OVERLOAD EFFECTS ON THE FATIGUE CRACK PROPAGATION IN FERRITE-PEARLITE RAILWAY WHEELS

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A study of the influence of single overload cycles analysing the effects of K_{OL} and ΔK_b on the fatigue crack propagation in a 0,5% C ferrite-pearlite steel has been carried. The results show that the overloads produce a fatigue crack retardation, being more severe the number of delay cycles for higher values of the baseline stress intensity factor, ΔK_b, and the overload value, K_{OL}. After the delay period is over, the fatigue crack growth rate and the micromechanisms that interact are similar to those that usually appear at constant load amplitude conditions. The magnitude of the post-overload retardation can be related with $(K_{OL}/\sigma_{YS})^2$, a parameter representative of the overload plastic zone size.

INTRODUCTION

It is well established that when single or multiple overload cycles are applied during a constant amplitude test, the fatigue crack growth significantly changes during a certain number of cycles after the overload. The application of an overload of value K_{OL}, being ΔK_b the baseline stress intensity factor range before the overload, produces a transient retardation in the subsequent crack growth. If the $K_{OL}/\Delta K_b$ ratio is sufficiently high, even a crack arrest can be induced. After a number of delay cycles, N_d, in which the crack has propagated a distance Δa_d, the effect of the overload disappears and the previous da/dN value is restored. Crack delay effects have been attributed to different processes: crack tip blunting, crack tip branching, residual stresses and crack closure (1,2). The present investigation was focussed on the study of the influence of single overload cycles on the fatigue crack propagation in a 0,5%C ferrite-pearlite steel, analysing the effects of K_{OL}, ΔK_b and the load ratio parameters.

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EXPERIMENTAL PROCEDURE

The material examined was a 0,5%C ferrite-pearlite carbon steel from the rim of a 910 mm ϕ UIC R7 grade railway wheel (a hot forged and rolled, rim quenched wheel) supplied by CAF, S.A. Quantitative metallographic data and conventional mechanical properties for different rim levels and orientations have been previously published (3). Fatigue crack propagation experiments were conducted on a 100KN servohydraulic Instron machine, according to ASTM E 647. CT specimens (W = 50 mm, B = 12,5 mm) were used with their crack plane normal to the wheel disc. All tests were performed under load control employing 35 hz sinusoidal waves. Constant ΔK regimes were run at two load ratio values, $R \simeq 0$ (actually $0{,}02 \leq R \leq 0{,}03$) and R = 0,3. Single overloads were applied at different ΔK_b levels (15,20,26,30 and 40 $MNm^{-3/2}$) and K_{OL}/K_{max} values (1,5, 1,75, 2,5 and 3,25). Crack length was measured at both sides of the specimen with the help of two 20x optical microscopes at the load constant regime and with two 100x optical microscopes after the application of the overload. Fractographic examination was performed in a Philips 501B SEM.

RESULTS AND DISCUSSION

Fig. 1 shows a typical ΔK - da/dN curve corresponding to a specimen tested at R = 0. After the application of the overload a big retardation in da/dN is always observed. After the retardation period, the crack growth rate is similar to that found in tests without overloads. In Fig. 1 the continuous line corresponds to the Paris equation excluding the overload transients and the dotted line to a constant amplitude test (3). The results are similar in both cases considering the normal variability of this type of tests. The affected crack length, Δa_d, and the number of cycles of retardation, N_d, were measured considering the period in which the a-N curve needs to resume the previous slope to the overload. The main characteristics are:

- for the same ΔK_b value, N_d increases notably for higher values of peak stress intensity factor, K_{OL} (Fig. 2).
- when the baseline stress intensity range increases for the same K_{OL}/K_{max} ratio, the N_d retardation period decreases (Fig. 2).
- the overload affected crack increment, Δa_d, increases notably with higher values of K_{OL} (same ΔK_b) and ΔK_b (same K_{OL}/K_{max}) (Fig. 3).

The fractographic analysis shows that immediately after the overload there are not different features comparing to the previous zone and the general appearance corresponds to a constant load amplitude test, this is, flat and amorphous (3). Nevertheless, for high overload values ($K_{OL} > 70$ $MN/m^{3/2}$) in the moment of the overload application a band appears in which the crack propagates in a static mode with voids corresponding to ductile fracture. Finally, for high N_d values, there are oxide layers on the fracture surface immediately after the application of the overload.

The influence of ΔK_b and K_{OL} in N_d (Fig. 2) can be understood considering the effects of an overload. The application of an overload creates a residual stress zone at the crack tip (4). For the same K_{OL} the opposite phenomenon happens. For the same ΔK_b and K_{OL} values, the load ratio is an important parameter in the delay period. The difference between delay periods for R = 0 (N_d = 186500 c.) and R = 0,3 (N_d = 40.000 c.) applying the same overload (ΔK_b = 20 and K_{OL} = 50 MN/m$^{3/2}$), (see Fig. 2), can be related to the existence of a crack closure phenomenon. Firstly, in the studied ferrite-pearlite steel fatigue crack growth is different for specimens tested under constant load amplitude conditions at R = 0 and R ≥ 0,3 (3), ascribing this influence to a plasticity-induced crack closure effect. Secondly, due to the overload application, da/dN has drastically decreased in specimens tested at R = 0, and developing near threshold conditions at the crack tip with oxide-induced crack closure. The combination of these two mechanisms can explain the influence of the load ratio on N_d.

The overload affected crack length, Δa_d, can be related to the overload plastic zone size (4). Fig. 4 shows the variation of Δa_d with $(K_{OL}/\sigma_{YS})^2$. If the results at which a static crack propagation has happened are not considered, the values can be fitted to a straight line of equation:

$$\Delta a_d \text{ (mm)} = 0{,}500 + 0{,}080\,(K_{OL}/\sigma_{YS})^2$$

So, it is obvious that in the analysed material there is a relation between the overload affected crack length and the corresponding plastic zone size, as it has been previously observed in other materials (4,5).

CONCLUSIONS

- In the 0,5% carbon steel, single overloads produce a fatigue crack retardation, being influenced the number of delay cycles by the baseline stress intensity factor (ΔK_b), the overload value (K_{OL}) and the load ratio.
- the affected crack length is related to the overload plastic zone size.

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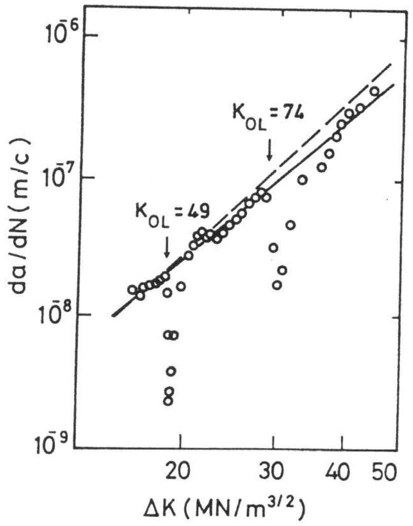

Fig.1 Effect of application of an overload on da/dN

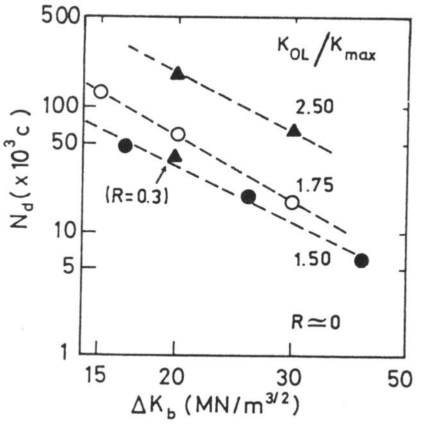

Fig.2 Influence of K_{OL} and Δ K_b on N_d

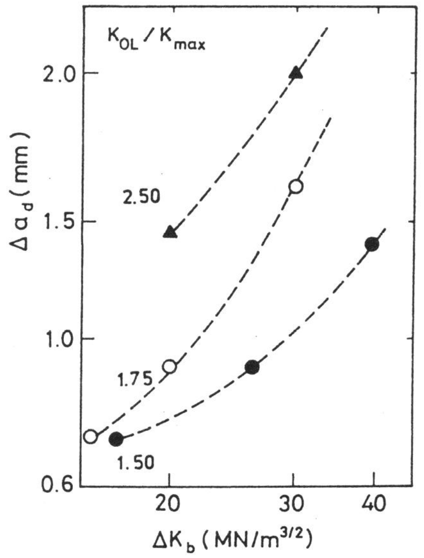

Fig.3 Influence of K_{OL} and Δ K_b on Δa_d

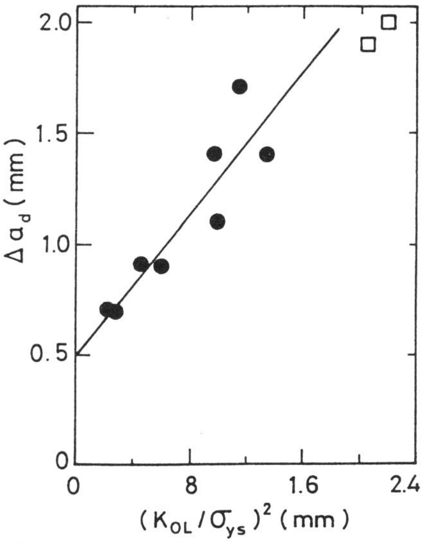

Fig.4 Relation between Δa_d and (K_{OL}/σ_{YS})^2