Then, they were austenitized at 870°C and water quenched and subsequently subjected to tempering treatment at different temperatures, namely, 600°C, 525°C, 450°C, 350°C, for two hours. One group of specimens was spheroidized by furnace cooling from austenite range to 700°C and held at this temperature for 40 h. Mechanical properties of the specimens after heat treatment are given in Table 2.

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TABLE 1- Chemical composition of the steel (weight %).

C	Si	Mn	S	P	Ni	Cr	Mo	Sn	Al
0.36	0.22	0.9	0.027	0.028	0.08	0.14	0.02	0.02	0.004

TABLE 2- Mechanical properties of the specimens.

Tempering Temperature (°C)	Yield Strength σ_{YS}(MPa)	Tensile Strength σ_{TS}(MPa)	Elogation (%)	Reduction (%)
Spher.	500	624	32	59
600	690	786	26	55
525	866	957	22	48
450	1015	1085	1.6	1.6
350	1220*	675	-	-

* Obtained from compression test

Precracked Charpy-type three point bend test pieces with LT orientation were used. They had 1 mm side grooves to eliminate shear lips. The resistance to crack initiation and crack propagation were characterized in terms of $\delta_i(J_i)$ and $d\delta/da(dJ/da)$ respectively. δ values were calculated according to the procedure given in BS 5762. J values were estimated by applying the formula (Rice et al (3):

$$J = 2U/B_N(W-a_o) \quad \ldots\ldots\ldots\ldots \quad (1)$$

where U is the area under the load-deflection curve, B_N net thickness (8 mm), W width (10 mm) and a_o original crack size (4-6 mm).

The yield strength of a quenched and tempered steel had been shown to vary linearly with the reciprocal square root of the carbide spacing (Lui and Gurland (4), (2)). For this reason, the yield strength was taken as a parameter representing the carbide spacing.

RESULTS AND DISCUSSION

Figures 1 and 2 show the dependence of δ_R and J_R curves on the yield strength. The values $\delta_i(J_i)$ and $d\delta/da(dJ/da)$ obtained from Figures 1 and 2 are given in Table 3.

TABLE 3- Effect of yield strength (σ_{YS}) on $\delta_i(J_i)$ and $d\delta/da(dJ/da)$ values.

σ_{YS} (MPa)	δ_i (μm)	J_i (kJm^{-2})	$d\delta/da$ (-)	dJ/da (MPa)
500	45	30	0.54	500
690	32	30	0.27	350
866	25	30	0.15	260
1015	20	30	0.09	200
1220	18	30	0.02	13

The specimens with the yield strength below 1220 MPa were found to satisfy the following conditions for specimen dimention (ASTM E 318) and J-controlled crack growth (shih et al (5):

$$a_o, (W-a_o), B_N > 25J_i/\sigma_{YS} \quad \text{.......} \quad (2)$$

$$(dJ/da)/\sigma_{YS} > 0.1 \quad \text{.......} \quad (3)$$

J_i values were found not to be dependent on the yield strength as reported by Curry and Pratt (2). On the other hand, δ_i values were found to be strongly dependent on the yield strength as shown in Figure 3. Figure 3 shows that the relationship,

$$\delta_i = 22000\,\sigma_{YS}^{-1} \quad \text{.......} \quad (4)$$

exists between δ_i and σ_{YS} where δ_i is in (μm) and σ_{YS} in (MPa). This relationship also proves the constancy of J_i values, since,

$$J_i \propto \sigma_{YS}\delta_i \quad \text{.......} \quad (5)$$

As the yield strength of a quenched and tempered steel varies linearly with the reciprocal square root of the carbide spacing (2), equation (4) also suggests that δ_i varies linearly with the square root of the carbide spacing, D. This result also agrees with the relationship given by Curry and Pratt (2):

$$\delta_i \propto X_o D^{1/2} \quad \text{.......} \quad (6)$$

where X_o is the inclusion spacing which is constant for all specimens used in the present study.

Figure 4 shows the relationship between the non-dimensional slope of J_R curve and the slope of δ_R curve. Figure 4 suggests that the relationship,

$$(dJ/da)/\sigma_{YS} = 1.87\,(d\delta/da) \quad \text{.......} \quad (7)$$

exists between the slopes.The data in Table 3 also suggests the following relationships:

$$d\delta/da = 2.63 \text{ x } 10^{-4}\,\delta_i^2 \quad \ldots\ldots \quad (8)$$

$$dJ/da = 10.8\,\delta_i \quad \ldots\ldots \quad (9)$$

where δ_i is in (μm) and dJ/da in (MPa). From equations (6), (8) and (9) it can be concluded that the slopes of δ_R and J_R curves vary linearly with carbide spacing and with the square root of carbide spacing, respectively.

ADDITIONAL SYMBOLS

$d\delta/da$ = initial slope of δ_R curve

dJ/da = initial slope of J_R curve (MPa)

D = carbide spacing (μm)

U = area under load-deflection curve (kJ)

X_o = inclusion spacing (μm)

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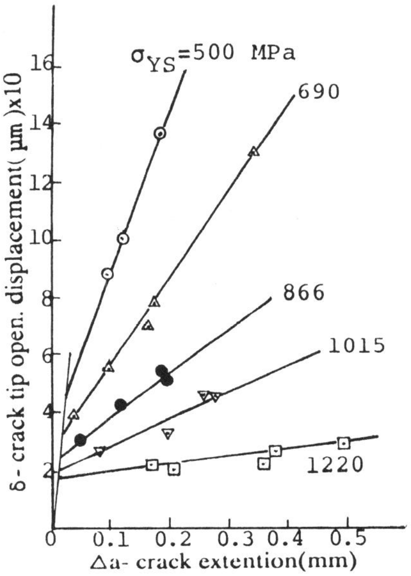

Figure 1 Effect of yield strength on δ_R curves.

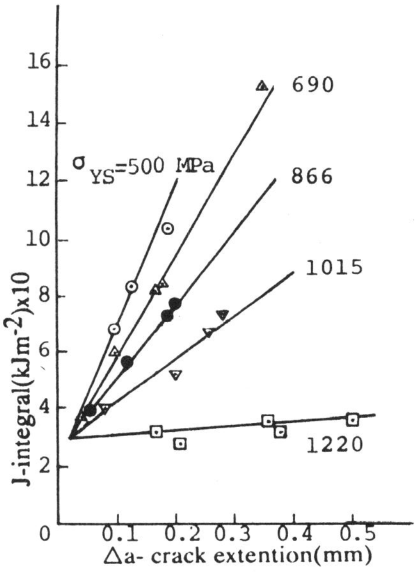

Figure 2 Effect of yield Strength on J_R curves.

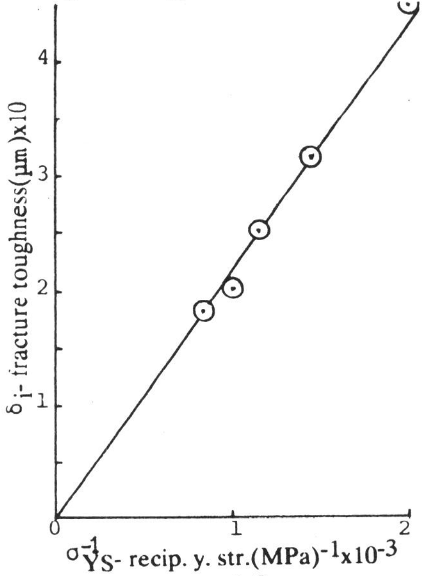

Figure 3 Variation of δ_i with the reciprocal of σ_{YS}.

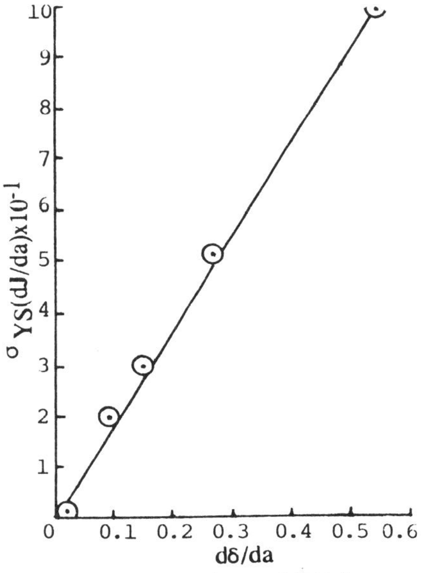

Figure 4 variation of $\sigma_{YS}(dJ/da)$ with d δ /da.