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ECONOMIC ASPECTS OF DISSIMILAR BRAZE WELDING OF AUSTENITE-COPPER FOR RAIL TRANSPORT APPLICATIONS

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Purpose: Novelty of the paper is to present the economic aspect of austenite-copper alloy braze welding for rail transport application. Braze welding copper with austenite is treated as a difficult and expensive procedure. The aim of the article is to develop the MIG (Metal Inert Gas) welding process for dissimilar austenite-copper joining without preheating that is much less expensive process of welding with preheating.
Design/methodology/approach: Main parameters of the braze welding process were tested and then the quality of the obtained joint was checked.
Findings: Filler materials were determined without preheating to 600° C, that is much more energy-intensive process.
Research limitations/implications: It was suggested to investigate the effect of modified dissimilar austenite-copper joining.
Practical implications: The proposed process innovation will result in savings of production of cost of the elements of the locomotive transformer holder.
Social implications: New dissimilar austenite-copper joining process allows for energy savings.
Originality/value: It is to propose a new solution in rail transport. The article is especially addressed to the elements of the locomotive transformer holder.
Keywords: production savings, transport, braze welding.
Category of the paper: Research paper.

1. Introduction

In recent years, great importance has been attached to savings during production and the search for new solutions that will guarantee good results, environmental benefits and large savings. Braze welding of austenitic steel with copper is a much cheaper process than classical welding. This is because the expensive preheating of copper to approx. 600°C can be eliminated. Dissimilar joining copper and austenitic steel is a rather specific process because it combines two materials with very different physical and chemical properties. Copper has very good thermal and electrical conductivity and a low melting point (approx. 1085°C). Austenitic steel (in this case material 304) has much lower thermal and electrical conductivity and has a much higher melting point (approx. 1434°C). This is important information from the point of view of production management (in this case, locomotive transformer holders). It be easily calculated that the approximate value of energy needed to heat a copper element with dimensions of 300 × 300 × 8 mm is 0.4 kWh, the amount of propane needed to heat this element is 0.1 kg (Li, Hou, Tian, Hong, Nord, Rohde, 2022). Copper welding was the successful work of great Polish scientist Prof. Jan Węgrzyn, a pioneer of modern welding. He developed an innovative method of cold welding of copper, which was patented in Poland under the number PL 54612 in 1966. This method involves the use of a specially designed coated electrode, which allows for welding copper without the need for prior heating. The new electrode allows for welding with an efficiency up to 30 times greater than traditional gas methods. Welds made using this method are characterized by high quality, do not require additional heat treatment or forging, and their electrical and thermal conductivity is similar to that of wrought copper. This method was developed by Prof. Jan Wegrzyn was constantly improving and patented the research results in 1987: "Coating of electrodes for welding copper and copper alloys (patent PL 153863). The method of cold welding of copper was considered a breakthrough in the field of welding and was included among the ten most important achievements in this field in the world. Additionally, prof. Jan Wegrzyn is the author of other patents related to non-conformal welding of copper, such as "Method of welding a copper strip with a steel element" (PL 158594). Laser welding of copper alone has begun to replace the previous methods: gas welding and welding with coated electrodes. It was noted that the preheating temperature should reach up to 600°C for Punzel, E., Hugger, F., Dörringer, R., Dinkelbach, T.L., & Bürger, A. (2020). In copper laser welding, attempts were made to use lower and lower preheating temperatures (Punzel, Hugger, Dörringer, Dinkelbach, Bürger, 2020). In the following years, attempts were made to make non-similar joints. An important and well-recognized process is the welding of copper with titanium. A welding process without preheating was used here (Yee et al., 2023). Welding copper with austenitic steel is more difficult. Laser welding gave good results, but preheating was necessary (Mannucci, Tomashchuk, Vignal, Sallamand, Duband, 2018). Similar results were also obtained by other researchers (Lee, Jeong, Lee, Fujii, Shin, Lee, 2023). Currently, attempts are being made to weld Cu using methods related to green energy (Beck, Bantel, Boley, Bergmann, 2021). Dissimilar copper laser welding was tried to be associated with environmental protection (Kumar, Arya, Palani, Madhukar, Sathiaraj, Patel, 2022). Currently, copper welding using the TIG method has been mastered, paying attention to environmental issues (Sairam, Balaji, Menon, Manikandan, 2023). The authors of this article attempted to weld Cu to austenitic steel using the MIG process to also contribute to environmental protection and reduce production costs, in this case related to the needs of the railway industry.

2. Materials

A single lap joints were made of 8 mm thick copper sheet and 10 mm thick austenitic steel. Two electrode wires with silicon (CuSi3) and silicon and manganese (CuSi3Mn1) additions were selected for braze welding. Table 1 presents the mechanical properties of tested materials in dissimilar braze welding process.

Table 1.
Tensile strength of tested materials

Material	YS, MPa	Elongation A5	Hardness, HB
Cu	220	41	60
Austenite steel 304	570	45	170

Austenitic steel 304 is a commonly used stainless material of the 18-8 grade (18% Cr, 8% Ni). This steel additionally contains 0.08% C, 2% Mn, 1% Si. The two tested braze welding wires (diameter 1 mm) have a chemical composition other than austenite, and more similar to the second jointed material, which is pure copper. The chemical composition of the wires is presented in Table 2.

Table 2.
Chemical composition of wires for braze welding

wires	Si, %	Mn, %	Fe, %	Zn, %	Ni, %	Cu, %
CuSi3	2.9	1.2	0.5	0.1	0.05	bal
CuSi3Mn1	3.9	1.5	0.4	0.2	0.5	bal

The main alloying elements in wires are Si and Mn, which is consistent with the symbol of the material. It was decided to realize MIG braze welding with a single lap joints character. Joints were made of 8 mm thick copper sheet and 10 mm thick austenitic steel. The weld was formed as single-pass. The joint was protected by argon as shielding gas with constant flow on the level of 13 dm^3/min.

At the beginning of welding process, the current and the voltage parameters were suggested:

- welding current was varied 3 times: 155 A, 165 A, 175 A,
- arc voltage: 23 V,
- welding speed was varied twice: 250 mm/min and 290 mm/min,

The use of high purity argon is important to avoid braze welding incompatibilities Actually helium is occasionally used in argon gas mixture.

3. Methods

After the MIG braze welding process, the non-destructive test (NDT) and also destructive tests (DT) were realized. Firstly, VT - visual test (using EN ISO-17638 standard) and TP - penetration test was realized. Penetrant was DBR, cleaner was BRE-S, developer was BEA. Time of penetration was 30 min. Secondly destructive test was carried out mainly based on EN ISO 14273:2016 (Resistance welding - destructive testing of welds - specimen dimensions and procedure for tensile shear testing resistance spot and embossed projection welds (ISO 14273:2016) and bending test according to PN-EN ISO 5173 standard.

4. Results and discussion

Dissimilar lap joints were made using two wires (CuSi3 and CuSi3Mn1) and with 2 various welding speed. Welding was realized without heat treatment. Following all the experiments, 12 different samples were made (tab. 4).

Table 4.
Samples designations

Sample	Current, A	wire	Welding speed mm/min
U1	155	CuSi3	250
U2	165	CuSi3	250
U3	175	CuSi3	250
U4	155	CuSi3	290
U5	165	CuSi3	290
U6	175	CuSi3	290
U7	155	CuSi3Mn1	250
U8	165	CuSi3Mn1	250
U9	175	CuSi3Mn1	250
U10	155	CuSi3Mn1	290
U11	165	CuSi3Mn1	290
U12	175	CuSi3Mn1	290

Only three samples marked as U2, U5, U11) were free from welding defect and incompatibilities (table column are marked in green), but nine samples were prepared incorrectly (table column marked in pink). The VT (visual test) and TP (penetration tests) results with observation comment are presented in Table 5.

Table 5.
VT results for tested dissimilar braze welds

Sample	Observation
U1	Small cracking in weld from the face and root sides
U2	Small cracking in HAZ
U3	Correct weld, defect free, correct form and dimension of HAZ
U4	Small cracking in HAZ
U5	Correct weld, defect free, correct form and dimension of HAZ
U6	Small cracking in weld from the face and root sides
U7	Small cracking in HAZ
U8	Small cracking in HAZ
U9	Small cracking in weld from the face side
U10	Small cracking in weld from the root side
U11	Correct weld, defect free, correct form and dimension of HAZ
U12	Small cracking in weld from the face and root sides

First of all, it was found that the selection of current and kind of wire is more important than welding speed. The welding current should be on the level of 165 A. Initial observations indicate that CuSi3 wire is more suitable for the tested brazed joint. Based on visual tests, it can also be concluded that a faster welding speed may be more suitable for solving the welding problem. The next part of the investigation was to perform a tensile strength of the dissimilar lap braze weld. Only samples that tested positive in NDT tests were taken to the account (U2, U5, U11). Table 7 presents the tensile strength (UTS) of the of the dissimilar lap braze weld.

Table 7.
Tensile strength of the dissimilar lap braze weld

Sample	UTS [MPa]
U2	134
U5	145
U11	103

The data from the Table 7 prove that there is high tensile strength of all tested joints over the 100 MPa. The analysis of Table 7 shows that the joints made using the CuSi3 wire electrode have much more advantageous mechanical properties. A bending tests was carried out to check the plastic properties of the joints as a last point of investigation. A bending test was realized at room temperature. The bending angle was 30 degrees. The results of bending test are demonstrated in Table 8.

Table 8.
Bending test of braze weld

Sample	observations
U2	No cracks
U5	No cracks
U11	small cracks

The bending angle was 30 degrees. The joints U2 and U5 (using wire CuSi3) showed no defects or discrepancies, the test result according to the standard is positive. The joint U11 had minor defects in the form of cracks.

5. Summary

The article presents the possibility of economic dissimilar braze welding Cu-austenite without preheating, that is treated as expensive procedure due to the consumption of energy and propane preheating, gas for heating. Based on the literature included in the introduction, it can be easily calculated that one propane bottle, which costs 40 euros, is needed to make 100 tested dissimilar braze welds. Joints of this type are made on a large scale for use in the railway industry. The newly developed method allows for large savings, as the use of expensive propane for preheating is completely eliminated. The properties of braze welding were tested using non-destructive and detractive methods. The joints, despite the much cheaper production method, are characterized by good properties. It is difficult to determine the optimal process parameters, because only 3 trials out of 12 different parameters gave a positive result. Based on the dissimilar braze welding study it was possible to conclude that:

1. Braze welding of Cu-austenite steel without preheating leads to process savings, because welding without using propane for heating is much cheaper.
2. Braze welding parameters (wires, current and speed) should be selected with great knowledge and sensitivity.
3. The best mechanical properties of braze welds were obtained when:
   - the electrode wire CuSi3 gives better results than CuSi3Mi1,
   - the welding speed on the level of 290 mm/min gives better results than 250 mm/min; this also translates into the economic aspects of the process, because the efficiency increases,
   - for this type of joint, the welding current should be on the level of 165 A.

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