Mechanical and microstructural properties of robotic Cold Metal Transfer (CMT) welded 5083-H111 and 6082-T651 aluminum alloys

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ARTICLE INFO

Article history:
Received 19 June 2013
Accepted 5 August 2013
Available online 14 August 2013

ABSTRACT

5083-H111 and 6082-T651 aluminum alloys used particularly in shipbuilding industry especially for the sake of their high corrosion resistance and moderate strength, were welded using Pulsed Robotic Cold Metal Transfer (CMT)-Metal Inert Gas (MIG) technology. Joints were fabricated as both similar and dissimilar alloy welds using plates with a thickness of 6 mm. Non-destructive tests such as visual and radiological examination were conducted before further destructive tests. Tensile, bend and fatigue tests were applied to specimens extracted from welded joints. Fracture surfaces of fatigue samples were examined by light optical microscopy (LOM) and scanning electron microscopy (SEM). Also macro and microstructures of weld zones were investigated and micro hardness profiles were obtained. In accordance with results, CMT-MIG provides good joint efficiency with high welding speed, and good tensile and fatigue performance.

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1. Introduction

5083 aluminum–magnesium alloys are strain hardenable alloys and have excellent corrosion resistance, toughness, weldability and moderate strength. 6082 aluminum–magnesium–silicon alloys are heat treatable types and have high corrosion resistance, excellent extrudability and moderate strength. Especially with their high corrosion resistance and moderate strength these aluminum alloys are widely used in shipbuilding industry. Single- or multiple-hull high speed ferries employ several aluminum alloys, 5083, 5383 and 5454 as sheet and plate (along with 6082 extruded shapes) with all-welded construction [1–3].

Aluminum welding was once considered limited due to the problems associated with welding processes such as oxide removal and reduced strength in the weld and heat affected zone (HAZ). New aluminum welding techniques have been developed and commercialized significantly over the past 30 years that solves these problems [1,3]. Although MIG and Tungsten Inert Gas (TIG) welding were invented in 1940s and used in many industries, there were still some joint problems that reduced joint efficiency under 50% [1,4–6]. To improve weld performance, friction stir welding (FSW) that is solid state welding and a milestone in aluminum welding was invented in 1991 by TWI, laser beam–Gas Metal Arc (GMA)-hybrid welding that is first hybrid method ever applied in industrial scale manufacture was invented in 2000 in Germany, and finally conventional Metal Inert Gas welding process equipped with Cold Metal Transfer (CMT) technology was invented in 2004 and is likely to be a milestone in aluminum welding [7–9]. CMT is completely new technology with respect to both welding application and welding equipment. CMT is not only completely new technology, but it also enhances MIG application areas, allowing the arc joining of steel to aluminum in a reproducible manner for the first time. CMT can be described as a Gas Metal Arc Welding (GMAW) process where heat input is low compared to the conventional dip arc process. The CMT-process is a dip arc process with a completely new method of the droplet detachment from the wire. In the conventional dip arc process the wire is moved forward until a short circuit occurs. At that moment the welding current increases, causing the short circuit to re-open, allowing the arc to ignite again. There are two main features of the Metal Inert Gas/Metal Active Gas (MIG/MAG) process: on the one hand the high short circuit current corresponds to a high heat input. On the other hand the short circuit opens in a rather uncontrolled manner, resulting in lots of spatters in the conventional dip arc process. In the CMT process the wire is not only pushed but also drawn back from the work piece – an oscillating wire feeding with an average oscillation frequency up to 70 Hz is used [9]. In CMT, the term “cold” has to be understood in terms of a welding process, but when set against the conventional MIG/MAG process, CMT is still a cold process that constantly alternates between hot and cold phases. During the arcing period, the filler metal is moved towards...
the weld pool (Fig. 1a, hot phase). When the filler metal dips into the weld-pool, the arc is extinguished and the welding current is lowered (Fig. 1b, cold phase). The backward movement of the wire assists droplet detachment during the short circuit and the short circuit current is kept small (Fig. 1c, cold phase). Finally, the wire motion is reversed and the process begins all over again (Fig. 1d, hot phase) [10].

Since CMT is relatively a recent technology, there are few studies about CMT welding of aluminum alloys. All studies are interested in welding success of thin plates of aluminum and magnesium alloys. In some studies, 1–3 mm thin plates of Al–Mg dissimilar joints were successfully made by CMT-MIG [11–13]. Feng et al. [14] successfully welded pure aluminum with no-spat-ter and low heat input that promotes the gap bridging ability.

<table>
<thead>
<tr>
<th>Aluminum alloy</th>
<th>Chemical composition (in wt.%)</th>
<th>Mechanical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Si</td>
<td>Fe</td>
</tr>
<tr>
<td>5083</td>
<td>0.076</td>
<td>0.13</td>
</tr>
<tr>
<td>6082</td>
<td>1.02</td>
<td>0.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aluminum alloy</th>
<th>$R_{p0.2}$ (MPa)</th>
<th>$R_m$ (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5083</td>
<td>239</td>
<td>331</td>
<td>16.4</td>
</tr>
<tr>
<td>6082</td>
<td>321</td>
<td>329</td>
<td>11.1</td>
</tr>
</tbody>
</table>
Packin and Young [15] has successfully welded 3 mm thick AA 6111 aluminum alloys and founded CMT welding process highly competitive for automated welding of aluminum parts. Hence, this study aims investigating microstructure and mechanical behavior of 6 mm thick 5083-H111 and 6082-T651 aluminum alloys as similar (joints called as M55, M66 referring to welded joints of 5083 to 5083 and 6082 to 6082 respectively) and dissimilar (M56 referring to welding of 5083 to 6082 alloys) joints.

2. Materials and experimental procedure

In this study, 5083-H111 and 6082-T651 aluminum alloys were used as base metals. Chemical composition data obtained by glow discharge optical emission spectroscopy (GDOES) and mechanical properties obtained by tensile test are given in Table 1.

Aluminum alloy plates were cut into coupons with 150 × 330 × 6 mm³ dimensions with 30° level of each plate to provide 60° groove angle for V-groove butt joint geometry. ER5183 with 1.2 mm diameter was used as filler metal. Welding parameters for Robotic CMT-MIG were implied as 194 ± 5 A welding current, 19.5 ± 1 V welding voltage, 0.4 m min⁻¹ welding speed and 11 ± 0.2 m min⁻¹ wire feed rate.

Visual and radiographical examination was performed in order to detect possible surface and inner errors after welding. Test samples were obtained in accordance with TS EN ISO 17637 for visual examination before further destructive tests. According to test plan, test samples suitable for TS EN ISO 15614-2 were extracted from weld plates which had past visual and radiological examination. Tensile test specimens were prepared according to TS EN ISO 4136:2012, bending test specimens were prepared according to TS EN ISO 5173, fatigue test specimens were prepared according to

![Fig. 3. Macrograph and SEM photos of fracture surfaces of (a) M55, (b) M56 and (c) M66 fatigue specimens.](image)

![Fig. 4. Microhardness profiles of CMT Pulse welded joints (a) M55, (b) M56 and (c) M66.](image)

![Fig. 5. Comparison of average tensile properties of the base metal with welded joints.](image)

![Fig. 6. Fatigue test results of base metals and welded joints.](image)
3. Results and discussion

The microstructural behavior of aluminum alloys joined by CMT Pulse welding was studied by LOM. Images of weld zone cross section are outlined in Fig. 2. In robotic CMT welded joint M55, the base metal will have a fine-grained structure composed of a matrix of a solid solution of magnesium in aluminum. Although it was expected that Mg2Al3 would be formed which could begin to coalesce and coarsen in the HAZ where the temperature raised to around 250 °C further, there were no coalescence or coarsening in the far HAZ. Nevertheless, fine grain microstructures were produced by processes which involved static recrystallization in HAZ close to fusion line [1,3]. In robotic CMT welded joint M66, partial melting of the grain boundaries has resulted in coalescence and coarsening with weld metal in the fusion line because of solution treatment resulted in aging after welding [3]. In robotic CMT welded joint M56, grain structure showed same results as M55 and M66 depending on their base metal side.

For further microstructure analysis, fractured surface of fatigue test specimens were examined by SEM (Fig. 3a–c). Porosities in fractured surfaces were little [19,20]. Evaluated with tensile test results, these porosities had no significant negative effect on joint strength. Porosity levels were 2% and “B” quality for M55, 3% and “C” quality for M56 and M66 according to ISO 10042:2005(E) standard.

Microhardness measurements were completed under 200 g load (Fig. 4). Although results were similar to characteristic hardness traverse across weldments [1], hardness drops were slightly close to the base metal. While hardness drops were around 22–35% in previous studies [21,26,28], hardness drops were maximum 18% level in this study. 5083 similar alloy weld joint (M55) microhardness values were measured between 77 and 92 HV0,2 and hardness drops with minimum hardness value were just in the weld zone as expected. 6082 similar alloy weld joint (M66) microhardness data were measured between 79 and 96 HV0,2, hardness increase in weld zone were measured around 96 HV0,2, while hardness decrease at the HAZ were measured 79 HV0,2. 6082 base metal hardness were measured around 82 HV0,2. 5083 and 6082 dissimilar alloy weld joint (M56) microhardness data were measured between 76 and 96 HV0,2. 5083 and 6082 similar weld joint (M55) showed best fatigue performance, then respectively 6082 similar weld joint (M66), and 5083&6082 dissimilar weld joint (M56). These results were parallel with porosity and yield stress values of the welded joints.

Acknowledgements

Authors would like to thank to the technical support of the following industrial companies: Fronius TR, Assan Aluminum, End Denetin.

References