DOI: 10.24425/amm.2019.130108

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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF BRAZE WELDED JOINTS OF COPPER WITH AUSTENITIC STEEL MADE BY CMT METHOD

This paper outlines issues associated with gas-shielded braze welding of CU-ETP copper with austenitic steel X5CrNi18-10 (1.4301) using a consumable electrode. The possibilities for producing joints of this type using innovative low-energy welding methods are discussed. The paper provides an overview of the results of metallographic and mechanical (static shear test, microhardness) tests for braze welded joints made on an automated station using the Cold Metal Transfer (CMT) method. Significant differences in the structure and mechanical properties are indicated, resulting from the joint configuration and the type of shielding gas (argon, helium).

Keywords: arc welding-brazing, CMT method, dissimilar joints

1. Introduction

The continued development of technology, determined by constantly increasing quality, economic and environmental demands, forces manufacturers to create products that are suitable for difficult or special operating conditions and specific applications. In consequence, increasingly often there is a need to join materials of different physical, chemical and mechanical properties. However, the joining of materials that differ significantly in terms of their properties, i.e. “dissimilar metals welding” poses a great number of technological and metallurgical problems [1]. These problems also occur when welding austenitic steel with copper and connections of these materials are increasingly often used in many branches of the industry. One of the greatest problems occurring when joining these materials is a significant difference in the thermal conductivity of these two metals, which is 26 times higher for copper than for austenitic steel of 18/10 type. Another problem is the presence of oxides of different melting points and chemical durability. However, there is one factor which has an advantageous influence on the possibility of joining such materials, that is, they have similar linear expansion coefficients and this reduces the risk of residual stress and cracks during joint cooling [1,2].

There are numerous technologies available which enable the welding of austenitic steel with copper, starting with brazing, through special sealing methods, i.e. friction or diffusion thermal sealing, explosion welding and pressure welding and ending with welding methods. The most common welding methods include TIG arc welding and laser welding [1-6]. At the moment, the substantial technical progress also enables a significant development of traditional welding methods, mainly arc welding and gas-shielded braze welding using a consumable electrode (GMA process). New, low-energy welding techniques by the MIG/MAG method have been developed, amongst which the Cold Metal Transfer (CMT) technology from Fronius plays an important role [7].

When materials of different physical, chemical and mechanical properties are welded, including austenitic steel with copper, the braze welding technique, particularly the CMT method, gains in importance. To a large extent this is caused by the possibility of joining thin metal sheets and/or components of a small size, which would be impossible with traditional welding methods because the amount of heat introduced would be too large, preventing the correct making of a joint.

In the case of braze welding of dissimilar materials, it is not always possible to conduct the process without melting the edge of the material with a lower melting point, in particular, when the gradient between its melting point and the melting point of the solder is small. This makes the evaluation of the quality of such joints challenging, because edge melting of the substrate material in the braze welding process is a nonconformity – this applies, in particular, to a system of the same materials, while for materials with significantly different melting points, edge melting of the material with a lower melting point is acceptable [8].

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2. Materials and test methodology

2.1. Materials

For dissimilar joints, 2.0 mm thick copper of the Cu-ETP type and 1.0 mm thick austenitic steel of the X5CrNi18-10 type were selected. They represent standard engineering materials joined directly in various types of structures of heat exchangers, for example, in cooling and heating appliances and equipment for the chemical industry.

The selection of additional materials for the braze welding process is difficult, taking into account the specific nature of the process, in which, by definition, the welded materials should not be melted but only wetted with the solder, obtaining a joint as a result of diffusion mechanisms. The lack of melting, characteristic for the braze welding process allows, in particular, to avoid metallurgical difficulties related to mixing of the additional material (solder) with the substrate material [10]. Therefore, the greatest problem is the selection of the solder for braze welding of dissimilar materials. Usually, it is selected by adapting its melting point to the substrate material with a lower melting point [9,10]. When a gradient between the melting points of the solder and the substrate material is small, the melting of the edge of the material with a lower melting point cannot always be avoided [9]. For the process of braze welding of Cu-ETP copper with X5CrNi18-10 steel a copper-based alloy, silicon bronze (CuSi3) of 1.0 mm in diameter was selected. The chemical composition of the substrate materials and the solder selected for their welding is shown in Table 1 [11-13].

In the processes of arc welding and braze welding of copper and austenitic steel, inert shielding gases are used. Argon of a minimum purity 4.0 (99.99% Ar) is most commonly used in the European welding industry. The purity of the shielding gas is of great importance for the quality of the obtained joint - the purer the gas, the lower the risk of porosities in the weld. The selection of argon results mainly from economic considerations as in the European market its price is nearly half the price of helium (assuming the same purity of both gases). The use of helium results in an electric arc with a greater heat output so the process capacity can be increased as it is possible to weld faster and this is advantageous for welding of large-size items. In the experimental part, the effect of the welding gas type on the quality of the braze welded joints was compared. Two types of inert shielding gases were selected: I1 (100% Ar) and I2 (100% He) according to EN ISO 14175:2009. The chemical purity of selected shielding gases was the same and amounted to 4.5 (99.995%).

2.2. Test methodology

Joining of dissimilar materials with the braze welding technology is associated with various problems that may significantly affect the quality and the mechanical properties of the obtained joints. This technology is usually used for overlapping joints, due to the adhesive-diffusive character of the joint.

When dissimilar materials are joined, with this type of the joint structure, the mechanical properties of the joint can be strongly influenced by its configuration, i.e. arrangement of the substrate materials. Therefore, joints in two configurations were prepared for the tests - in the first, Cu-ETP copper was placed on the X5CrNi18-10 austenitic steel, while in the other austenitic steel was placed on copper (Fig. 1). The welding wire (solder) was directed towards the bottom sheet at the edge of the overlap. The way in which the torch is set in relation to edges of the joint components can also be of a great significance for the quality of

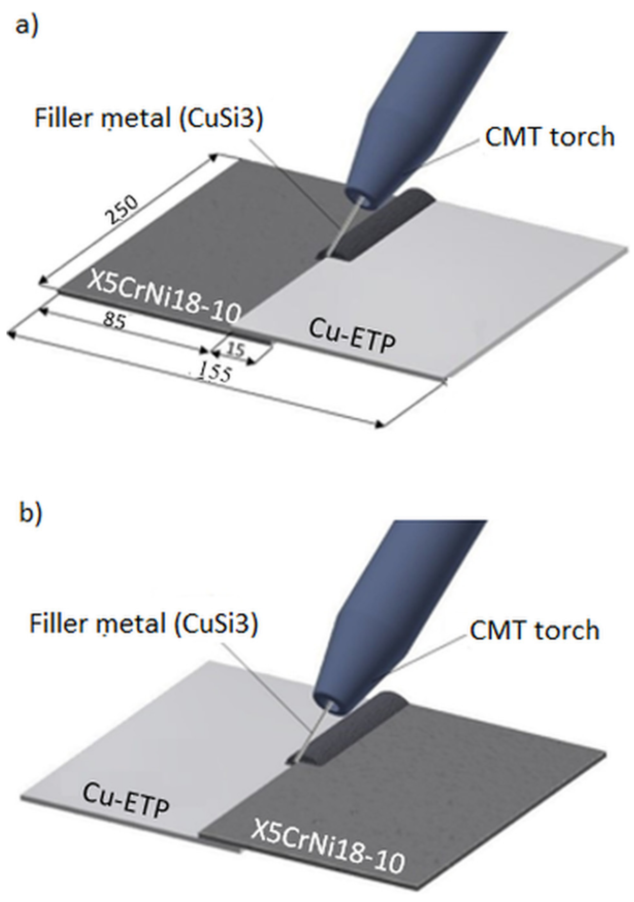

Fig. 1. Scheme of overlap joints in the configuration: copper-steel (a) and steel-copper (b)

TABLE 1

Chemical composition of base materials and filler metal [11-13]

Material	Chemical composition, % wt.												
	C	Si	Mn	Cr	Ni	P	S	Fe	Cu	B	O	Pb	Sn	Zn
Cu-ETP	—	—	—	—	—	—	—	—	bal.	0.0005	0.04	0.005	—	—
X5CrNi18-10	<0.07	<1.0	<2.0	17.5÷19.5	8.0÷10.5	0.045	0.015	bal.	—	—	—	—	—	—
CuSi3	—	<3.0	<1.0	—	—	—	—	0.07	bal.	—	—	—	<0.1	<0.1

the obtained joints, e.g. for the degree of melting of the material with a lower melting point. However, this study did not analyse the above-mentioned influence.

Braze welding of Cu-ETP copper with the X5CrNi18-10 steel was conducted on an automated workstation using the low-energy CMT method. An important part of the equipment at that station is a synergistic Fronius welding machine TransPuls Synergic 3200, enabling precise control of the welding wire fiddling which eliminates the spattering almost completely. The source was synchronised with a digitally controlled wire feed, FRONIUS VR 7000-CMT 4R/G/W/F++ and the working movements during the process were performed by a Kawasaki robot from the BA006 series with a welding torch Robacta Drive CMT PAP W installed on its arm, with an internal digitally controlled asynchronous alternate current motor responsible for back movement of the wire [15].

The selection of braze welding parameters started with setting the parameters implemented on the synergic line for CuSi3 solder. The program was set for the metal sheet thickness of 1.5 mm, i.e. for an intermediate value between the thickness of the copper (2.0 mm) and the steel (1.0 mm) sheets and then it was adjusted by changing the welding speed. The initial trials involving the making of dissimilar joints showed that the CMT arc braze welding process requires a very precise selection of the technological parameters and even a small changes in them negatively affect the process stability and result in numerous welding nonconformities in the joints. Furthermore, the process was made difficult due to a small gradient between the melting points of Cu-ETP copper and CuSi3 solder and a significantly fluent solder. Even slight changes in the parameters caused, for example: spatters due to a decreased process stability, excessive weld height a lack of wetting of one of the materials and adherence or excessive melting of the edges of the joint items. The parameters used to make the braze welded joints were selected experimentally on the basis of the visual inspection of the successively obtained joints. The final parameters for the CMT braze welding process, used to make joints for the tests are shown in Table 2. The braze welding process was carried out at different travel speeds depending on the type of gas shield. Because more heat in the arc is generated in the helium than in the argon shield, the process can be carried out at a higher travel speed.

TABLE 2

Parameters of welding-brazing process of copper with austenitic steel

No.	Parameter	Value	
		Argon 4.5	Helium 4.5
1.	Current, I_S	130 A	140 A
2.	Arc voltage, U	12 V	16 V
3.	Wire feeding speed, V_f	8.0 m/min	8.0 m/min
4.	Welding-brazing speed, V_w	60 cm/min	80 cm/min
5.	Gas flow rate, Q	16 dm^3/min	24 dm^3/min

The braze welded joints differ from the welded joints mainly by a different (diffusive) mechanism for forming the joint; therefore, they usually do not undergo impact and bending tests. A basis for their evaluation (particularly, for the joints of the overlapping structure) are macro- and microscopic examinations, the static shear test and hardness measurements. Due to the different physical and chemical phenomena occurring in the braze welding process, the nonconformities occurring in the braze welded joint are also different from welding nonconformities [10]. Therefore, the quality assessment of the braze welded joints was conducted using the standards for nonconformities found in welded and brazed joints. Internal nonconformities found in the braze welded joint were classified in accordance with EN ISO 18279 and external nonconformities concerning its geometry were evaluated according to the guidelines of EN ISO 6520.

3. Results and discussion

3.1. Microstructure of braze welded joints

Before test samples were cut out from joints for macro- and microscopic examinations, they underwent visual tests (VT) in accordance with the guidelines provided in DIN EN ISO 17637:2017. No external welding nonconformities were found in the joints in which the steel sheet was placed on the copper one. The joints were made correctly – the weld face was smooth and aesthetic, without splatters. Regardless of the shielding gas used, the copper sheet was not burned. The only visible difference was the height of the braze welded joint. For argon, it was slightly higher and reached 3.0 mm (Fig. 2a) and for helium, it reached 2.3 mm (Fig. 2b). This difference results from a greater amount of heat generated in the helium shield and this causes a slightly better wetting of the steel sheet by the solder and, in consequence, lower excess weld. When the weld structure was changed, with the copper sheet placed on the austenitic steel, this improved the appearance of the braze welded joint, which resembled the fillet joint and did not reach above the upper edge of the copper sheet (Fig. 2 c,d). This may be advantageous in certain application solutions in which the braze weld should not extend above the joint edge. This also greatly influences the esthetic appearance of joints, which, similarly as in the first solution, do not have external nonconformities and splatters.

In macroscopic photographs (Fig. 2), it can be seen that regardless of the shielding gas and the joint configuration used, the edge is slightly melted in at least one of the substrate materials. As braze welded joints are verified similarly as brazed welds then this is a nonconformity labelled as 7UAAC in PN-EN ISO 18279, belonging to group VI "Various nonconformities" – excessive reaction between the solder and the substrate material. In dissimilar joins, particularly of austenitic steel and copper an observation which material was melted may be of importance. As the chemical composition of the solder is similar to copper, the more advantageous situation is when copper is melted. When steel is melted, this may lead to the formation of hot cracks resulting from copper diffusion from the solder into steel along the edges of the austenite grains as reported in the paper [4].

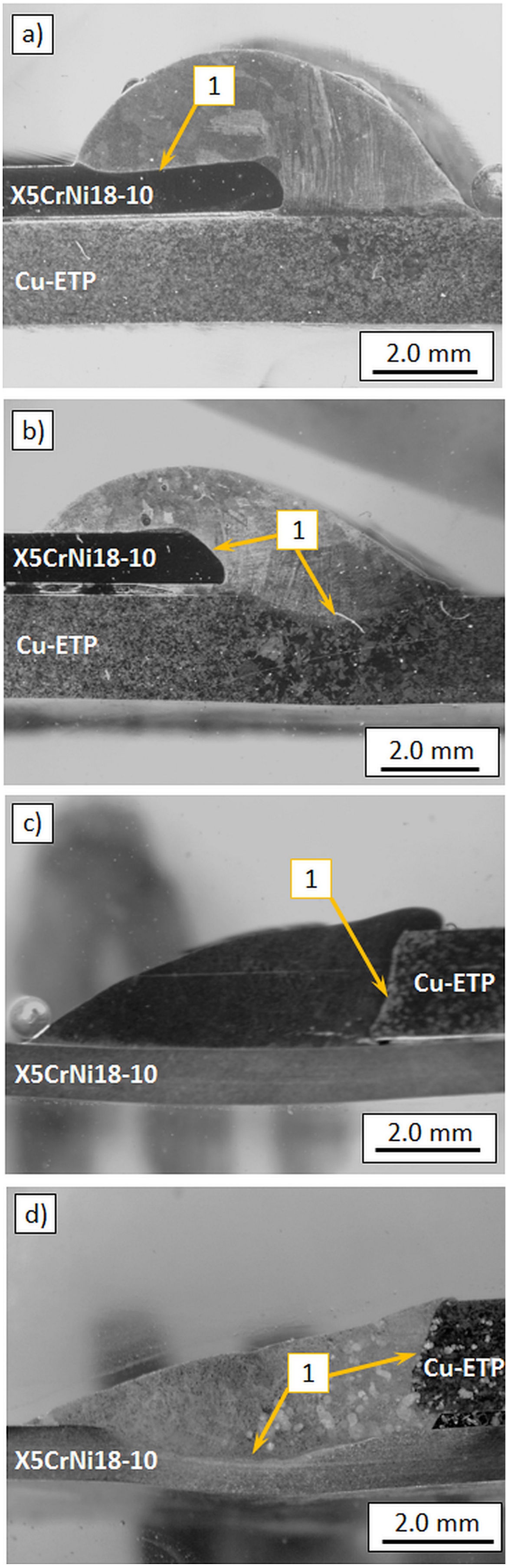

Fig. 2. Macrostructure of overlap joints in the configuration: steel-copper (a,b), copper-steel (c,d) in argon shield (a,c) and helium shield (b,d); 1 – 7UAAC irregularities

When argon was used as the shielding gas, regardless of the joint configuration, in the macroscopic photographs it can be seen that only the edge of one material was melted. The austenitic steel when it was placed on copper (Fig. 2a) and of copper when the arrangement was reversed (Fig. 2c). The use of helium, regardless of the joint configuration resulted in melting of the edge of the material placed on top of the joint and its penetration into the material placed on the bottom (Fig. 2b,d). The depth of that penetration was similar for copper and for austenitic steel and amounted to ca. 0.4 mm. Therefore a solution in which argon is used as the shielding gas and copper is placed on top of austenitic steel appears to be most advantageous. It is also a solution with the best appearance and currently many branches of the industry consider this a crucial aspect.

In the joint configuration, in which the austenitic steel sheet was placed on copper, the steel sheet edge melted, creating a reaction zone (1) along edges directly in contact with the braze welded joint (Fig. 3a). The copper sheet is not melted (Fig. 3b), but only wetted with the solder and a joint is formed due to diffusion. A crack (2) between copper and the braze weld is visible near the overlap, which was possibly formed when the joint was cooling, because the difference in the thermal expansion of copper and steel was too excessive. In consequence of these differences, both materials disperse the heat from the joint at a different rate, thus causing large internal tensions which may

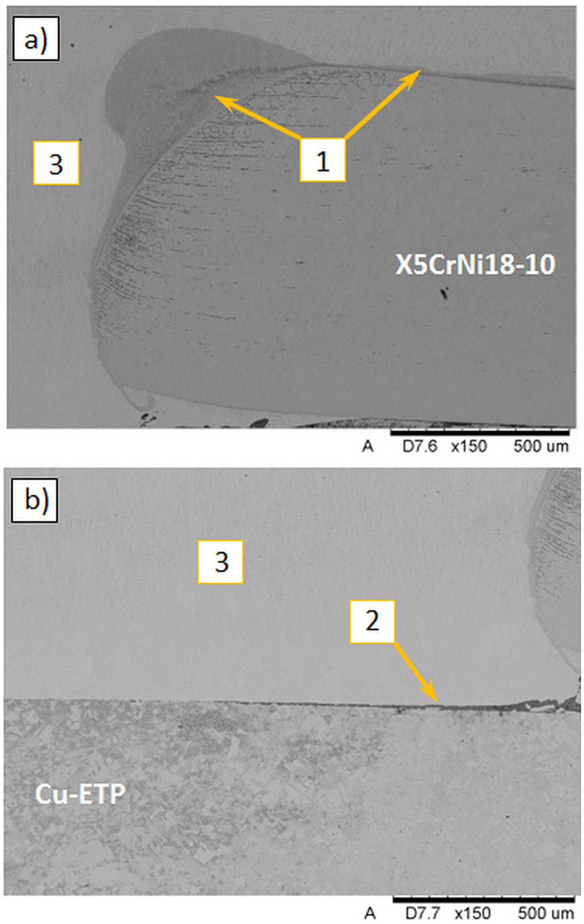

Fig. 3. Microstructure of steel-copper configuration overlap joint in argon shield: 1 – reaction zone, 2 – cracks, 3 – brazeweld

result in the cracking of joints, particularly those of a diffusive character, created without mixing of the materials.

Melting of austenitic steel results in numerous spherical steel inclusions (1) in the joint, of a small diameter (Fig. 4). Melting of copper from the solder (2) in the structure of austenitic steel can be more dangerous and cause more serious consequences, because when relevant concentrations are reached, it may result in stress corrosion cracking and hot cracks in steel. In the discussed case, copper from the solder melts only in the reaction zone and does not penetrate into the structure of the steel and this is confirmed by the linear EDS analysis (Fig. 5). To facilitate analysis, the elements distribution (EDS) in the joint was limited to only two main components (Cu and Fe).

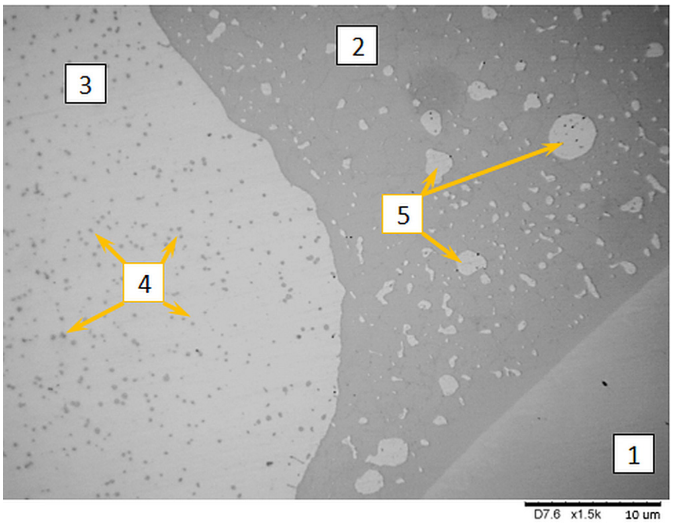

Fig. 4. Microstructure of steel-copper configuration overlap joint in argon shield: 1 – austenitic steel, 2 – reaction zone, 3 – brazeweld, 4 – steel inclusions in the brazeweld, 5 – copper inclusions in the reaction zone

The case in which the copper from the solder diffuses along the edge of the austenite grains causing hot cracks in the steel was described in the report [4,19] and shown in (Fig. 6). The mechanism underlying the formation of hot cracks depends on the diverse speed of heat dissipation from the joint through the joined materials. In the case described, the joints were made in the butt formation and the much faster rate of heat transfer through the copper sheet led to the development of tensile tensions in austenitic steel, enabling solder to migrate to the edge of the grains and, in consequence, resulted in the formation of hot cracks. These cracks appeared solely under the braze welded joint and were not observed in the material not wetted by the solder. Due to the overlapping arrangement of the joint, the steel is outside the area of tensions supporting the solder diffusion along the edge of the austenite grains, despite the different rate of heat dissipation by both materials.

In the braze welded joint of the same material configuration, in which helium was used as the shielding gas, in the braze welded joint (3) there were single large inclusions of a larger size and a reaction zone (4) along the edge of the steel sheet apart from small steel inclusions (5) (Fig. 7). These inclusions

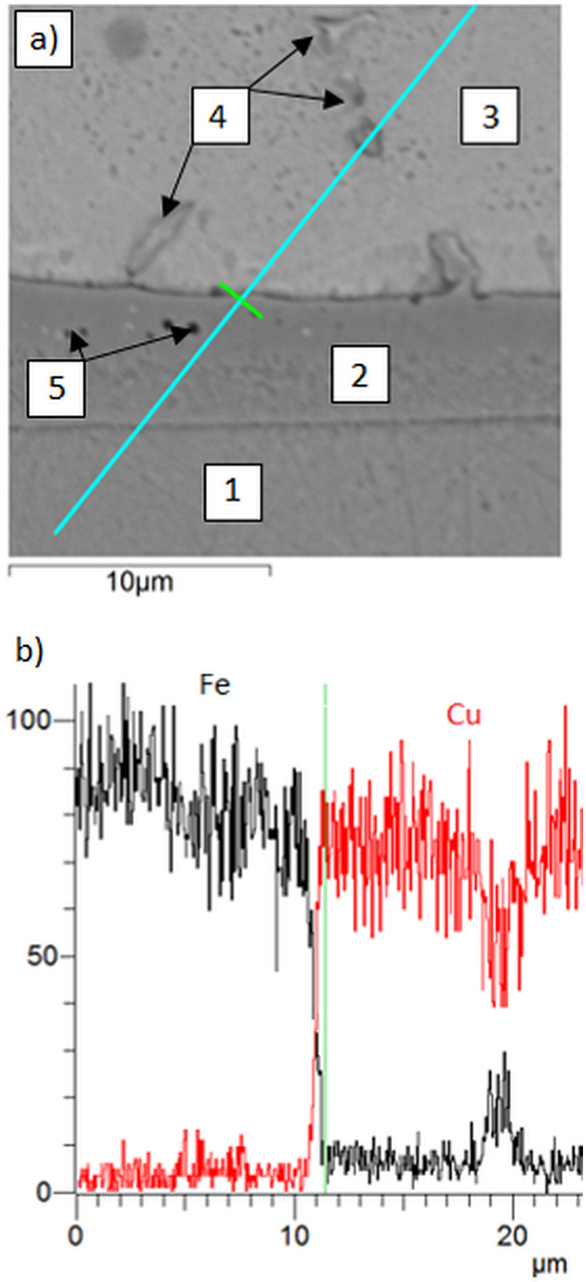

Fig. 5. SEM image with decomposition of EDS elements in steel-copper configuration overlap joint in argon shield: 1 – austenitic steel, 2 – reaction zone, 3 – brazeweld, 4 – steel separation, 5 – copper separations

are found only in the upper part of the braze welded joint (grey zones) above and on the left side of the steel sheet (1). The main difference is seen in copper (2), in the which penetration is visible along the whole width of the braze welded joint of the greatest depth (0.5 mm) in its middle part. Taking into account the great chemical identity between the solder and the substrate material – copper, the reaction zone at the edge between copper and the braze weld is not formed, only the mutual welding of the alloy components. Similarly as when argon is used as the shielding gas, copper from the solder is found only in the reaction zone in the form of inclusions of an irregular shape and does not penetrate into steel along the edge of austenite grains, limiting to the minimum the risk of developing hot cracks in it.

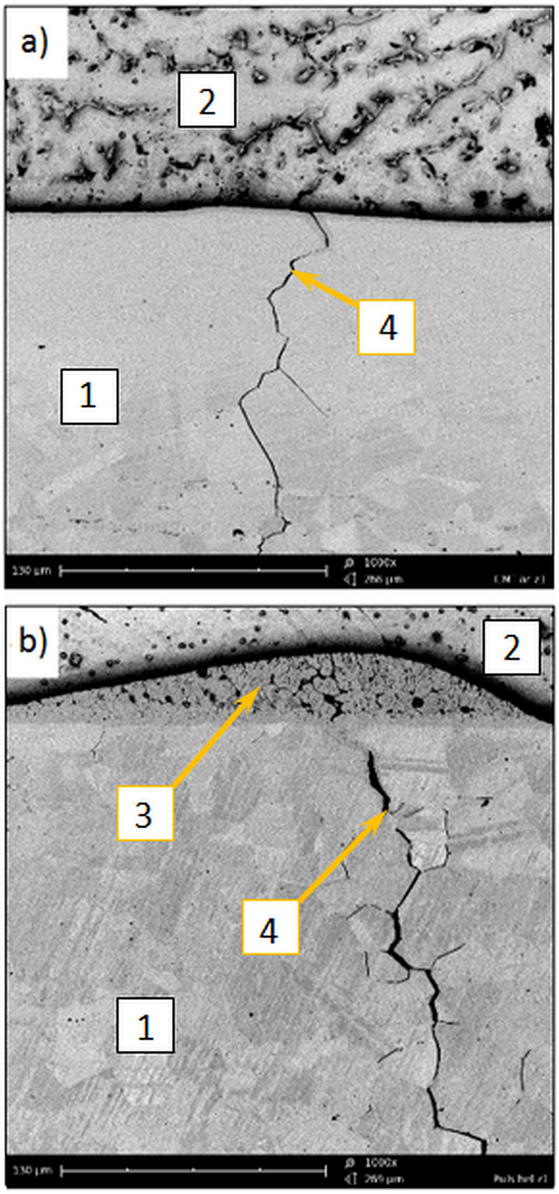

Fig. 6. Microstructure of butt joints cupper witch austenitic steel viewed in SEM microscopy: 1 – austenitic steel, 2 – brezeweld, 3 – reaction zone, 4 – intercritical cracks (×1000)

A change in the material configuration had an advantageous influence on the joint appearance, because a flat face was achieved, which did not reach above the top sheet – in this case – a copper sheet. In macroscopic photographs, the melting of the steel sheet (1) in the argon shield was not visible. However, microscopic examinations showed that the steel sheet was slightly melted along the entire width of the braze welded joint (Fig. 8b). The width of the reaction zone formed (4) was 5÷8 μm. In consequence, there were small spherical inclusions of austenitic steel (5) in the braze welded structure. The copper shield was melted only on the butt surface (Fig. 8c) with the penetration line visible (8). Also in this case, copper from the solder did not penetrate into steel along the edge of the austenite grains (Fig. 8d).

A change of the shielding gas to helium in the discussed joint configuration resulted in a significant increase in the amount

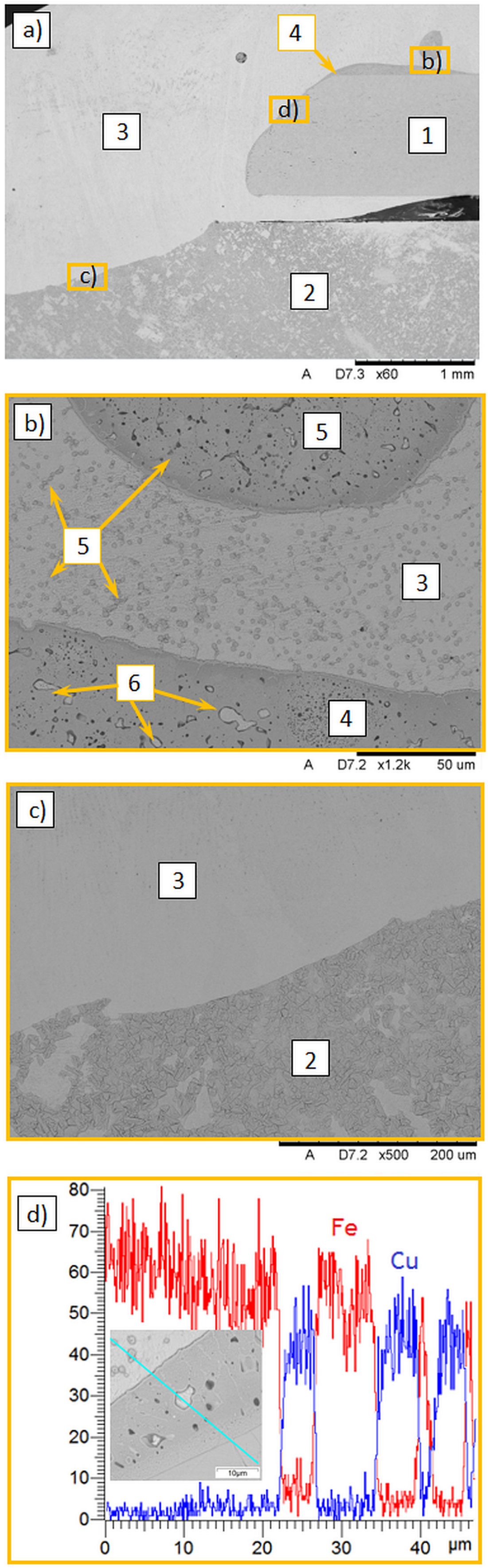

Fig. 7. Microstructure of steel-copper configuration overlap joint in helium shield (a,b,c) and decomposition of EDS elements (d): 1 – austenitic steel, 2 – copper, 3 – brazeweld, 4 – reaction zone, 5 – steel inclusions in the brazeweld, 6 – copper inclusions in the reaction zone

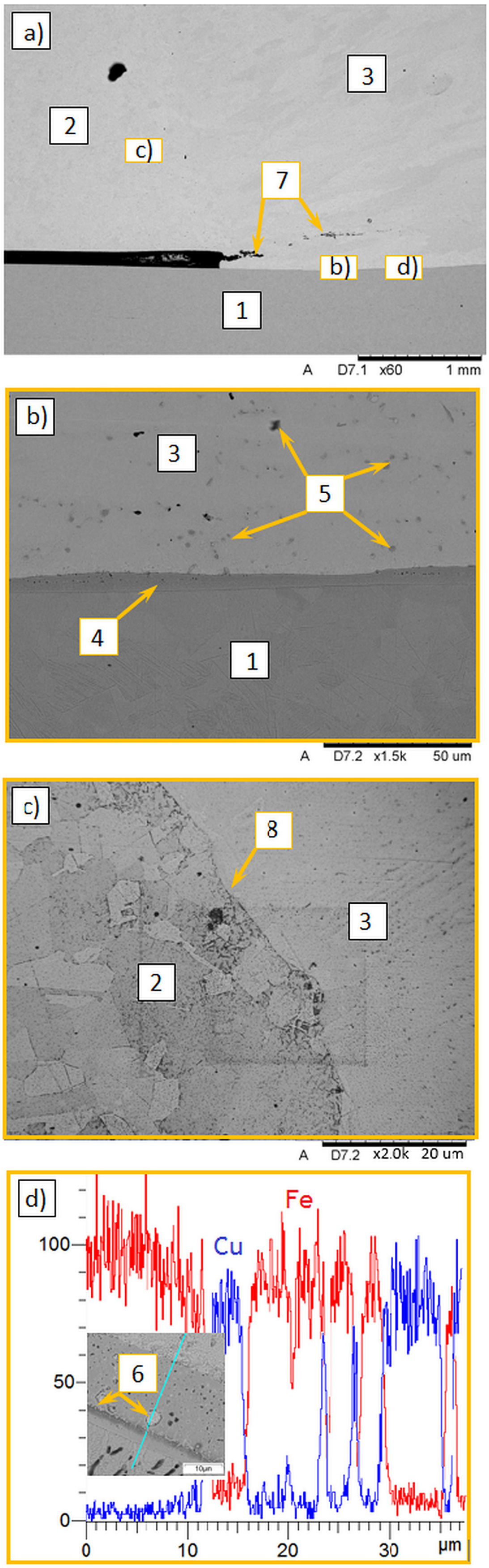

Fig. 8. Microstructure of copper-steel configuration overlap joint in argon shield (a,b,c) and decomposition of EDS elements (d): 1 – austenitic steel, 2 – copper, 3 – brazeweld, 4 – reaction zone, 5 – steel inclusions in the brazeweld, 6 – copper inclusions in the reaction zone, 7 – porosity, 8 – fusion line in copper

of heat present in the braze welding zone and this had a negative influence on its quality at a macroscopic level. The larger amount of heat resulted in penetration into the steel sheet in the middle part of the braze welded joint (Fig. 9). In the copper part, which dissipates the heat from the joint well, penetration into the steel sheet is negligible and progresses with a distance from the copper sheet. The influence of the increased temperature is also visible in the structure of the braze welded joint, in which numerous larger steel inclusions, frequently of irregular shape are found besides small steel inclusions. The width of the reaction zone is also much larger than for argon and ranges from 35 to 50 µm.

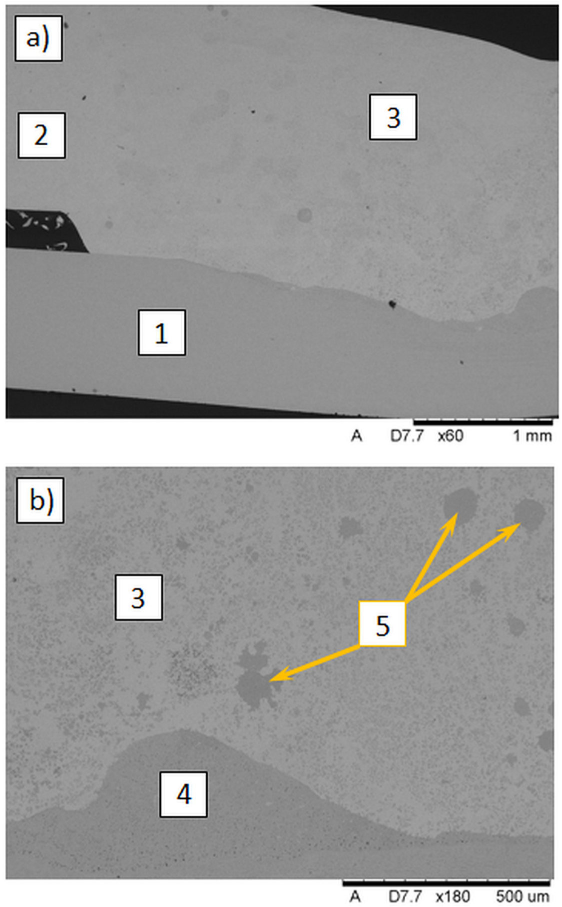

Fig. 9. Microstructure of copper-steel configuration overlap joint in helium shield (a,b): 1 – austenitic steel, 2 – copper, 3 – brazeweld, 4 – reaction zone, 5 – steel inclusions in the brazeweld

The irregular, dendrite-like shape of the steel inclusions may indicate that they started to melt in the braze welded joint due to a greater amount of heat. The distribution of elements, EDS, is characteristic for the analysed parts (Fig. 10).

3.2. Mechanical properties of brazewelded joints

Samples for the static shear test were prepared in accordance with the guidelines of EN ISO 4136:2013-05. The 25 mm-wide samples were routed in the measured part to 12 mm. The static shear test for braze welded overlapping joints was conducted

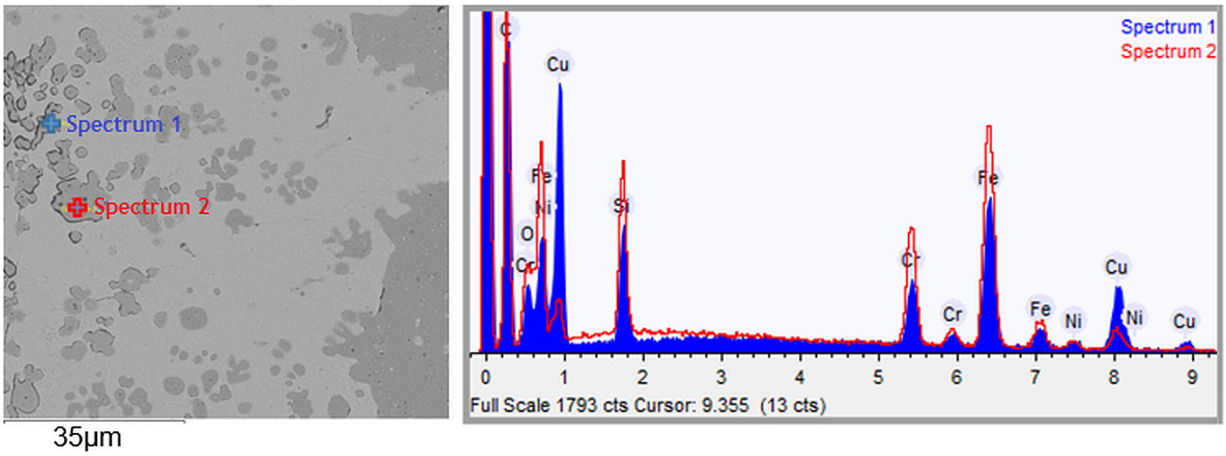

Fig. 10. SEM image with EDS spectra of the elemental composition in brazeweld joint made in a helium shild in a copper-steel configuration

on a standard tensile test machine with a hydraulic drive. To ensure the greatest possible measurement precision, the measuring range was set to 10 kN (measurement precision 50 N) and the transverse beam moving speed was set to 0.2 cm/min. The obtained results are shown in the chart (Fig. 11). Three sets of samples were prepared for each group of joints made for the process variables under analysis. All samples apart from joints made in the configuration in which austenitic steel was placed on copper, made in the argon shield, were destroyed on the side of copper in the heat influence zone (HIZ). For these joints, the elongation strength was calculated. The above-mentioned joints in the steel-copper arrangement in the argon shield were destroyed at the braze welded joint – it was detached from the copper substrate. However, it was possible to define the joint surface, which was determined in the DP-Soft Olympus application with a planimetry function. For these joints, the shear strength was calculated.

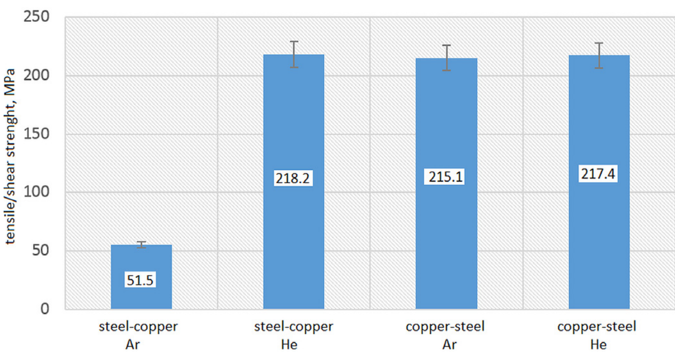

Fig. 11. Mechanical strenght of brazewelded overlap joints

Figure 12 shows examples of cross-sections of the braze welded joints in which the damage occurred in the substrate materials – HIZ on the copper side. In these cases, the joint strength exceeds the strength of the material of lower mechanical properties.

The joints made in the steel-copper configuration shielded in argon demonstrated characteristics of the soldered joints, in which the connection between the solder and copper was created due to wetting and diffusion. For this reason, the mechanism of the joint destruction was adhesive – the braze welded joint was detached from the substrate in the reaction zone on copper (Fig. 13).

Joints of austenitic steel and copper of similar mechanical strength, which are destroyed outside the joint in the substrate material, may also be obtained by using the friction thermal sealing or explosion welding [1], brazing with flux using solders in silver [1], laser welding [1,3], welding with TIG method using solders Cu Ni-Cu-Fe [1,5] and laser soldering using Ni-Cu solders [22]. It is also possible to braze without flux, using solders based on Cu-P (e.g., CP 102), so-called "phosphor bronzes". Joints of this type are used in the construction of stator coils for high-power generators, in which brazing with fluxes is not recommended due to problems with removing flux slag. However, obtaining durable joints of a strength exceeding the strength of copper depends on an application of a Ni + Cu intermediate layer on the austenitic steel surface with a galvanic method [1,2]. Otherwise, intermetallic phases of the Fe2P and Ni2P exhibiting high hardness values (above 350 HV) develop at the edge of the joint with steel, causing brittle cracks of the brazed joints and the generator failure [1].

Microhardness measurements were also conducted using guidelines included in ISO 6507-1:2018, using a stationary hardness tester Sinowon HVS 1000 enabling measurements with the penetrator loading ranging from 10 to 1000 G. On the basis of the initial measurements, the measuring load was set to 100 G. Microhardness measurements were conducted along two measuring lines, covering all zones of the braze welded joints, i.e. substrate materials, HIZ and the braze welded joint. In each zone, at least 5 measurements were conducted. The measurement line L1 run from austenitic steel to the braze welded joint and the L2 line run from copper to the braze welded joint.

During the measurements, certain regularities were observed, that is, there were no clear differences in the hardness of the substrate materials in their individual zones, as it is seen in the welded joint, in which the difference between the hardness of HIZ and the hardness of the substrate material is usually significant. Regardless of the joint configuration and the type of the shielding gas, a slight increase in hardness in HIZ, by

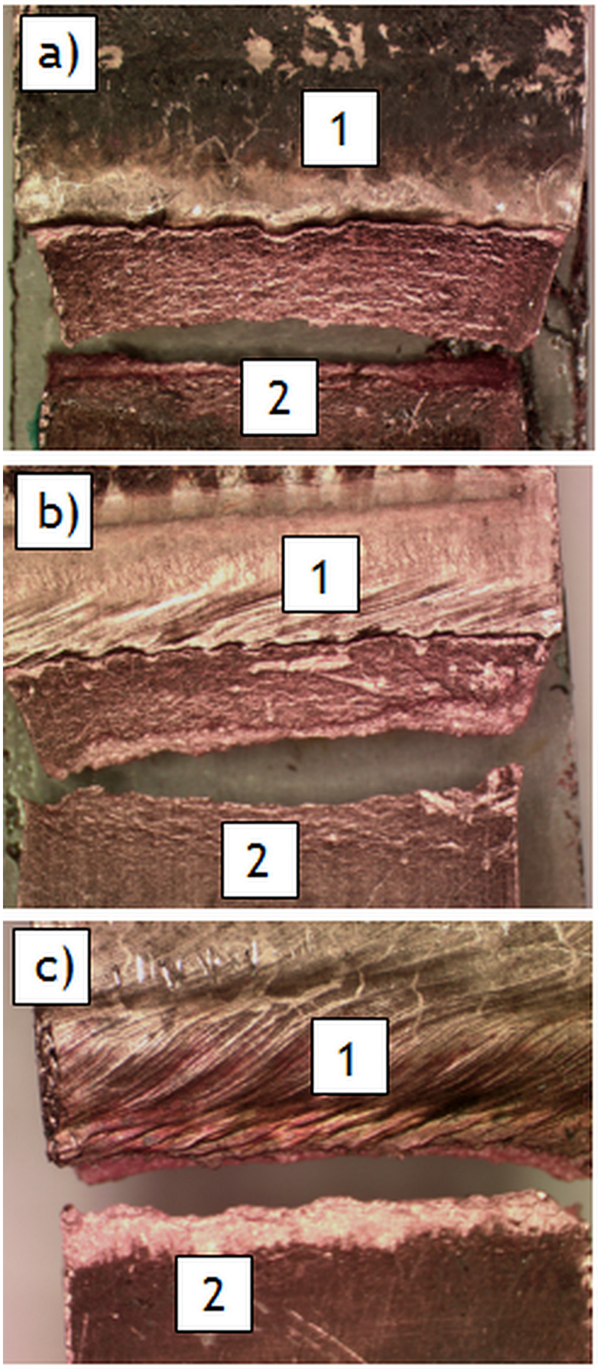

Fig. 12. Examples of breakthroughs of austenitic steel brazewelded joints with copper: a joint in a steel – copper system in helium shield (a), joints in a copper – steel system in argon (b) and helium (c) shield; 1 – brazeweld, 2 – copper Cu-ETP

4 HV0.1 was visible in austenitic steel, while for copper in that zone a slight decrease was observed, by 5 HV0.1 on average. More pronounced differences are seen in the braze welded joint itself, where zones of various hardness are observed and this situation is also influenced by the type of the shielding gas. Regardless of the joint configuration, the braze welded joints can be divided into two zones – the zone near copper and the zone near austenitic steel. In each analysed case, hardness is higher in the zone near steel by 10 HV0.1 on average. Depending on the shielding gas, hardness in the braze welded joint is different

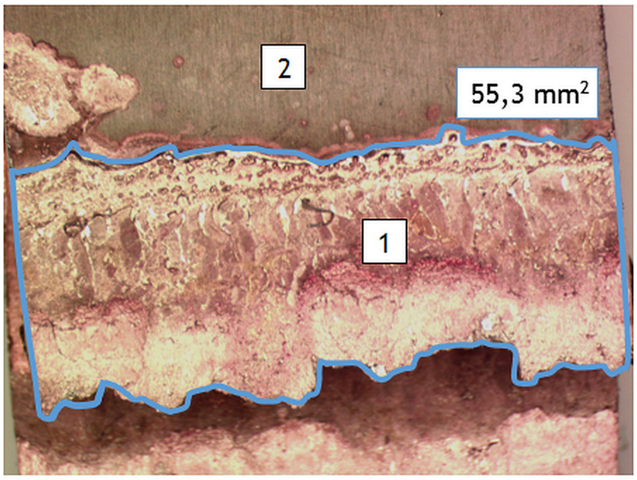

Fig. 13. Example of a breakthrough of a brazewelded joint in a steel – copper system in an argon shield; 1 – surface at the breakthrough point in the diffusion zone on copper, 2 – copper Cu-ETP

and ranges from 101 to 118 HV0.1 for argon and from 117 to 141 HV0.1 for helium. These differences result from the number of austenitic steel inclusions in the braze welded joint, with their number significantly higher in joints made in the helium shield, due to large quantities of heat introduced into the joint. To emphasise these differences, a chart was drawn presenting the influence of the type of the shielding gas and the joint configuration on hardness in the braze welded joint (Fig. 14).

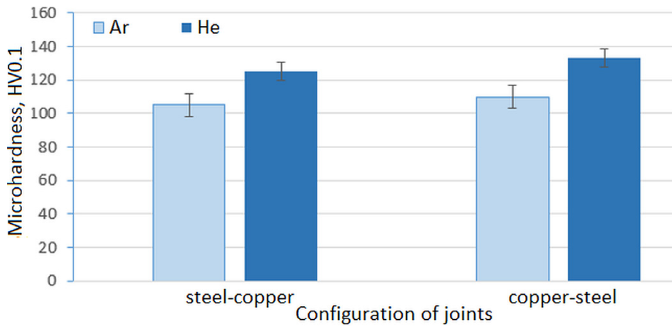

Fig. 14. Microhardness in brazeweld depending on the configuration of the joints and the type of gas shield

4. Conclusions

The use of the low-energy CMT method for braze welding of X5CrNi18-10 austenitic steel with Cu-ETP copper allows obtaining joints of good quality, good appearance and without splatters. The joint esthetics depends mainly on the joint configuration. A more advantageous solution is an arrangement where the copper sheet is placed on the austenitic steel sheet. This way, the braze welded joint with a flat face can be obtained, regardless of the shielding gas. The type of the shielding gas (Ar, He) significantly influences the quantities of heat introduced into the joint. Much more heat is generated in the helium shield and even though the speed of braze welding is greater, the solder penetrated into both joined substrates. This also influences the structure of the braze welded joint obtained, in which the quantity of melted austenitic steel inclusions is greater than in argon. Mechanical properties (hardness, strength) are similar, regardless of the above-mentioned process variables. The braze welded joint was only destroyed in the steel-copper joints made in the argon shield. The strength of these joints was over four times lower than in other cases and amounted to 51.5 MPa on average. In other cases, the substrate material of weaker mechanical properties was destroyed, i.e. Cu-ETP copper. The microhardness distribution in all joints was similar, the only noticeable differences were observed in the braze welded joint, which hardness depended mainly on the number and the distribution of the austenitic steel inclusions, which, in turn, depended on the type of the shielding gas. In consequence, the hardness was higher by ca. 20 HV0.1 in joints made in the helium shield.

Acknowledgments

The authors would like to thank the ASTOR and FRONIUS companies for providing the components of the robotic CMT welding station (Fig. 15) and great help in its construction.

Fig. 15. Robotic welding station for CMT process assembled of Kawasaki BA006 welding robot and Fronius TransPuls Synergic 3200 welder with equipment

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