NEAR THRESHOLD STAGE I TYPE PROPAGATION.

J. PETIT*, N. RANGANATHAN* and J.P. BAILON**

Fractographic features associated with fatigue cracking at very low rates are studied on a 2024 T351 aluminium alloy tested in vacuum. A transition from stage II to stage I type propagation is observed near threshold condition. Identification of the cracking mechanism at the crystallographic level is made by an etch-pit technique. The mechanisms governing the propagation in both stages are discussed.

INTRODUCTION

Fatigue crack growth in crystalline materials is classically divided into two successive stages (1). In stage I the crack propagates along crystallographic slip planes which experience maximum resolved shear stress. This stage has been considered as essentially an extension of the crack nucleation process (2,3). As the stage I crack extends along the active slip plane, a gradual macroscopic rotation of the crack (generally first inclined about 45° against the tensile stress axis) to a plane approximately normal to the direction of the applied stress takes place, and this marks the onset of stage II propagation as observed, for example, on Aluminum alloys (3) or copper (4) single crystals.

Experiments performed on polycrystalline 7075 Aluminum alloys in several aged conditions (5-7) have shown that the crack propagation at low rate under dry atmosphere (5) or in vacuum (6,7), can occur in individual grains along shear bands, i.e. by a stage I type mechanism.

* LMPM, URA CNRS 863, ENSMA, 86034 POITIERS Cedex, FRANCE.
** Dpt. Génie Mécanique, Ecole Polytechnique, MONTREAL, CANADA.

The present work reports results on a transition from stage II to stage I type propagation observed in vacuum on a technical 2024 T351 alloy near threshold condition.

EXPERIMENTAL DETAILS

The material used was a 30 mm plate of the 2024 T351 alloy (Al - 4.4 w/o Cu - 1.5 w/o Mg - 0.66 w/o Mn) quenched and aged at room temperature after cold stretch of 1.5 to 3 %. The microstructure consists of typical pancake-shaped grains (190 x 60 x 70 μm) hardened by GP zones.

Compact tension specimens 75 mm large and 10 mm thick machined in TL orientation were tested on a servohydraulic machine equipped with a chamber providing a vaccum better than 5.10^{-4} Pa. The test frequency was 35 Hz and the load ratio R = 0.5.

RESULTS AND DISCUSSION

Crack growth data

The relation between the propagation rate da/dN of a long fatigue crack versus the stress intensity factor range ΔK in the 2024 T351 alloy is plotted in figure 1. This test was performed using a shedding procedure in accordance to the ASTM recommendation (E 647-86a) for threshold determination. The threshold range is about 4.7 MPa $\sqrt{m}$.

Crack profiles

Optical observations of crack profiles on the specimen surface have been performed at two different growth rates near threshold conditions.

At 2.10^{-10} m/cycle a stage II crack is observed which develops macroscopically along a plane normal to the stress axis. At 2.10^{-11} m/cycle the crack presents enhanced branching and deviation at the grain scale corresponding to an out of plane propagation.

Microfractographic analysis

The fracture surface at 2.10^{-10} m/cyle is essentially marked by the wake of large intermetallic precipitates mainly localized at grain boundaries and by large flat transgranular facets or facetted striations (Fig.3a) . At high magnification (Fig. 3b) the etch-pit technique indicates clearly that the large facets correspond to grains having a {100} plane approximately perpendicular to the load axis while striations correspond to {100} facets inclined to the macroscopic crack plane. These crystallographic features can be explained assuming that fine-scale microscopic decohesion occurs in an alternating manner on two (or more) sets of {111} slip planes. Such a mechanism is characteristic of a stage II propagation as described on single crystals for FCC metals (1-4).

If the fatigue propagation test is patiently carried out at ultra low growth rate (~ 200 μm at 2.10^{-11} m/cycle) the fractographic aspect becomes very rough and highly crystallographic (Fig. 4a). Most of the geometrical facets are {111} planes identified by triangular etch-pits (Fig. 4b). The corresponding profile (Fig. 2b) suggests a localisation of the plastic deformation along a single system of {111} slip planes which experience the maximum resolved shear stress in each grain. Such single slip mechanism is characteristic of a stage I propagation at the scale of each individual grain. Consequently, it can be called a stage I type mechanism as proposed earlier for another Al alloy (5). However, at the macroscopic scale, the crack front runs across more than 100 grains and, globally, the crack remains in a plane normal to the stress axis.

Previous observations on a 7075 alloy have shown that such a crystallographic stage I type mechanism corresponds to a slower propagation than a stage II mechanism when da/dN is expressed in terms of the nominal ΔK (6-8) as well as in terms of the effective stress intensity factor range ΔK_{eff} (7) . A deeper analysis of near threshold stage I type propagation needs complementary experiments to compare pure stage I cracking in well oriented single crystal and stage I type cracking in polycristals (with grain boundary barriers) and in not well oriented single crystals.

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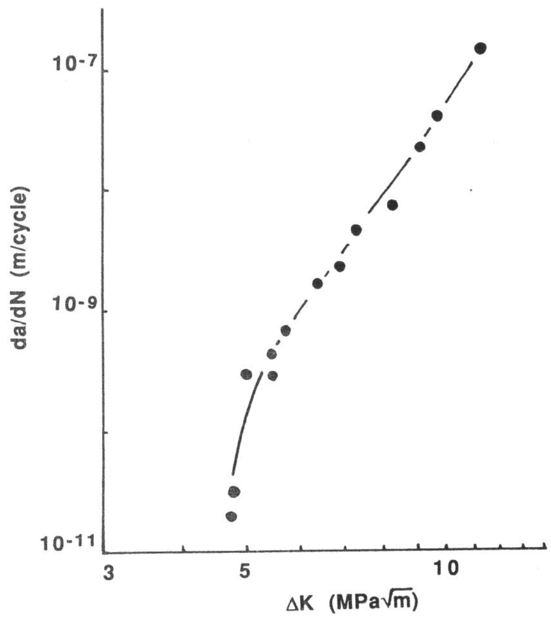

Figure 1- da/dN vs ΔK relationship for the 2024 T351 alloy tested in vacuum at 35 Hz and R = 0.5.

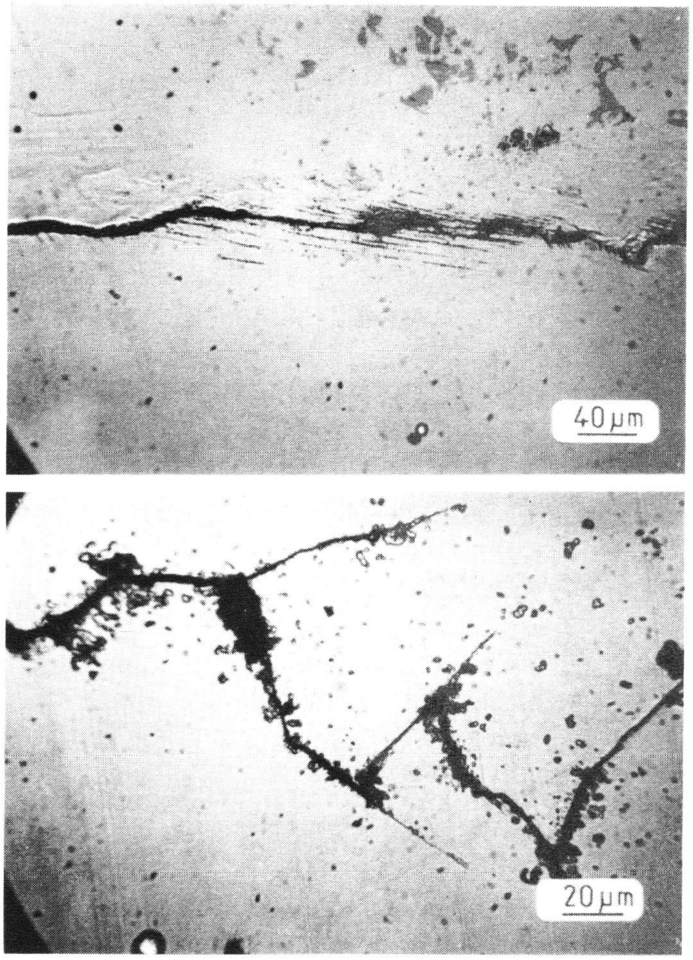

Figure 2 - Near threshold crack profile of the 2024 T351alloy in vacuum (R = 0.5).
a) da/dN = 2.10^{-10} m/cycle
b) da/dN = 2.10^{-11} m/cycle

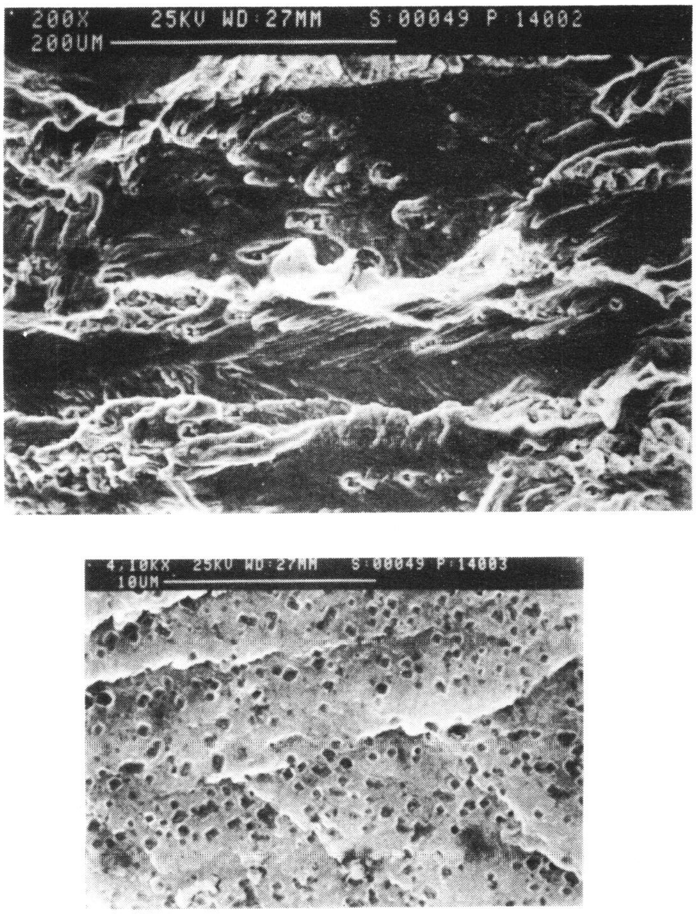

Figure 3 - a) stage II fracture surface morphology of the 2024 T351 alloy tested in vacuum : da/dN = 2.10^{-10} m/cycle, R = 0.5.
b) {100} facets identified by etch-pit technique.

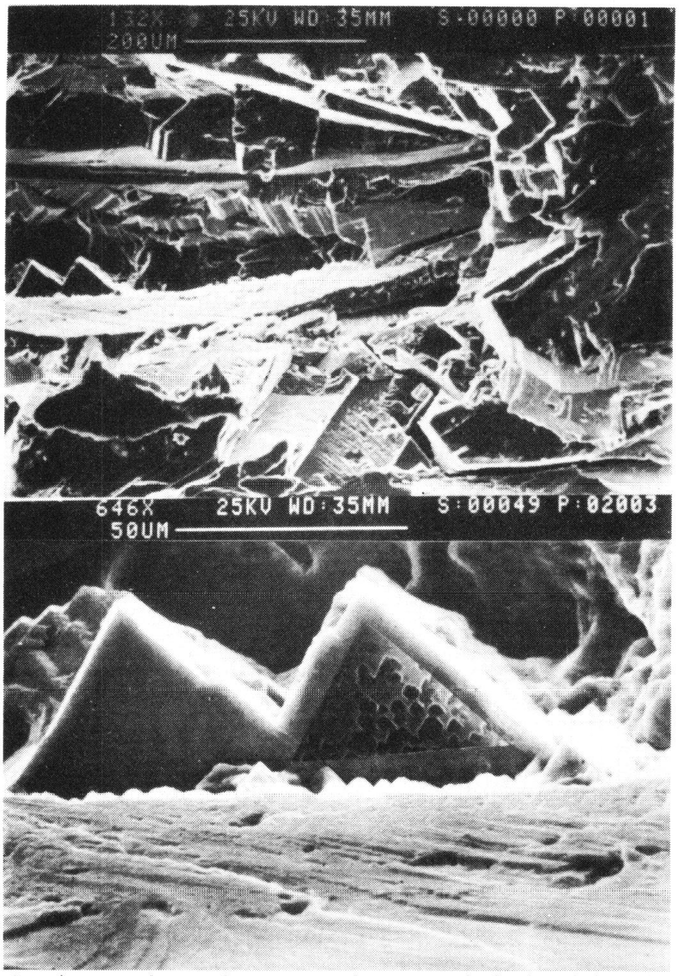

Figure 4 - a) stage I type fracture surface morphologie of the 2024 T351 alloy tested in vacuum : da/dN = 2.10^{-11} m/cycle, R = 0.5.
b) Etch-pit identification of {111} geometrical facets.