Fatigue Behaviour of Medium Strength Al-Mg Alloy 5083

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ABSTRACT

The paper reports the results of a fatigue crack propagation study on the Al-Mg alloy 5083-O. da/dN, ΔK data was obtained in tension and bending and for three different stress ratio values. The fatigue crack propagation of both straight and semi-elliptical cracks was analysed. For that purpose crack aspect ratio data was generated and a good correlation was obtained against available theoretical solutions in the literature.

Crack closure data was obtained and used to calculate effective values of ΔK Fatigue crack growth rate when plotted as a function of ΔK_{ef} has shown not to be dependent of stress ratio. For $R > 0.8$ the amount of crack closure at the crack tip is negligible.

The fatigue crack propagation curves have shown different types of behaviour requiring a more detailed investigation.

KEYWORDS

Fatigue, aluminium alloys, crack closure, semi-elliptical cracks

INTRODUCTION

Medium strength Al-Mg alloy 5083 is quite extensively used as a structural material. Fatigue data in this material is however comparatively scarce in comparison with higher strength alloys and therefore it was decided to initiate a detailed experimental fatigue test programme in order to obtain additional and more complete data. This is part of a research project concerning the development of damage tolerance acceptance methods in ductile structural materials where short cracks and plasticity and crack closure effects will be incorporated.

Available results in the literature were recently obtained in welded joints (Kosteas, 1987, 1988). Older work in this material mainly reported fracture toughness data (Kaufman, 1974, 1976) and also fatigue crack propagation but for other thicknesses and testing conditions (Argy et al, 1975). Semi-elliptical crack growth and short crack analysis were not, to the authors knowledge, being reported yet.

The medium strength Al-Mg alloy 5083 was chosen due to its high toughness values as revealed in previous investigations carried out by the authors in a wide range of temperatures from - 120^{oC} to 40^{oC} and with results published in the literature (Branco and Costa, 1985, 1986).

Load and strain cycling data was also obtained previously (Costa and Branco, 1987) with the objective of incorporating the data in an elastic-plastic fatigue crack propagation model developed by the authors. The work now in progress is concerned with analysis of short crack behaviour which is the main objective of the investigation.

Since long crack data is required to complement short crack results. it was decided to initiate this study carrying out fatigue crack propagation and crack closure tests, in specimens with long cracks. Hence this paper reports the first series of experimental results obtained in this project concerning crack closure measurements and fatigue crack growth data for long cracks. Stress ratio, loading mode and crack shape (straight and semi-elliptical) were the main variables analysed.

EXPERIMENTAL

Fatigue crack growth rate data was obtained both in CT specimens (Fig.1) and center cracked plates with a semi-elliptical notch (Fig.2). The specimen thickness was 12mm and the tests were conducted in air in constant amplitude loading at a frequency of 20Hz. To study the influence of stress ratio tests were carried out at three different values; 0.05, 0.5 and 0.8. In the CCP, tests were conducted in tension and cantilever bending.

The fatigue cracks were monitored with the ACPD technique and with a travelling microscope. The latter equipment was only used to measure the length of the semi-elliptical crack in the CCT tests (Fig.2). Crack closure measurements were made with a clip gauge on both sides of crack plane. Appropriate load-extension plots at the crack tip area were obtained and from these the opening loads of the crack were taken for different crack lengths and ΔK values.

Fatigue thresholds were obtained at crack speeds below 10^{-7} mm/cycle. For the determination of thresholds loading frequency was increased to 70Hz. The load shedding technique was used and appropriate procedures were taken to avoid crack acceleration or delay effects. The K reduction rate was step wise and comprised between 0.1 and 0.5 MPa$\sqrt{m}$/mm. The threshold level was defined as the point where no detectable crack growth was observed for a certain K level attained on the conditions defined above, and after 5×10^6 cycles were ellapsed. For each load level attained in the load shedding tests the crack has grown a distance between 0.25 and 0.5mm.

The da/dN, ΔK plots were obtained accordingly with the procedure (secant method) defined in ASTM E-647-81.

Chemical composition, and mechanical and cyclic properties of the material are given in Table 1.

Table 1 - Chemical composition and mechanical properties of the Al-Mg alloy 5083 (Costa,1986)

CHEMICAL COMPOSITION

Mg	Mn	Fe	Ni	Cu	Zn	Si	Sn	Pb	Ti	AL
4.5	0.55	0.37	<0.5	0.12	0.10	<0.10	<0.05	<0.05	<0.05	Balance

MECHANICAL PROPERTIES (Tensile tests; strain cycling)

	Longitudinal Direction	Transverse Direction
Hardness HRF	78	72
σ_{ys} (MPa)	179.7	159
σ_{UTS} (MPa)	320.8	314.1
ε_f(%)	18.2	24.0
K_1 n_1	369.9; 0.129	379.4 ; 0.156
K_2 n_2	609.8; 0.253	616.6 ; 0.276
Correlation Coeficients	0.997; 0.9996	0.996 ; 0.9998
Strain Cycling curve (Reversed)	$\frac{\Delta\varepsilon_p}{2}=0.273(2N_r)^{-0.664}$	$\frac{\Delta\varepsilon_p}{2}=0.154(2N_r)^{-0.555}$

σ_{ys} - 0.2% Yield stress

σ_{UTS} - Ultimate Tensile Strength

$\Delta\varepsilon_p$ - Plastic strain range

$\bar{\sigma}=K\bar{\varepsilon}^n$

The monotonic stress-strain curve was approximated by two straigt lines in the logatitmic plot true stress $\bar{\sigma}$ against true strain $\bar{\varepsilon}$ (Table 1).

RESULTS AND DISCUSSION

The da/dN, ΔK plots obtained in the CT specimens are shown in Fig.3. da/dN increases with R specially in the low values of crack growth rate. There is a kink in the curve after region I of crack propagation which should be attributed to mettalurgical factors. A detailed investigation of this behaviour with the SEM is in progress. A considerable drop in threshold values was obtained when the stress ratio changed from 0.05 to 0.8. The ΔK_{th} values obtained are 4.0 MPa$\sqrt{m}$ for R=0.05, 3.1 MPa$\sqrt{m}$ for R=0.5 and 1.8 MPa$\sqrt{m}$ for R=0.8.

The present results are compared in Fig.3 with data recently obtained by Pusch and Hohne (1988) in a similar alloy. There is good agreement in region II of crack propagation despite the fact that only one slope in the curve was obtained by Pusch (Fig.3). However the threshold value is lower and that is probably due to the different thickness and loading mode used in their work.

In the CCT plates with the semi-elliptical cracks both da/dN and dc/dN plots against ΔK were obtained. K was calculated with the Raju and Newman (1984) equation for a plate with a semi-elliptical crack loaded in bending and tension and using the appropriate values of the constant C taken for both directions of crack propagation. It was found that the value of m was the same in both the "c" and "a" directions. No significative difference was observed between the tension and bending cases.

A typical plot crack aspect ratio, a/c, against normalized crack depth, a/B is shown in Fig.4. These results were obtained in tension and similar plots were obtained in bending. For example, in Fig.4 starting with the initial flaw ratio of a/c=1.5/4.7, a/c increases up to near 1 and then has a slight drop till a/c=0.85÷9. This shows clearly that in tension the crack grows towards a semi-circular stable shape. The agreement of the experimental results against the predictions made with the Raju and Newman equations is good. In bending crack front shape exhibited a different behaviour; a/c decreasing with a/B (shallow crack fronts). Again good agreement was obtained against the Raju and Newman model.

Since fatigue crack growth rate has shown a strong dependence on stress ratio a crack closure analysis was carried out to correlate the results with the ΔK_{ef} parameter initially proposed by Elber (1971).

Typical plots of the crack opening loads obtained with the clip gauge are shown in Fig.5. P_{op} is the opening load. Closure was obtained for R=0.05 and R=0.5 but for R=0.8 no significant closure was detected for the range of ΔK values analysed.

From the P_{op} values obtained both in the CT and CCT specimens the parameter U and the effective ΔK corrected for closure were calculated. The equations were those derived by Elber.

It should be pointed out that while for the CT specimens crack closure data has shown little scatter the same did not apply to the semi-elliptical cracks in the CCT specimens. In the latter case opening load measurements are strongly dependent on the point chosen at the crack front and hence all the readings were taken at the deepest point of the crack.

The parameter U is plotted against ΔK in Fig.6. The data is for the CT and CCT specimens. In region I of crack propagation where $\Delta K<5$ MPa$\sqrt{m}$ crack closure is significant. For example for R=0.05 the values of U are all below 0.75 and reach 0.35.Also U is independent of ΔK when ΔK is above 7 MPa$\sqrt{m}$ (U=0.75). For R=0.5 the values of U are above those for R=0.05 as expected and crack closure only occurs for ΔK values below 5 MPa$\sqrt{m}$ ($U\simeq1$ for $\Delta K>5$ MPa$\sqrt{m}$). For R=0.8 crack closure was not observed and therefore U=1 for the entire range of ΔK values analysed.

The plot da/dN against ΔK_{ef} show the data in one single scatter band giving a better correlation than ΔK. ΔK_{ef} is the parameter controlling crack propagation. The effective threshold is 1.8 MPa$\sqrt{m}$. Note the slight curvature in region II also revealed in this plot which requires a more detailed investigation in progress.

The influence of initial flaw ratio is presently being studied (different values of initial crack aspect ratio). Application of crack closure models is also under investigation.

CONCLUSIONS

1. Fatigue crack growth rate and threshold values are dependent on stress ratio in medium strength Al-Mg alloy 5083.

2. The da/dN, ΔK curves have shown different types of behaviour requiring a more detailed investigation.

3. Both for through and semi-elliptical cracks fatigue crack growth rate was shown to be independent of stress ratio when plotted against the effective ΔK value corrected for crack closure.

4. Good agreement of da/dN, ΔK data was obtained against results published in the literature.

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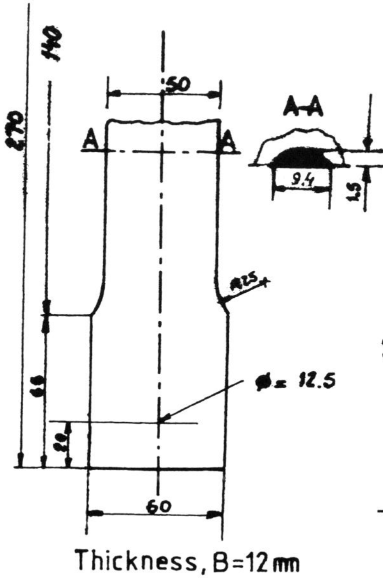

Fig.1 – CCT specimen with semi-elliptical crack. Tension and bending. Al-Mg alloy 5083-O.

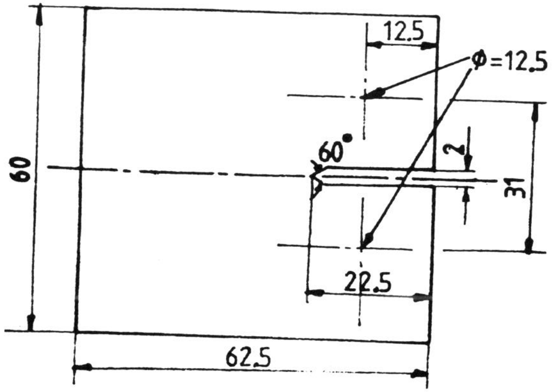

Fig. 2 – CT specimen. B=12mm. Al-Mg alloy 5083-O.

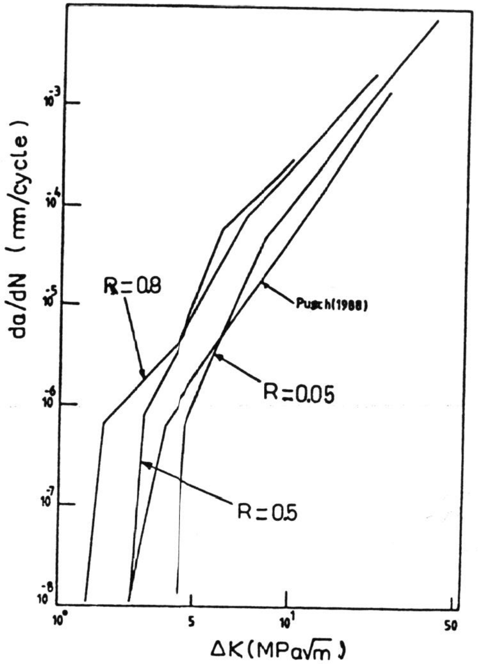

Fig. 3 – da/dN against ΔK. B=12mm. Al-Mg alloy 5083-O.

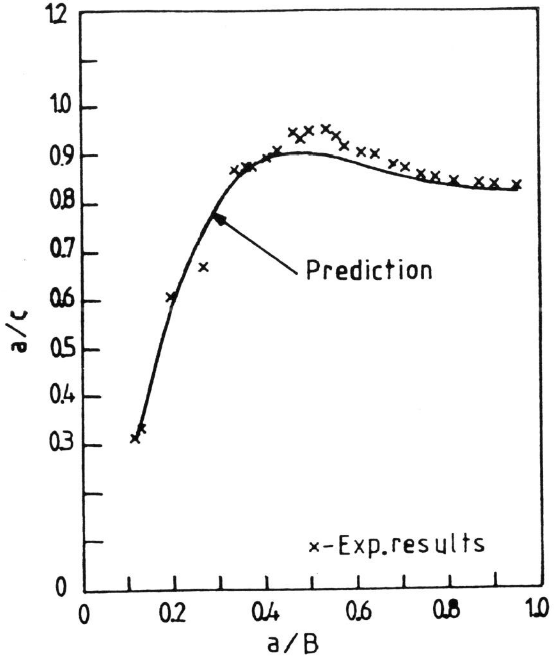

Fig. 4 – Typical plot crack aspect ratio against a/B. Tension. Al-Mg alloy 5083-O.

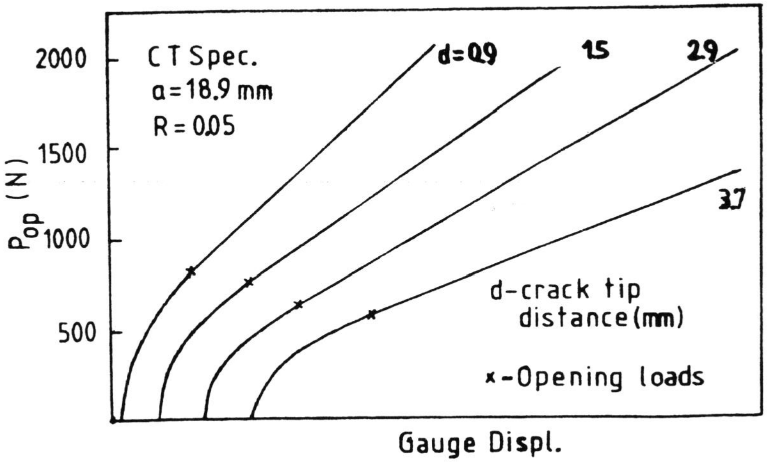

Fig. 5 – Typical plot P_{op} against gauge displacement. Al-Mg alloy 5083-O.

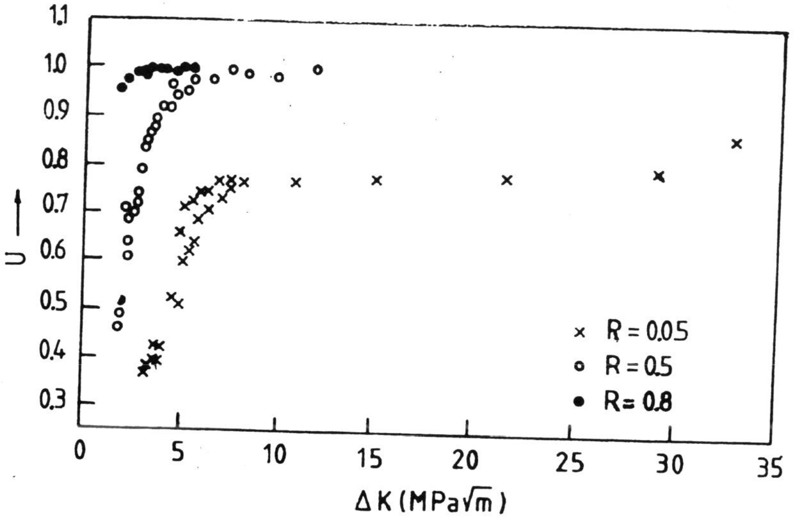

Fig. 6 – U against ΔK. Al-Mg alloy 5083-0.

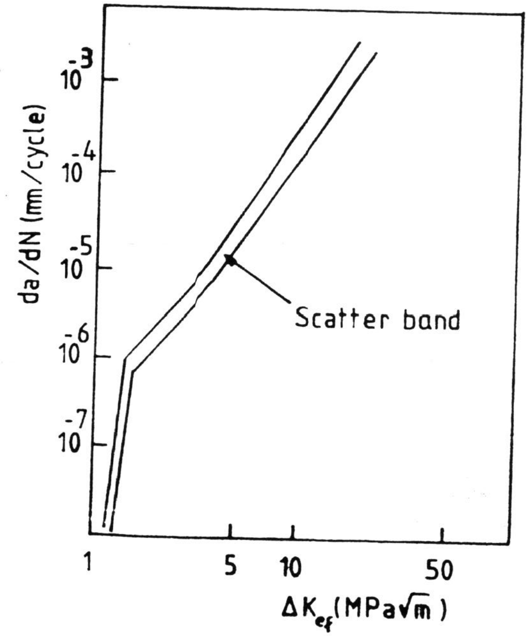

Fig.7 – da/dN against ΔK_{ef}. Al-Mg alloy 5083-0.