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ABSTRACT

The effect of Kmax and R ratio on the crack closure of titanium grade 2 has been studied. Crack closure decreases as Kmax or ratio increases and two equations, for L-T and T-L orientations, have been proposed. The use of these equations seems to evaluate correctly the crack closure effect on the crack growth rate during constant load amplitude tests.

INTRODUCTION

The use of commercially pure titanium in chemical processing equipment has increased markedly within last years. Greater sophistication in this equipment and the one for one replacement of other materials with titanium have created the need for considering fatigue properties in design or life prediction (1).

It is now widely recognized that the phenomenon of crack closure affects the crack growth of metallic materials and hence any attempt to predict the usable life of components is influenced by crack closure. The concept of crack closure was introduced by Elber (2) who showed that crack propagation can occur only when the crack is fully open, proposing the use of an effective stress intensity amplitude (ΔKeff= Kmax-Kop) instead of the nominal one (ΔK=Kmax-Kmin). He suggested that crack closure characterized in terms of the effective stress intensity amplitude ratio U=ΔKeff/ΔK was a linear function of the stress ratio R and independent of Kmax. However, subsequent

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studies conducted over a wider rande of fatigue loading variables showed that U could depend on Kmax as well as au R (3).

The purpose of this paper is to examine the effect of the stress ratio and the maximum stress intensity factor on the fatigue crack closure behaviour of a 12 mm thick titanium grade 2 plate.

EXPERIMENTAL PROCEDURE

The base material chosen for the present work was a 12 mm thick plate of commercially pure titanium conforming to ASTM B265 grade 2, whose chemical composition and mechanical properties are given in Tables 1 and 2, repectively. Fatigue CT specimens (B=12 mm, W=108mm) were machined from the plate in both L-T and T-L orientations. Test were conducted in constant Kmax condition and the R ratio was varied in discrete steps of 0.05 by reducing Kmin. Six different Kmax levels were considered for this study. Crack closure was monitored using a crack mouth opening displacement clip gage. Load versus COD data were recorded for each R ratio dropping the test frequency to 0.5 Hz and the opening load was determined as the tangent point between the curved and the linear portions of this data.

RESULTS AND DISCUSSION

Figures 1 and 2 exhibit the effect of R and Kmax on the effective stress intensity ratio U measured in L-T and T-L specimens, respectively. It is seen that the extent of crack closure becomes smaller as Kmax increases. This influence seems to be more pronounced is specimens with L-T orientation. Although no clear reason for this difference has been found, a plausible explanation could be based on the existence of a rolling texture in the plate which induces an anisotropy of mechanical properties (4).

Moreover, a marked effect of the stress ratio R on crack closure is observed and even at ratios as high as 0.6 the crack is not fully open during a portion of the load cycle for most of the Kmax values considered in the present study. From multiple regression analysis of the experimental data the following equations were obtained:

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

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 y Bachman and Munz (5) for a Ti-6Al-4V alloy.

The degree of accuray of these equations in evaluating crack closure was checked with data from constant load amplitude test of specimens machined from the same plate (6). As figures 3 and 4 show the effect of stress ratio R on the fatigue crack growth rate is near negligible when ΔKeff= U.ΔK is used as a correlating parameter. Even if some additional testing is needed to study the near threshold condition and the influence of compressive loads on crack closure the results look promising.

CONCLUSION

a) The effect of Kmax and R ratio on the crack closure of a 12 mm thick titanium grade 2 plate in two different orientations has been studied.

b) Crack closure diminishes as Kmax or R ratio increases two equations to quantify the influence of these parameters have been proposed.

c) The use of these equations to evaluate crack closure effect in constant amplitude load crack propagation looks promising.

ACKNOWLEDGEMENT

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Table 1. Chemical composition of the plate

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

Table 2. Mechanical properties of the plate

Orientation	Y.S.0.2% (MPa)	U.T.S. (MPa)	Elong. (%)
Longitudinal	383	480	26.6
Transverse	480	529	26.9

L-T
U

R	Km=17,5	20	22,5	25	30	35
0,05	0,777	0,782	0,790	0,793	0,801	0,803
0,10	0,786	0,796	0.803	0,804	0,810	0,820
0,15	0,799	0,806	0,813	0,823	0,829	0,833
0,20	0,810	0,823	0,831	0,834	0,847	0,849
0,25	0,823	0,836	0,842	0,852	0,860	0,871
0,30	0,837	0,850	0,862	0,865	0.885	0,894
0,35	0,849	0,867	-	0,890	-	-
0,40	0,860	0,881	0,893	0,906	0,922	0,929
0,50	0,899	0,919	0,931	0,950	0,967	0,984
0,60	0,937	0,960	0,980	0,997	1	1

T-L
U

R	Km=17,5	20	22,5	25	30	35
0,05	0,836	0,841	0,850	0,853	0,857	0,866
0,10	0.839	0,851	0,854	0,864	0,870	0,877
0,15	0,851	0,855	-	0,867	0,881	0,881
0,20	0,854	0,867	0,876	0,882	0,890	0,897
0,25	0,867	0,872	-	0,889	0,896	0,905
0,30	0,875	0,885	0,891	0,895	0,908	0,912
0,35	-	0,890	-	0,910	-	-
0,40	0,885	0,903	0,907	0,914	0,932	0,940
0,50	0,906	0,917	0,932	0,941	0,954	0,957
0.60	0,927	0,937	0,952	0,961	0,977	0,988

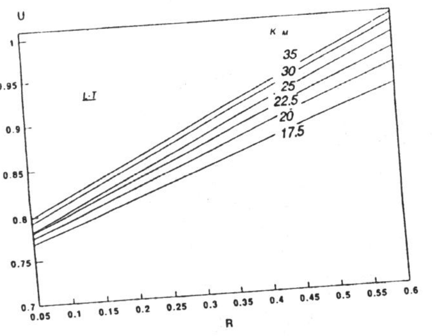

Fig. 1. Effect of R and Kmax in L-T specimens.

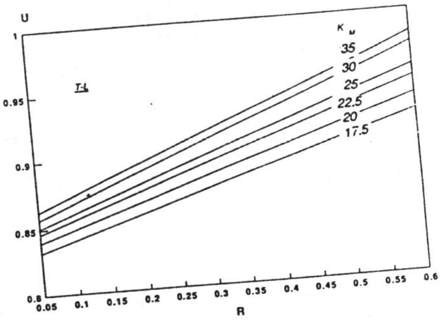

Fig. 2. Effect of R and Kmax in T-L specimens.

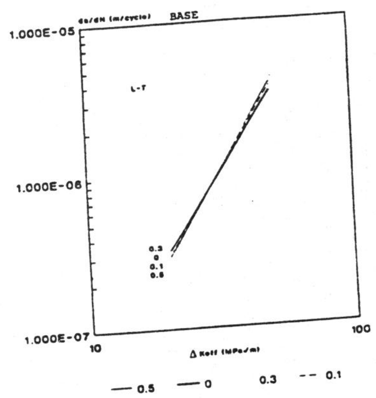

Fig.3 Delta Keff versus da/dn L-T specimens

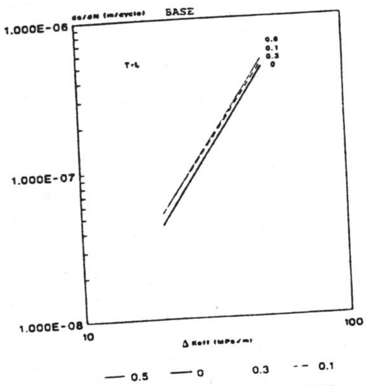

Fig.4 Delta Keff versus da/dn T-L specimens