Microstructural and fatigue crack growth characterization of the AA7050-T7451 Al alloy

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Abstract

The aim of this work was to characterize the AA7050-T7451 fatigue crack growth behavior evaluating the crack growth rates and micromechanisms in both T-L and L-T directions. Compact tension specimens (CT) and the compliance method were used in this work to determine crack growth rates. The data showed that the L-T orientation presents a slightly lower crack growth rate in the 9-15 MPa√m range.
Keywords: aluminum alloys; fatigue crack growth; AA7050; aeronautical materials.

Introduction

The AA7050 aluminum alloy is one of the most used alloys of the 7xxx series due to its high strength and good fracture toughness. In the T7 heat treatment the microstructure is capable of enhancement of the stress corrosion resistance without compromising its mechanical properties, thus making it one of the most used aluminum alloy for aeronautical applications [1]. However, the 7050-T7451 alloy tends to be highly anisotropic and so it is needed to fully characterize its properties for use, with load and frequency representative of those expected in service [2].

It is known that the structure, including grain size, crystallographic orientation and precipitate type and grain boundary free zones play an important role on the enhancement of fatigue crack propagation resistance. However, there is a great challenge on evaluating the effects of crack deflection across the grain boundaries, which exhibit specific crystallographic features, indicating that the grain boundaries and grain orientation may play an important role in controlling fatigue crack propagation in Stage I. In Stage II, the crack tip plastic deformation is different from Stage I, since it presents multiple slip bands, the size of the plastic zone at the crack tip extends to many grains, and the crack plane changes into the plane normal to the maximum principal stress, leading to a different grain/orientation effect on fatigue crack growth [3].

The results presented here are part of a research project that aims to investigate the micromechanisms of fatigue crack growth in the AA7050 Al-Cu-Li alloy considering air environment. In addition, the effects of grain orientation, grain boundaries, crystallographic features and precipitates on the propagation behavior of the AA7050-T7451 aluminum alloy are considered.

Experimental Procedure

The material used in this work was the Al-Cu-Li alloy AA7050-T7451. Metallographic samples were prepared using Keller etchant and examined in a Carl Zeiss ™ model AxioLab A1 optical microscope. Specimens were machined following the ASTM E647-15 in the T-L and L-T directions. Figure 1 presents the size and geometry of the C(T) type specimens. Prior to the fatigue tests, the specimen surfaces were manually grinded and finished with manual polishing using 1μm-diamond suspension. The fatigue tests were performed in air (15 Hz) with load ratio R=0,1 in a close loop servohydraulic dynamic test system with 100 kN of maximum capacity. The tests were conducted following the ASTM E647-15 standard in load control for evaluation of the stage II of the da/dN x ΔK curve.

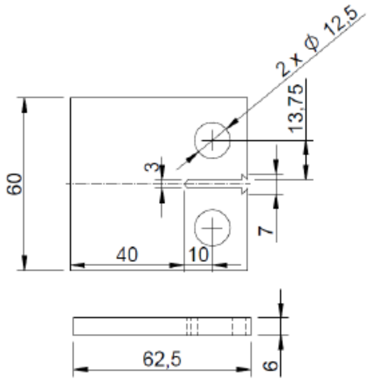

Figure 1 - Size and geometry of the C(T) type specimens.

Results and Discussion

The heat treated, rolled plate form of the AA7050 is highly anisotropic and has a pancake shaped grain morphology in longitudinal and transversal directions, as can be seen in Figure 2, obtained by optical microscopy (OM). Observations made by OM showed grains strongly elongated in the rolling direction, with a large discrepancy in size from one grain to another when comparing different directions such as longitudinal and short transverse (ST).

Figure 2 – 3D grain morphology.

Comparisons of the fatigue crack growth behavior were made between L-T and T-L directions. Growth rate data for both directions is shown in Figure 3.

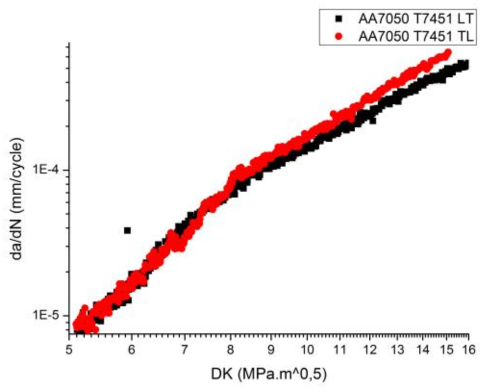

Figure 3 – Fatigue crack growth curves (R=0,1).

It can be noticed that the FCGR for the L-T orientation is slightly lower than that of the T-L orientation. This occurs mostly because the T-L direction allows the crack to grow in a straight fashion along the grains and grain boundaries whereas in the L-T direction cracks tend to deviate more with directional changes. These deviations in the crack path are probably due to the grain boundary barrier effect. Also, L-T orientation showed a "curve" shaped crack morphology, shown in Figure 4, probably due to the grains being oriented in the transverse direction which caused deviations in the crack path, thus decreasing the FCGR [4].

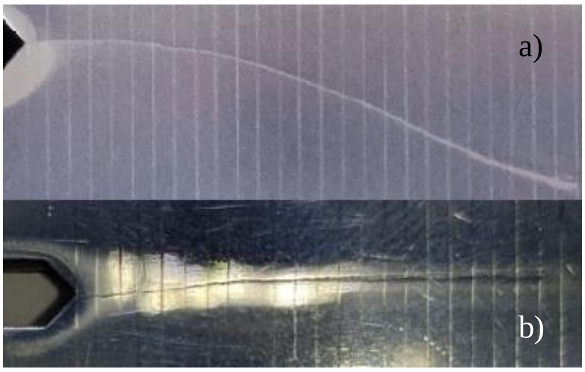

Figure 4 – Comparison between crack morphologies. In a) L-T direction and b) T-L direction.

Paris law constants were calculated by the polynomial fitting method in the stage II of the da/dN x ΔK curve. The stage II portion of the curve can be seen in Figure 5 and the Paris equation is shown in Table 1.

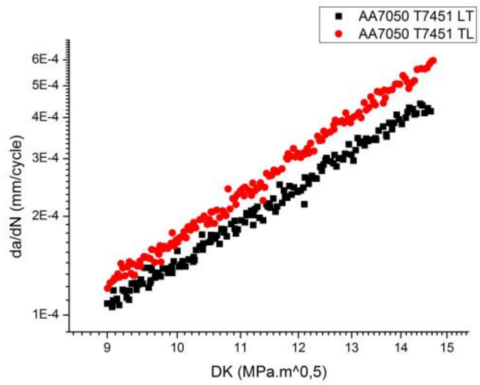

Figure 4 – Stage II region of the FCG curves.

Table 1 – Paris law equations.

Reference Direction	Paris Equation
L-T	$da/dN = 1{,}67.10^{-7}(\Delta K)^{2{,}93}$
T-L	$da/dN = 1{,}01.10^{-7}(\Delta K)^{3{,}23}$

Conclusions

The grains are elongated, “pancake” like shape, in longitudinal and transversal directions. Fatigue crack growth rates were slightly different with the L-T direction showing a lower crack propagation rate when compared to the T-L direction, probably due to the deviation caused by the grain orientation in the L-T direction, in which the grain barrier effect is more prominent.

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References

[1] K. S. Al-Rubaie, M. A. Del Grande, D. N. Travessa, and K. R. Cardoso, “Effect of pre-strain on the fatigue life of 7050-T7451 aluminium alloy,” *Mater. Sci. Eng. A*, vol. 464, no. 1–2, pp. 141–150, 2007.

[2] K. V. Jata, K. K. Sankaran, and J. J. Ruschau, “Friction-stir welding effects on microstructure and fatigue of aluminum alloy 7050-T7451,” *Metall. Mater. Trans. A Phys. Metall. Mater. Sci.*, vol. 31, no. 9, pp. 2181–2192, 2000.

[3] T. Zhai, A. J. Wilkinson, and J. W. Martin, “Crystallographic mechanism for fatigue crack propagation through grain boundaries,” *Acta Mater.*, vol. 48, no. 20, pp. 4917–4927, 2000.

[4] J. J. Schubbe, “Fatigue crack propagation in 7050-T7451 plate alloy,” *Eng. Fract. Mech.*, vol. 76, no. 8, pp. 1037–1048, 2009.