ELECTRON BEAM BRAZING OF STAINLESS STEEL

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Abstract

Electron beam brazing combines the advantages of carrying out the process in a vacuum with the possibilities of precisely controlled heat source. Under high-temperature vacuum conditions the oxide layer is decomposed, which improves the wetting properties of the base metal, thus resulting in better joint properties. Brazing in an inert vacuum atmosphere also allows the use of a very reactive base and filler materials. Compared to brazing in vacuum furnaces, electron beam brazing enables the heating of precisely selected areas without the need to heat the entire element, which results in less significant structural changes in the base material and less energy consumption. In this article, AISI 304 grade stainless steel sheets were brazed with the use of various copper or silver fillers. The joints were subjected to microstructure, hardness and shear strength tests. The results show the effectiveness of the electron beam method in making brazed joints on the example of stainless steel base material and the copper and silver-based fillers.

Keywords: Metallurgy, electron beam, brazing, soldering, stainless steel, vacuum

1. INTRODUCTION

Nowadays, the development of industry requires making joints from materials with significantly different physical and chemical properties. However, in some cases, the joining of these materials poses many problems. The effects of poorly chosen parameters are the appearance of excessive stresses and cracks, in addition, the joints may be characterized by high brittleness. To prevent this, these elements are joined using brazing methods, where during the connection there is a relatively low temperature, which reduces the amount of heat and thus the adverse structural changes and deformation. Brazing also makes it possible to form joints from dissimilar materials that are difficult or impossible to join by other methods [1-3].

The use of electron beam in the brazing process, the configuration of parameters such as beam current, accelerating voltage, beam focusing control or beam splitting, allows (within a wide range) to control the amount of heat introduced to the elements being joined. Conducting the process under high vacuum conditions not only ensures high precision, but also reduces the formation of oxides on the surface of brazed materials, improving the wettability of the binder, which affects the good quality of brazed joints. When using electron beam it is also important to remember about the disadvantages of this method. It is not suitable for joining metals and their alloys containing easily evaporating (in vacuum) elements (e.g. zinc, phosphorus). This poses a certain difficulty in the selection of binders due to the fact that a significant part of the adhesives used, especially for flux brazing, are not suitable for this purpose [1-6].

The paper [7] presents problems related to the manufacturing of new effective tools from advanced superhard materials (SHM) based on cubic boron nitride (CBN) and polycrystalline diamond (PCD). It was found that the optimal method to obtain the joints is brazing with the use of adhesion-active binders. The study focused on the fabrication of SHM-steel (or hard alloys based on tungsten carbide) joints using electron beam heating. The course of chemical and physical reactions occurring during brazing of SHM to the substrate was studied. The conducted theoretical and experimental research made it possible to introduce unique ceramic tools for machining. In the work [8], a team from the Harbin Institute of Technology (China) described the problem of brazing hard WC-Co alloys with SAE1045 steel, with a carbon content of 0.45 wt%. The joint was fabricated using Fe-Ni spacer. The joints obtained in this way were characterized by high quality and significantly lower hardness than in the case of traditional electron beam welding (EBW). In paper [9], the authors described the effect of beam current on the microstructure and mechanical properties of brazed joints of aluminum with 304 austenitic steel. In paper [9], the authors performed brazed joints at different accelerating voltage values. In conclusion, the authors pointed out that the joints made using the EBB method had high quality and shear strength of 93 MPa. The quality of the joints was also significantly affected by the proper selection of brazing parameters. Too high intensity resulted in the appearance of cracks in the joint. Important applications of electron beam brazing also include joining technologies in space. The article [10] presents the possibility of using spot brazing in a vacuum, in the repair of such components as telescopes, antennas or energy sources. The author [10] points out that electron beam brazed joints are characterized by high quality and resistance to space conditions (vacuum, radiation).

Based on the examples described above, it can be concluded, that with appropriately chosen parameters of the electron beam, the amount of heat introduced into the joints can be controlled, which makes it possible to obtain joints of high quality and mechanical strength.

The aim of this study was to carry out an appropriate selection and optimization of electron beam brazing parameters for joints made of corrosion-resistant steel. The scientific objective was to determine the influence of the binder type and basic electron beam brazing parameters on the geometry and quality of the joints obtained. The practical goal, on the other hand, was to develop technological conditions for electron brazing of components made of steel sheets to ensure the best quality and strength properties of the joints.

The scope of research included:

- selection of additional materials and carrying out electron beam brazing tests,
- examination of the quality and durability of the obtained joints,
- determination of conditions and technological parameters that ensure the optimum quality and durability properties of the joints, development of a technology of electron beam brazing of steel sheets.

2. RESEARCH METHODOLOGY

In the first stage of the research, the feasibility of electron beam brazing process was analyzed. Steel grade X5CrNi18-10-1.4301 (AISI 304 [11]), in the form of sheets with dimensions of about 150×50×1.5 mm, was taken for testing.

Brazing was conducted using the binders summarized in **Table 1**.

Table 1 List of binders used for testing (according to PN-EN 17672:2016-12 [12])

Binder type according to PN-EN ISO: 2016-12	Elements (wt%)							T_{sol} (°C)
	Ag	Cu	Zn	Mn	Ni	Sn	Ni	
Ag 449	49.0	16.0	23	7.5	4.5	-	-	680
Ag 272	72.0	28.0	-	-	-	-	-	780
Ag 463	63.0	28.5	-	-	-	6.0	2.5	690
Cu 773	-	48.0	-	<0.1	10.0	-	-	890
Cu 595	-	71.5	-	12.0	2.0	-	-	965

Figure 1 View of the electron device, model XW150:30/756

Binder materials were provided in the form of tape with thicknesses ranging from 0.2 to 0.5 mm. Before the brazing process, all samples were cleaned and degreased with acetone (not etched). The brazing process was carried out under high vacuum (10^{-2} Pa) on an electron beam machine, model XW150:30/756 (**Figure 1**), designed for welding and surface modification. The cleaned components were then placed, according to the selected configuration, in the prepared fixture (**Figure 2**).

The first stage of the research was focused on determining the optimum way of guiding the electron beam on the materials to be joined. It was important to set the process parameters in such a way that the electron beam would only properly heat the material and not lead to its melting. On the basis of the conducted experiments, the method of brazing with a defocused beam falling on both metal sheets simultaneously was chosen (**Figure 2**), due to more uniform heating, and thus also wetting of the elements. A test series of joints was then made using different binder materials. **Table 2** summarizes the brazing parameters used.

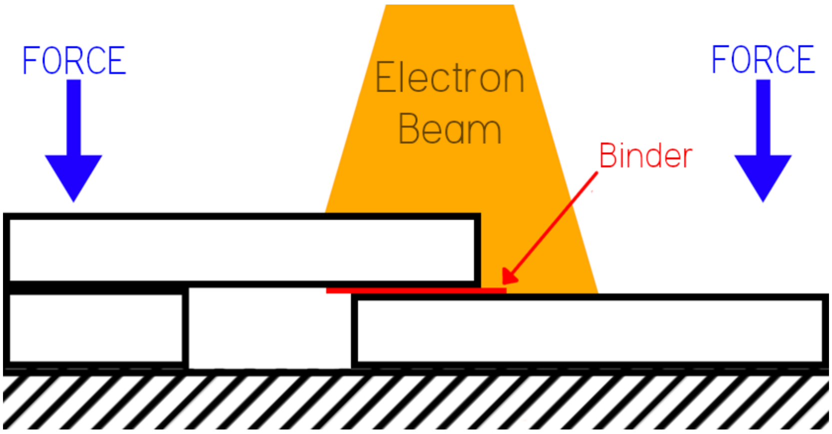

Figure 2 Schematic of sample preparation for electron beam brazing

The brazed joints were then subjected to mechanical (static shear test by stretching the joints) and metallographic macro- and microscopic tests to confirm the quality of the brazed components.

Table 2 Test joints brazing parameters with different additive materials

Sample no	Binder type according to PN-EN ISO 17672: 2016-12	Accelerating voltage (kV)	Beam current (mA)	Linear brazing speed (mm/min)	Focal distance (mm)
1	Ag 449	60	14	135	402
2	Ag 272	60	13	120	402
3	Ag 463	60	17	150	402
4	Cu 773	60	15	100	402
5	Cu 595	60	18	150	402

2.1. Microstructure study

Metallographic tests were conducted in accordance with the requirements of PN-EN 17639:2013-12 [13]. The samples were ground and then polished. The tests were carried out using an inverted metallographic microscope - model Eclipse MA 200 (Nikon). The results in the form of macro- and microstructures are shown in **Figures 3-7**.

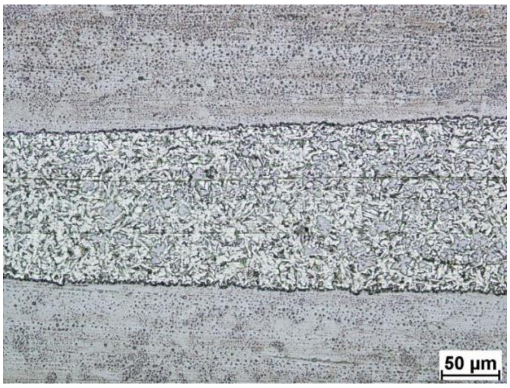

Figure 3 Microstructure of a joint made of AISI 304 grade steel, brazed with electron beam using Ag 449 binder, chemical etching in dilute aqua regia

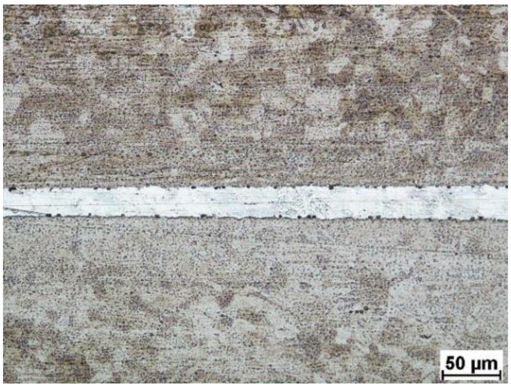

Figure 4 Microstructure of an AISI 304 electron-beam brazed joint using Ag 272 additive material, chemical etching in dilute aqua regia

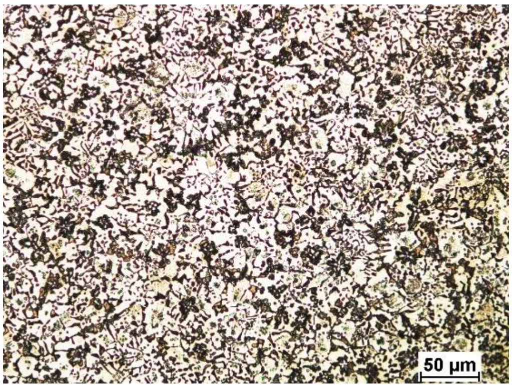

Figure 5 Microstructure of an AISI 304 electron-beam brazed joint using Ag 463 additive material, chemical etching in HCl and CrO_3 dilute solution

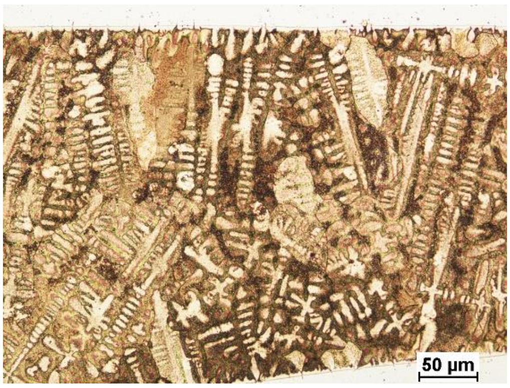

Figure 6 Microstructure of an AISI 304 electron-beam brazed joint using Cu773 additive material, chemical etching in HCl and $FeCl_3$ dilute solution

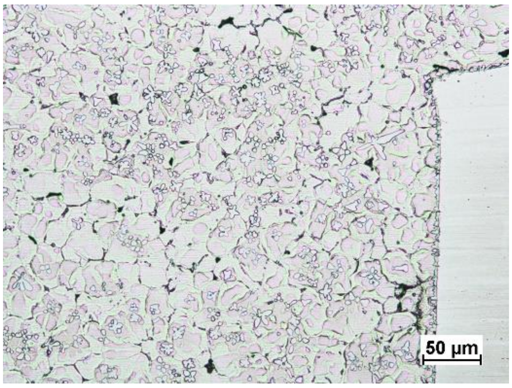

Figure 7 Microstructure of an AISI 304 electron-beam brazed joint using Cu595 additive material, chemical etching in 1:4 HF:HNO_3 dilute aqueous solution

2.2. Shear tests

Static tensile shear test of brazed joints (**Figure 8**) was carried out using MTS Criterion C45 testing machine, up to 100 kN, at cross beam feed rate of 5 mm/min, according to the requirements of PN-EN 12797:2002 [14]. The obtained results are summarized in **Figure 8**.

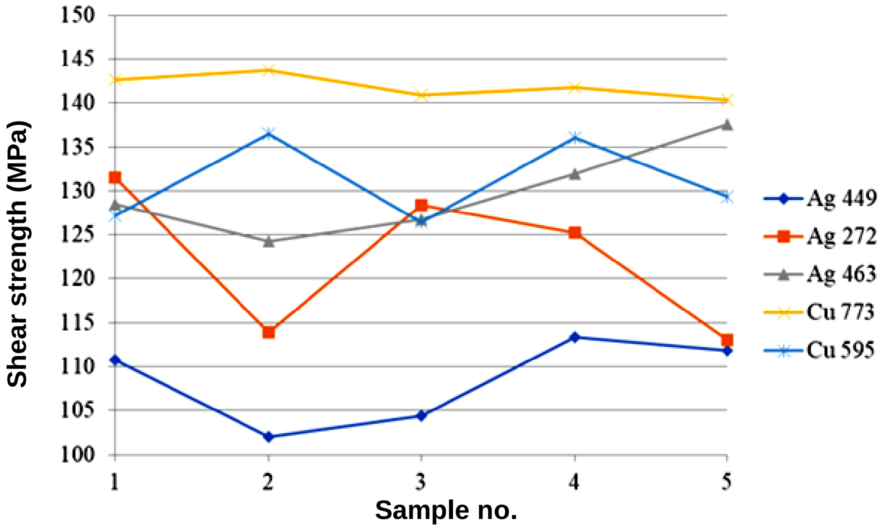

Figure 8 Shear test results

3. DISCUSSION OF RESULTS

The purpose of this paper was to test the feasibility of using electron beam in the brazing process of AISI 304 steel. To do so, numerous brazing tests were conducted to confirm the suitability of this technology. After selecting a suitable method for heating the material, preliminary brazing tests were conducted on AISI 304 steel using various additional materials. Metallographic tests showed that the joints made of AISI 304 steel, using all binder materials were of high quality. The macro- and microstructures of the joints obtained showed no defects (**Figures 3 to 7**). Mechanical tests showed that the joints were characterized by high shear strength. The best results were obtained for the joints made with copper-based binders, i.e. Cu 773 (average shear strength was 142 MPa) and Cu 595 (average shear strength was 131 MPa). The best results among silver-based binders were obtained for the joints with Ag 463 (average shear strength was 130 MPa), whereas the lowest strength among all the tested joints was observed for the joints made with Ag 449 binder (average shear strength was 109 MPa).

Brazing tests carried out confirmed the validity of using an electron beam as a heat source in the brazing process. The process conducted in a vacuum allows to maintain metallurgical purity. This is also due to the decomposition of oxide layers and lack of re-oxidation. In the vacuum brazing process, the chemical composition of the binders used, devoid of easily evaporating components, is important. At the present stage of the research, no further analysis of the microstructure of the brazed joints obtained has been carried out.

4. CONCLUSION

The following conclusions were drawn from the study:

1) Brazing tests that were carried out, confirmed the validity of using an electron beam as a heat source in the brazing process. Joints made using defocused electron beam are characterized by proper geometry and high performance.
2) In the case of joints made of AISI 304 austenitic steel, the best results were obtained for Cu 773 binder (average shear strength 142 MPa).

3) On the other hand the worst results were obtained for Ag449 binder (average shear strength 109 MPa).

4) Defocusing the beam on the surface of both sheets at the same time resulted in more uniform heating and thus wetting of the elements.

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