Influence of the Number of Overload Cycles in the Fatigue Crack Growth Retardation

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ABSTRACT

The influence of overload on the fatigue crack growth retardation in a thin plate 2024-T3 aluminum alloy was studied. In the experimental program was used (5000 ± 2500)N as reference and overloads of (6500 ± 2500)N and (8000 ± 2500)N to analise retardation behavior. It was observed that crack retardation increases as the ratio of overload maximum stress intensity of subsequent constant amplitude (K_{ol}/K_{ca}) increase up to a limiting "Saturation Value". This effect is extremely more pronounced for high K_{ol} values.

KEYWORDS

Fatigue crack growth, overload cycles, retardation, stress intensity factor.

INTRODUCTION

The evolution of the fail safe design philosophy has presented designers with a number of new design considerations. One of the most important of these considerations is the prediction of fatigue crack propagation rates.

An important contribution to the study of fatigue crack propagation was made by Paris (Paris and Erdogan, 1963) proposing that crack growth rate data could be correlated with stress intensity range, ΔK, and found that

$$\frac{da}{dN} = C\ (\Delta K)^{n} \qquad (1)$$

Where:

C - materials constant

N - number of cycles

n - materials constant

In 1967, R.C.Forman, V.E.Kearney and R.M.Engle (Forman et al., 1967) introduced two effects which are not taken into account. One is the variation in the crack growth rate owing to the load ratio, R. The other is the instability of the crack growth when the value of the maximum stress intensity factor approaches the fracture toughness of the material, Kc.

The effect of load sequence on crack growth showed that the application of high to low load sequences could cause a greater crack propagation life than would have been predicted on the basis of the summation of crack growth for each cycle using constant amplitude growth rate data (Adetifa et al., 1976, Von Euw et al., 1972). The phenomenon has been termed crack retardation.

Just as a load sequence high to low can cause crack retardation, a low to high sequence can produce an acceleration of crack growth, which stabilize quickly when compared to the retardation (Jacoby et al., 1976, Mc Millan and Pelloux, 1967, Wheeler, 1972).

This paper will attempt to show increases in the fatigue crack growth retardation if a group of consecutive overloads is applied. This effect becomes more pronounced as the number of overloads is increased up to a limiting "saturation" value.

EXPERIMENTAL DATA

The material used in this testing program was 1,27 mm thick, 2024-T3 aluminum alloy. Mechanical proprierties of this material are shown in table 1.

Table 1. Mechanical proprierties of 2024-T3 aluminum alloy.

Yield Stress, MPa	417
Tensile Strength, MPa	516
Elongation, %	8,6

All tests specimens used in this experimental program were notch specimens. The thickness of the specimens was 1,27 mm, and width 90 mm. The stress intensity expression for this sample geometry is given by:

$$K = \sigma \sqrt{a} \; |1{,}99 - 0{,}41 \,(a/w) + 18{,}70 \,(a/w)^2 - 38{,}48 \,(a/w)^3 + 53{,}85 \,(a/w)^4| \qquad (2)$$

The entire test program was conducted on MTS Fatigue Testing Systems. Precracking was performed under constant amplitude loading cycled at (5000 ± 2500)N. All tests were run at a cyclic rate of 10 Hz at room temperature. Cyclic crack growth measurements were obtained using visual optics.

The experimental data used in the analysis of retardation in fatigue crack growth due to consecutive overloads, was obtained from the experimental program shown in figure 1.

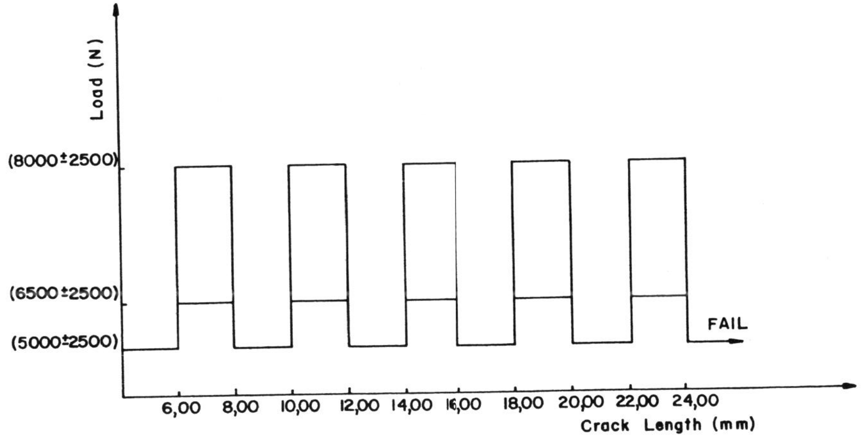

Fig. 1. Experimental Program

A load (5000 ± 2500)N was used as reference and the overloads were (6500 ± 2500)N and (8000 ± 2500)N. The ratio of overload maximum stress intensity, Kol, to the maximum stress intensity of subsequent constant amplitude loading, Kca, were 1,20 and 1,40, respectively. It was found that $\frac{Kol}{Kca} < 1,20$ produces no retardation and $\frac{Kol}{Kca} > 1,60$ produces temporary arrest (Voorwald, 1988).

RESULTS AND DISCUSSIONS

The data of constant amplitude cyclic load fluctuations are represented in figure 2. An increase in the magnitude of cyclic load fluctuations results in a decrease of fatigue life.

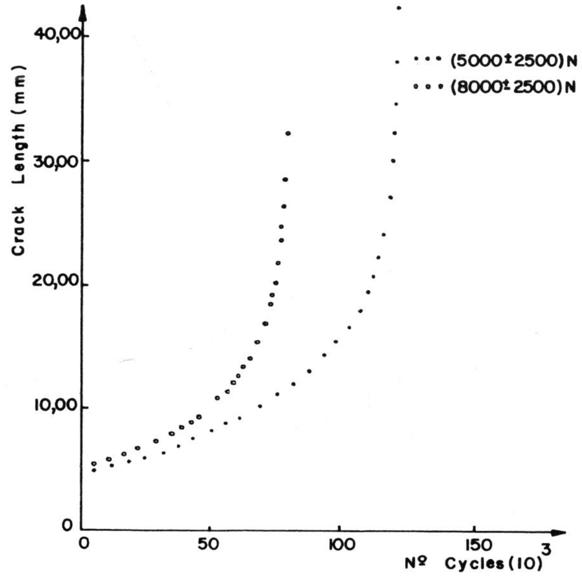

Fig. 2. Effect of cyclic stress range on crack growth

The effect of load sequences on crack growth is represented in figure 3, for the ratio of overload maximum stress intensity to the maximum stress intensity of subsequent constant amplitude loading of 1,40. Tests with high to low load sequences showed a greater crack propagation life.

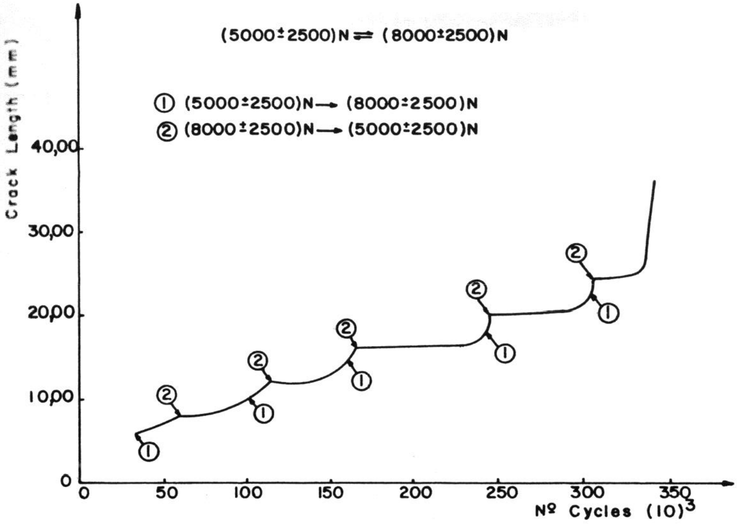

Fig. 3. High to low load sequences.

The crack propagation life for the tests with high to low load sequences and for constant amplitude growth rate are represented in table 2.

In table 2 we can observe that the amount of crack retardation increases as the ratio of overload maximum stress intensity to the maximum stress intensity of subsequent constant amplitude loading, increases. Otherwise, there are different number of cycles in the high load for the several blocks applied to the specimen.

The ratio $\frac{Kol}{Kca} = 1,20$ shows that crack retardation increases as the number of overloads in each group is increased; for the ratio $\frac{Kol}{Kca} = 1,40$ a different trend indicates that the effect of crack retardation becomes more pronounced as the number of overloads in each group is increased up to a limiting "saturation" value.

Table 2. Crack propagation life.

Crack Length (mm) / Load	(5000±2500)N → (6500±2500)N		(5000±2500)N	(6500±2500)N	(5000±2500)N → (8000±2500)N		(8000±2500)N
	(1°)	(2°)			(1°)	(2°)	
(6-8)	28500	28700	26707	29000	29700	24600	19530
(8-10)	25900	25300	19669	17000	49400	45300	14229
(10-12)	13100	13860	14139	12500	11200	11100	9983
(12-14)	15300	14600	9970	8800	38600	50050	6744
(14-16)	7200	6860	6974	6750	5850	5450	4409
(16-18)	11100	10740	4935	4750	41900	78650	2838
(18-20)	3400	3500	3630	3100	2950	2550	1868
(20-22)	8000	7460	2836	2100	81600	60300	1322
(22-24)	1700	1840	2340	1500	1400	1650	1028
(24-Rupt)	8940	8640	4797	2600	41570	35230	2356
Total	123140	121500	95997	88100	304170	314880	64307
C.A.	69240	66740			253070	269530	
%	56,2	54,9			83,2	85,6	
O.L.	53900	54760			51100	45350	
%	43,8	45,1			16,8	14,4	

The number of cycles of delay, ND, obtained as represented in figure 4, are plotted in figure 5 as a function of the number of overloads in each block.

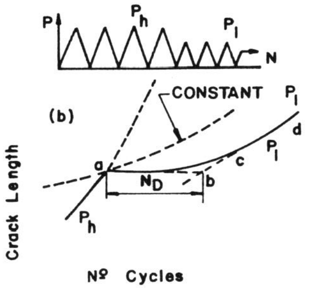

Fig. 4. Number of cycles of delay.

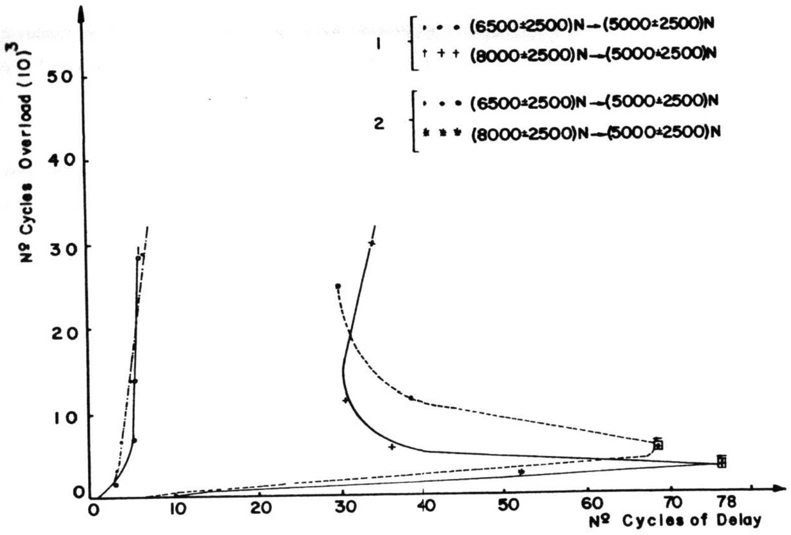

Fig. 5. Number of cycles of delay against number of overloads.

In figure 5 it is confirmed that the effect of crack retardation becomes more pronounced as the number of overloads is increased up to a limiting "saturation" value, between 4000 and 8000 cycles. For $\frac{Kol}{Kca} = 1{,}20$, if the number of overloads in each group is increased up above the limiting "saturation" value, there is no increase in the number of cycles of delay. When $\frac{Kol}{Kca} = 1{,}40$, increasing the number of overloads above the limiting, "saturation" value results in a decrease in the crack retardation. Obviously, the application of too many overloads will eliminate any possible benefits of crack retardation.

CONCLUSION

The amount of crack retardation increases as the ratio of overload maximum stress intensity, Kol, to the maximum stress intensity of subsequent constant amplitude loading, Kca, increases.

Crack retardation is a function of the number of overloads in each group.

The effect of crack retardation becomes more pronounced as the number of overloads in each block is increased up to a limiting "saturation" value, between 4000 and 8000 cycles.

For $\frac{Kol}{Kca} = 1{,}20$, if the number of overloads in each group is increased up above the limiting "saturation" value, there is no increase in the number of cycles of delay.

For $\frac{Kol}{Kca} = 1{,}40$, increasing the number of overloads above the limiting "saturation" value, results in a decrease in the crack retardation.

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