Journal of the Technical University of Gabrovo

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STRUCTURE AND MECHANICAL PROPERTIES OF Cu/Al6082T6 JOINTS PRODUCED BY WELDING WITH SCANNING ELECTRON BEAM

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ARTICLE INFO

Article history:
Received 11 May 2023
Accepted 12 June 2023

Keywords:
electron-beam welding, X-ray diffraction analysis, scanning electron microscopy, energy-dispersive X-ray spectroscopy, microstructure, microhardness

ABSTRACT

This study presents the results of the electron-beam welding of pure copper (Cu) and aluminum (Al6082T6) alloy. The effect of the beam power on the phase composition, structure, and microhardness of the welded joints was studied. The power of the electron beam was set to 2400 W, 2700 W, and 3000 W, respectively.The phase composition of the fabricated joints was investigated by X-ray diffraction (XRD). The microstructure and chemical composition were performed using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX), respectively. The mechanical properties of the welded samples wereexamined by microhardness investigation. The results obtained for the microhardness are discussed concerning the applied technological conditions, defined by the power of the electron beam. Furthermore, the possible applications of the obtained welded joints of copper and aluminum Al6082T6 alloy are discussed in the different fields in modern industry.

1. INTRODUCTION

Nowadays, the welding and joining of materials with different thermo-physical properties are of major importance for the modern industry due to the combination of the characteristics of each of them [1]. In this sense, the welding of Cu and Al is applicable in a large number of industrial branches, such as aerospace, aircraft, automotive, railway, and other manufacturing directions [2]. However, the welding of Cu and Al can be considered a challenge due to the very different melting temperatures, thermal capacity, coefficient of thermal expansion, thermal conductivity, etc [3].

It should be noted that the electron-beam welding technology is very promising for the joining of metals and alloys withdifferent thermo-physical properties [4, 5]. At this technology, the process is realized in a high-vacuum state, leading to a high purity of the obtained joint, and the weld is characterized as very deep and narrow [6]. Furthermore, the electron-beam welding technique is known as highly reproducible and cheap.

The authors of [7] have studied the influence of the offset towards the Al plate at an electron-beam welding of Cu and Al6082T6 alloyand the results showed that welded joint in the above-mentioned system was successfully formed. Our previous investigations demonstrate the electron-beam welding of Cu and Al alloy using a circular beam oscillation where the radius of the circle was varied. The results showed that welded joints between both materials were formed in all considered cases, where the application of a smaller radius of the circular beam deflection leads to a higher hardness.

However, it should be noted that the influence of the beam power on the possibilities of the formation of welds between Cu and Al plates, as well as the resultant structure and properties are currently not yet studied. Therefore, the aim of this paper is to investigate the influence of beam power on the structure and microhardness of electron-beam welded Cu and Al alloy plates.

2. MATERIALS AND METHODS

The experiments were conducted on substrates of copper (Cu) and aluminium Al6082T6 alloy with a size of 100 x 50 x 8 mm. The electron beam welding was carried out on the Evobeam Cube 400 unit using the following technological conditions: accelerating voltage $U = 60$ kV; welding speed $v = 15$ mm/s; beam frequency $f = 20$ kHz; offset of 0.4 mm toward the aluminium alloy's side. The welded specimens were obtained by varying the beam current from $I_1 = 40$ mA, $I_2 = 45$ mA to $I_3 = 50$ mA. The corresponding beam power was $Q_1 = 2400$ W, $Q_2 = 2700$ W, and $Q_3 = 3000$ W, respectively. The applied technological conditions are presented in Table 1. The scheme ofthe EBW of Cu and Al6082T6 alloy is presented in Fig. 1.

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http://doi.org/10.62853/ELEV1494

The phase composition of the obtained welded joints was studied by X-ray diffraction experiments using CoKα characteristic radiation. The measurements were realized within the range from 20 to 120° at 2θ scale with a step of 0.1° and a counting time of 0.5 sec per step.

The microstructure and chemical composition of the formed welded joints were studied by scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX), respectively. During the measurements, back-scattered electrons were used.

The microhardness measurements were performed on microhardness tester "ZWICK/Indentec - ZHVμ-S", ZwickRoell GmbH & Co. KG, Ulm, Germany. A load force of 0.49 N was used for all experimental points.

Table 1 *Technological conditions of electron-beam welding of Cu and Al6082T6 alloy*

Sample	U, kV	I, mA	Q, W	v, mm/s	$r_{osc.}$, mm
1	60	40	2400	15	0.1
2	60	45	2700	15	0.1
3	60	50	3000	15	0.1

3. RESULTS AND DISCUSSIONS

The experimentally obtained X-ray diffraction patterns of the formed welded joints are shown in Fig. 2. The diffractograms of the pure Cu and the Al alloys are also shown. All diffraction maxima are indexed. The obtained patterns exhibit peaks corresponding to the pure Al, the pure Cu, and the intermetallic Cu_2Al phase, which is also known as the θ phase. No changes regarding the power of the electron beam can be observed, meaning that the discussed technological parameter does not influence the phase composition.

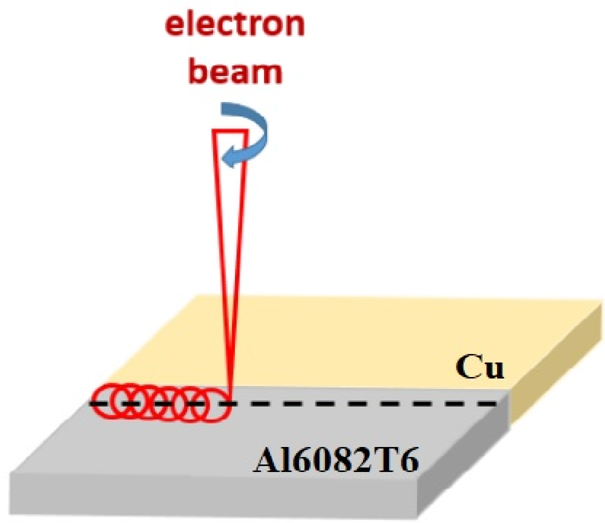

Fig. 1. Schematic of the EBW process of Cu and Al6082T6

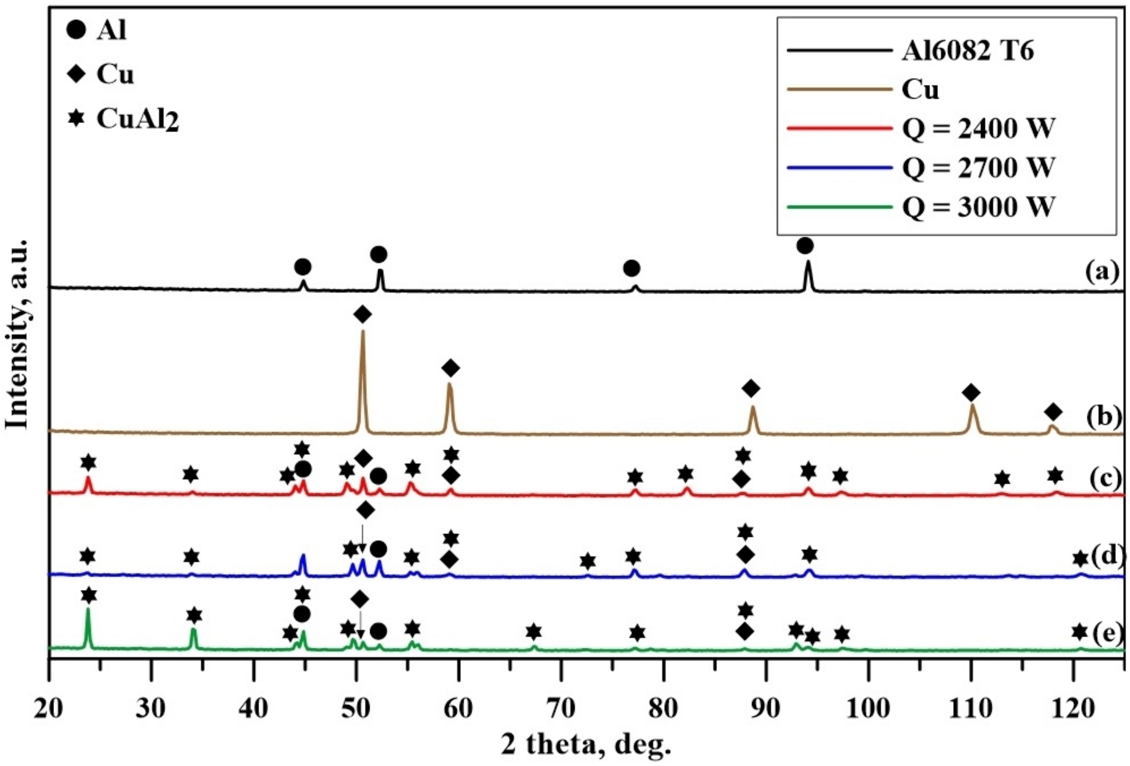

Fig. 2. X-ray diffraction patterns of: (a) Cu; (b) Al6082T6; (c) weld joint with beam power of 2400 W; (d) weld joint with beam power of 2700 W; (e) weld joint with beam power of 3000 W

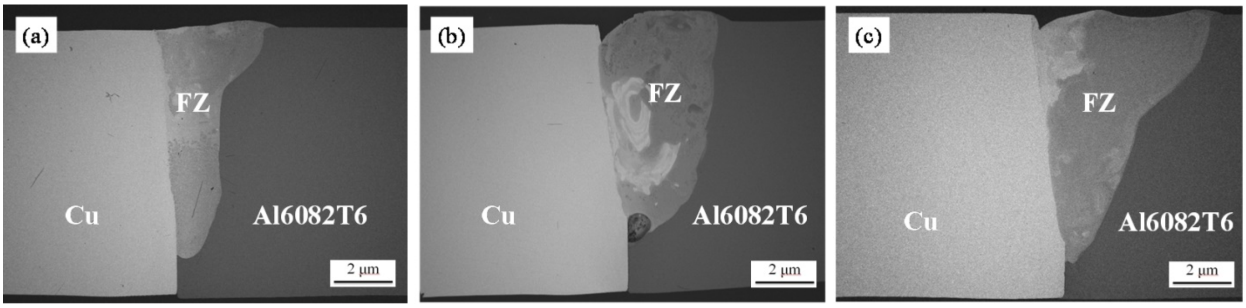

Fig. 3. Cross-sectional SEM images of: (a) sample 1 (beam power of 2400 W); (b) sample 2 (beam power of 2700 W); (c) sample 3 (beam power of 3000 W)

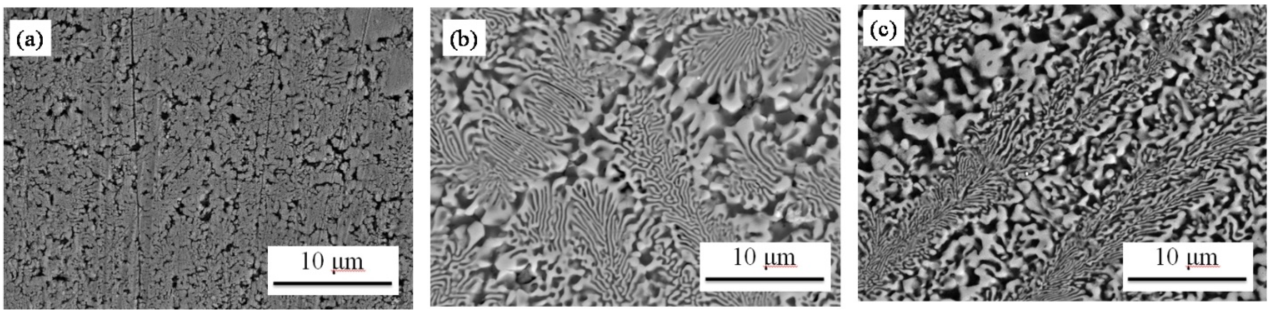

Fig. 4. SEM micrographs of the fusion zone of the samples welded with a beam power of: (a) 2400 W; (b) 2700 W; (c) 3000 W

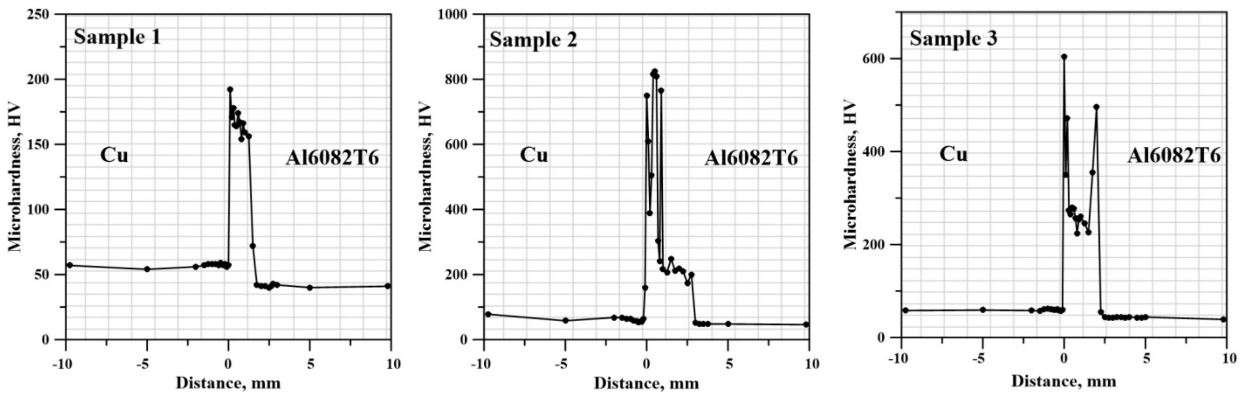

Fig. 5. Microhardness distributions of the weld formed using a beam power of: (a) 2400 W (sample 1); (b) 2700 W (sample 2); (c) 3000 W (sample 3)

The experimentally obtained cross-sectional low magnification SEM images of the considered welded specimens are shown in Fig. 3. Fig. 3a presents the specimen welded by a beam power of 2400W; figure 3b shows the welded joint using a power of the electron beam of 2700 W; figure 3c exhibits the welded seam witha beam power of 3000 W. It is obvious that the deeper and narrower joint is formed in the case of application of the lowest value of the electron beam power, namely 2400 W. At an increase of the beam power, the seam becomes wider. In the cases of EBW with a beam power of 2700 and 3000 W, the weld pool becomes larger, leading to a fusion zone with larger dimensions. Also, at higher beam powers of 2700 and 3000 W can be seen that the structure is much more inhomogeneous in comparison with that of the welded joint by a power of 2400 W. In this case,a higher amount of Cu is introduced into the molten material, leading to the formation of a larger amount of intermetallic phases, which however, cannot be distributed homogeneously due to the very short lifetime of the weld pool.

Fig. 4 presents higher magnification SEM images of the considered welded joints. Figure 4a presents the specimen welded by a beam power of 2400W; figure 4b shows the welded joint using a power of the electron beam of 2700 W; figure 4c exhibits the welded seam witha beam power of 3000 W. It is obvious that the microstructure of the welded joint obtained at the lowest beam power (2400 W) the microstructure is finer in comparison with the structures of the seams obtained at the power of the electron beam of 2700 and 3000 W. It should be noted that the formation of finer microstructure at the electron-beam welding processed materials is due to the very rapid cooling during the process. In the case of the beam power of 2400 W, the cooling rate is the highest since the liquid mixing processes become predominant at higher values of the discussed technological parameter. This leads to lower thermal gradients and a coarser structure.

Fig. 5 presents the microhardness results of the welded joints obtained at the beam powers of 2400, 2700, and 3000 W (samples 1,2, and 3, respectively). The measurements were performed at a cross-section in the middle of the welded joints. The Cu and Al-alloy sides are indicated in the figure. The results show that the specimen welded by the lowest beam power has the lowest hardness with a maximum value of about 200 HV. As already mentioned, at this value of the power of the electron beam, the seam is characterized by the lowest amount of Cu as compared with the other specimens and the amount of the intermetallics, and therefore the hardness should be the lowest as well. The seam of the specimen welded by a beam power of 2700 W (sample 2) reaches values of the microhardness of more than 800 HV. In this case, a significant amount of Cu is introduced into the molten material, leading to a much higher amount of intermetallic phase. This leads to a significant rise in the microhardness [8]. Considering the specimen welded by a beam power of 3000 W, the hardness reaches values of about 600 HV, where the measured values scatter significantly from the Cu to the Al alloy sides. As already mentioned, the microstructure in this case is coarser than that of the other two specimens (i.e. samples 1 and 2), leading to a reduction in the discussed mechanical characteristic as compared with the results obtained at sample 2 (i.e. welded by a beam power of 2700 W). Moreover, the distribution of the intermetallic phase in the case of electron beam welding with the highest beam power is much more inhomogeneous in comparison with the other two specimens, leading to a significant scattering of the measured microhardness values.

The results obtained in this study demonstrate the influence of the beam power on the microstructure and microhardness of electron-beam welded Cu and Al-alloy specimens. It was found that the discussed technological parameter has a significant influence on the structural and functional characteristics. It was demonstrated that the microstructure differs significantly as a function of the power of the electron beam, leading to very different values of the measured microhardness. It should be noted that the electron-beam welding procedure is a very nonequlibrium process, leading to a number of structural features, such as the formation of preferred crystallographic orientation, residual stresses, etc [9, 10]. It is well known that welded joints formed by a scanning electron beam are characterized by a significant amount of residual stresses and the application of different technological conditions of the welding significantly influences their amount and distribution [11, 12]. However, there are no significant studies performed on the investigation of the residual stresses, as well as the influence of the technological conditions on their amount and distribution in the cases of welding of dissimilar metals and alloys, such as Cu and Al-alloy. This question still remains open in the case of welding of Cu and Al6082T6 alloy. Such results are expected to add knowledge about the processes occurring during electron-beam welding under different technological conditions and their influence on structure formation in Cu-Al6082T6 alloy welded joints and will be of major importance to the scientific community.

4. CONCLUSIONS

The results obtained in the present study demonstrate the influence of the beam power on the structure and microhardness of electron-beam welded plates of Cu and Al alloy, where the beam power was chosen to be 2400, 2700, and 3000 W. It was found that in all considered cases, the phase composition is in the form of pure Al and Cu, as well as the Al_2Cu intermetallic compound. The microstructure of the formed welded seam by a beam power of 2400 W is the deepest and narrowest one, while the joints obtained by the power of the electron beam of 2700 and 3000 W are much wider. The application of the lowest value of the power of the electron beam leads to the finest microstructure among all considered specimens. The results obtained for the microhardness show that the specimen welded by the lowest beam power has the lowest hardness with a maximum value of about 200 HV. At the higher values of the power of the electron beam, the discussed mechanical characteristic increases significantly. In the case of the electron-beam welding with 2700 W, it is about 800 HV and slightly decreases at 3000 W, to about 600 HV.

ACKNOWLEDGMENT

This research was supported by the Bulgarian National Science Fund (Grant No. KP-06-N47/6/2020), and by the Ministry of Education and Science of Bulgaria (DO1-224/25.10.2021, part of the Bulgarian National Roadmap for Research Infrastructure).

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