Influence of Inclusion Content on Fatigue Crack Propagation in Aluminum Alloys

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Fatigue crack growth rates were measured at room temperature in dry air for three 7075-T6 aluminum alloys with different inclusion content. Volume fractions of inclusions were determined for each alloy by the point count method with two different automated systems. Plots of the fatigue crack growth rate \((\frac{da}{dN})\) vs the stress-intensity-factor range \((\Delta K)\) show a well defined change of slope at the transition between plane strain and plane stress fracture. This transition is associated with a marked increase in the amount of fracture by void growth around inclusions. The volume fraction and mean spacing of voids within the cyclic plastic zone have been determined as a function of \(\Delta K\) by quantitative fractography. Fracture by voids is important when the mean spacing of such voids is approximately equal to the width of the cyclic plastic zone in the plane of the crack. It is concluded that the inclusion content increases the fatigue-crack growth rates only within the plane stress range, that is for values of the stress-intensity-factor range \(\Delta K > 20\) kpsi/in.

Another goal of this work was to understand the origin of the sigmoidal shape of the fatigue crack growth rate \((\frac{da}{dN}) vs (\Delta K)\) curves of high-strength aluminum alloys. Most often the exact shape of the curve is disregarded and a straight line of slope 4 is drawn through the data points. Is the sigmoidal shape of the curves due to an environment effect, or due to the transition between plane strain and plane stress fracture or finally, is it due to a change of fracture mode related to the volume fraction of inclusions?

Also a side objective of this research was to determine the feasibility of the application of automated quantitative metallography to the determination of relatively small volume fractions of inclusions.

MATERIALS AND TEST PROCEDURES

Chemical Composition of Alloys

Table I gives the chemical composition of 7075-T6 aluminum alloys of different purities, high purity (HP), medium purity (MP), and commercial purity (CP) which contain chromium as a grain growth inhibitor.

Processing History

The three 7075 alloys (HP, MP, and CP) were received in the as-rolled condition (sheets 0.16 in. thick) and were heat treated to the T6 condition as follows:
- Solution heat treatment: 2 h at 900°F
- Water-quench to room temperature
- Precipitation hardening for 48 h at 250°F and air cooling to room temperature

The microstructures of these alloys are given in Fig. 1.

Mechanical Properties

The room temperature mechanical properties, Table II, were measured on specimens with a gage length of 1 in. and a section of 0.5 in. by 0.125 in. at a strain rate of 0.02 in./ipm. The CP alloy shows a
Table I. Chemical Composition of Aluminum Alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Ni</th>
<th>Zn</th>
<th>Ti</th>
<th>Zr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 7075-T6-HP</td>
<td>0.02</td>
<td>&lt;0.01</td>
<td>1.44</td>
<td>&lt;0.01</td>
<td>2.52</td>
<td>0.18</td>
<td>&lt;0.01</td>
<td>6.06</td>
<td>0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Al 7075-T6-MP</td>
<td>0.05</td>
<td>0.06</td>
<td>1.43</td>
<td>0.01</td>
<td>2.44</td>
<td>0.17</td>
<td>&lt;0.01</td>
<td>6.00</td>
<td>0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Al 7075-T6-CP</td>
<td>0.08</td>
<td>0.22</td>
<td>1.30</td>
<td>0.03</td>
<td>2.32</td>
<td>0.16</td>
<td>&lt;0.01</td>
<td>6.05</td>
<td>0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

markedly lower yield strength probably due to the fact that the iron and silicon impurities are tying up some of the alloying elements (Cu, Mg, Zn) in the inclusions.

Testing Procedure

A 12 by 3 by 0.155 in. specimen was used for longitudinal crack propagation tests (tensile axis parallel to the rolling direction). A hole 0.04 in. in diameter was drilled in the center of the plate and a crack 0.12 in. long was cut with a jeweler's saw.

In order to distinguish between this crack orientation and others in rolled sheets, it is convenient to use the following notation: R—rolling direction, W—width direction, T—thickness direction.

Since we are dealing only with through-thickness cracks, the identification of the fracture plane is sufficient to define the test direction. Therefore, the TW fracture plane corresponds to a tensile load parallel to the rolling direction and a crack propagating in the W direction in the TW plane.

A closed-loop, servocontrolled, hydraulic testing system was used for fatigue testing at a frequency of 5 cps with a sinusoidal stress wave. The nominal maximum stress was 15,000 psi and the ratio, \( \sigma_{\text{min}} / \sigma_{\text{max}} \), was 0.0175. Alignment of the grips and of the test specimen was achieved by freezing the lower grip in a Wood's Metal pot. The tests were conducted in dry air with 200 to 300 ppm relative humidity. The dew point