ON THE CONDITIONS OF FATIGUE CRACK PROPAGATION UNDER PROGRAMMED LOADING

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ABSTRACT

Experimental results on the conditions of fatigue crack propagation under biaxial state of stress in ARMCO-steel with approximately 0.04 % C are presented. The influence of stress concentration due to preexisting notches, in conjunction with programmed constant amplitude loading and overloading on the initiation and propagation of fatigue cracks is discussed.

KEYWORDS

Programmed load; cyclic overload; crack initiation; crack propagation; retardation.

INTRODUCTION

The phenomena of fatigue crack initiation and propagation under constant-amplitude and spectrum load in view of predicting the minimum structural life has been the subject of several experimental and theoretical studies over recent years. Though the effect of single, intermittent and cyclic overload on fatigue crack retardation has been investigated (Morman and Dubensky, 1975), few data were reported regarding the effect of cyclic overload applied before crack initiation in notched structural elements. This effect appears to be important, since a large percent of the useful structural life can actually be spent during the initiation and early-stage propagation of crack and cyclic overload may affect both of them. As theoretical K_I analyses in the near vicinity of notches are available (Tada, Paris and Irwin, 1973; Novak and Barsom, 1975) providing an acurate evaluation of the interaction between the stress fields of crack starter (notch) and crack, in the present study the stress concentration due to preexisting notches has been assessed as a main parameter of real service-behaviour. The characterization of the influence of cyclic overload of different extent on the conditions of crack initiation and propagation rely on constant-amplitude propagation data, covering the range of usual concentration factor values. In conjunction, stress-amplitude values were chosen so that initiation and subcritical crack propagation will occur below 2.10^6 cycles. Finally, by analytical fitting, data referring to the conditions of crack initiation and propagation are correlated in terms of the considered parameters.

EXPERIMENTAL WORK

The material used throughout the study was ARMCO-steel normalized at 950° C, 15 min., air cooling, for homogenity and isotropy of its microstructure and mechanical behaviour. Chemical composition and mechanical properties are given in Table 1.

TABLE 1 Chemical Composition and Mechanical Properties of ARMCO-steel

Composition %	Yield strength MPa	Tensile strength, MPa conv.	Tensile strength, MPa real	Elongation, % unif.	Elongation, % fract.	Reduction of area, %
0.04 C, 0.07 Si, 0.11 Mn, 0.006 P, 0.015 S, 0.0004 N_2	240	320	512	16.6	38	65

Double-edge-notched tension specimens of 2.5 mm thickness were utilized, with notch-radius values varying from r= ∞ to r= 0.2 mm, providing stress concentration factors of α_k= 1 ÷ 7.3 . Tests were conducted on a closed-loop servohydraulic testing machine. Constant amplitude tests were performed at stress levels of 200; 170; 150 and 120 MPa (maximum stress values, i.e. 2 x amplitude for the stress ratio R= 0) and programmed overload tests at a nominal stress of 200 MPa and 10% overload according to the loading schedule shown in Fig. 1, where N_{fI} is the number of cycles to fracture under constant-amplitude conditions, at the same stress level.

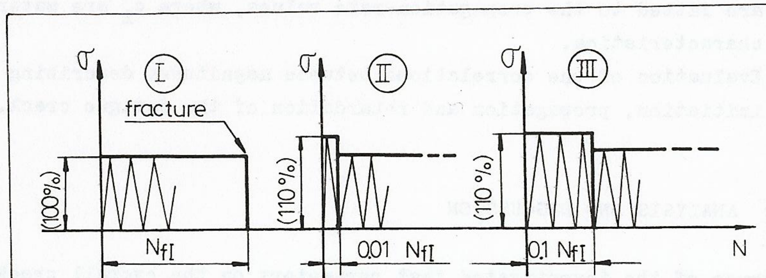

Fig. 1. Overload schedule.

Crack length measurements were performed by means of an optical device with an accuracy of $\pm 2.10^{-4}$ mm in the range up to 1 mm and $\pm 2.10^{-3}$ mm in the range over 1 mm.

DATA PROCESSING

Primary experimental data were obtained as crack length (a) - number of cycles (N) relationships, in terms of the parameters: stress level σ , stress concentration factor α_k and extent of overload (no overload, 0.01 N_{fI} respectively 0.1 N_{fI} extent). A computer program has been developed to evaluate crack initiation and propagation data in following steps:

1. Nonphenomenological, versatile power and exponential function series with up to 10 terms are fitted to experimental a-N plots and propagation-rate values analytical derived.

2. Propagation-rate values are computed by a digital derivation procedure fitting parabolic functions to 4 successive experimental points in the vicinity of the derivation point.
3. Data obtained thus far are compared and the best fittings are chosen.
4. Stress intensity factor values are computed according to a relevant analytical model, for the given configuration of the specimen and actual crack length and corrections are made to account for the size of the plastic zone.
5. Several analytical propagation expressions $da/dN = f(\Delta K, c_i)$ are fitted to the propagation-rate values, where c_i are material characteristics.
6. Evaluation of the correlations between magnitudes describing initiation, propagation and retardation of the fatigue crack.

ANALYSIS AND DISCUSSION

The influence of the investigated test parameters on the overall crack propagation behaviour under constant-amplitude load is shown in Fig. 2.

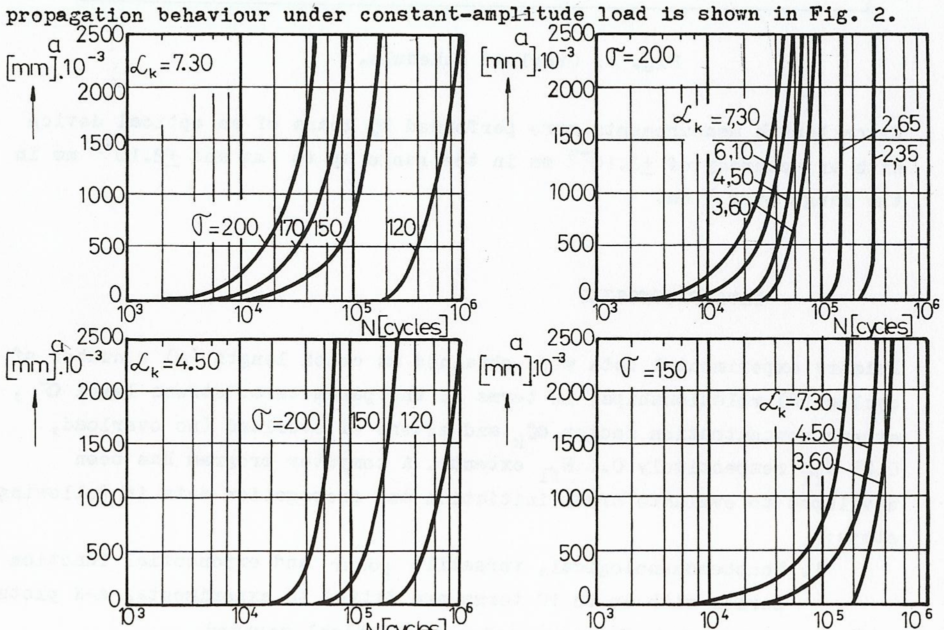

Fig. 2. a - N plots (constant-amplitude load).

For constant values of one of the parameters (α_k and σ respectively), the curves are arranged according to the varying values of the other parameter (σ and α_k respectively), shifting with decresing stress levels as well as decreasing concentration factors toward higher numbers of cycles. The a-N relationships generated by programmed overload tests exhibit, as shown in Fig. 3, phenomena of retardation subsequent to combination of high stress levels and high stress concentrations; the effect on the initiation may be an acceleration or retardation of the occurance of the crack (expressed by the number of cycles N_o when the macroscopic crack starts), depending on whether the extent of overload, in conjunction with the stress concentration, has produced only early stage cyclic hardening or has already started the nucleation of microcracks at the tip of the notch.

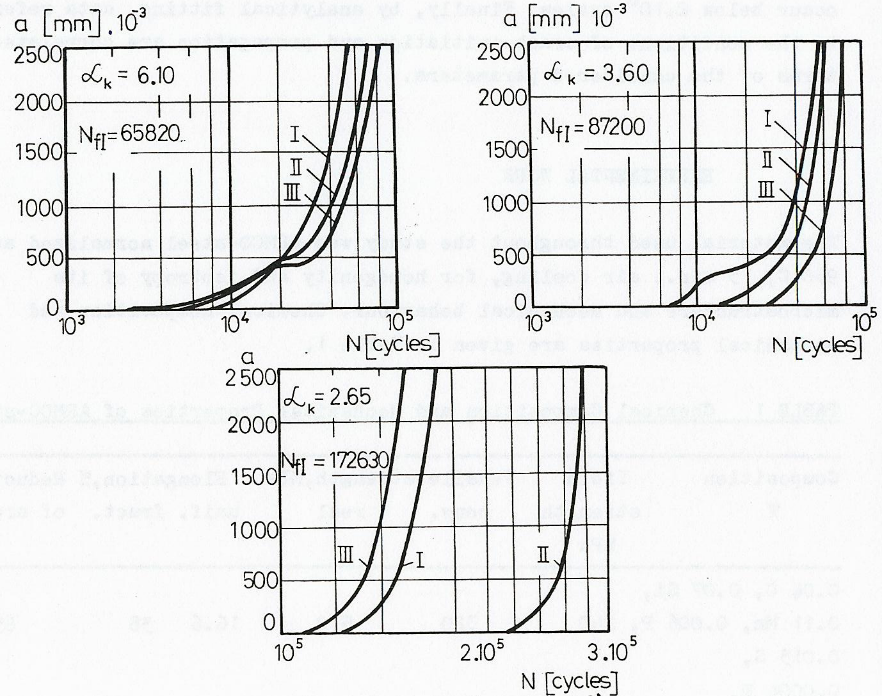

Fig. 3. a - N plots (programmed overload)

The analysis of crack initiation data under constant-amplitude load, Fig. 4, indicate no significant influence of the stress concentration at higher stress levels (>150 MPa), fact related to the almost equal extent of hardening at the tip of the notch.

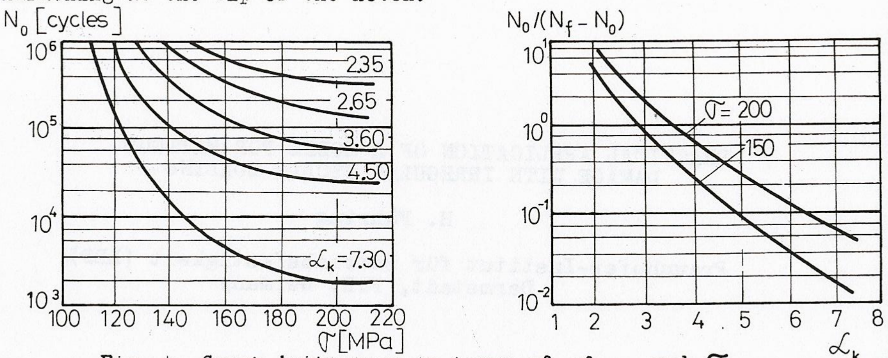

Fig. 4. Crack initiation in terms of α_k and σ (constant-amplitude load)

Figure 4 shows also the dependence of the ratio initiation versus propagation life in terms of the test parameters. This ratio may decrease nearly 100 times for the variation of α_k from 3.00 to 7.30, since at lower hardening rate the decrease of propagation rate is more relevant than the decrease of the initiation life. Under overload conditions, initiation is generally accelerated, since for high stress concentration, regardless of the number of overload cycles, microcracks were observed very soon and the crack propagation starts at smaller number of cycles, Fig. 5.

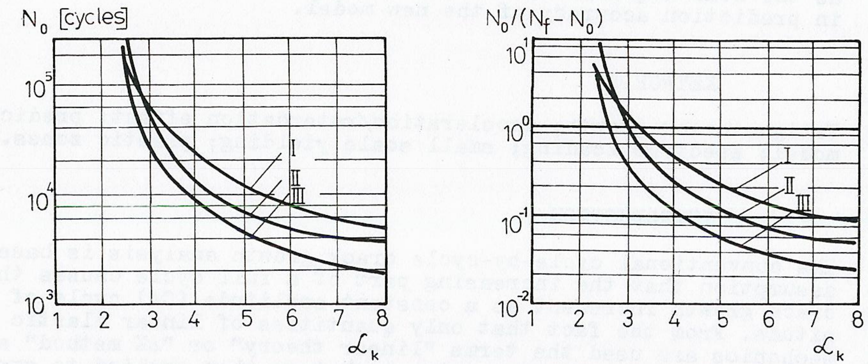

Fig. 5. Crack initiation under programmed overload.

In contrast, for lower stress concentration ($\alpha_k \leq 3$), the effect of overload differ essentially in terms of the extent (number of overload cycles): while the smaller extent produces hardening much below saturation

and delays the initiation-period up to the double amount, the larger extent may already produce microcracks and thus shorten the iniation-period. Matters are essentially the same for the $N_o/(N_f - N_o)$ ratio plots, since effects of retardatio are relatively short-timed and do not affect too much the overall propagation-period. The correlation between propagation rate and the reported number of cycles, Fig. 6, for constant -amplitude load, indicate a consistent arrangement of the plots in terms of the parameters α_k and σ, being also in good agreement with propagation prediction models (e.g., for the Paris relation the constant determined are: C= 6.2 10^{-11}; m= 1.97).

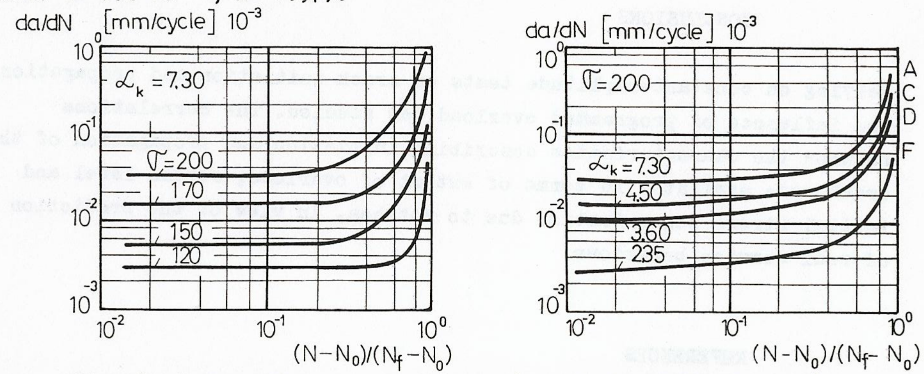

Fig. 6. Curves of propagation rate (constant-amplitude load).

Propagation rate analysis under programmed overload conditions indicates, according to the registered retardation phenomena, a decrease to a 10-th of the initial amount of the rate, Fig. 7.

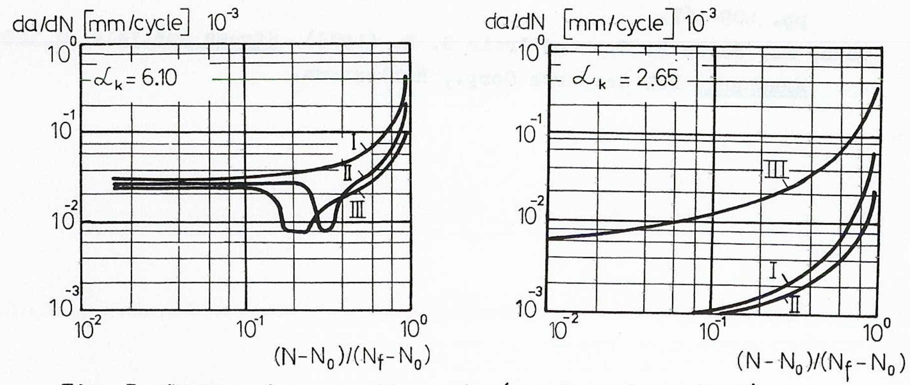

Fig. 7. Curves of propagation rate (programmed overload).

Due to overload and high stress concentration, at low numbers of cycles microcracks were observed and cracks started with approximately the same initial rate. No retardation was observed at low stress concentration ($\alpha_k \leqslant 3.00$), where the initial propagation rate value differ significantly due to low rated hardening under small extent overload (0.01 N_{fI}), when up to 80 percent of the initiation period no microcracks have been observed.

CONCLUSIONS

Relying on constant-amplitude tests on crack initiation and propagation, the influence of programmed overload was studied. The correlations between the characteristics describing initiation and propagation of the crack were evaluated in terms of extent of overload, stress level and initial stress concentration due to notches, in view of the prediction of real service behaviour.

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