VACUUM EFFECT ON FATIGUE CRACK PROPAGATION AT LOW RATE

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ABSTRACT

Crack closure measurements were made during fatigue crack growth at low rates and near threshold conditions in air and in vacuum on a 2618 T651 Aluminium alloy. The techniques used to detect crack closure were the compliance variation and the potential drop techniques. The results obtained suggest a definition of the effective stress intensity factor taking into account both the effects of the load ratio and of the environment.

KEYWORDS

Fatigue - Threshold - Crack Closure - Vacuum - Load ratio - Aluminium alloy - Effective stress intensity factor.

INTRODUCTION

A number of studies has been carried out on fatigue crack growth in the range of low rates and near threshold conditions (Baïlon, 1978). Previous works carried out to describe the differences in crack propagation behaviour between air and vacuum on high strengh Aluminium alloys have allowed us to present a suitable empirical relation for da/dN vs ΔK (Petit, 1980)*. These results also showed that crack growth near threshold is essentially ΔK controlled in vacuum and

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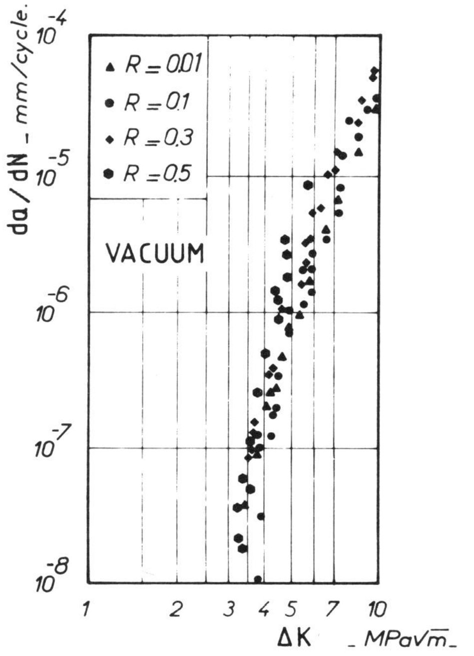
This relation takes into account the effect of the load ratio R and shows that the environmental effect can be brought in with a unique environmental coefficient α which can be related to the Klesnil and Lucas (1972) coefficient γ :

$$\frac{da}{dN} = C(R,\alpha)\left[\left(1-\frac{K_{th}}{K_{max}}\right)^{\alpha}\frac{K_{max}}{K_{th}}\right]^{m}$$

with $\alpha = 1 - \gamma^{1/2}$ *and* $K_{th} = K_{tho}\,(1-R)^{\gamma-1}$

K_{max} controlled in air (fig. 1 and 2), which is in accordance with Kirbyand Beevers (1979) observations on different aluminium alloys.



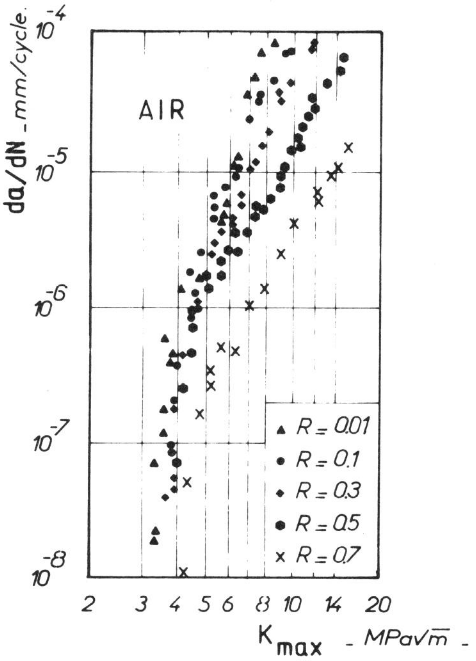


Fig. 1. Threshold tests in vacuum on 2618 T651 alloy : da/dN vs ΔK for different values of R ratio.

Fig. 2. Threshold tests in ambiant air on 2618 T651 alloy : da/dN vs K_{max} for different values of R ratio.

But previous attempts to describe the differences in crack propagation between air and vacuum in terms of crack closure as defined by Elber (1971) fails to do so (Schijve and Arkena, 1976 ; Unangst and co-authors, 1977 ; Amzallag and co-authors, 1980).

This paper presents furthers results obtained in both air and vacuum environments on an aluminium alloy and proposes a definition of the effective stress intensity factor taking into account both the effects of the load ratio R and of the environment.

EXPERIMENTAL CONDITIONS

Tests were carried out in an environmental chamber mounted on an electrohydraulic machine providing a vacuum of 10^{-4} Pa. Crack growth was optically monitored with a travelling microscope and measurements were performed at successively decreasing loads (Maillard, 1978).

The specimens were of 10 mm thick CT 75 type of the aluminium alloy 2618 T651. The alloy composition and mechanical properties are given in table I.

TABLE 1 2618 T651 alloy composition

Cu	Mg	Mn	Si	Fe	Ti	Ni	Al
2,47	1,58	0,06	0,25	1,08	0,10	1,18	rem.

Mechanical properties

σ_y = 400 MPa
σ_u = 450 MPa
A% = 7,1%
K_{1C} = 20 MPa $m^{1/2}$

Test frequencies were 35 Hz during propagation and 0.2 Hz or 0.02 Hz during Crack closure measurements.

The two techniques used to measure crack closure are :
- a compliance method, with a C.O.D. gauge mounted at the notch mouth, complemented with an improved differential method to detect small variations of compliance (Ohta and Sasaki, 1975) ;
- a potential drop technique used only for tests in vacuum, i.e. when this technique gives analysable results (Bachman and Munz, 1975 ; Maillard, 1978).

The correspondance between the results of these two techniques has been previously analysed (Lafarie-Frenot, Petit and Gasc, 1979).

EXPERIMENTAL RESULTS

The analysis of the measurements made by the two techniques used during all the propagation tests was made as shown schematically in the fig. 3 where δ is the displacement measured by the C.O.D. gauge, $\delta' = G.(\delta-\alpha_o P)$ where G is an electronic amplification factor (about 10 to 20 times) (Maillard, 1978 ; Amzallag and co-authors, 1980), α_o the compliance of the cracked specimen and P the applied load during a loading cycle describe at 0.2 Hz for mechanical tracing. The curves δ'vs P amplifie the variations of the slope $\alpha = d\delta/dP$ near P_{min}. Crack opening as interpreted in terms of Elber's model occurs at P_o and the effective stress range is $\Delta K_{eff} = K_{max} - K_o$ where K_o corresponds to P_o.

It is difficult to define the load P_o from the curve P-V (obtained for tracing at 0.02 Hz) (Führing, 1976 ; Lafarie-Frenot, Petit and Gasc, 1979), the large variation of V under vacuum depending essentially upon contacts localized near the surface of the specimen when P becomes higher than P_o.

One observes a maximum of potential for P = P_V corresponding to a crack fully open along all the crack front. Then one can notice a decrease of V for P greater than P_V (fig. 3). The amplitude of this phenomena depends upon ΔK and R, as shown in examples presented in fig. 4.

From the electrical point of view, potential measurements during a loading cycle show a maximum of opening in vacuum for P_V lower than

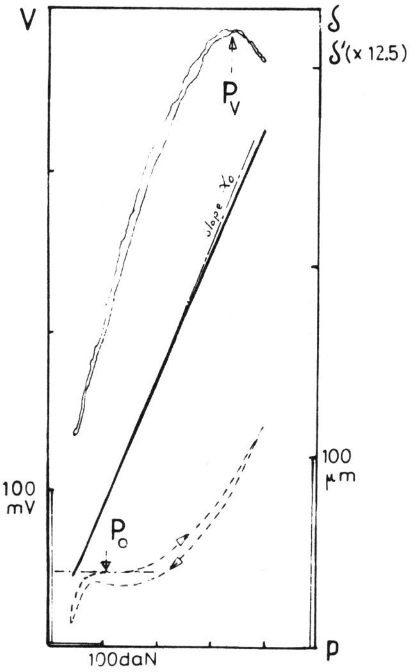


Fig. 3. Determination of α_o from δ-P curves, P_o from δ'-P differential curves and of P_V from potential diagrams (in vacuum only).

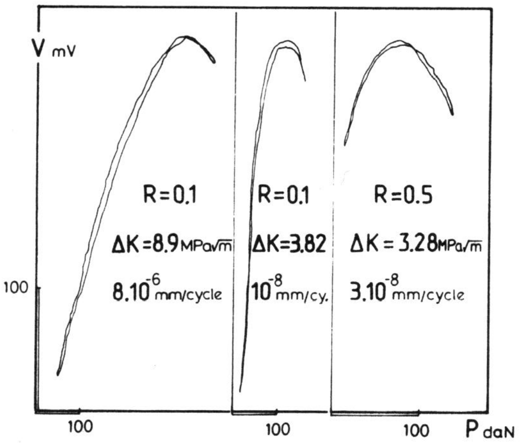


Fig. 4. Typical examples of P-V diagrams on 2618 T651 alloy during threshold tests in vacuum.

P_{max}. This result is in accordance with those obtained elsewhere in U.S. attenuation technique showing that this maximum is only observed in vacuum (Buck, Frandsen, Ho and Marcus, 1975).

DISCUSSION

Initially, we attempted to verify if the effective stress intensity range as defined by Elber (here $\Delta K_{eff} = K_{max} - K_o$) can explain the crack propagation behaviour.

Figures (5,6) confirm that this concept can account for the R ratio effect for each environment. This result is in accordance with those previously obtained (Amzallag and co-authors, 1980).

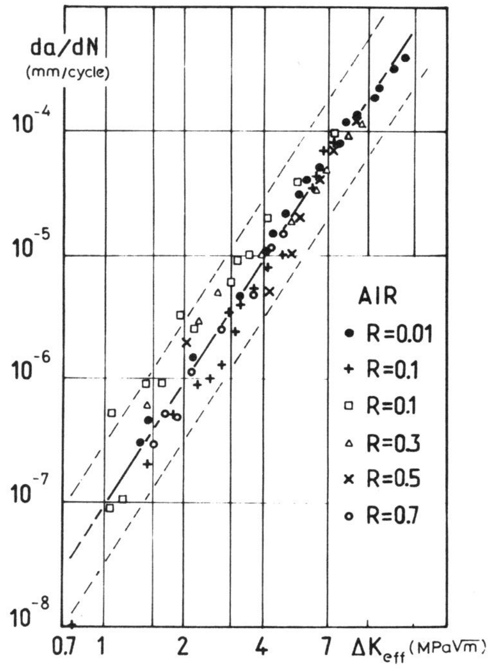


Fig. 5. Threshold tests in air on 2618 T651 alloy : da/dN vs $\Delta K_{eff} = K_{max} - K_o$ for different values of R ratio.

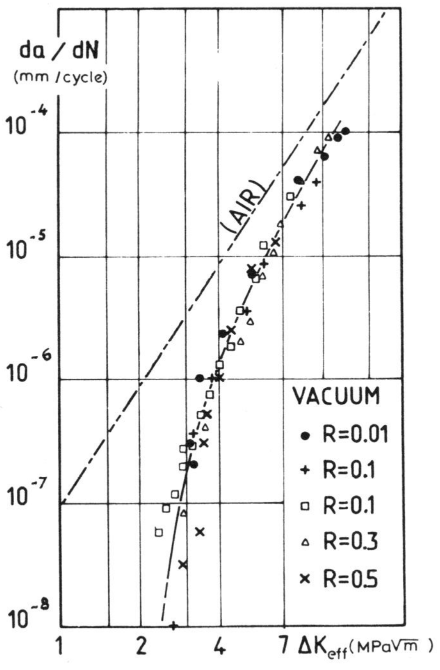


Fig. 6. Threshold tests in vacuum on 2618 T651 alloy : da/dN vs $\Delta K_{eff} = K_{max} - K_o$ for different values of R ratio.

But this ΔK_{eff} concept cannot explain the differences in crack growth rates in air and vacuum.

In the light of our potential measurements and of Buck's results in U.S. attenuation, one can suppose that the effective part of the loading occurs betwen P_o and P_v which corresponds to a maximum of opening. In the case of gazeous environment one can expect P_v to be equal to

P_{max} as shown by U.S. curves. The effective stress intensity factor may be written as $\Delta K^*_{eff} = K_V - K_o$. The figure 7 compares the relation between log da/dN and log ΔK^*_{eff} in vacuum and the mean curve obtained in air (in which case $K_v = K_{max}$: fig. 5).

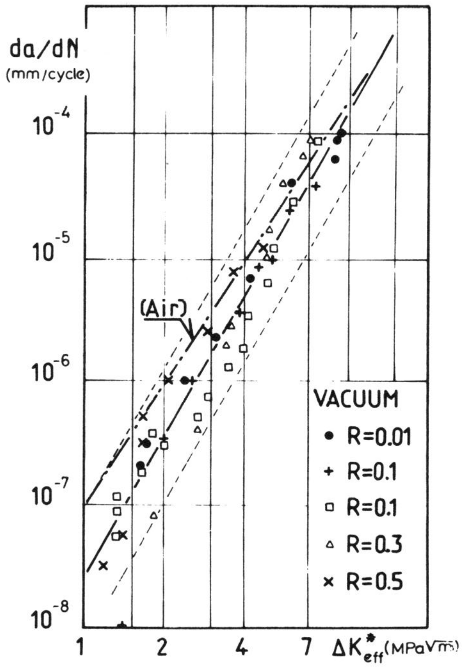
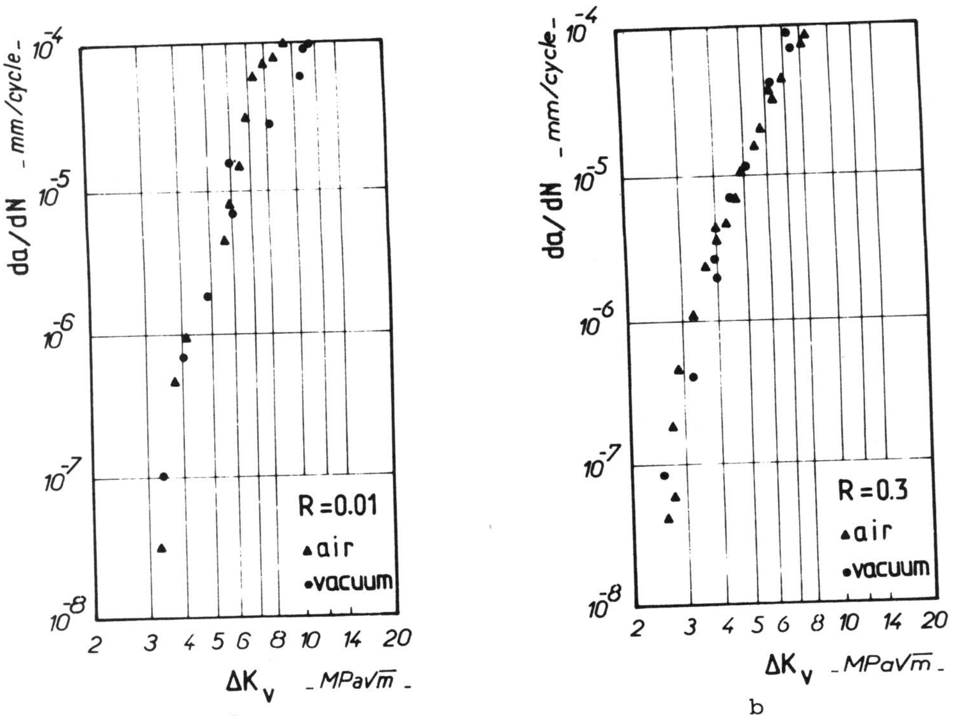


Fig. 7. Threshold test in vacuum on 2618 T651 alloy :
da/dN vs $\Delta K^*_{eff} = K_v - K_o$ for different values of R ratio.
(In air $\Delta K^*_{eff} = \Delta K_{eff}$ as represented by the mean curve of fig. 5).

In spite of scatter, the large number of values taken into account allow us to say that there exists an acceptable correlation between air and vacuum results whatever be the value of R.

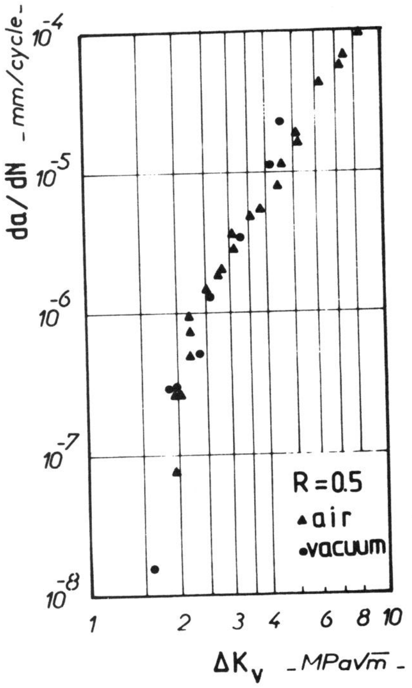
It is difficult at the moment to understand the mechanical behaviour resulting in a drop in potential near P_{max} as observed in vacuum. The existence of crack closure near P_{max} seems inconcievable at first sight.

But apparently there exists a mechanism leading to a contact between the cracked surfaces near P_{max} which need not necessarily be the same as that observed near P_{min}. For example, recent results of Davidson (1979) following in situ S.E.M. studies of Aluminium alloys in vacuum have shown the occurence during a loading cycle of crack surface displacements parallel to the crack plane, superposed with the crack opening displacement normal to this plane, and which might be



a

b



c

Fig. 8. Threshold tests on 2618 T651 alloy : da/dN vs $\Delta K_V = K_V - K_{min}$ for three values of R ratio. (In air $K_V = K_{max}$, i.e. $\Delta K_V = \Delta K$).

a. R = 0.01
b. R = 0.3
c. R = 0.5

attributed to the existence in vacuum of a mixed mode of deformation (mode I plus mode II) at the crack tip. The crack surfaces being rough, these displacements can lead to contacts between the two surfaces near P_{max}. One can expect that these contacts occur particularly at low value of ΔK in which case the C.O.D. values are lower than the size of the surface irregularities. This might be an explanation for the observed phenomena.

After linear fitting, these curves can be represented by the following relation :

$$da/_{dN} = 9.5\ 10^{-8}.\ (\Delta K^{*}_{eff})^{3.3}$$

and $$da/_{dN} = 2.5\ 10^{-8}.\ (\Delta K^{*}_{eff})^{3.8}$$

A slight difference can be noticed which can be attributed to the method used to determined K_o (compliance gauge at the notch mouth) which probably gives systemalically lower values of ΔK_o as indicated by Clerivet and Bathias (1979). But, at the moment, it is the only one method which can be used in a vacuum chamber. Comparing the curves log da/dN vs log $(K_V - K_{min})$ in vacuum and in air (in which case $K_V = K_{max}$, i.e. $\Delta K_V = \Delta K$), one can see that there is very little scatter (fig. 8) which shows that the environmental effect can be explained with the unique introduction of the concept of K_V in the studied rate range.

CONCLUSION

The analysis of the results obtained shows the following points :
a) It is confirmed that $\Delta K_{eff} = K_{max} - K_o$ can account the effect of R ratio for each environment but not the differences due to the environmental effect.

b) Potential measurements during a loading cycle in vacuum show a maximum of opening for K_V lower than K_{max}. This result is in accordance with those obtained elsewhere in U.S. attenuation showing that this maximum is only observed in vacuum.

c) $\Delta K^{*}_{eff} = K_V - K_o$ appears to give in air and in vacuum comparable descriptions of da/dN and results in a possible definition of the effective stress intensity factor in the experimental conditions used and the studied alloy. But the mechanical behaviour leading to closure near P_{max} is difficult to explain at the moment.

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