DISSIMILAR JOINING A6061 ALUMINUM ALLOY AND SUS304 STAINLESS STEEL BY THE TUNGSTEN INERT GAS WELDING PROCESS

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ABSTRACT

Welding dissimilar materials has been widely applied in industries. Some of them are considered this as a strategy to develop their future technology products. Aluminum alloy and stainless steel have differences in physical, thermal, mechanical and metallurgic properties. However, selecting a suitable welding process and welding rods can solve this problem. This research aimed to investigate the T-joint welding between A6061 aluminum alloy and SUS304 stainless steel using new welding rods, Aluma-Steel by the Tungsten Inert Gas (TIG) welding process. The mechanical properties, the characteristics of microstructure, and component analysis of the welds have been investigated by the mechanical testing, microhardness testing, scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). As a result, the fracture occurred at the adjacent area between welding seam and A6061 aluminum alloy plate. The average microhardness between welding seam and SUS304 stainless steel is 279.72 HV, welding seam and A6061 aluminum alloy of 274.50 HV. A large amount of copper elements found in the welds due to using the new welding rod, Aluma-Steel rod.

Keywords: TIG welding, T-joint, A6061 alloy, SUS304 stainless steel, Aluma-Steel rod.

1. INTRODUCTION

Dissimilar materials welding helped the potential provided the advantages of two materials often providing for the solutions to engineering requirement order to reduce the weight and corrosion resistance of materials have been a major concern and a big challenge for researchers in recent years in the techniques and technology, dissimilar welding often use in industrial applications having complex functions but retaining stability of textures during the used process. The combinations of dissimilar materials have been widely applied for car-body construction, shipbuilding, aerospace body structures and skin panels in order to reduce the weight and decrease of the fuel consumption levels and greenhouse gas emission. This process have been widely applied mainly on the industries such as car-body construction, shipbuilding, aerospace body structures and railway transportation and skin panels. However, the process combination
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Dissimilar materials become inevitable to hybrid structure formation between two materials by the differences in thermal-physical properties and melting temperatures of two materials and especially the formation of brittle intermetallic layer (IMCs) during welding process at high temperature [1 - 5]. Many authors have been successfully applied welding between aluminum alloys and stainless steel by bonded weld and mechanical fastening by others methods such as Laser welding [6 - 8], Metal inert gas welding [9 - 11], Friction stir welding [12 - 14], Ultrasonic welding [15, 16], … Using one method with the welding filler material to get the best result is always a desire of the manufacturers because it will bring them many advantages such as: reducing production cost and providing a better choice for the new welding process of aluminum to steel. Nowadays, tungsten inert gas (TIG) welding is used as a common approach to weld aluminum alloy to steel; the base and filler metals are melted by arc and welding rods will be supplied by hand throughout the process. The welding heat sources generate high temperature distributed around the welds, the molten welding pools are protected from the outside environment by an inert gas flow which can be Argon, Helium or their mixed gas. During the welding process, the brazing joint happens at the stainless steel surface plate and in aluminum alloy it is diffusion joint. This aim investigates the weld joint properties and characteristics of dissimilar TIG welding between A6061 aluminum alloy and SUS304 stainless steel using the new filler metal is Aluma-steel welding rod, the material could be successful welded and reduced hardness and brittle of intermetallic layer in dissimilar metal welding helped weld joint better strength. This research particular was concentrated on interface microstructure characterization and microstructure welded joint.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Fe</th>
<th>Ni</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>P</th>
<th>S</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUS304</td>
<td>8.19</td>
<td>0.06</td>
<td>0.04</td>
<td>0.96</td>
<td>18.22</td>
<td>0.027</td>
<td>0.002</td>
<td>0.002</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of A6061 aluminum alloys (wt %) [17].

<table>
<thead>
<tr>
<th>Material</th>
<th>Al</th>
<th>Si</th>
<th>Mg</th>
<th>Cu</th>
<th>Cr</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A6061</td>
<td>Bal</td>
<td>0.4-0.8</td>
<td>0.8-1.2</td>
<td>0.15-0.4</td>
<td>0.04-0.35</td>
<td>&lt;0.7</td>
<td>&lt;0.15</td>
</tr>
</tbody>
</table>

Table 2. Chemical composition of SUS304 stainless steel (wt %) [18].

<table>
<thead>
<tr>
<th>Material</th>
<th>Cu</th>
<th>P</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>C</th>
<th>O</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluma-Steel</td>
<td>Bal</td>
<td>5.0</td>
<td>0.4</td>
<td>0.7</td>
<td>0.2</td>
<td>13.2</td>
<td>3.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The materials used were A6061 aluminum alloy and SUS304 stainless steel sheets with a size of 150 mm × 70 mm and a thickness fixed of 6 mm. The Aluma-Steel welding rods with the diameter of 2.4 mm were chosen to be the filler metal. They are new welding rods distributed by a welding rod distributor, Whittier, CA 9065, United States. The chemical compositions used in
research shown in Table 1, 2 and Table 3 was analyzed by Spectrotest and PMI - UV Plus equipment.

2.1. Experimental Procedures

Before welding, the material sheets were cut with the size of 150mm x 70mm. The aluminum alloy edge chamfered double-bevel angle at 40°. The surface of materials cleaned by the sandpapers. The gap between two sheets was 2.5-3 mm. The schematic geometrical of welding between A6061 aluminum alloy and SUS304 stainless steel was shown in Figure 1.

The equipment used in the experiment are: Master Tig pulse AC/DC 3500 W welding machine; universal testing machines; Vickers hardness testing machines; Axiovert 40 MAT optical microscopy equipment; and SEM/ESD system. The experimental process used Argon industrial protective gas with a purity of 99.999 %. According to the producer’s recommendation, Tungsten electrodes were selected at 2.4 mm, the gas nozzle was at the size of 6 mm. The shield gas was 12 L/min, the welding speed of 4 mm/s, the arc length was 4 mm, the welding voltage was 17 V, and the pulse of the pulse welding current intensity of 95 and 160 A. After welding, these external samples were examined and then cut the weld sections, and mounted in the epoxy resin mold to polish the weld as a mirror before testing the microscopic structure, the microscopic hardness with the Vickers hardness test, the characteristics using a scanning electron microscope (SEM), and the X-ray energy dispersive spectrometer (EDS). Finally, some samples were chosen to be tested the bending and tensile strength.

![Figure 1. Schematic of A6061 aluminum alloy/SUS304 stainless steel by the TIG welding process.](image)

3. RESULTS AND DISCUSSION

Figure 2 presented the cross-section of weld joint. From results could see that if the aluminum alloy beveled and the welding gap were equivalent to the welding rod diameter, the welding process would be more advantageous because the wide welding gap of the first side helped the welding rod fused equally to the second side and limited the welding defects when welding the second side so that the quality of the weld joint was better. At the aluminum alloy sheets, the melting temperature was low so it was easy for the Aluma-Steel welding rod and the sheets to combine better to make a unity. At the stainless steel surface, the melting temperature was higher so that combination was less than that of the aluminum alloy sheets.
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Figure 4(a) shows the microhardness of the welding seam and SUS304 stainless steel. The minimum value is 161.75 HV, and the maximum value is 295.97 HV. Figure 4(b) shows the microhardness of A6061 alloy and the welding seam. At the area, the minimum value is 120.56 HV, and the maximum value is 221.18 HV. From the results, we can conclude that the hardness of the adjacent position between the welding seam and SUS304 stainless steel sheet is higher than that of the position between the welding seam and A6061 alloy because there is a combination of the welding rod with the available elements at the stainless steel plate, which increases the hardness and forms the brittle and hard intermetallic layer which makes the load capacity of the area between welds and the stainless steel is less than that of the area between the welds and the steel. The results of the hardness testing of the positions and the average values are shown in Tables 4 and 5.

![Figure 4](image)

**Figure 4.** (a) The microhardness between the welding seam and SUS304 stainless steel, (b) the microstructure between the A6061 alloy and the welding seam.

**Table 4.** Results of hardness test at 9 points between the welding seam and SUS304 stainless steel area.

<table>
<thead>
<tr>
<th>Points</th>
<th>M-1</th>
<th>M-2</th>
<th>M-3</th>
<th>M-4</th>
<th>M-5</th>
<th>M-6</th>
<th>M-7</th>
<th>M-8</th>
<th>M-9</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values (HV)</td>
<td>161.76</td>
<td>176.39</td>
<td>170.6</td>
<td>260.3</td>
<td>295.97</td>
<td>282.9</td>
<td>216.77</td>
<td>172.19</td>
<td>182.96</td>
<td>213.23</td>
</tr>
</tbody>
</table>

**Table 5.** Results of hardness test at 7 points between the welding seam and the A6061 alloy area.

<table>
<thead>
<tr>
<th>Points</th>
<th>H-1</th>
<th>H-2</th>
<th>H-3</th>
<th>H-4</th>
<th>H-5</th>
<th>H-6</th>
<th>H-7</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values (HV)</td>
<td>Bal.</td>
<td>8.19</td>
<td>0.06</td>
<td>0.04</td>
<td>0.96</td>
<td>18.22</td>
<td>0.027</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 5 shows the results of the X-ray energy dispersive (EDX) analysis in the jointing area between the welding seam and A6061 aluminum alloy sheets. The results shows that there are six elements including Al, Cu, P, O, Fe, and Si at the survey area. Figure 5 (a) shows the surveyed position. Figure 5 (b) shows the diffusion of a small amount of P atoms shifted from welding rod into the welding seam. Figure 5 (c) shows that there is a large amount of Al atoms at the survey area. It is easy to understand this because the molten welding process happens in this area so most of the Al atoms tend to shift from the A6061 alloy sheet into the welding seam and it diffuses into the welding seam. Figure 5 (d) shows the diffusion of a large amounts of...
copper atoms in the survey area because the welding process used the Aluma-Steel welding rod whose main element is copper counting for 77.1% so this element and other elements in the welding rods diffused a respective amount of these to the weld with the available elements in the aluminum alloy plate. Because Si and Fe have been a small amount in two basic materials and in Aluma-Steel welding rods so we can see their diffusion in the survey area is very low. We have seen them be scattered and evenly distributed throughout the survey area in Figure 5 (e), and (f).

From the results of the EDX analysis in the area between the welding seam and A6061 alloy sheets, we see that Al and Cu are the two main elements involved in the formation of the welds and occupy the majority percentage of the weld volume. The volume percentage of these elements at the surveyed position between A6061 alloy and welding seam is shown in Figure 5(g) and Table 6.

Table 6. The results of the EDX analysis at the welding seam and A6061 alloy sheet (wt %).

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>Cu</th>
<th>P</th>
<th>O</th>
<th>Fe</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values</td>
<td>65.31</td>
<td>30.74</td>
<td>1.89</td>
<td>1.34</td>
<td>0.66</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Figure 6 shows the results of the X-ray energy dispersive (EDX) analysis at the 002 position, a joint between the welding seam and SUS304 stainless steel plate. The results showed that there were six elements such as: O, P, Cr, Fe, Ni, and Cu at the area. Figure 6 (a) shows the surveyed position. A small amount of the O element was found in the process of forming the welds shown in Figure 6(b). It is smallest compared with the remaining elements were found in the welds. Figure 6 (c) shows the diffusion of P atoms shifting from the welding rod and the stainless steel into the welding seam with the volume of 7.17%. Figure 6(d), (e), (f), and (g) shows the diffusion of the elements Cr, Fe, Ni and Cu in the welding seam. The same as the diffusion of elements in the surveyed position of the border between the welding seam and A6061 alloy plate, the copper element occupied the most in forming the welds, the highest percentage among the 6 elements found in the surveyed area. The volume percentage of these elements at the surveyed position between A6061 alloy and the welding seam is shown in Figure 6(g) and Table 7.

Table 7. The results of the EDX analysis at the welding seam and SUS304 stainless steel sheet (wt %).

<table>
<thead>
<tr>
<th>Elements</th>
<th>O</th>
<th>P</th>
<th>Cr</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values</td>
<td>1.04</td>
<td>7.17</td>
<td>9.01</td>
<td>32.31</td>
<td>3.59</td>
<td>46.89</td>
</tr>
</tbody>
</table>
Figure 5. The results of the EDX analysis at the joint area between the welding seam and the A6061 alloy
(a) the EDX analysis position       (b) the distribution of P atoms,
(c) the distribution of Al atoms      (d) the distribution of Cu atoms,
(e) the distribution of Si atoms      (e) the distribution of O atoms, and
(g) the distribution of Si atoms, and  (h) the total spectrum.
Figure 6. The results of the EDX analysis of the joint area between the welding seam and SUS304 stainless steel

(a) the EDX analysis position,   (b) the distribution of O atoms
(c) the distribution of P atoms,   (d) the distribution of Cr atoms
(e) the distribution of Fe atoms,   (f) the distribution of Ni atoms
(g) the distribution of Cu atoms, and  (h) the total spectrum.
4. CONCLUSIONS

The T-joint between A6061 alloys and SUS304 stainless steel was made by the TIG welding process with Aluma-Steel welding rods. The microstructure, microhardness and the microstructural characteristics were investigated. The major conclusions of this research should be summarized as follows:

Firstly, To make the welding process successfully, we should choose the appropriate welding materials and good welding gaps, clean the surface of the materials well after each welding layer, select pulse welding amperage range from 90-160A, welding voltage at 16-18V, the arc length at 3-4mm and use an appropriate gas shield to protect the welding pool well during the welding process.

Secondly, not only must the welders be very skillful but also the Aluma-Steel welding rod must be used to make this research successfully. After each welding layer, the joint should be cool down from 35 - 65° before welding the next layer to reduce the cracking.

The average microhardness between the welding seam and A6061 alloy was 177.81 HV; between welding seam and SUS304 stainless steel was 213.23 HV. In addition, the presence of copper atoms in two surveyed areas between the welding seam and the aluminum alloy sheet, between the welding seams with stainless steel sheet showed that the diffusion of this atom contributes greatly to the success of the welding process of the materials A6061 alloy to SUS304 stainless steel.

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REFERENCES

TÓM TÁT
HÀN KHÁC NHAU GIỮA HỘP KIM A6061 VÀ THÉP KHÔNG GIÍ SUS304 BẰNG QUÁ TRÌNH HÀN TIG

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Hàn các vật liệu khác nhau đã được ứng dụng rộng rãi trong các ngành công nghiệp. Một số ngành đã có độ như một chuyên lực để phát triển các sản phẩm công nghệ trong tương lai của họ. Hợp kim nhôm và thép không gỉ có sự khác biệt lớn về tính chất lì, nhiệt, cơ khí và luyện kim. Tuy nhiên có thể giải quyết vấn đề này bằng cách lựa chọn một phương pháp hàn thích hợp. Nghiên cứu này nhằm mục đích điều tra hàn liên kết chủ T giữa hợp kim nhôm 6061 với thép không gỉ 304 sử dụng que hàn mới Aluma-Steel bằng quá trình hàn TIG. Các tính chất cơ học, đặc điểm vi cấu trúc và phân tích thành phần của các mối hàn đã được nghiên cứu bởi các phương pháp: thử nghiệm cơ khí, kiểm tra độ cứng, kính hiển vi điện tử quét (SEM) và phân tích sắc năng lượng tia X (EDS). Kết quả cho thấy các vật liệu được gia cố trên hàn gang nhôm và thép không gỉ của chủ T giữa các mối hàn do sử dụng que hàn mới Aluma-Steel.

Tiết khẩu: phương pháp hàn TIG, liên kết chủ T, hợp kim nhôm A6061, thép không gỉ SUS304, que hàn Aluma-Steel.