INFLUENCE OF OVERLOADS ON THE SUBSEQUENT CRACK GROWTH OF A FATIGUE CRACK IN A E 36 STEEL.

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This study is concerned with the influence of overloads on the subsequent rate of growth of a fatigue crack in a E 36 steel. Retardation increases with increasing overload ratio and increasing number of overload peaks. The crack opening load was measured during all tests. It is shown that the Elber's crack closure concept is not able to explain the effect of overloads. It seems that the residual stress state induced by the overload is the major factor causing retardation.

INTRODUCTION

The effect of overloads on the fatigue crack growth rate has received a considerable amount of attention during the last few years because of the need for better design procedures for predicting the fatigue behaviour under complex service loads. It is found in the litterature (Trebules et al (1), Bathias and Vancon (2), Matsuoka and Tanaka (3) that retardation depends on many factors. For a given materiel, retardation increases with increasing overload ratio or increasing number of overload peaks. Factors such as environment, frequency the yield stress of the material, the load ratio and the initial stress intensy factor range influence retardation too.

The present work is concerned with the influence of the overload ratio and the number of overload peaks on the subsequent crack propagation rate. Particular attention is given to the crack closure phenomenon and residual stresses.

EXPERIMENTAL PROCEDURE

A low strength steel with a yield stress of 380 MPa and an ultimate tensile stress of 522 MPa was investigated. The tests were performed on a load-controlled servo-hydraulic machine. Compact tension specimens of thickness B=15 mm and width W=80 mm were used. The crack growth was mesured with an optical microscope (x50) on one side of the specimen. The crack opening point P_{op} was determined by a compliance technique. Differential diagrams were plottet in order to facilitate the detection of the opening point. Examination of surface plastic zones was performed by optical microscopy or by a roughness technique.

The tests were run at a constant stress intensity factor range $\Delta K =$ 16.2 $MPa\sqrt{m}$ and at a constant load ratio $R=P_{min}/P_{max} = 0.1$. After the applicationof overloads the initial stress intensity factor range was resumed and kept constant to within 2% of K_{max} by manual load shedding.

RESULTS

The crack growth retardation can be described with the help of the parameters described in fig. 1 . During all tests, the evolutions of the crack growth rate and of the crack closure load were recorded, the value of the U ratio was calculated.

A first group of tests consisted in examining the effect of the overload ratio R_p when applying a single peak overload. The following ratios were tested : R_p = 1.3, 1.6, 1.9, 2.2, 2.8 and 3.1 . Retardation increases with increasing overload ratio. Crack arrest is observed with R_p larger than 2.8 .

In a second group of tests, the influence of the number of overload peaks was studied. For a given overload ratio equal to 2.2; 1, 10, 35, 50, 600 and 8000 overload peaks were successively applied. Crack arrest is obtained with N_p larger than 35.

The evolution of the crack growth rate is plotted versus the crack length in fig. 2 . When no crack arrest is observed, all the curves show the same characteristics. After or during overload, depending on the number of overload peaks, there is an immediate acceleration in growth rate followed by a decrease until the minimum crack growth rate is reached, and then a progressive return to the original value. The minimum crack growth rate V_{min} decreases with increasing overload ratio and increasing number of overload peaks. (table 1). The quantity $a_{V_{min}}$ remains quasi constant whatever the values of R_p and N_p. No delayed retardation is observed when several overload peaks are applied : after 50 or 600 peaks, the crack growth rate continuously decreases until the crack advance becomes null; if N_p=8000, the crack immediately stops after overload application.

The evolution of the U ratio is reported in fig.3 . In the case of the first group of experiments, the variation of U is significant for an overload ratio larger than 1.6 . Above 1.6, the curves show a similar evolution to that of the crack growth rate curves. Results (table 1) indicate that the length $a_{U_{min}}$ does not depend on the overload ratio whilst the crack length a_d^U and the number of cycles N_d^U rapidly increase with the overload ratio. Finally the value U_{min} decreases with increasing R_p. The variation of the U ratio is smaller in the second group of experiments. When crack arrest is observed, the U ratio does not decrease after overload.

Examination of the plastic zone surrounding the crack was done by optical microscopy. Its evolution is shown in fig.4.Lüder's bands represents the boundary of the overload plastic zone w_s^m. Enclosed in it, the current plastic zone w_o^m decreases progressively till a crack length equal to a_1 is very small in a zone of length a_2 and finally increases to reach its initial value at a length equal to a_3. It is observed that for overload ratios greater than 1.6 the value of a_1 is a constant and is approximatively equal to $a_{V_{min}}$; a_2 only depends on R_p : a_3 depends on R_p and N_p.

Table 1 - Effect of the overload ratio and the number of overload peaks on the parameters which describe the changes in crack growth rate and U ratio.

	Influence of R_p (N_p = 1)						Influence of N_p (R_p=2.2)		
R_p N_p	1.3	1.6	1.9	2.2	2.5	2.8	1	10	35
$V_{min} \times 10^{-6}$ (mm/cycle)	7.3	4.4	3.0	1.2	0.2	0.05	0.23	0.42	0.09
$a_{V_{min}}$ (mm)	0.13	0.43	0.39	0.48	0.4	0.43	0.27	0.4	0.4
a_d^* (mm)	0.35	1.2	1	1.4	2.3	4	1.1	1.1	1.0
a_d (mm)	0.75	2.5	2	3.5	4	6.8	the same as a_d^*		
N_d x 10^5	0.5	0.85	1.8	2.4	3.5	26	4.9	5.35	11
U_{min}	/	0.84	0.74	0.52	0.42	0.22	0.74	0.61	0.58
$a_{U_{min}}$ (mm)	/	0.75	0.36	0.37	0.39	0.4	1	1.05	1.05
a_d^u (mm)	1	3.75	5.8	10.7	15.5	22	6.8	7.0	5.3
N_d^u x 10^5	0.6	2.4	3	6	10	37	9.85	9.9	13.5
a_1 (mm)	/	/	0.34	0.4	0.4	0.46	0.39	0.35	0.34
a_2 (mm)	/	/	0.1	0.3	0.6	0.8	0.35	0.35	0.34
a_3 (mm)	/	/	0.5	0.7	1.0	1.3	0.76	0.7	0.89

DISCUSSION

The crack closure concept is frequently used in the litterature (1), Schijve (4), tó explain crack growth retardation. In our experiments, the variation of the effective stress intensity factor range as defined by Elber (5) is not related to the variation of the crack growth rate. There is a large difference between the values of a_d and a_d^u , and also between N_d and N_d^u. Only concocordance between $a_{V_{min}}$ and $a_{u_{min}}$ is observed in some cases (table 1)

When crack arrest is obtained, the value of U does not decrease after overload, shaving that blunting of the crack tip is still effective. The two empirical models used most often are the models of Wheeler (6) and Willenborg (7). In both models, it is assumed that retardation occurs as long as the current plastic zone remains inscribed in the overload plastic zone. Comparison of the affected crack length a_d and of the size of the overload plastic zone calculated with the Irwin formula is given in table 2.

R_p	1.3	1.6	1.9	2.2	2.5	2.8
a_d^* a_d (mm)	0.35,0.75	1.2,2.5	1,2	1.4,3.4	2.3,4	4,6.8
$w_s^m - w_o^m$ (mm)	0.49	1.12	1.89	2.75	3.75	4.9

Table 2 - Comparison of the measured affected crack lengths and the values predicted by models.

As noted in fig. 1, two values of the affected crack length a_d^* and a_d are sometimes defined. In this case, the value $w_s^m - w_o^m$ is included in the interval $(a_d^* \; a_d)$. Otherwise, the measured value (1.1 mm) is smaller than the predicted one (2.75 mm). No good agreement in then observed between results and models.

However, examination of the surface plastic zone indicates that the crack length for which the minimum value of the crack rate is observed coincides with the region where the plastic zone is very small and not detectable by the experimental methods used here. So it will be necessary to take into account the development ot the plastic zone to find accurate models of crack retardation. The models of Fuhring (8) and Matsuoka (3) are an attempt to do such a calculation. Both models predict the correct form of the growth rate transient following an overload; however, agreement between experiment and models is more qualitative than quantitative.

CONCLUSIONS

From this study concerning the influence of overloads on the propagation of fatigue cracks in E 36 steel, the following conclusions can be drawn.

1. Retardation increases with increasing overload ratio and increasing number of overload peaks.
2. The Elber crack closure concept cannot explain the retardation phenomenon since changes in the crack growth rate and the U ratio are not similar.

3. Analysis of the residual stresses at the crack tips seems to lead to the best solution.

However, calculations conducted by Fuhring and Matsuoka are not entirely satisfactory.

SYMBOLS USED

a_d, a_d^u	= cracks lengths necessary for the crack growth rate or the U ratio to recover their initial value
$a_{V_{min}}$, $a_{U_{min}}$	= crack lengths associated with V_{min}, U_{min}
$N_{V_{min}}$, $N_{U_{min}}$ N_d , N^u_d	= number of cycles respectively associated with V_{min}, U_{min}, a_d and a_d^u
P_{op}, K_{op}	= crack opening load or stress intensity factor
U	$= \Delta K_{eff} / \Delta K$; $\Delta K_{eff} = K_{max} - K_{op}$
V_{min}, U_{min}	= minimum values of the crack growth rate and of the U ratio after overload.
w_o^m	= current plastic zone size = $1/\pi \, (K_{max} / \sigma_y)^2$
w_s^m	= overload plastic zone size = $1/\pi \, (K_{peak} / \sigma_y)^2$

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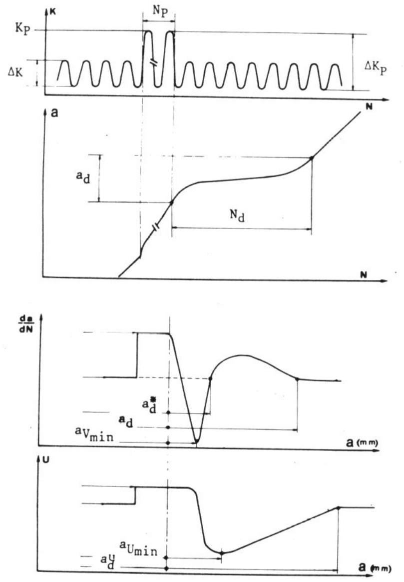

Figure 1. Illustration of the overload parameters

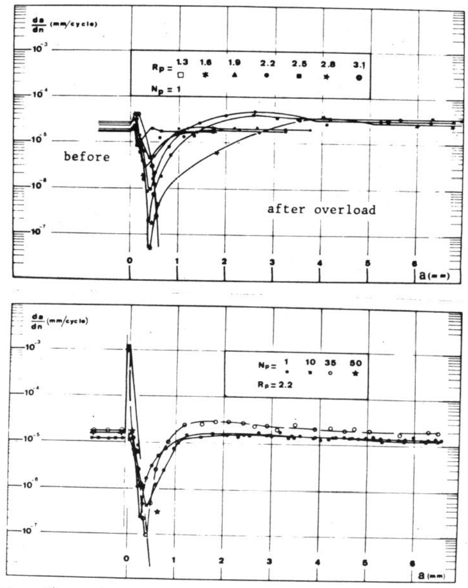

Figure 2. Crack growth rate versus crack length a)- for different R_p b)- for different N_p

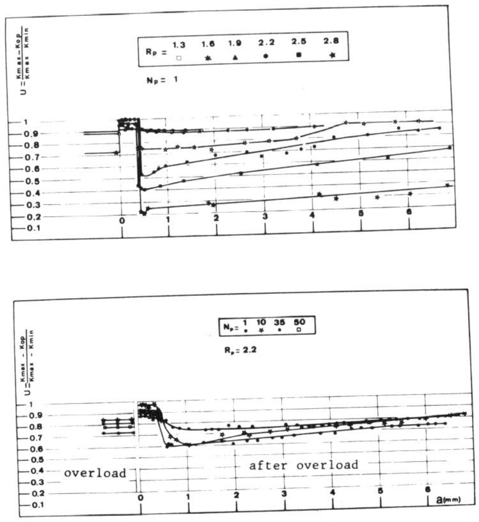

Figure 3. U ratio versus the crack length. a)- for different R_p b)- for different N_p

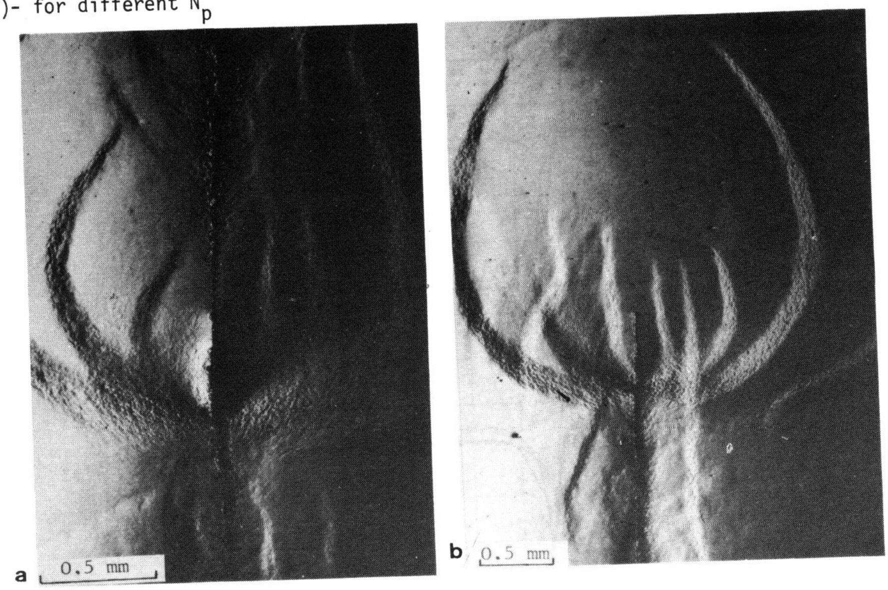

Figure 4. Evolution of the plastic zone after overload.
a)- N_p = 35 b) N_p = 50