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A CONTRIBUTION TO THE STUDY OF THE INFLUENCE OF ENVIRONMENT ON THE CRACK GROWTH RATE OF HIGH-STRENGTH ALUMINUM ALLOYS IN FATIGUE

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I - INTRODUCTION

Many experiments on high-strength aluminum alloys have shown that fatigue crack propagation is strongly affected by the atmospheric environment [1, 2, 3]. The predominant effect of water vapor content, and the existence of a threshold pressure as a sensitive function of the test frequency, have been clearly recognized [4, 5]. However these experimental data are not sufficient to mark out the specific effect of several mechanism [6, 7]: crack closure, crack tip deformation, chemical adsorption, etc. In this paper, results are presented concerning three aluminum alloys A-U4, A-U4G1, A-U2GN. For da/dN determination, experiments were made on compact testing size specimens in tension tension loading and sinusoidal load-time variation, with a servo-hydraulic closed loop machine, inside a vacuum chamber where pressure may get down to 10^{-3}Pa. The air vacuum compared effects on crack growth rate have been studied for medium rates (Paris law) and low or very low rates, i.e., about threshold below which fatigue crack growth will not occur.

II - CRACK GROWTH RATE IN AIR AND IN VACUUM

Two kinds of experiments have been made:

- crack propagation at constant loading amplitude ΔP, corresponding to increasing ΔK when the crack grows;
- crack propagation with ΔK decreasing, in order to reach the threshold below which crack growth can't occur. In this case, for each value of loading amplitude lowered by decrements of 10%, the crack is allowed to extend beyond the plastic zone of the preceding value.

These tests were made on C.T. 75 specimens. Table 1 indicates the alloys composition, heat treatment and specimens thickness.

II.1 - Crack Propagation at Constant ΔP (Increasing ΔK)

Figure 1 shows the experimental curves log da/dN versus log ΔK for A-U4G1 alloy. These results are in good agreement with Paris law, in laboratory air as well as in vacuum: the exponent m (da/dN = $C\Delta K^m$) is about 3.5 and 4 respectively. The crack growth rate is always lower in vacuum for each ΔK value and the ratio of both rates in air and vacuum decreases when ΔK or da/dN increases. Besides, these experiments have shown that crack propagation on sharply notched specimens is much longer in vacuum (10^5 cycles versus 10^4 cycles in air), whereas propagation final rates, just before fracture, are nearly the same.

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II.2 - Crack Propagation at Decreasing ΔK

Figure 2 shows experimental results for A-U4G1 and A-U2GN; the variations of the ratio of the crack growth rates are in good agreement with the previous observations. The conventional threshold at da/dN = 10^{-6}mm/cycle, appears to be dependent on the environment, (see Table 2).

The shapes of the curves are not the same, according to the environment: in air a break can be observed when the threshold is reached at about 10^{-6}. On the other hand, in vacuum, the rate decreases progressively with ΔK, and the actual ΔK_{th}, probably reached only below 10^{-8}mm/cycle, might be the same as in air.

Moreover, the ratio of rates between air and vacuum may reach a value of one hundred for the same ΔK.

After threshold determination, crack propagation is performed at constant ΔP. Figure 3 shows that the curves obtained on A-U2GN alloys are exactly the same as with decreasing ΔK in air as well as in vacuum. That is the demonstration of the validity of the experimental procedure used for ΔK_{th} determination. Moreover, for each ΔK value, the plastic zone size must be the same for increasing or decreasing curves since da/dN values are the same.

III - PLASTIC ZONE SIZE DETERMINATION

Microhardness measurements and slip lines observations mainly performed on A-U4 single crystals in the vicinity of the crack show that, for crack growth rate between 10^{-3} and 10^{-5}mm/cycle, plastic zone is almost twice as wide in vacuum as in air for the same crack length and the same ΔK [9]. In both cases, reversed yield zone is included in the former; its hardness is much higher and its width is about 0,1 mm. To specify the structural state of that zone, the same specimen have been recrystallized. After polishing and etching, in the case of vacuum experiment (Figure 4), a narrow strip can be seen composed of little uniform recrystallized grains about 0,1 mm wide. In the case of the laboratory air environment, the recrystallized grains are bigger and more irregular in size, showing that work hardening is smaller.

Therefore, in vacuum, the whole yield zone is twice wider, and the reversed yield zone more damaged than in air.

IV - DISCUSSION

The fatigue crack propagation rate is lower in vacuum than in air and the ratio air rate/vacuum rate increases when ΔK decreases.

Several mechanisms are probably involved for the different ΔK values and for the different environments.

We have shown that in vacuum the plastic zone is wider and more damaged, i.e., more energy is necessary to propagate the crack and therefore fatigue crack propagation rate is lower.

Moreover, the fragilisation mechanism in agressive environment is due to chemical adsorbtion [8, 9] which induces brittle fracture. On the fracture

surface for air environment we've observed very characteristic pseudo-cleavage features corresponding to (111) planes. The more brittle behaviour of the alloys in agressive atmosphere is also consistent with a crack propagation rate higher than in vacuum.

Moreover, crack closure phenomenon is generally considered to be more extensive in vacuum than in wet air [10, 11]; consequently the ΔK_{eff} values are distinctly lower than the ΔK values used for plotting our experimental results; especially for the lowest values of da/dN, this phenomenon becomes very important, and the curves under vacuum might be very different if we make use of ΔK_{eff}. Then the curves in air and vacuum would be more easily comparable, close to ΔK_{th}.

V - CONCLUSION

From the experimental results presented it can be concluded that:

1) the crack propagation rates ratio in air and in vacuum, for a given ΔK, is liable to vary more than one hundred for the smallest ΔK to the unity for the highest ΔK. In the domain of application of the Paris law, this ratio remains from 10 to 2.5.

2) the crack propagation rates measured at increasing or decreasing ΔK are the same, in air as well as in vacuum.

3) the values of ΔK_{th} at 10^{-6}mm/cycle are different according to the environment. But for lower rates they seem to be closer in both cases. However, it is not possible to conclude definitely upon actual ΔK_{th} especially under vacuum.

4) plastic deformation is stronger and wider in the case of vacuum for the same length of crack, i.e., for the same ΔK.

5) If the influence of crack closure would be able to allow a better comparison of crack propagation in air and in vacuum, we don't think that the propagation mechanism, especially the differences observed in the plastic zone, could be described by only one parameter [10]. The most important brittleness of these alloys under agressive environments like ambient air, moist air or H_2S, induced by chemical adsorbtion [5], furthers the propagation: this phenomenon would be another main parameter for the analysis of the comportment of these alloys in fatigue under different environments.

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Table 1

	Heat Treatment	B mm	Cu	Mg	Mn	Si	Fe	Ti	Ni	Al
AU4G1 (2024)	T 351	10	4,73%	2,58%	0,61%	0,13%	0,23%	0,03%	0,01%	rest
AU2GN (RR58)	T 651	20	2,47%	1,58%	0,06%	0,25%	1,08%	0,10%	1,18%	rest

Table 2

	Air	Vacuum
A-U4G1	5 $MPa \cdot m^{1/2}$	7 $MPa \cdot m^{1/2}$
A-U2GN	3 $MPa \cdot m^{1/2}$	5 $MPa \cdot m^{1/2}$

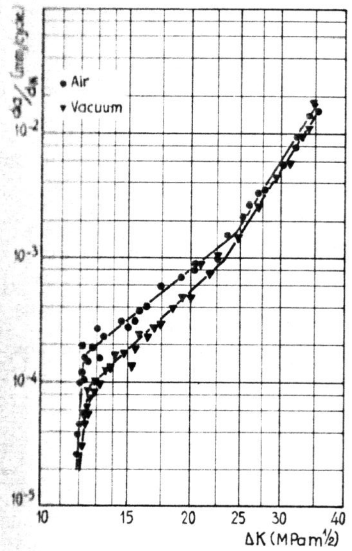

Figure 1 Crack Propagation in A-U4G1-T 351 at Constant Loading Amplitude P = 615 daN. R = 0,01

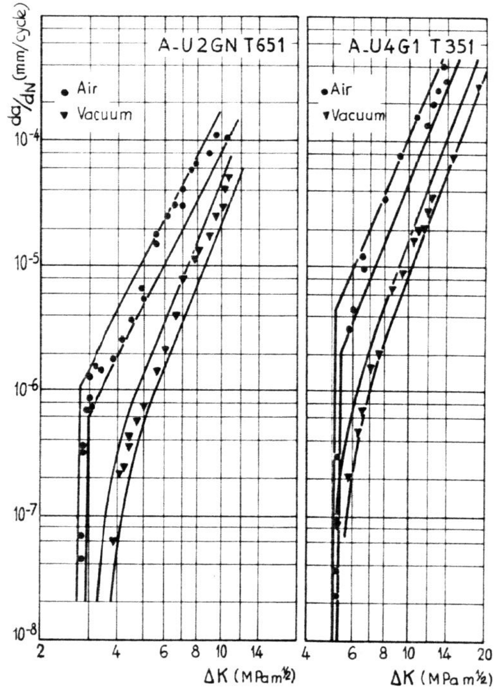

Figure 2 ΔK_{th} Determination in A-U4G1-T 351 and A-U2GN-T 651 (R = 0,01)

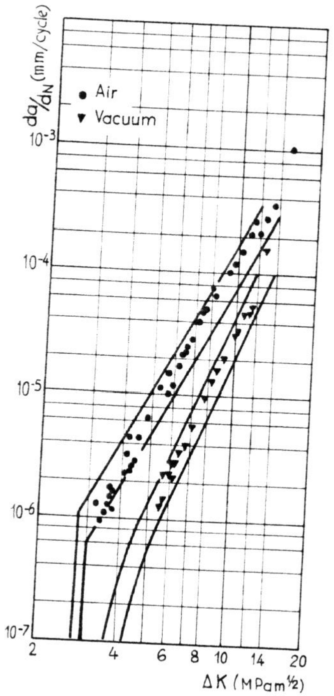

Figure 3 Crack Propagation in A-U2GN-T-651 at Constant Loading Amplitude (R = 0,1) after ΔK_{th} Determination. (The Continuous Lines are Reported from the Figure 2)

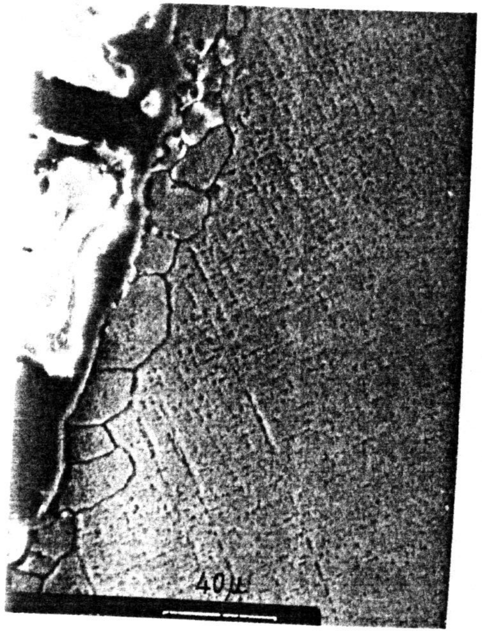

Figure 4 Recrystallization of the Plastic Zone in the Case of Vacuum Environment (AU4 : 14 hours 520° C, Quench in Water, after Cracking 30 hours 160°C)