STRUCTURE-PROPERTY CORRELATION IN AN AIRCRAFT SHEET METAL ALLOY Ti-15V-3Cr-3Al-3Sn

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Abstract
This paper presents the age hardening behavior of solution treated metastable beta titanium alloy Ti-15V-3Cr-3Al-3Sn (Ti-15-3) as monitored by hardness measurements, tensile testing and microstructural examinations. The alloy was subjected to various single and duplex aging treatments. Single aging was carried out in the range from 200-550 °C for times up to 150 h. For the duplex aging first step aging was performed in two different ways. (i) 24 h at 250 °C (ii) 10 h at 300 °C ; second step aging was carried in the range 350-500 °C, for times up to 150 h. In general, duplex aging treatments resulted in higher hardness values compared to single step aging. Amongst all the duplex aging treatments, two aging treatments – 24 h / 250 °C followed by 8 h / 500 °C and 10 h / 300 °C followed by 10 h / 500 °C resulted in good balance of tensile strength and ductility; however, only the former treatment resulted in homogenous precipitation with no precipitate free zones.

1. Introduction
Metastable beta titanium alloys have been developed to overcome the shortcomings of alpha (α) and alpha+beta (α+β) titanium alloys – low hardenability, inadequate deformability and poor machinability. The alloy Ti-15V-3Cr-3Al-3Sn (Ti-15-3) is one of the beta alloys being commercially produced and has been finding increasing application in aerospace due to its superior cold formability at room temperature, high strength after aging, deep hardenability, excellent corrosion resistance. The excellent cold formability enables production of this grade in the form of thin strips and sheets. The grade Ti-15-3 found many applications in aircraft and other industry sectors - airframe structure, ducts, fire extinguishers, body armour, springs, fasteners, foil, clips, brackets and metal matrix composites [1].

The nature of precipitation of α phase has a strong influence on the mechanical behavior of β titanium alloys [2-5]. Duplex aging is known to lead to improved performance of metastable β titanium alloys through homogeneous α precipitation. For example, studies by Krugmann and Gregory [2] and Wagner and Gregory [3] proved that duplex aging of the metastable β-Ti alloy Ti38-644 (β-C) leads to a more homogenous distribution of α precipitates. Schmidt et al [4] showed that carefully designed duplex aging treatments can improve the tensile ductility and high cycle fatigue life of β-C alloy. Furuhara et al [5] brought out that a low temperature – high temperature two step aging treatment of Ti15-3 alloy results in a more uniform and finer distribution of α precipitates than when single step aging is carried out. These authors have also shown that higher hardness levels can be obtained by resorting to two stage aging.
There is a need to identify optimum two step aging treatments for Ti-15-3 alloy, aiming at substantially superior combination of mechanical properties than what is possible with single step aging and a microstructure devoid of features which are known to adversely affect the fatigue life. The objective of the research reported here has been to establish an optimized two step aging cycle for the alloy Ti15-3 which yields a good strength-ductility combination and a microstructure conducive to a high fatigue limit. Detailed studies on mechanical properties obtained after single step aging and two step aging have been reported elsewhere [6]. The abbreviations SA and DA shall be used in this paper to denote single aging and two step / duplex aging respectively.

2. Material and Experimental Methods

The Ti15-3 alloy used in the present study was supplied in the form of rods 16 mm in diameter by GE Wick, China. The alloy was in the solution annealed condition; solution annealing was carried out at 850 °C. The detailed chemical composition is given in Table 1.

<table>
<thead>
<tr>
<th>V</th>
<th>Cr</th>
<th>Sn</th>
<th>Al</th>
<th>Fe</th>
<th>O</th>
<th>H</th>
<th>N</th>
<th>C</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.0</td>
<td>3.1</td>
<td>3.0</td>
<td>2.7</td>
<td>0.18</td>
<td>0.09</td>
<td>0.003</td>
<td>0.027</td>
<td>0.008</td>
<td>Bal</td>
</tr>
</tbody>
</table>

Discs of 6 mm in height were cut from the as-received rods using electro discharge wire cutting machine for both the SA and DA studies. Aging was carried out in an inert atmosphere furnace which is heated by SiC heating elements and the temperature was controlled within ± 2 °C. SA studies were carried out in the temperature range 200-550 °C, at 50 °C temperature interval. In the case of DA, two different cycles were used for the first step aging (i) 24 h at 250 °C (ii) 10 h at 300 °C, while the second step aging was carried out in the temperature range 350-500 °C at 50 °C temperature interval.

In both SA and DA, age hardening was monitored by carrying out micro Vickers hardness measurements, tensile testing and microstructural examinations. Hardness was measured using a standard Vickers diamond pyramid hardness tester with 500gm load and dwell time of 10 seconds on a metallographically polished specimens. The hardness values reported in the paper are average of at least 10 random measurements made on the sample.

Tensile testing in select cases was performed at room temperature to supplement the hardness tests to monitor the age hardening reaction taking place during SA and DA. Round tensile test specimens conforming to ASTM E8M requirements were used. Tensile testing was performed using electromechanical universal testing machine supplied by TE, China. Testing in any given condition was carried out on at least triplicate number of specimens and the test results reported herein are the average values.

Special etching was carried out using Ammonium bifluoride (NH4HF2) based etchant, prepared by dissolving 5 grams of NH4HF2 in 100 ml of distilled water for optical microscopic examination.

Metallographic polished specimens were etched with Kroll’s etchant were used for microstructural examinations. Microstructural examination of select specimens in the aged condition was carried out using Zeiss-Supra™ 55 Field Emission Scanning Electron Microscopy (FESEM) with Back Scattered Electron Imaging (BSEI). Fractographic studies were carried out on broken tensile test samples using the FESEM in Secondary Electron Imaging (SEI) mode.