FATIGUE BEHAVIOUR OF A 12 MM THICK TITANIUM GRADE 2 PLATE

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ABSTRACT

CT specimens machined from a 12 mm thick titanium grade 2 plate with L-T or T-L orientation have been tested using load ratios of 0, 0.1, 0.3 or 0.5. A quicker crack growth in specimens with L-T orientation was observed, having been atributed to the rolling texture of the plate. Moreover, crack growth rate increases as R ratio rises due to the crack closure phenomena. This hypothesis has been confirmed by the results obtained in a second group of tests where crack opening load has been measured.

KEYWORDS

Titanium, fatigue, crack growth, anisotropy, crack closure.

INTRODUCTION

Within the last years commercially pure titanium has progressed significantly from a curiosity through laboratory testing and plant evaluation to full acceptance as an essential material of construction for a number of industrial applications such as power and chemical plants (Bomberger, 1.981). Commercially pure titanium contains from 99.0 to 99,5% titanium plus small amounts of iron, carbon, hydrogen, nitrogen and oxygen. Higher contents of these elements increase the strength at room and at elevated temperatures while ductility decreases (Rudinger, 1978). Titanium grade 2 offers a good combination of medium tensile properties with satisfying cold formability being the most widely used of all commercially pure titanium grades.

Greater sophistication in this processing equipment and the one to one replacement of other materials with titanium have created the need of considering fatigue properties in design of life prediction. Nevertheless, the amount of data avalaible is very limited (Wardlaw and Hall. 1.981).

The aim of this paper is to investigate the influence of crack orientation, stress ratio R and crack closure on the fatigue crack growth behaviour of a 12 mm thick titanium grade 2 plate.

EXPERIMENTAL PROCEDURE

The base material chosen for the present study was a 12 mm thick plate of commercially pure titanium conforming to ASTM B 265 grade. 2, whose chemical composition and mechanical properties are given in Tables 1 and 2, respectively.

Fe	C	O	N	H	Ti
0.12	0.02	0.14	0.014	0.0020	Balance

TABLE 1. Mechanical properties of the plate.

Orientation	Y.S. 0.2% (MPa)	U.T.S. (MPa)	Elongation (%)
Longitudinal	383	480	26,6
Tranverse	480	529	26,9

TABLE 2. Mechanical properties of the plate.

Fracture toughness characterization consisted of CTOD test of 110x24x12 mm SENB specimens. Two different crack orientations (L-T and T-L) were considered. These specimens were tested in the temperature range from-60 to 20°C according to B.S. 5762 (1979).

Fatigue CT specimens (B=12 mm, W = 108 mm) were machined from the plate in the L-T or T-L orientations. Fatigue crack propagation tests were performed in a servohydraulic machine under constant amplitude following the guide lines of ASTM E 647 (1988) standard. As maximum and minimum load were kept constant during the test ΔK increased with the crack length. The tests were conducted at a frequency of 8 Hz with stress ratios R=0, 0.1, 0.3 and 0.5. Crack length was measured by means of an optical travelling microscope (X40) and the incremental polynomial technique was used to determine the crack growth rate versus stress intensity factor amplitude plots.

RESULTS AND DISCUSSION

The mean values of CTOD obtained for both crack orientations versus testing temperature are summarized in figure 1. It is observed that the strong directionality of the fracture toughness being roughly 2.3 times higher in the T-L specimens than in the whole temperature range. These results wich are opposite to those obtained with most metallic materials (higher toughness for the L-T specimens) are, nevertheless, in good agreement with

those found in different titanium alloys as reported by other researches (Rosenberg et al, 1.982 Schutz and Hall, 1.987) In a previous work, where even a more marked anisotropy was observed in a 6 mm thick titanium grade 2 plate, this behaviour was atributed to the rolling texture developed in H.C.P. titanium (Irisarri et al, 1.991) Although pole figures were not generated for the 12 mm thick plate a plausible explanation in a similar sense could be argued.

Log-log plots of da/dN versus ΔK were constructed as shown in figures 2 and 3 for the L-T and T-L orientations, respectively. Over the whole range of stress intensity factor amplitudes investigated in this study the fatigue crack growth rates conform to equations of the type $da/dN = C(\Delta K)^m$, which is the well known Paris law (Paris and Erdogan 1.963) Table 3 lists the values of C and m constants obtained in the different tests.

Orientation	R	C	m
L-T	0	1.76×10^{-8}	2.96
	0.1	3.18×10^{-8}	2.85
	0.3	$5.61 \times 10_{-8}$	2.77
	0.5	$7.07 \times 10_{-8}$	2.59
T-L	0	$0.81 \times 10_{-8}$	2.70
	0.1	$1.22 \times 10_{-8}$	2.65
	0.3	2.16×10^{-8}	2.52
	0.5	3.35×10^{-8}	2.44

TABLE 3.- Values of C and/ m

As it is easily seen in Table 3, L-T orientation specimens exhibit higher m values, which means an easier crack propagation, than T-L, ones. Once again a plausible explanation for this anisotropy is based on the existence of a rolling texture in the plate.

Moreover, figures 2 and 3 indicate that crack growth rate depends on stress ratio R, at least inside the range considered in this study. Crack growth rate rises as stress ratio increases. This behaviour has been attributed to the phemomenon of crack closure introduced by Elber in the early seventees (Elber, 1.971) assuming that the crack was partly closed during the loading cycle even though the applied loads were greater than zero. Hence, an effective stress intensity factor amplitude (ΔK eff) was defined as being equal to the difference between the maximum and opening levels of the crack tip stress intensity factor.

In a previous paper (Plaza and Irisarri, 1.992) crack closure load was measured by means of o crack mouth compliance gage during tests conducted in constant maximum stress intensity factor (Kmax) conditions and the R ratio incremented in discrete steps of 0.05 by reducing the minimum stress intensity factor (Kmin). From these experimental results the influence of stress ratio and Kmax on U= ΔKeff/ ΔK was evaluated obtaining the equations.

$$U=\frac{1}{2.1-R}\left[1.7-\frac{1.6+6R}{Kmax}\right]$$

and

$$U=\frac{1}{3.93-R}\left[3.48-\frac{4+5R}{Kmax}\right]$$

for L-T and T-L orientations, respectively. These equations are similar to those proposed by Bachman and Munz (1975) for a Ti-6AL-4V alloy.

When crack growth rate was plotted versus the effective stress intensity factor obtained as ΔKeff-U.Δk using the values of U. obtained from equations (1) and (2), the graphs of figures 4 and 5 were obtained. These figures clearly show that stress ratio R has a near negligible effect on the fatigue crack propagation rates when ΔKeff is used as a correlating parameter. The only exception is the graph obtained in T-L specimens at stress ratio R=0 which is placed sligthtly below the remaining ones. This could be due to some short loads excursion into the compressive field produced during R=0 testing which increase the crack closure measurement while in those test used for crack closure measurements the minimum load was always Kept positive (the minimum value of stress ratio R achieved was 0.05). Even if some additional testing is needed to overcome this difficulty the evaluation of crack closure looks promising.

CONCLUSIONS

a) A marked anisotropy of properties with higher toughness and slower crack propagation in T-L specimens than in L-T ones is observed.

b) Crack growth rates exhibit a marked effect of stress ratio R when these are plotted versus nominal stress intensity factor amplitue (ΔK). This behaviour has been attributed to the crack closure phenomenon

c) Crack closure depends not only on stress ratio but on the maximum value of stress intensity factor. Two equations to quantify the effect of this variables on crack closure have been proposed.

d) The influence of stress ratio on crack growth rates is much more reduced when plotted versus effective stress intensity factor amplitude (ΔKeff=U.ΔK). Even if some additional testing is needed the evaluation of crack closure effect looks promising.

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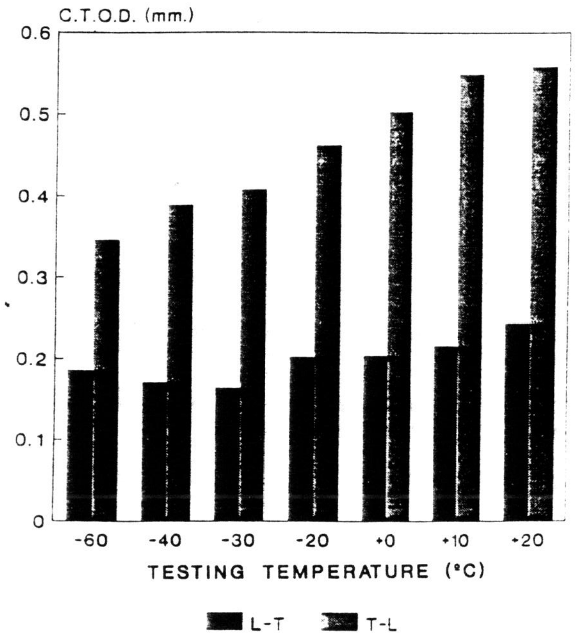

Fig. 1.- CTOD values versus testing temperature

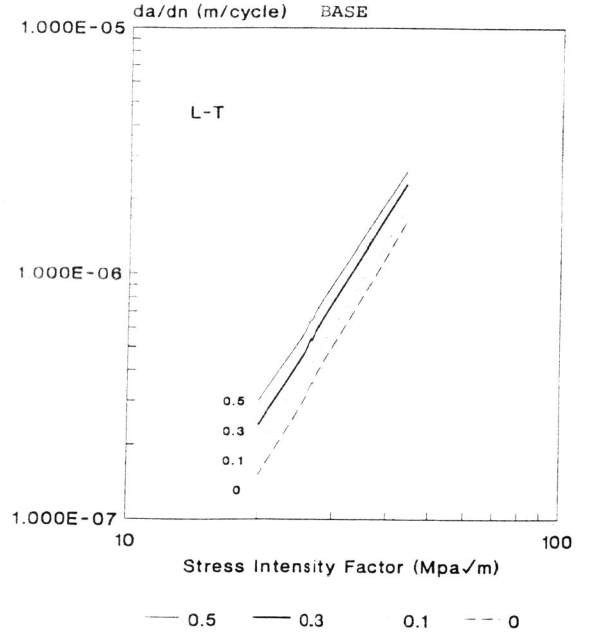

Fig.2. Stress Intensity versus da/dn L-T specimens

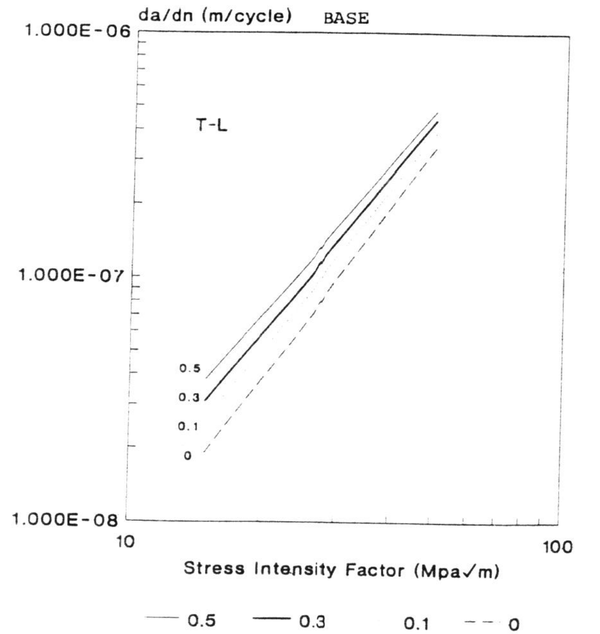

Fig.3. Stress intensity versus da/dn T-L specimens

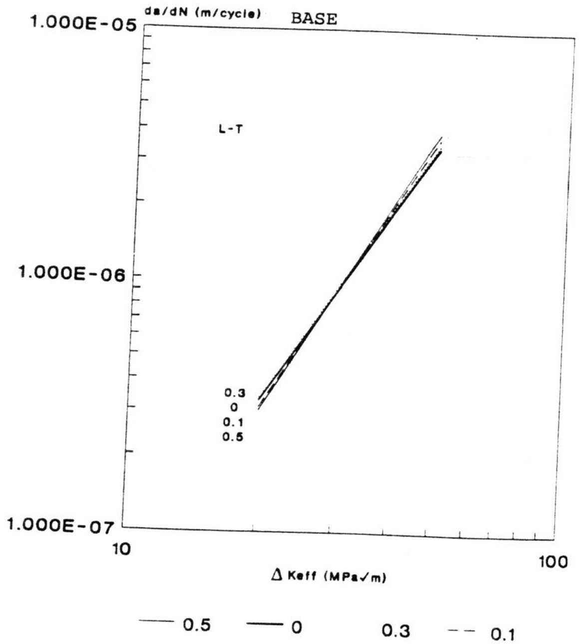

Fig.4. Delta Keff versus da/dn L-T specimens

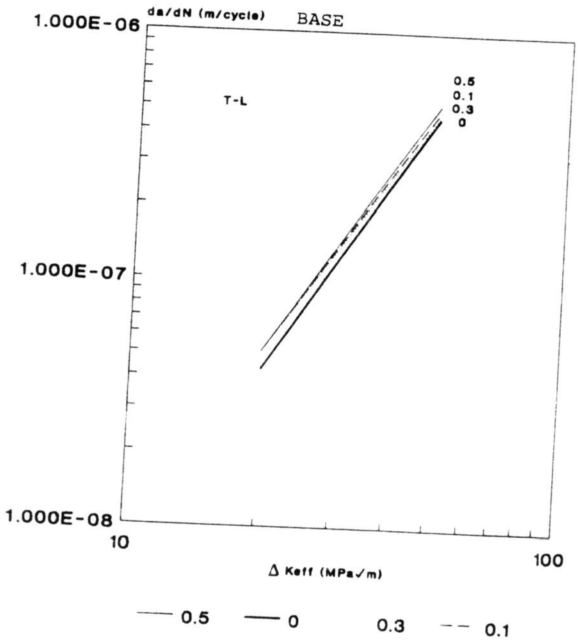

Fig.5. Delta Keff versus da/dn T-L specimens