Short Communication

Butt brazing of titanium alloys/stainless steel plates by MIG-TIG double-sided arc welding process with copper filler metal

Zhi Cheng, Jihua Huang *, Zheng Ye, Jian Yang, Shuhai Chen

School of Material Science and Engineering, University of Science and Technology Beijing, Beijing 100083, PR China

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ABSTRACT

Butt brazing of titanium alloys with stainless steel by MIG-TIG double-sided arc welding (DSAW) process with copper filler metal has been performed. The microstructures and mechanical properties of the joint were investigated. The results show that a butt brazing joint with sound double-sided appearance was achieved. With low heat input of brazing mode and rapid cooling rate of arc welding process, the joint is free of brittle Ti-Fe intermetallic compounds (IMCs). The phase compositions in the joint are TiC6/Ti3Cu + TiCu/TiCu + Ti5Si3/Cu + (Ti5Si3 + Cu + β TiCu+3)/Fe5Si3 + (Cu) + FeSi/Fe(5,5)/304ss orderly from Ti6Al4V to 304ss. The average tensile strength of the butt joint reaches 278 MPa. Compared with the fusion welding joint, the tensile strength of the arc-brazing joint is significantly increased because of the elimination of Ti-Fe IMCs.

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1. Introduction

The welding of titanium alloys and stainless steel can combine the advantages of lightweight and excellent corrosion resistance of titanium alloys and the low cost and high strength of the stainless steel. Thus, the titanium alloys and stainless steel dissimilar metal joints have many applications in aerospace and industrial fields. However, because the hard and brittle Ti-Fe IMCs could be formed in the joint, it is difficult to obtain a sound titanium alloys/stainless steel dissimilar joints by common fusion welding methods [1]. Currently, indirect joining was generally realized by adding a filler metal such as Cu, Nb, V or Mg to prevent atomic diffusion between Ti and Fe [2–6]. Among them, copper was used the most frequently owning to its lower price and excellent performance. Unfortunately, whatever kind of filler metal was used, as long as the joint fused entirely, Ti and Fe elements would mix and react in the fusion pool rapidly. As a result, the brittle Ti-Fe IMCs were still formed in the joint, reducing the mechanical properties of the joints [2].

As is well known, the melting point of copper is lower than that of the titanium and steel, resulting in the possibility to braze titanium alloys/stainless steel plates by fusion welding with copper filler metal. For brazing joint, the amount of the Ti and Fe elements entering into the welding pool is decreased

* Corresponding author.
E-mail: jihuang62@sina.com (J. Huang).
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as the base metal keeps solid state, then the formation of Ti-Fe IMCs can be suppressed greatly [7]. Besides, the application of the fusion welding method can also improve the welding efficiency. Xiao Hao [8] successfully suppressed the formation of TiFe and TiFe2 IMCs in TC4/304ss lap joint by GTAW with copper-base filler metal. The lap configuration shows advantages in controlling the melting of base metals by adjusting the arc location and welding heat input. However, the lap configuration cannot suffer a high load. Compared to lap configuration, butt configuration has a wider application for the low material consumption and high load-bearing capacity. However, although the achievement of butt brazing joint of titanium alloys/stainless steel through the fusion welding methods has numerous advantages, the research on this technology has not been reported so far. In fact, it was pretty hard for traditional welding process to obtain the butt joint in pure brazing mode. It is known that the brazing joint is formed under low heat input conditions. During the common single-sided welding process, the joint was locally heated. There was a significant temperature gradient along the thickness direction of the plate, which often led to insufficient heating on the back of joint [9]. To enhance the back joint appearance, it was necessary to improve the heat input of the whole joint. As a result, the plate near the heat source melted, and expected brazing process was challenging to achieve [10,11].

In this work, MIG-TIG double-sided arc welding process was proposed to obtain the pure brazing of titanium alloys/stainless steel plates with copper filler metal. The Ti-Fe IMCs free titanium alloys/stainless steel joining was realized by arc welding process with high welding efficiency. This paper reported on the microstructure and the tensile strength of the brazing joint. The brazing mechanism of the Ti6Al4V and 304ss joint by arc welding process was comprehensively discussed.

2. Experimental

The base materials used were 2 mm thick commercial available TC4 (Ti6Al4V) and 304 stainless steel (1Cr18Ni9Ti). The common CuSi-3(Cu97Si3) wire with a diameter of 1.0 mm was employed as the filler metal. Butt joint configuration was performed with a gap of 0.3 mm in the welding process.

The assembled MIG/TIG double-side arc welding equipment is shown in Fig. 1(a), which is similar to the previous study [9]. According to our preliminary experiments, the temperature distribution between the dissimilar base metals can be adjusted flexibly by offsetting the top and bottom welding heads (MIG and TIG). Therefore, to promote the spreading of liquid copper filler metals on the 304ss side, the TIG torch was placed on the SS side of 1 mm from the center of the weld to enhance the temperature on the 304ss side, as shown in Fig. 1(b). To achieve the brazing, the processing parameters were selected as follows: The TIG welding parameters were welding current of 70A, arc length of 4 mm, and argon flow rate of 15 L/min. And the MIG welding parameters were welding voltage of 13 V, wire extension length of 10 mm and wire feed of 3 m/min with the same argon flow rate as TIG’s. The welding speed was 20 mm/s. Fig. 2

The microstructures and fracture morphologies were observed by scanning electron microscopy (SEM) (FEI Quanta250) equipped with energy dispersive X-ray spectroscopy (EDS). The elemental composition was evaluated by SEM-EDS in spot modes. In order to examine the quality of the joint between TC4 and 304ss, the tensile strength test was performed. The tensile test was carried out according to ISO 4136 Destructive tests on welds in metallic materials – transverse tensile test. Three samples in the same condition were tested and the average value was recorded, the specimen of the tensile test is shown in Fig. 1. And the fractured surfaces were analyzed using X-ray diffraction (SmartLab) with the copper target.

3. Results and discussion

Fig. 3(a) and (b) shows the appearance of the Ti6Al4V-304ss butt joint made by MIG-TIG DSAW process. Both sides of the joint, the copper filler metal fully spread on the parent metals. A good front and back forming was obtained and no defect appeared in the joint. Fig. 3(c) presents the photograph of the cross-section of the joint by SEM. The picture shows that the interface keeps flat as the original state of the sheet edge. It was clear that the base metals were not melted during the welding and the brazing process was achieved. In the DSAW process, the heat was input from top and bottom of the joint by MIG and TIG arc respectively, which made the heat distribution more uniform on both sides of the joint. Besides, the MIG arc only provided part of the heat, resulting in the reduction of the heat on the top part of the joint compared to the traditional single-sided welding. Thus, the sound butt arc-brazing titanium/stainless steel joint was created.

![Fig. 2 – The specimens of the tensile test.](image)

![Fig. 3 – (a) Front appearance; (b) back appearance; (c) cross-section of the DSAW joint.](image)

![Fig. 1 – (a) Experimental setup; (b) schematic diagram.](image)
Table 1 – EDS results of intermetallics phases in the joint (at%).

<table>
<thead>
<tr>
<th></th>
<th>Ti</th>
<th>Cu</th>
<th>Fe</th>
<th>Si</th>
<th>Al</th>
<th>Ni</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>58.86</td>
<td>32.61</td>
<td>0.44</td>
<td>1.23</td>
<td>6.86</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>II</td>
<td>47.01</td>
<td>45.12</td>
<td>0.56</td>
<td>1.64</td>
<td>5.66</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>III</td>
<td>52.75</td>
<td>13.66</td>
<td>0.45</td>
<td>32.15</td>
<td>1.00</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>IV</td>
<td>0.93</td>
<td>90.59</td>
<td>0.43</td>
<td>8.05</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>V</td>
<td>10.48</td>
<td>78.86</td>
<td>0.87</td>
<td>9.79</td>
<td>–</td>
<td>1.32</td>
<td>5.77</td>
</tr>
<tr>
<td>VI</td>
<td>5.55</td>
<td>54.5</td>
<td>22.59</td>
<td>11.26</td>
<td>–</td>
<td>3.21</td>
<td>16.40</td>
</tr>
<tr>
<td>VII</td>
<td>2.04</td>
<td>9.43</td>
<td>55.43</td>
<td>13.49</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Possible phase
- Ti<sub>2</sub>Cu + TiCu
- TiCu
- Ti<sub>5</sub>Si<sub>3</sub>
- Cu
- Ti<sub>5</sub>Si<sub>3</sub> + Cu + βTiCu<sub>4</sub>
- Fe<sub>3</sub>Si<sub>2</sub> + (Cu) + FeSi
- Fe(s,s)

**Fig. 4 – Microstructure of the joint: (a) cross-section; (b) TC4-weld interface; (c) weld; (d) 304ss-weld interface.**

Fig. 4(a) shows that the microstructures of the arc-brazing joint, and Fig. 4(b)–(d) represent the magnified features of the areas marked by letters (B, C and D) in Fig. 4(a). From Fig. 4(b), a thin intermetallic compound layer with an average thickness of 60 µm was formed at the TC4-weld interface. The melted zone, as shown in Fig. 4(c), is mainly composed of the light gray matrix and dark dispersed phase. For the 304ss-weld interface, as shown in Fig. 4(d), two layers are discovered, one is a dark banded-like layer near the 304ss, and another is a discontinuous black layer near the weld.

To identify the phase pointed by arrows in Fig. 4, the EDS analysis was carried out. Referring to the relevant phase diagrams (Ti-Cu [12], Ti-Si [12], Ti-Cu-Si [13], Cu-Fe-Si [14]), the phases are recognized as listed in Table 1. According to the EDS analysis, the joint was free of Fe element except for the 304ss-weld interface, indicating that the diffusion of Fe was suppressed. In contrast, the Ti element was detected not only at the TC4-weld interface but also at the weld zone and 304ss-weld interface, suggesting that the diffusion of Ti element within the Cu bead was still not blocked in brazing joint. However, the Ti content near the 304ss side is only 5.5%, which was much smaller than that of joints by other fusion welding process [1,10]. Besides, due to the suppression of diffusion of Ti and Fe elements in the welding pool, Ti-Fe brittle IMCs were not found in the brazing joint.

The tensile test results show that the average strength of the arc-brazing joint reaches 278 MPa, and the joint fractured at the brazing 304ss-weld interface, as shown in Fig. 5(a). The tensile strength of the arc-brazing titanium/stainless steel joint welded by MIG-TIG DSAW is significantly increased compared with its counterpart welded in fusion welding by CMT process [10]. This is mainly attributed to the improvement of Ti/Cu interface strength in the brazing joint. Benefiting from the low heat input of brazing mode and rapid cooling rate of arc welding process, the interface reaction between the TC4 and weld was effectively suppressed, resulting in the limited thickness of the reaction layer produced at TC4-weld interface. Besides, because of the absence of the Fe element at the TC4 side, the main reaction productions at TC4-weld interface are Ti-Cu based phases, which show lower brittleness compared to Ti-Fe IMCs. Therefore, the tensile strength of the TC4-weld interface is significantly increased, thus improving the overall strength of the joint. However, as the 304ss and weld was joined in brazing mode, a discontinuous IMCs layer with a flat morphology was formed at the 304ss-weld interface, as shown in Fig. 4(d). In this situation, such flat brazing
interface became the weakest zone during the stretching, and the crack tended to initiate and propagate along this zone, as shown in Fig. 5(a). As a result, the joint fractured at the brazing 304ss-weld interface.

The morphology of the fracture surface is shown in Fig. 5(b). Fracture surface shows flat cleavage fracture characteristic, indicating the brittleness of the 304ss-weld interface. According to EDS and XRD analysis, as shown in Fig. 5(b)–(d), the phases of Fe, Cu, and Fe-Si, Cu-Si are identified on the fracture surface, suggesting that the crack initiated and propagated along the IMCs layer during the stretching. It is noted that the XRD analysis of the fracture surface also confirmed the absence of the Ti-Fe IMCs in the arc-brazing joint.

4. Conclusions

1. The butt brazing of Ti6Al4V/304ss plates with sound double-sided weld appearance was achieved by MIG-TIG double-sided arc welding with copper filler metal.
2. Owing to the low heat input of brazing mode and rapid cooling rate of arc welding process, the Ti-Fe IMCs free titanium alloy/stainless steel joint was obtained. The phase compositions in the joint are TC4/Ti2Cu + TiCu/TiCu + Ti5Si3/Cu + (Ti5Si3 + Cu + βTiCu)/Fe3Si3 + (Cu) + FeSi/Fe(s,s) /304ss orderly from TC4 to 304ss.

3. The tensile strength of the butt brazing joint reaches 278MPa. The fracture surface of the joint locates at the 304ss-weld interface, which is composed of Fe, Cu and Fe-Si, Cu-Si phases.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES


