Crack Propagation Properties in Low Alloy Carbon Steels and Their Microfractographic Analysis

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1. Experimental Procedure

Fatigue crack propagation properties in structural low alloy carbon steels under pulsating tension were studied. 130 mm wide test pieces with a central through notch were prepared from steels ranging in tensile strength from 48 kg/mm^2 to 103 kg/mm^2 (see Table 1 and Fig. 1).

Further microfractographic analysis of fractured surfaces was applied to correlate the fatigue crack propagation rates and the striation spacings.

2. Test Results

Following conclusions were derived,

(1) The crack propagation rates dl/dN (l: the half crack length, mm N: number of cycles) were plotted against the ranges of stress intensity factor at the crack tip $\triangle K$ using the analysis of Paris. The following relationships were obtained (see Fig. 2),

$$dl/dN = 7.54 \times 10^{-12} (\triangle K)^{3.80} \quad \text{for Steel A} \quad (1)$$

$$dl/dN = 1.39 \times 10^{-11} (\triangle K)^{3.70} \quad \text{for Steel B} \quad (2)$$

$$dl/dN = 2.09 \times 10^{-9} (\triangle K)^{2.44} \quad \text{for Steel C} \quad (3)$$

$$dl/dN = 5.82 \times 10^{-9} (\triangle K)^{2.27} \quad \text{for Steel D} \quad (4)$$

(2) The material constants of C and m in the relationship $dl/dN = C (\triangle K)^m$ were well correlated with the yield strengths σ_y(kg/mm²) and tensile strengths σ_B(kg/mm²) of steels tested as follows (see Fig. 3).

$$m = 4.52 - 0.026\ \sigma_y \quad (5)$$

$$m = 5.19 - 0.0297\ \sigma_B \quad (6)$$

$$\log C = 0.0483\ \sigma_y - 12.432 \quad (7)$$

$$\log C = 0.0556\ \sigma_B - 13.726 \quad (8)$$

(3) The transition point of the fracture mode, i. e. the change from normal type fracture to shear type fracture has appeared at $\triangle K$ = 150, 170, 200, and 210 $kg{\cdot}mm^{-3/2}$ for steel A; B, C and D respectively.

(4) For steel C the crack propagation rate was measured in sea water as well as in air, but no significant difference was observed (see Fig. 4).

(5) Influence of plate thickness on the crack propagation rate was examined for steel A and B. In both steels the propagation rate of 15 mm thick specimens was greater than that of 3 mm thick specimens for a given $\triangle K$ value (see Fig. 5).

(6) In steel A and B the intergranular fracture was observed for the $\triangle K$ value below 60 $kg{\cdot}mm^{-3/2}$ (see Photo. 1).

(7) Spacings of the fatigue striations were assessed quantitatively and found to be directly correlated with the crack tip stress intensity factor range $\triangle K$ and following relationship was obtained (see Fig. 5).

$$\text{Striation spacing (microns)} = 1.11 \times 10^{-3} (\triangle K)^{1.2} \quad \text{for Steel A} \quad (9)$$

Table 1. Chemical composition and mechanical properties of steel used.

Steel	Chemical composition (%)											Mechanical properties			
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	Aℓ	σ_y (kg/mm²)	σ_B (kg/mm²)	Eℓ (%)	RA (%)
A	0.14	0.25	0.91	0.015	0.020	—	—	—	—	—	—	28.5	47.9	38.7	69.5
B	0.17	0.40	1.26	0.027	0.028	—	—	—	—	—	—	31.8	49.6	43.1	74.1
C	0.16	0.26	0.89	0.012	0.005	0.31	0.05	1.00	0.44	—	—	77.3	86.0	23.5	68.1
D	0.11	0.30	0.43	0.002	0.002	1.05	5.60	—	0.61	0.10	0.026	90.9	103.0	24.0	65.0

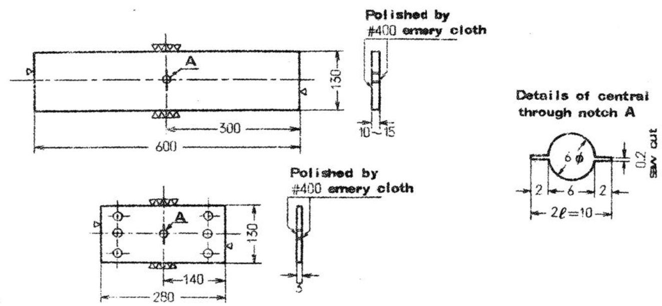


Fig. 1. Specimen geometry for fatigue crack propagation tests.

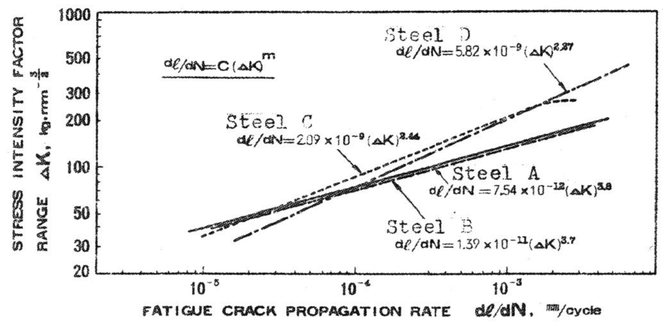


Fig. 2. Relation between fatigue crack propagation rate and stress intensity factor range.

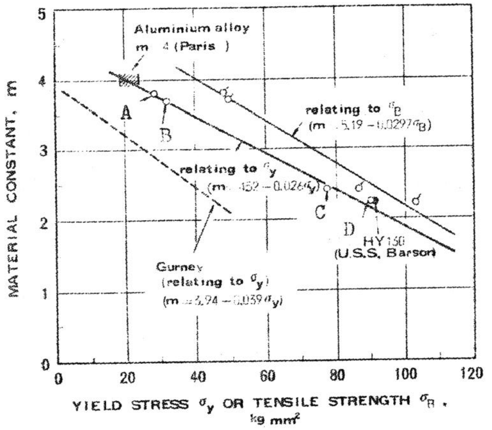


Fig. 3. Relation between material constant m (in equation $d\ell/dN=C(\Delta K)^m$) and yield stress or tensile strength.

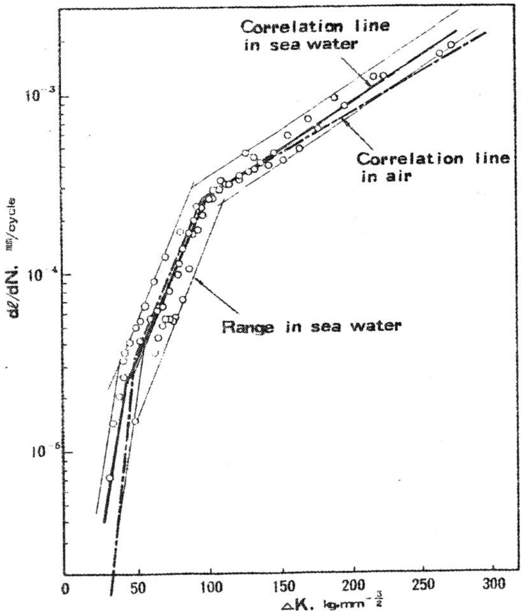


Fig. 4. Crack propagation properties of steel D in air and sea water.

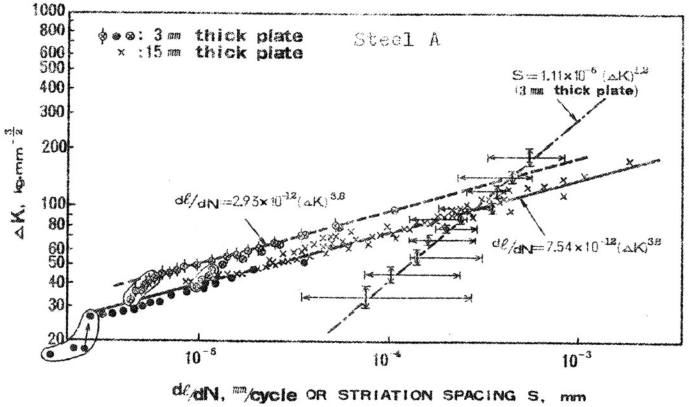
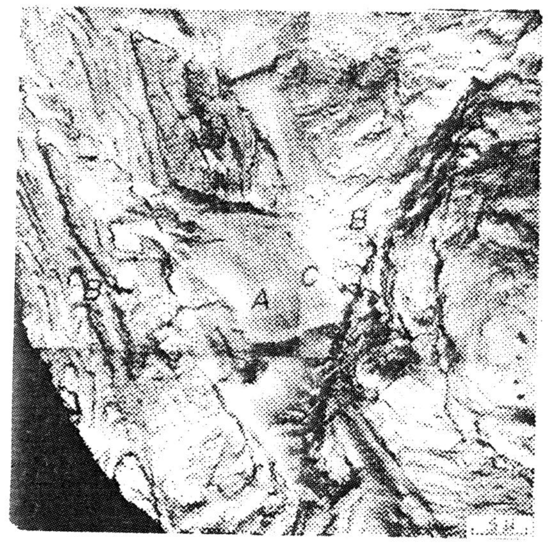


Fig. 5. Fatigue crack propagation rate and striation spacing



(ΔK : 29～34, ℓ : 5～7 mm).

Arrow indicates direction of macroscopic crack propagation.

A : Intercrystalline fracture

B : Dendritic pattern (River like pattern)

(Plate thickness : 3 mm
Stress range : $\Delta\sigma_g$ 7.0 kg/mm²
Nf 322.2 × 10^4)

Photo. 1. Fatigue fracture surface of steel A.