High Temperature Low Cycle Fatigue in Beta Processed Ti-5Al-5Sn-2Zr-2Mo-0.25Si

D. EYLON, T. L. BARTEL, AND M. E. ROSENBLUM

The effects of β heat treatment and β-work on microstructure and high temperature low cycle fatigue properties of Ti-5Al-5Sn-2Zr-2Mo-0.25Si were investigated. Strain control tests at total strains ranging from 1.2 to 2.5 pct were conducted at 427, 482, and 538 °C with frequencies of 10 and 0.4 cpm. The results showed shorter fatigue life at the higher temperature and lower frequency for all microstructural conditions. β-worked material with shorter α-platelet structure showed the highest fatigue strength for all test conditions. At these high temperatures, fatigue cracks initiate along the α/β interfaces with longer initial cracks in the β-annealed condition which had longer interfaces. It is suggested that oxygen diffusion along the α/β interfaces is responsible for surface connected interfacial cracking leading to the observed temperature and frequency dependence. The better HTLCF life of the β-worked material is related to the shorter initial interface cracks.

In recent years the aircraft industry has expanded the use of titanium alloys into the 500 °C temperature range to produce lighter rotating jet engine components and lighter airframe elements. High temperature titanium alloys in current use are defined as near alpha alloys with relatively low content of beta stabilizing elements. Alloys such as Ti-6Al-2Sn-4Zr-2Mo, Ti-11, 2 IMI-685 and Ti-5Al-5Sn-2Zr-2Mo 4 were developed to operate under prolonged exposure at 500 °C. The alloy Ti-5Al-5Sn-2Zr-2Mo-0.25Si (Ti-5522S), the subject of this work, was developed through an effort sponsored by the Air Force Materials Laboratory. 4, 5 Microstructures resulting from cooling through the β-transus temperature proved, in most cases, to have best creep resistance of this alloy group. 4, 5 These microstructures typically consist of packets of α-platelets, similarly aligned and crystallographically oriented, separated by films of β-phase. In wrought material, these microstructures can be obtained either by solution treatment or work in the β-phase field; this super transus working offers the advantage of lower press load requirements 8,9 and better shape definition.

Recent work by Bania 10 showed that strain control high temperature low cycle fatigue (HTLCF) strength of β-processed Ti-5522S is inferior to α + β processed material. The objective of this work was to study in more detail the behavior of the microstructures resulting from β-processing and determine the mechanisms responsible for their poor HTLCF properties.

EXPERIMENTAL PROCEDURE

Material

The Ti-5522S tested in this investigation and in the previous work, 10 was taken from a single heat produced by RMI and supplied in 75 mm diam round bars. The β-transus temperature (Tb) of this heat was determined to be 986 ± 2 °C. A small amount of Y2O3 (Yttria) was added to the alloy (approximately 250 ppm) to improve hot work-ability; chemical composition of the as-received material is given in Table 1.

Processing and Microstructure

To produce the desired microstructures, two combinations of processing and heat treatment in the α + β phase fields were used. The material was worked in a two-step process; a 6:1 ratio extrusion (from 76 mm to 32 mm diam) followed by a 3:1 ratio hot swage (from 32 mm to 19 mm diam) with an air cool. Processing temperatures of the examined conditions are summarized in Table II and Figs. 1(a) and (b); β-solutioning time was 1 h and stabilizing treatment time was 2 h, both followed by an air cool. The α-grain structure, as well as the prior beta grain (PBG) structure of the two conditions, can be seen at low and high magnifications in Figs. 1(c) through (f). Specimens were etched with Kroll's reagent and all photomicrographs were taken with polarized light and Nomarski differential interference contrast technique.

Strain Control High Temperature Low Cycle Fatigue

Strain control tests were performed in a 30 ton servohydraulic MTS machine capable of generating triangular load-displacement waveforms with a 20 mm span strain-gage extensometer attached to the specimens. Temperature was held to within ±2 °C by induction heating; the temperature gradient along the 25 mm gage length was determined to be no greater than 10 °C.

To allow tension-compression loading (R = -1.0), round buttonhead specimens with a mirror finish gage section were machined from the swaged and heat treated 19 mm diam rods. The specimen buttonheads (Fig. 2) were compression clamped to water cooled grips.

Cyclic loads and strains were continuously recorded and calibrated stress-strain loops were taken.
periodically on an X-Y recorder. The number of cycles to failure ($N_f$) was determined at the point where the tensile load dropped 5 pct from the average value.

Tests were performed in ambient air and humidity conditions. After mounting, specimens were soaked for two hours at test temperature to thermally stabilize the load system. The test variables, microstructure, total strain range, temperature, and frequency are summarized in Table III.

Total strain range ($\Delta \varepsilon_f$) was defined as the overall elastic and inelastic strain between the maximum tension and compression load points of the cycle and was

![Diagram](image1)

**Table I. Chemical Analysis of the Ti-5522s Bar Stock**

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>Sn</th>
<th>Zr</th>
<th>Mo</th>
<th>Si</th>
<th>Fe</th>
<th>O</th>
<th>Y</th>
<th>N</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. Pct</td>
<td>4.9</td>
<td>5.0</td>
<td>1.9</td>
<td>1.9</td>
<td>0.24</td>
<td>0.05</td>
<td>0.164</td>
<td>0.026</td>
<td>0.11</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

![Microstructures](image2)