EFFECT OF R RATIO ON FATIGUE CRACK GROWTH CHARACTERISTICS OF MARAGING STEEL

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ABSTRACT

The fatigue crack growth characteristics of maraging-350 was investigated at different stress ratios. The material was solution annealed and plastically deformed. Tests were performed at a stress ratios (R) of 0.0, 0.1, 0.5 and 0.8 using center-cracked tension specimen. Crack length was measured using travelling microscope and linear elastic fracture mechanics approach was used to analyse the experimental data. Comparison was made between different stress ratios. At a stress intensity factor range of 25 MPa$\sqrt{m}$, a crack growth rate of 2.08×10^{-4}, 2.25×10^{-4}, 3.56×10^{-4} and 5.83×10^{-4} mm/cycle was observed at R=0.0, 0.1, 0.5 and 0.8, repectively. A crack growth equation which considers the effect of stress ratio was used to compare the experimental and predicted growth behaviour.

KEYWORDS

Crack growth, stress ratio, maraging steel

INTRODUCTION

The maraging steels are being considered for an increasing number of critical application due to its unique combination of high strength and good toughness. A number of investigations have been conducted on maraging steels to study the strengthening mechanism, heat treatment, toughness and fatigue behaviour (2,3,5,6,9,10). Thermo-mechanical treatments have also received considerable attention to increase the tensile strength and fatigue resistance in a variety of carbon steels. It has been shown that the low cycle fatigue resistance of grade 350 maraging steel was not affected by thermo-mechanical treatments but in the high cycle fatigue a 30% improvement was acheived. Fatigue crack growth behaviour of thermo-mechanically treated maraging steels has received little attention so far.

The objective of this study was therefore to determine the fatigue crack growth characteristics of thermo-mechanically treated 350-maraging steel at different stress ratios.

EXPERIMENTS

The chemical composition of the material used for the investigation is shown in Table I. The crack growth study was conducted on the material which was solution annealed at 810° for 30 minutes and its thickness was reduced upto 75%. Crack growth tests were carried out on center cracked tension (CCT) specimens, as shown in Fig. 1. The micrograph depicted in Fig. 2 shows the flow forming line in cross-section of the material after flow forming.

The tests were performed under constant amplitude loading at stress ratios (R), 0.0, 0.1, 0.5 and 0.8, at a frequency of 10 HZ at room temperature. Crack length was measured from a polished precracked surface using travelling microscope. The following formula was used to calculate the elastic stress intensity factor range (ASTM, 1986).

$$\Delta K = \frac{\Delta P}{BW}\sqrt{\pi a \sec \frac{\pi a}{W}} \tag{1}$$

where ΔP, a, B and W are the applied load range, half of the crack length, thickness and width of the specimen, respectively.

RESULTS AND DISCUSSION

Crack length versus number of stress cycles is presented in Fig. 3, which shows an increase in crack growth with increase in stress ratio (R). Growth rate was calculated by secant method (ASTM,1986) and is presented as a function of stress intensity factor range in Fig. 4. The results showed an increase in growth rate with increase in R ratio. The crack growth direction shown in Fig. 5 follows the flow forming pattern of the material shown in Fig. 2. The best fit the experimental data, for different stress ratios, according to the Paris law is the following:

$$R = 0.0, \qquad \frac{da}{dN} = 1.08 \times 10^{-7}(\Delta K)^{2.35} \tag{2}$$

$$R = 0.1, \qquad \frac{da}{dN} = 1.166 \times 10^{-7}(\Delta K)^{2.35} \tag{3}$$

$$R = 0.5, \qquad \frac{da}{dN} = 1.85 \times 10^{-7}(\Delta K)^{2.35} \tag{4}$$

Elemnet	C	Ni	Mo	Ti	Co	Al	Fe
Wt%	0.005	18	3.7	1.6	12.6	0.1	Balance

Table I: Chemical composition of maraging-350 steel.

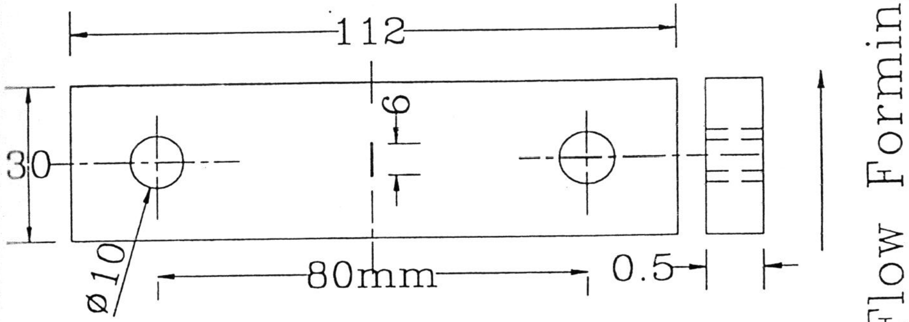

Fig. 1: Center cracked tension specimen.

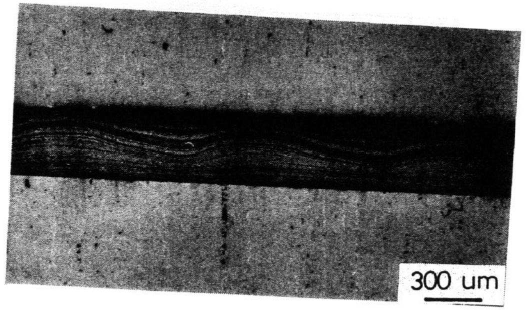

Fig. 2: Micrograph showing the flow forming line in the cross-section of the material.

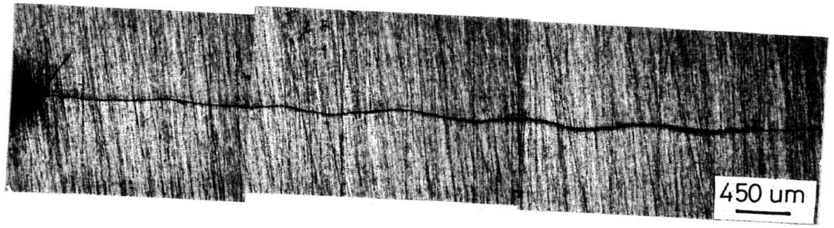

Fig. 3: Fatigue crack growing along the flow forming lines.

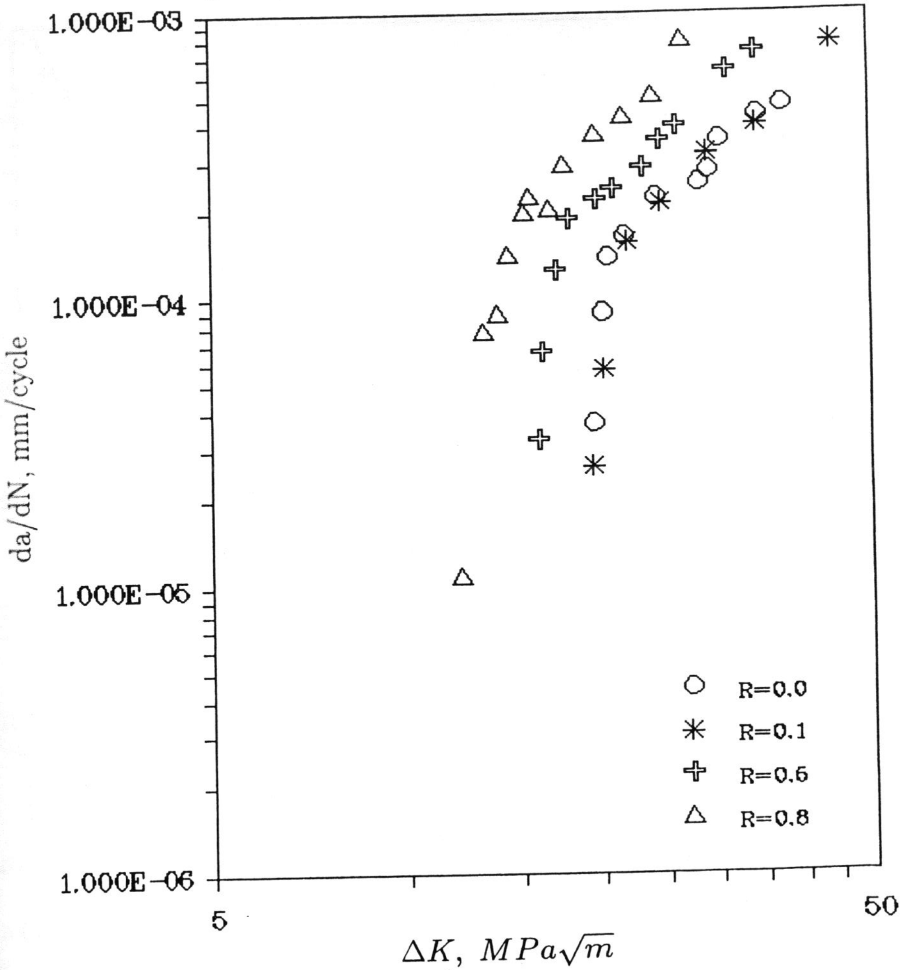

Fig. 4: Crack growth behaviour at different R ratios.

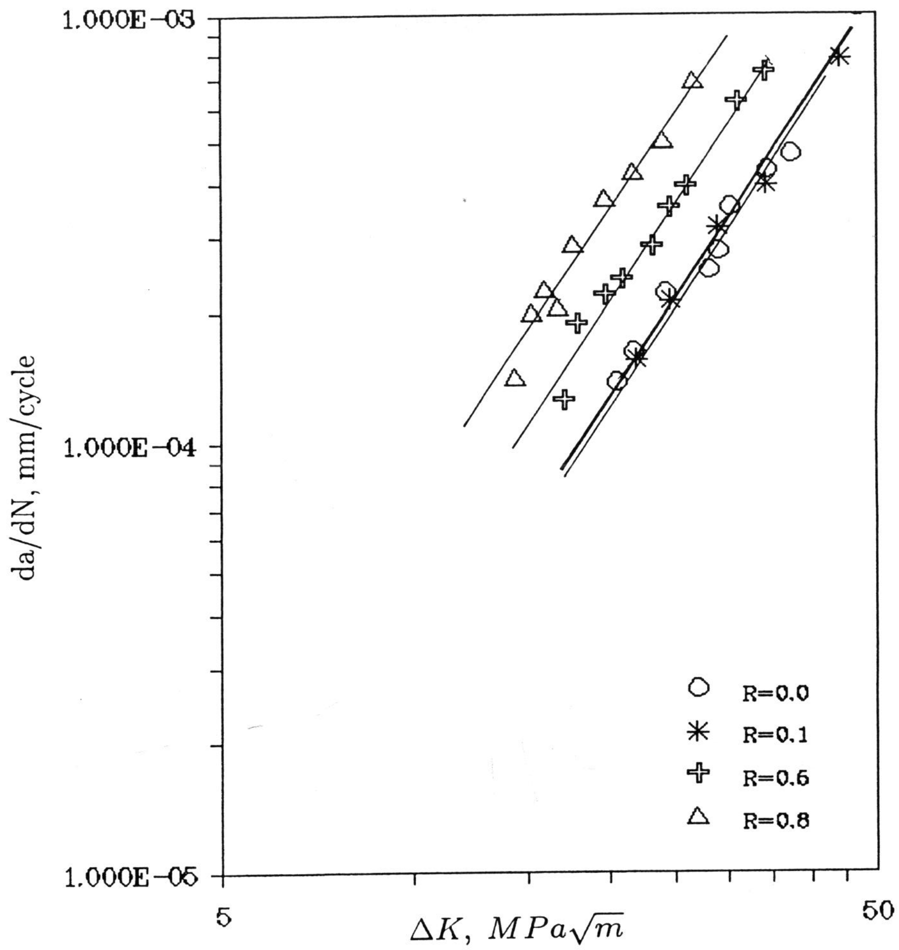

Fig. 5: Crack growth behaviour in region II. The solid lines represent the best fit Paris type equations.

$$R = 0.8 \qquad \frac{da}{dN} = 3.79 \times 10^{-7}(\Delta K)^{2.28} \tag{5}$$

The above equations show that for this material, at different stress ratios the coefficients changed but the exponents of the Paris type equation remained the same. Similar observations were reported by Radhakrishnan (1979) and Hussain and Rios (1994). The most commonly used equation depicting mean stress effects is the Forman equation (1967) which is the modified form of Paris law:

$$\frac{da}{dN} = \frac{C(\Delta K)^m}{(1-R)K_c - \Delta K} \tag{6}$$

Forman's equation required an extra value of K_c for different stress ratios. Further more it overestimates growth rates at low ΔK and at high stress ratio. Radhakrishnan (1979), developed a simple equation based on a crack growth model, which considers the stress ratio effect as:

$$\frac{da}{dN} = C_o(\frac{1}{1-R})^n \Delta K^m \tag{7}$$

where the exponent m is independent of stress ratio and $C_o(\frac{1}{1-R})^n$, represents the coefficient C which depends on stress ratio i.e:

$$C_R = C_o(\frac{1}{1-R})^n \tag{8}$$

C_o corresponds the condition when R=0. Equations 2 to 5 can therefore combine into one equation as:

$$\frac{da}{dN} = 1.08 \times 10^{-7}(\frac{1}{1-R})^{0.77} \Delta K^{2.35} \tag{9}$$

This equation is plotted in Fig. 6 for various stress ratios and is in good agreement with experimental crack growth observations.

SUMMARY

An investigation was made of crack propagation in thermo-mechanically treated 18%Ni maraging steel under high cycle, low stress fatigue loading at different stress ratios. The results showed that the rate of fatigue crack propagation were sensitive to stress ratio (R). At the stress ratios of 0 and 0.1, the growth rate was nearly the same but at a stress intensity factor range of 25 MPa$\sqrt{m}$, a crack growth rate of 2.08×10^{-4}, 2.25×10^{-4}, 3.56×10^{-4} and 5.83×10^{-4} mm/cycle was observed at R=0.0, 0.1, 0.5 and 0.8, repectively. The exponent (m) of the Paris equation was found to be independent of the stress ratios while the coefficient C was shown to vary with stress ratios. The predicted crack growth rates were in good agreement with experimentally observed growth rates.

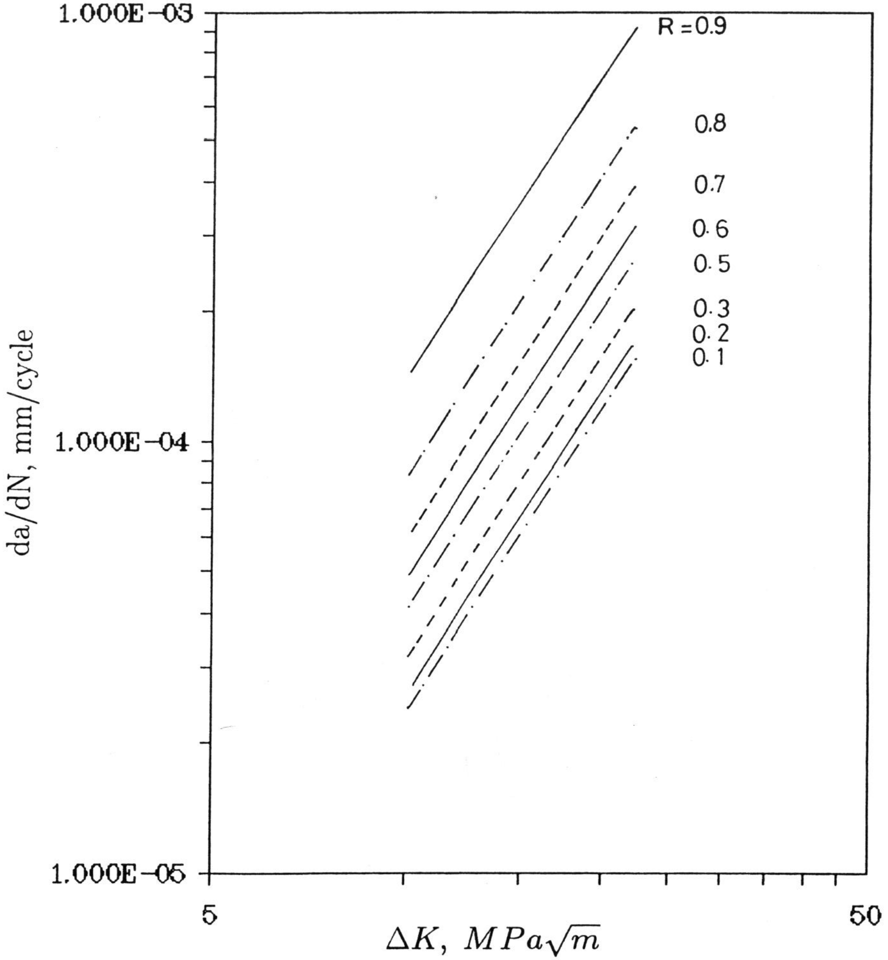

Fig. 6: Predicted crack growth behaviour at different R ratios.

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REFERENCES

ASTM stanard (1986). 03.01, 722.

Bathias, C. and R. M. Pelloux (1973). Fatigue crack propagation in martensitic and Austenitic steels. Metall. Trans., 4, 97.

Diwakar, V., S. Arumugam, T. S. Lakshmanan and B. K. Sarkar (1989). J. Mater. Sci., 24, 881.

Forman, R. G., V. E. Kearney and R. M. Engle (1967). Numerical analysis of crack propagation on cyclic-loaded structure. J. Basic Eng., Trans. ASME, 89, 3, 459.

Hussain, K. and E. R. de los Rios (1994). Application of short and long fatigue crack growth behaviour in lifetime prediction of mine auxiliary ventilation fans. Mater. Trans., JIM, 35, 9, 585.

Landgraf, R. W. (1979). In: Fatigue and Microstructure (M. Meshii,ed), 439, Metals Park, OH.

Rack, R. H. and D. Kalish (1974). Improved fatigue resistance of 18Ni (350) maraging steel through thermo-mechanical treatments. Metall. Trans., 5, 685.

Radhakrishnan, V. M (1979). Eng. Fract. Mechanics, 11, 359.

Spitzig, W. A., P. M. Talda and R. P. Wei (1968).Fatigue crack propagation and fractroghraphic analysis of 18Ni (250) maraging steel tested in argon and hydrogen environments. Eng. Fract. Mechnics, 1, 155.

Tuffnell, G. W., D. L. Pasquine and J. H. Olson (1966). An investigation of fatigue behaviour of 18% nickel maraging steel. Trans. ASM, 59, 769.