The influence of post-weld heat treatment on microstructure of TC4 weld joints

J. Liu*, H. Qiao and Y. Hu

The effect of one two-step high-temperature post-weld heat treatment on the microstructure of TC4 weld joints has been studied in our experiment, and as a result, the weld joints with attractive mechanical property have been obtained. The weld joints consisted of lamellar martensitic α, retained β and primary α, therefore microstructure of the weld joints would be kept in balance, and spheroidised α phase both in the crystalline grain and grain boundary, which could improve attractive balance of mechanical properties.

Keywords: Two-step heat treatment, Microstructure, TC4 alloy weld joint, Spheroidised α phase, Lamellar α phase

Introduction
Titanium alloy TC4 (Ti–6Al–4 V) has been extensively used in a wide range of industries and is established as a major structural material in the aerospace industries. It accounts for more than half of all titanium tonnage in the world, for their excellent combination of mechanical properties, such as high specific strength, low density, toughness, high fatigue life, resistance to corrosion and thermal stability in high temperature.1–3 Gas tungsten arc welding is the most preferred welding method for reactive materials like titanium alloy for its comparatively easier applicability and better economy.4 However, the welding of the titanium alloy exhibits quite a few problems and this may lead to inferior mechanical properties.5 These problems could either be the phase changes or residual stresses inside the weld joints. During the cooling after welding, the fusion zone (FZ) had to be cooled down via α/β region, thus undesirable structure brought by conventional welding would depress the properties of this material.6,7 The prominent increase of martensite basketweave in FZ and heat affected zone led to reduction in strength and ductility of weld joints.5 However, the post-weld heat treatment could control welding properties through the development of structural relationship. The final microstructure of transformed β and variation of α phase played an important role in the attractive balance of mechanical properties.8

Experimental: materials, procedures and detection methods
The material used in this study is supplied by BaoTai Titanium Industry Co., Ltd, China as plate (1-8 mm) of TC4 alloy, and the main chemical composition of it has been shown in Table 1 (mass fraction).

1Shenyang Ligong University, Shenyang 110159, China
2Shenyang Institute of Automation, Chinese Academy of Science, Shenyang 110016, China
*Corresponding author, e-mail lj-mail-sut@163.com

The TC4 plates with the dimension of 200 mm × 100 mm × 1-8 mm are welded in butt along the longitudinal direction. Tensile specimens of welding were made parallel to the rolling direction. The gas tungsten arc-optimised welding parameters are listed in Table 2. Figure 1 is an optical microscopy image of welding surface microstructure, including base metal in Fig. 1c, consisting of duplex microstructure with primary equiaxed α phase and partly acicular β phase, which could distribute in the interface of zonal α phase. Figure 1a showed FZ, which was made by martensite basketweave. Moreover, the structure of base metal was a small percentage of the β phase distributed at the elongated α grain boundary, which was shown in Fig. 1c. For the optical microstructure studies, specimens were mechanically polished and etched in an etchant with the following ratio: $V_{\text{HF}}:V_{\text{HNO}_3}:V_{\text{H}_2\text{O}} = 2:3:95$. The tests of metallographic surfaces were observed by OLYMPUS BHM.

We discussed that the changes in the microstructure of FZ were influenced by different factors. The heat treatment processes are designed based on the β transition temperature which had been confirmed as 1000°C by previous experiments. We defined the first heat treatment temperature as first temperature (FT), first heat treatment preservation as first preservation (FP), the second heat treatment temperature as second temperature and the second heat treatment preservation as second preservation. The specific data of the process were presented in Table 3 and the influence of different factors would be discussed separately.

The microstructure in FZ was shown in Fig. 1 and the morphology of SEM was exhibited in Fig. 2. The base metal consisted of partially spheroidised starting microstructure of equiaxed and remnant lamellar α. We call the microscopic structure as tri-modal microstructure which has better plasticity maintaining high tensile strength and good ductility.

Results and discussion
After alpha/beta solution heat treatment in the temperature between α and β and then being quenched in water,
which would reduce the concentration of β phase stabilising of martensite, the equilibrium α appeared. The cooling happened in an extremely rapid rate during water quenching after the first heat treatment. The microstructure which consisted of lamellar martensitic α, retained β and primary α changed. The compositional change in α phase took place because of resolving β-phase. Similar to the initial thermo-mechanical processing in high temperature, the objective of subsequent heat treatment below the temperature $\beta \rightarrow \alpha + \beta$ is to break down the colony-alpha structure into a fine and uniform equiaxed-alpha morphology during the cooling down by water quench method after treatment.10-12

Table 1 The various elements content of TC4

<table>
<thead>
<tr>
<th>Element</th>
<th>Al</th>
<th>V</th>
<th>Fe</th>
<th>C</th>
<th>N</th>
<th>H</th>
<th>O</th>
<th>Ti</th>
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</thead>
<tbody>
<tr>
<td>Content</td>
<td>6.24</td>
<td>4.48</td>
<td>0.11</td>
<td>0.007</td>
<td>&lt;0.01</td>
<td>&lt;0.002</td>
<td>&lt;0.008</td>
<td>Balances</td>
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</tbody>
</table>

Table 2 Gas tungsten arc optimised welding parameters

<table>
<thead>
<tr>
<th>Working distance L (mm)</th>
<th>Thick of slab h (mm)</th>
<th>Weld current I (A)</th>
<th>Welding voltage U (V)</th>
<th>Welding speed V (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>1.8</td>
<td>110-120</td>
<td>9-10</td>
<td>20</td>
</tr>
</tbody>
</table>

1 Optical microscopy image of welding surface microstructure before heat treatment: a Fusion zone; b Heat affected zone; c base metal

Conclusions

High temperature post-weld heat treatment, such as two-step heat treatment, had a strong effect on improving the mechanical property and made the microstructure well distributed. The lamellar martensitic α can be destroyed by the changes in β phase. Also, the columnar α began to coarsen and finally spheroidised α came into being both in crystalline grain and on the grain boundary.

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References

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The influence about the first heat treatment temperature in FZ: 

- a 970°C; 
- b 975°C; 
- c 980°C; 
- d 985°C; 
- e 990°C; 
- f 995°C; 
- g 1000°C; 
- h 1005°C

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- g 1000°C; 
- h 1005°C