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TECHNOLOGIES FOR ELECTRON BEAM WELDING OF COPPER AND ALUMINUM ALLOY

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ABSTRACT

In this work the results from electron-beam welding of copper and Al6082T6 aluminum alloy are presented. The different technologies for sample preparation and process conditions were applied to achieve strong connection between these two dissimilar materials. The influence of the filler presence on the structure and mechanical properties of the welded joint is studied in comparison with these without filler. The X-ray diffraction (XRD) method was used to obtain the phase composition of the welded joints. Scanning electron microscopy (SEM) was used for the study of the microstructure of the welds. The mechanical properties were studied and proved by means of micro-hardness measurements and tensile tests.

1. INTRODUCTION

During the last decades, electron-beam technologies (EBT) have been widely used for welding, hardening, alloying and surface modification of metals and alloys [1]. Currently, the EBT receive much attention and are already successfully introduced in many industrial branches, such as aircraft and automotive industries, for the manufacturing of space ships, railway cars [2], etc. The welding of dissimilar materials is the main goal, especially for these materials which are hardly connected by the conventional methods [3, 4]. Due to the different materials that fuse together, in many cases intermetallic compounds are formed in the weld zone, which are often brittle and make the joint unsustainable [5, 6]. These brittle intermetallic compounds can initiate cracks, due to the significant difference in melting temperature, thermal conductivity and thermal expansion of the base metals, migration of the elements and the microstructural gradient [7].

Factors affecting the formation of intermetallic compounds when welding dissimilar materials are: dilution between the base metals, physical properties, welding parameters, presence of filler metal and heat treatment [5]. In order to reduce the influence of different thermo-physical parameters and the poor metallurgical compatibility, as a result of which intermetallic compounds are formed, it is necessary to take some actions: control the temperature and duration of the molten pool, control the ratio between the molten quantities of both metals, controlling the homogenization of the melt. Everything said can be done by choosing appropriate technological conditions. Technological conditions include the electron beam power, the welding speed, the scan geometry of the beam, etc., as well as the application of suitable fillers in the welding gap.

The copper and aluminum alloy are representative couple, and any successful techniques for joining them together is desirable due to their importance for a variety of practical applications. The weldments in these metals are highly valued for their corrosion resistance, heat and electricity conducting properties. The aim of the present work is to summarize the useful recipes concerning the applied technological conditions during the electron beam welding (EBW).

2. EXPOSITION

Methods and materials

The subjects of the investigation were the following electron beam welded samples: pure copper (Cu) and Al6082-T6 aluminum alloy with chemical composition of (wt %): 98.16% Al, 1.15% Mg, 0.32% Si and 0.36% Mn. The samples are prepared in form of plates with size of 100mm by 50mm by 8 mm. Subsequently, the welding position was grinded, polished and clean with acetone. Finally, the specimens were clamped before processing.

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Electron beam welding was carried out on the Evobeam Cube 400 welding machine manufactured by Evobeam GmbH. All experiments are conducted with preheated to a temperature of 200°C and offset of the beam toward the aluminum alloy [8], processed along the long contact side of the samples, shown in Fig. 1 [9].

Top view of the welded seam between Cu and Al6082-T6 is shown on Fig. 2.

Defect-free weldments were obtained within a restricted process window, as shown by the blue zone in Fig. 3. The figure indicates that beam offset values greater than 0.5 mm result in incomplete melting of copper, whereas the offset values smaller than 0.3 mm may lead to formation of intermetallic phases and/or macrocracks.

The region where the beam offset is too small is limited by the uncontrolled formation of intermetallic phases [8], as from a distance of smaller than 0.3 mm, longitudinal and transversal hardness cracks, due to the formation of intermetallic phases, occur in the weld seam. The offset on the copper side, as in [19], resulted in all cases in the failure of the weld seam during cooling.

Experiments

The technological parameters of provided EBW experiments are shown in Table 1.

1. Electron beam welding of Cu and Al6082-T6 alloy – Exp. 1 and 2.

The X-ray diffraction patterns of the welded pure copper, and Al6082-T6 are shown in Fig. 4. The main phase observed in the fusion zone is $CuAl_2$ with a body-centered tetragonal structure. In addition, aluminum and copper peaks having a face-centered cubic structure are also observed.

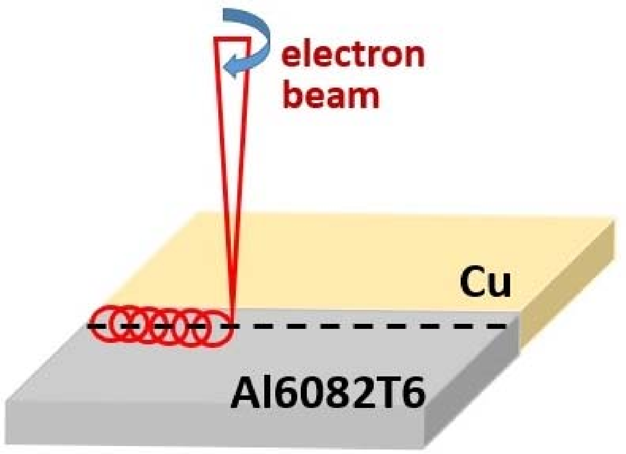

Fig. 1. Scheme of the EBW process [9]

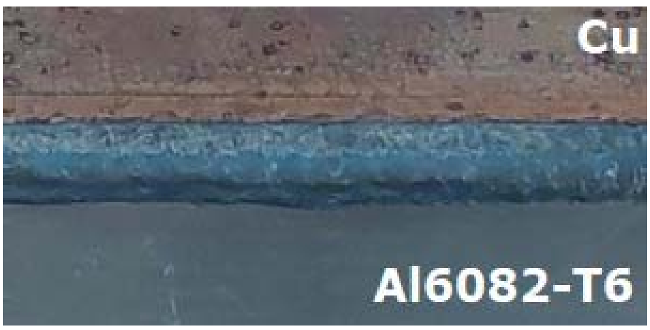

Fig. 2. Welded seam of Cu and Al6082-T6 aluminum alloy

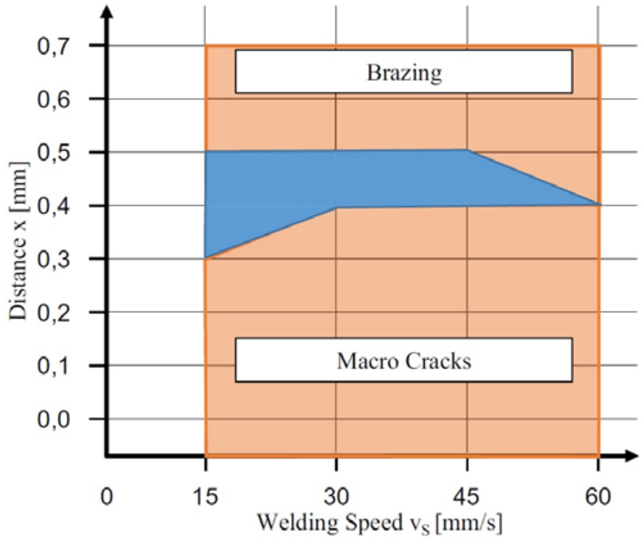

Fig. 3. Process distance and welding speed range [8]

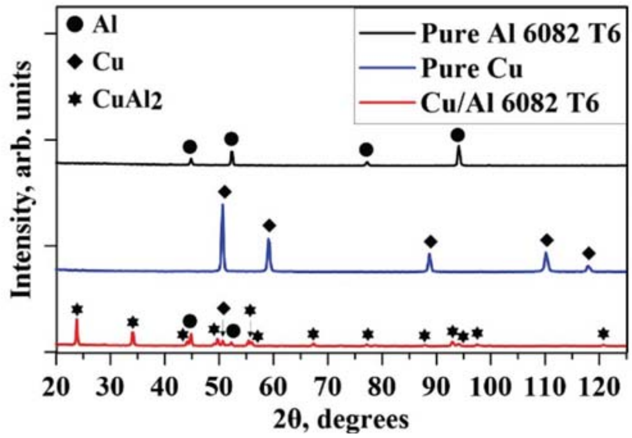

Fig. 4. X-ray patterns of the welded specimen, pure copper and pure Al6082-T6 [10]

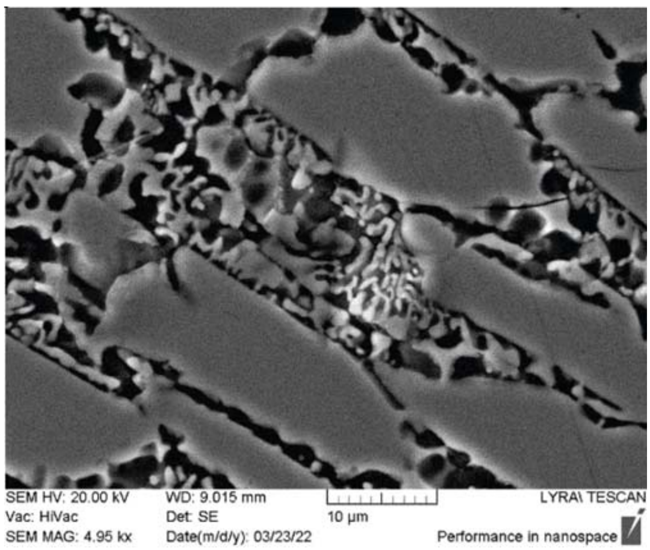

Fig. 5. SEM image of the fusion zone of the welded pure copper and Al6082-T6 [10]

The fusion zone of the specimen contains three phases – an aluminum matrix, an ordered solid solution of copper and aluminum in the form of $CuAl_2$, and pure copper in the region towards the copper plate, as can also be seen from the SEM image shown in Fig. 5 [10].

Table 1 *EBW technological parameters of Cu and Al6082-T6*

EBW Couple	Cu - Al6082-T6		
Experiment	1	2	3
Seam filler	-	-	Ti
Accelerating voltage Ua, kV	60	60	60
Beam current I, mA	45	45	45
Beam frequency f, kHz	20	20	20
Welding speed v, mm/s	15	15	15
Offset, mm	0.4	0.4	0.5
Offset direction	towards Al6082-T6	towards Al6082-T6	towards Al6082-T6
Circle beam oscillation r_{osc},mm	0.1	0.2	0.2
Preheating °C	200	200	200
max Microhardness, HV	820	210	235
Strength/tensile test	-	+	++

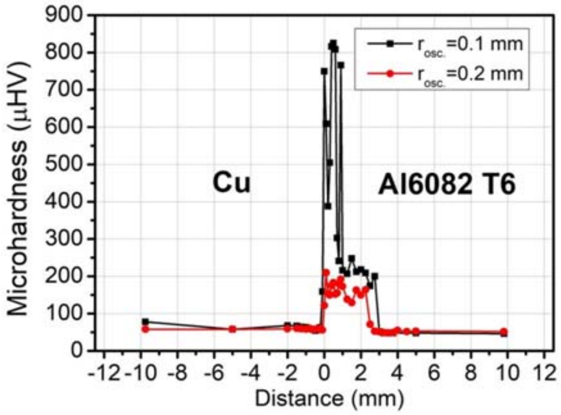

Fig. 6. Distribution of the microhardness's along the weld cross-section [9, 10]

In Fig. 6 is shown the microhardness distribution in the cross-section in the middle of its depth. At both edges of the fusion zone the hardness significantly increased compared to the initial materials.

2. Electron beam welding of Cu and Al6082T6 alloy and introducing of filler in the welding gap - Exp. 3.

Filler metal addition generally plays a vital role in welding of dissimilar joints. The selection of an appropriate filler metal depends the physical properties of the base metals and the welding process used.

Moreover, the joint design requirements should be compatible with the selected filler metal. Criteria have been presented for selection of filler metals for dissimilar joints to ensure better weld metal properties and successful joint without any discontinuities [11].

Additives in the weld zone such as Ti [12], Zn [13] and Ce [13, 14] can have beneficial effects on the weld properties [15]. In the recent experiment the Ti filler was deposited using a DC magnetron sputtering on the welding plates.

The influence of the Ti filler on the structure and mechanical properties of the welded joint is studied in comparison without filler [12]. The Ti filler significantly decreased the amount of molten copper introduced in the molten pool and the number of intermetallic compounds. This improved the strength of the joint; however, some quantity of intermetallic compounds was still present in the zone of fusion, which reflected the microhardness of the samples. The application of a titanium filler resulted in refining the electron beam weld's structure. The finer structure and the reduced amount of the brittle intermetallic phases has led to an increase in the strength of the joint.

The X-ray diffraction patterns of the welded specimens is shown in Fig. 7. The main phase observed in the fusion zone is also $CuAl_2$ and can be seen from the SEM image shown in Fig. 8 [12]. In Fig. 9 is shown the microhardness distribution in the cross-section in the middle of its depth.

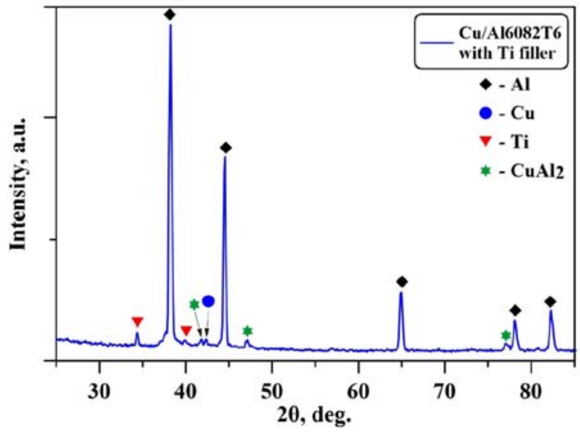

Fig. 7. X-ray patterns of the welded specimen, with Ti filler [12]

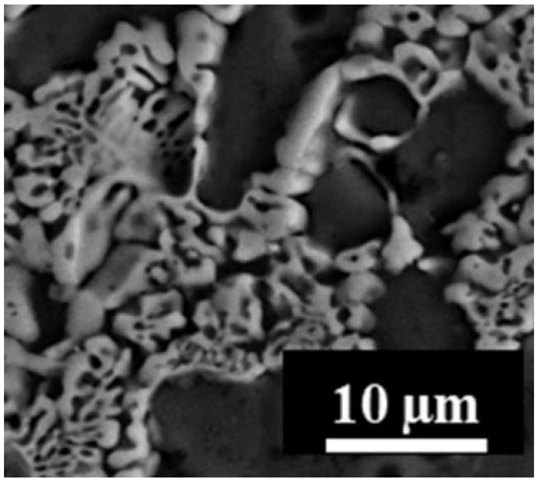

Fig. 8. SEM image of the fusion zone of the welded specimen, with Ti filler [12]

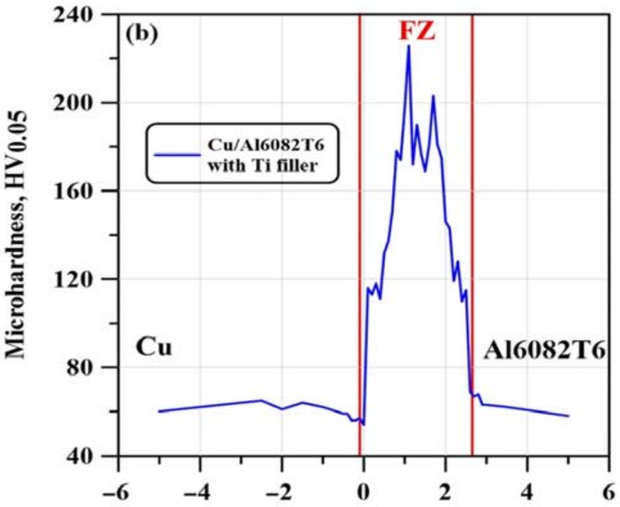

Fig. 9. Distribution of the microhardness's along the weld cross-section [12]

3. CONCLUSION

In this paper the possibilities for the fabrication of welded joints between Cu and Al6082-T6 alloy using electron beam technologies was demonstrated. Precisely selected technological conditions during the welding process led to obtaining strong and unbreakable welds. On the other hand, it contributes to the improvement of the mechanical characteristics (hardness and tensile strength) of the joints. These properties are very important for the implementation of dissimilar joints in various branches of modern industry.

The results exhibit the diffraction maxima of pure Al, pure Cu, and the intermetallic $CuAl_2$ phases. The $CuAl_2$ intermetallic compound, also known as the Θ phase, is characterized by a body-centered tetragonal structure. Aluminum and copper both have their typical face-centered cubic structure. From the acquired results, it can be seen that the circle radius does not affect the phase composition of the formed weld with respect to the number of detected diffraction maxima. In the experiments without filler in the welding gap the second one, which use oscillation radius 0.2 mm demonstrate better strength behavior then the 0.1 mm. It is due to four times lower level of measured microhardness. The result obtained is in relation to lower percentage of the $CuAl_2$ component in the weld seam [17].

The comparable results are obtained with applying a Ti filler. The filler was in the form of a thin layer deposited on the weld surface of each of the two plates. Since the solubility of copper in aluminum is low it is important for most of the energy to be distributed predominantly in the aluminum plate and the filler to limit the inclusion of Cu in the weld seam and thus limit the formation of intermetallic compounds. Applying a titanium filler on the contact surfaces between the plates had multiple positive effect on the welding process [18, 19].

The contribution of microhardness across the seam reveals smooth transition between the zones of the molten material and the plates. That led to best performance in the tensile test than previous without filler [20].

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