WELDING OF Cu - AlMg1 COMBINED METALS WITH Nd:YAG LASER

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Abstract

Contribution deals with welding Cu tube with AlMg1 plate for solar collectors. Owing to a high reflectance of laser beam from the mentioned metals, the Nd:YAG laser with $\lambda = 1.064 \, \mu m$ wavelength was suggested. Welding parameters were proposed and spot welds were fabricated. Argon was used as a shielding gas. Welding was performed without filler metal. The quality of fabricated joints was assessed by optical microscopy, microhardness measurement, SEM and EDX microanalysis.

Keywords: welding, laser, quality inspection of welds, SEM, EDX microanalysis

1. INTRODUCTION

Laser welding have become a significant technological process applicable for metallurgical joining of metallic materials [1,2]. This is confirmed by research, which takes place at several scientific institutions. For example, samples of 5083-T0 and 6082-T6 aluminium alloys have been welded under conduction regime using a high power diode laser at Universidad de Cadiz. Maximum penetration values of 3 and 2.3 mm were obtained for 5083 and 6082 alloys, respectively. Microhardness of the fusion zone was slightly higher than that of the base metal [3]. Other researchers dealt with characteristics of CO₂ laser butt welding of non heat-treatable AA5052-H12, AA5083-H12 and heat-treatable AA6061-T6 aluminium alloys. For alloys AA5052 and AA5083, softening of fusion zone due to loss of its work-hardened condition was much lower in comparison to AA6061 alloy [4]. Next work concerned the reduction of porosity content generated during Nd:YAG laser welding of A356 and AA5083 aluminium alloys [5]. The change in weld metal composition during conduction mode laser welding of aluminum alloy 5182 was studied at Pennsylvania State University [6]. Research was also focused on welding Cu sheets by diode laser [7]. Weldability of Al and Cu alloys has been studied. In such a case welding of combined metal is concerned. Combining different types of metals can allow better utilisation of properties of these materials for new applications. One of them could be the production of solar collectors. Based on the analysis of literary knowledge and experience attained, laser beam welding was proposed. The aim of present paper is to validate the welding parameters and conditions of welding AlMg1 - Cu combined materials with concentrated source of energy.

2. CHARACTERISTIC OF LASER AND WELDED METALS

Nd:YAG laser Lumonics JK 701 with the wavelength of $\lambda = 1.064 \, \mu m$ and a maximum power of 550 W was used for welding, due to high reflection of radiation from the surface of welded metals used. Welds were produced in the "Research Center of Manufacturing Technology" in Prague. The welded materials are used for production of solar collectors in the THERMOSOLAR Company, Žiar n/H. The collectors type TS 300 (Fig. 1) are the most widespread collectors from THERMOSOLAR Company. They are suitable for small and large solar systems. These collectors are connected parallely and can be mounted to blocks consisting from up to 10 collectors [8].
Fig. 1. The solar collector type TS 300 produced by THERMOSOLAR Company, Žiar n/H [8]

Copper tube with outer diameter of Ø 10 x 0.6 mm and AlMg1 alloy sheet with the thickness of 0.4 mm (Fig. 2) were used as the base materials. Laser spot welds were manufactured in the experiments.

![Fig. 2. a) Set up of welded materials, b) laser spot welds](image)

Chemical composition of AlMg1 alloy is given in Tab. 1. The welds were produced without the use of filler material. Argon was used as shielding gas. Spot welds were manufactured by focussing laser beam into gap between the Cu tube and AlMg1 sheet. Diameter of focused laser beam was about 500 µm and depth of focus was 3 mm. Laser beam with diameter of 300 µm was utilized for fabrication of penetration weld. Depth of focus was 1 mm in this case.

**Tab 1. Chemical composition of AlMg1 alloy [wt. %]**

<table>
<thead>
<tr>
<th>Mg</th>
<th>Si</th>
<th>Zn</th>
<th>Cr</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 to 1.10 %</td>
<td>&lt; 0.3 %</td>
<td>&lt; 0.25 %</td>
<td>&lt; 0.10 %</td>
<td>&lt; 0.07 %</td>
<td>&lt; 0.02 %</td>
<td>&lt; 0.02 %</td>
<td>balance</td>
</tr>
</tbody>
</table>

Optical microscopy (observation of macro and microstructures of welds), microhardness measurements across the welded joints, EDX analysis and study of fractured surfaces by SEM were used for quality assessment of welded joints.

### 3. ATTAINED RESULTS

Reduction of the base material in the peripheral zones of Cu tube and AlMg1 sheet was observed during macroscopic analysis. This material was used to fill-up the gap between the Cu tube and Al sheet. There was observed some capillary leaking of weld metal into the narrow gap between the Cu tube and Al alloy sheet during welding. The shielding gas (Ar) has contributed positively to this phenomenon. Complete gap
filling was observed in the spot welds (Fig. 3). Probably evaporation of some alloying elements occurred due to exposure to high power density.

**Fig. 3.** Macrostructure of laser spot weld

Significant intermixing of aluminium with copper in the weld metal was observed in the case of spot welded joints. Based on the binary diagram (Fig. 4), the presence of different types of alloys Al with Cu can be expected.

**Fig. 4.** Binary diagram Al-Cu [9]

Brighter zones present in the microstructure are the alloys with greater Al content. Darker zones are the alloys with higher Cu content. In a laser spot welded joint some minor cracks were observed. The reason of presence of these cracks can be supposed by creation of brittle intermetallic compounds (IMC) during rapid cooling down of weld metal. Intermixed weld metal extends into the Al sheet and Cu tube (Fig. 5).
The heat affecting of base metals is minimum during laser welding. HV 0.01 microhardness measurement across the spot weld was performed in the AlMg1 sheet base metal, weld metal and base material of Cu tube. The highest hardness values were measured in weld metals. Hardness in different zones varied considerably, which is associated with the presence of different Al-Cu based phases in the weld metal. Dark areas exhibited the highest microhardness values. The course of microhardness across laser spot welds is documented in Fig. 6.

The spot weld was ruptured in AlMg1 - weld metal interface. The fractured surface of spot weld (Fig. 7) was of a mixed nature comprising ductile and cleavage fracture. In the fractured surfaces the voids can be observed, probably resulting from the presence of H₂ or Al₂O₃ oxide.
Fig. 7. Fractured surfaces  a) cleavage fracture, b) brittle fracture

Line profiles of Al and Cu have shown that there was an intermixing of Al and Cu in the weld metal and a partial diffusion of elements across the interface of the weld joint occurred (Fig. 8).

Fig. 8. Line profiles of Cu and Al elements across the boundary of spot welds

CONCLUSIONS

The present work deals exclusively with fillet welds fabricated by use of laser beam without filler metal application. The positioning of laser beam to welding zone was of extreme importance especially in the case of fillet joints fabricated in pulsed regime. Owing to intricate positioning of laser beam it would be simpler to fabricate the penetration welds from the Al sheet side. However, the manufacturer of solar collectors preferred the welded joints without raster-like damage occurring on the side of anodised Al sheet. The manufacturer did not accept the penetration welding (with laser, electron beam) or ultrasonic welding process owing to raster-like surface damage, occurring on the anodised surface of Al alloy. Peculiar physico-metallurgical events were observed, regarding both, the welded materials and also surface oxides, including the anodised layer. From the viewpoint of welded joint metallurgy the Al₂O₃ oxide seems to be interesting, since it has exerted different behaviour at a direct interaction with laser beam and on the opposite side of Al sheet. EDX analysis has revealed that the boundary of welded joint has the character of weakly developed diffusion processes. The results of this work will serve for a further orientation in the field of research and development of a new generation of solar collectors. It should be taken into account mainly the fact, that in case of any fusion welding process applied for joining this combination of metals, brittle IMC will be formed which unfavourably affect the quality of fabricated joints. The greater these phases will be, the worse joint quality may be supposed.
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REFERENCES