Fatigue Crack Growth in Metals and Polymers

B. Mukherjee
Research Associate, University of Waterloo, Ontario, Canada

Fatigue crack growth rate in sheet specimens of 7075-T6 and 2024-T3 aluminium alloys under constant amplitude cyclic loading show significant mean load effect. Crack growth rate for these materials can be correlated using the model suggested by Erdogan [1]

$$\frac{da}{dN} = \beta_o \; (\Delta K)^{\beta_1} \; (K_{max})^{\beta_2} \tag{1}$$

where a is half crack length; N is number of cycles; (ΔK) and (K_{max}) are range of and maximum stress intensity respectively; β_o, β_1, and β_2 are parameters which are functions of material.

This paper examines published crack propagation data for 7075-T6 aluminium alloy [2], A212-B steel [3] and Polymethylmethacrylate (PMMA) [4] to see if equation (1) can also be used to correlate the effect of mean load on crack growth rate for these materials. Other models suggested by Forman [5] or Elber [6] can also be used in place of equation (1). Erdogan's model has an advantage above other models in that it does not require additional experiments to find critical fracture toughness K_c which is necessary for Forman's model or to find the effective crack opening load which is necessary for Elber's model. In addition slight modification of equation (1) to

$$\frac{da}{dN} = \psi_o \; (\Delta K)^{\psi_1} \; (K_{max})^{\psi_2} \; (V)^{\psi_3} \tag{2}$$

where V is a third variable such as temperature or frequency, is sufficient to account for the effect of these variables on (da/dN).

Effect of Mean Load

Figure 1 shows crack growth rate log (da/dN) plotted against log (ΔK) for mill-annealed A - 212 B steel plate for load ratios 0.0 and 0.67. The lines passing through the experimental points are crack growth rates predicted by equation (1). Table 1 shows crack growth rate equations for PMMA, 7075-T6 aluminium and A-212 B steel. An examination of the residuals and r^2, the fraction of sum of squares accounted for by the model, (see table 1) showed that equation (1) correlates the data for these materials adequately.

Effect of Temperature

Figure 2 shows log (da/dN) plotted against log (ΔK) for A-212 B steel at 23. 9, 251. 1, 315. 6 and 343.3 °C. The scatter in the experimental data is large and there is some overlap between the crack growth rate values at various temperature. The equation which correlates the experimental data is:

$$\frac{da}{dN} = 10^{-24.10} (\Delta K)^{3.98} (T)^{056} \text{ in/cycle} \qquad (3)$$

where T is temperature in °C. Figure 2 also shows log (da/dN) predicted by equation (3). The experimental data used to obtain equation (3) is based on zero to tension loading, that is (ΔK) = (K_{max}). Under this condition, the effect of (K_{max}) can not be separated from that of ΔK and the effect of both factors are included in the term $(\Delta K)^{3.98}$. A comparison of equation (1) and (3) suggest that the crack growth rate equation for A-212 B steel is expressed completely by equation (2) with

V replaced by temperature when all three variables ΔK, (K_{max}) and T are acting on the material

Further evidence for the applicability of equation (2) is obtained when the interaction and main effects of ΔK, (K_{max}) and frequency f on crack growth rate of PMMA is studied with a complete factorial experiment with replication [4]. The equation that correlates the experimental data for PMMA (Figure 3) is:

$$\frac{da}{dN} = 10^{-16.20} (\Delta K)^{1.16} (K_{max})^{3.37} (f)^{-0.43} \text{ in cycle} \qquad (4)$$

All log (da/dN) vs log (ΔK) plots show large scatter around the mean log (da/dN) - log (ΔK) line predicted by growth rate models. Therefore attempts to predict crack life by integrating growth rate equations result in large error for all these materials. To estimate safe crack life for design purpose, a method which uses an upper probability limit of predicted log (da/dN) should be used [7]

References

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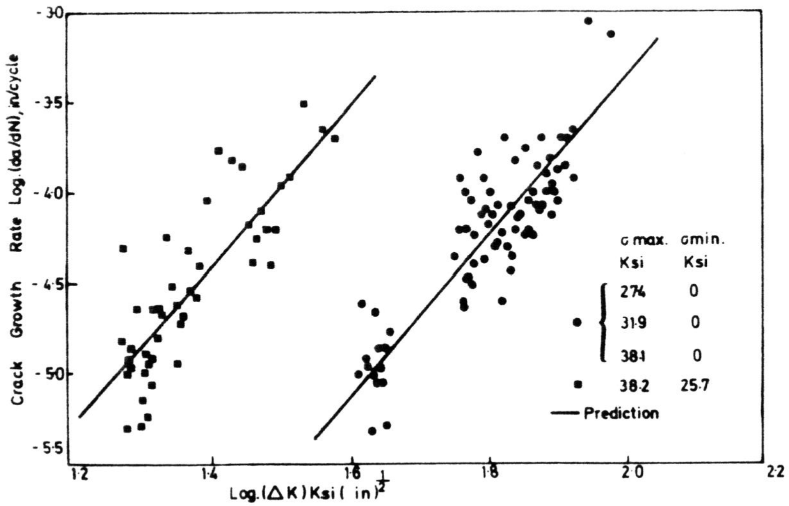

Figure 1 A-212 B Steel effect of mean load

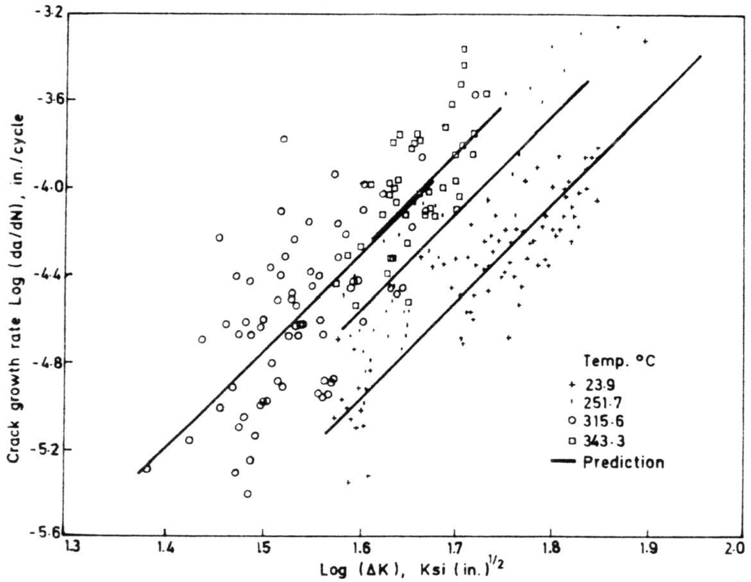

Fig.: 2. A-212B Steel effect of temperature.

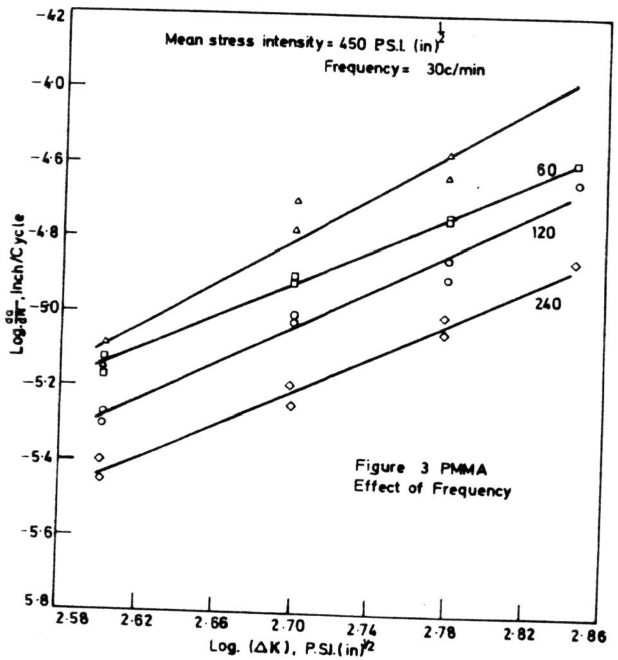

Figure 3 PMMA
Effect of Frequency

Table 1: Fatigue crack growth rate for 3 materials.

Material	Growth rate Eqn. inch/cycle	Range			Fre-quen-cy	Standard error	r^2	Figure of ref.
		ΔK Ksi√in.	Load ratio	da/dN in./cyc.				
PMMA	$\frac{da}{dN}=10^{-19.17}(\Delta K)^{1.19}(K_{max})^{3.87}$	0.4 to 0.6	0.1 to 0.5	10^{-6} to 10^{-4}	60	0.0513	0.97	Ref. 4
7075-T6	$\frac{da}{dN}=10^{-21.67}(\Delta K)^{1.61}(K_{max})^{2.29}$	5 to 53.3	-1.0 to 0.8	10^{-6} to 10^{-2}	30 to 1850	0.2103	0.95	Ref. 7,2
A-212B Steel plate	$\frac{da}{dN}\ 10^{-25.55}(\Delta K)^{1.61}(K_{max})^{3.28}$	15 to 100.0	0.0 to 0.67	10^{-6} to 10^{-3}	≈ 10	0.2385	0.77	Ref. 3 Fig. 1