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The Development of a Technology for the Welding of Dissimilar Joints of Copper and Austenitic Steel

Abstract: Welded joints made of copper alloys and austenitic steels are commonly used in heat exchangers, pipelines and other equipment typical of the power industry. The above-named materials are difficult to weld because of their varying thermal properties. The obtainment of proper welded joints necessitates the performance of tests aimed to develop a technology enabling the welding of copper and austenitic steels. This article provides insight into research dedicated to the development of a TIG welding-based technology enabling the joining of copper and austenitic steel.

Keywords: technology for the welding, dissimilar joints, TIG

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Introduction

Because of their favourable thermal conductivity, excellent corrosion resistance and high ductility, copper alloys are widely used as a heat conductor in the chemical, metallurgical, power, aviation and defence industries [1–4]. However, the low strength combined with the high thermal expansion of copper and its alloys restrict their application in a number of industrial solutions. For this reason, the joining of copper with high-strength alloys (e.g. austenitic steels) enjoys significant interest among researchers. Bimetallic joints of steel and copper are widely used in heat exchangers in the nuclear and power industries. Both electron beam welding and conventional arc welding processes have been used by researchers to obtain dissimilar joints of copper and steel [5–8]. The primary difficulty encountered when welding copper and steel is the enormous difference between the thermal properties of these materials, i.e. thermal expansion and thermal conductivity. The higher thermal conductivity of copper is responsible for the dissipation of heat from the welding area. In addition, the different thermal expansion coefficient results in different shrinkage during cooling. The foregoing leads to the generation of residual stresses and, consequently, to the formation of cracks in the welded joint. For this reason, it is particularly important to control both the heating and cooling processes in order to obtain dissimilar joints free from welding imperfections. In addition, differences concerning metallurgical properties affect the joining of these two materials both in the solid and liquid state. In the liquid phase (due to metallurgical differences), the materials tend to separate, which leads to copper inclusions and hot cracking [1, 3, 9].

Research problem

The authors made an attempt to identify possible reasons responsible for the formation of cracks in the welded joints of a nozzle made of a copper element joined with high-alloy austenitic steel as well as to develop a welding technology minimising the possibility of crack formation. According to available information, the above-mentioned cracks are formed during the reheating of the element taking place in the brazing process (constituting the subsequent stage of the fabrication of the aforesaid element).

The initial tests involved two welded joints. One of the joints was subjected to annealing aimed to obtain temperature conditions accompanying the brazing process. Figure 1 presents the welded elements. The authors were not in possession of detailed information concerning the base materials

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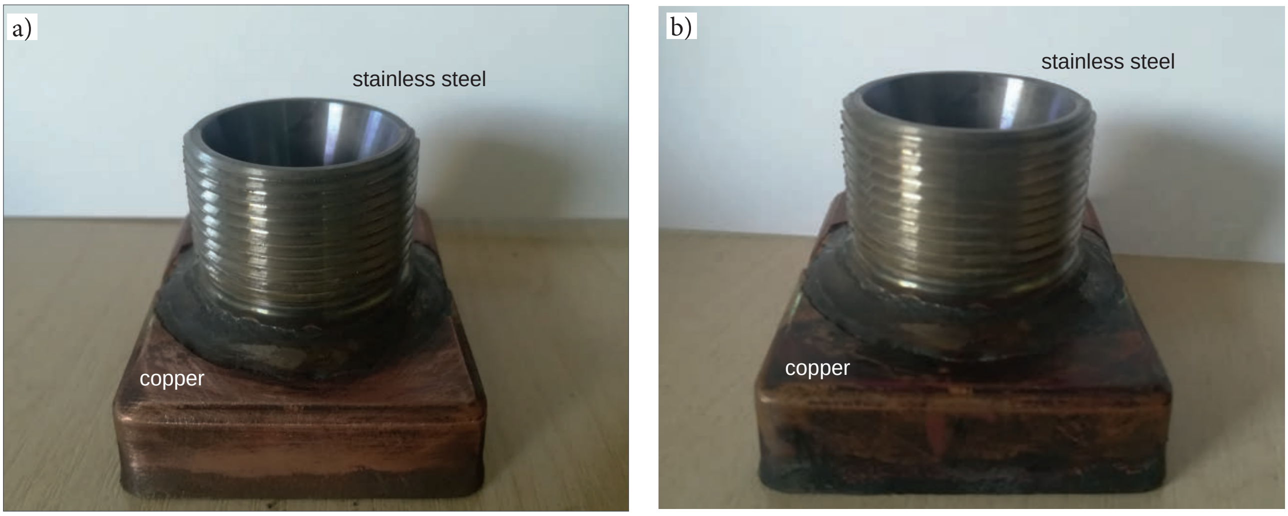

Fig. 1. Test joints: (a) specimen after annealing and (b) specimen after welding, not subjected to annealing

and the filler metal used in the welding process. Elements made of deoxidised copper CW008A (having external dimensions 65 mm × 31 mm and constituting the base of the nozzle) had a hole having a diameter of 38 mm. The hole was used for placing a sleeve made of austenitic steel X3CrNiMo17-12-2, which was subsequently welded to the elements using the TIG welding method.

Objective and scope of tests

The tests discussed in the article aimed to identify possible reasons for the formation of cracks in welded joints of copper elements and austenitic steel as well as to develop a technology enabling the obtainment of crack-free joints.

The scope of the tests included the following activities:

- performance of visual test of welded joints and the identification of crack initiation areas,
- making 5 tests joints using two different filler metals and the TIG welding method,
- performance of macro and microscopic metallographic tests,
- performance of leak tests of the joints,
- making 10 test joints (5 in each technology) and providing them to the ordering party to perform brazing under production conditions.

Tests and results

One of the specimens was subjected to annealing (performed in a vacuum furnace) at a temperature typical of the production brazing process, i.e. restricted within the range of approximately 680°C to 700°C. The annealing process was carried out to precisely identify areas containing cracks in the joints (made of austenitic steel and copper). Afterwards, the specimens were subjected to penetrant and visual tests. The identification of the structure and geometry of the weld necessitated the preparation of metallographic specimens subjected to macroscopic tests. The macroscopic test results are presented in item 4a.

The tests of the joints (performed at the Welding Centre) were followed by the development of a TIG welding method-based technology and the making of 5 test joints (using nozzle elements supplied by the ordering party). The test joints were made using two types of filler metals (discussed in item 4b). The welding process parameters were adjusted taking into account experience, information contained in reference publications and observations during the initial welding tests.

Tests of welded joints

The visual tests of the joints revealed that the shape and size of the weld indicated the proper performance of the welding process (manifested by the lack of cracks on the weld face side).

The penetrant tests involving the specimen subjected to post-weld heat treatment and the specimen not subjected to annealing did not reveal the presence of cracks or discontinuities in the welded joint.

The results of the macrostructural tests involving the specimens provided by the producer (ordering party) are presented in Fig. 2 a-d.

In both cases it was possible to observe the clearly visible lack of penetration in the weld root (the area of contact between the copper element and the element made of austenitic steel). Such a situation

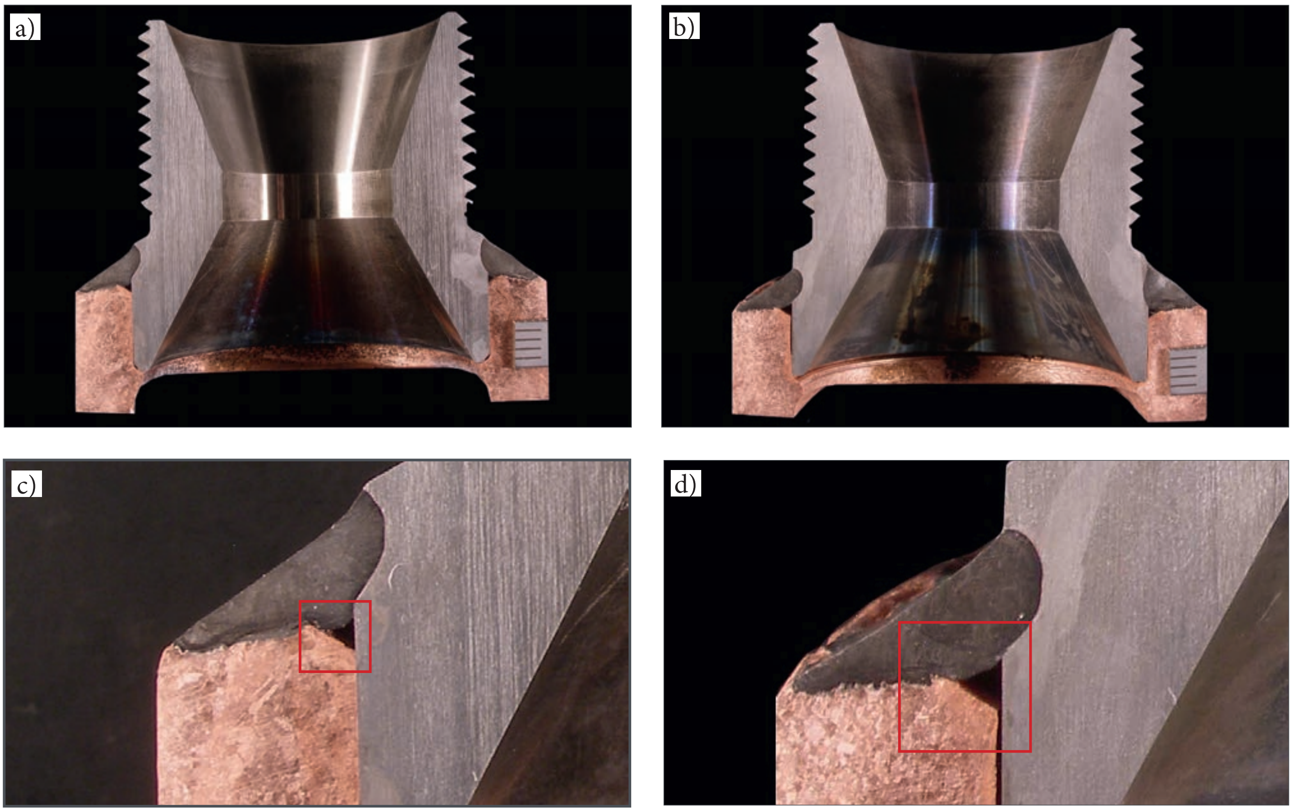

Fig. 2. Macrostructure of the test joints: not subjected to annealing (a, c), subjected to annealing for 30 minutes at temperature restricted within the range of approximately 680°C to 700°C (n/a)

was probably triggered by the insufficient wetting of the copper element during the welding process (excessively high filler metal wire feed rate) or the excessively long distance between the welding torch and the elements being welded (responsible for the reduction of arc concentration). Another reason for the lack of penetration in the weld root could be the performance of bevelling at the edge of the copper element.

The lack of information concerned with welding parameters (not provided by the ordering party) necessitated the performance of technological tests enabling the adjustment of appropriate process parameters. The subsequent stage involved the making of five test joints, three of which were subjected to annealing at the temperature corresponding to that applied during the brazing process.

Technological tests

Information contained in reference publications and that included in instructions provided by filler metal producers was used during the welding of the elements made of austenitic steel with the copper elements. The two filler metals used in the welding test were LNT NiCro 70/19 (nickel-chromium filler metal) and LNT NiTi (titanium-stabilised nickel filler metal). The shielding gas used in the process was the Argon-Hel 50/50 mixture (ALULINE He50, ISO 14175-I3-ArHe-50). The designation and the chemical composition of the filler metals are presented in Table 1.

The technological tests involved the making of five test joints and the adjustment of welding process parameters enabling the obtainment of quality level B in accordance with the PN-EN ISO 5817

Table 1. Designation and the chemical composition of the filler metals used in the technological tests

Filler metal	Chemical composition of the weld deposit according to the data provided by the producer, % by weight							
	C	Si	Mn	Cr /Ti	Ni	Nb	Cu	Fe
LNT NiCro 70/19, AWS 15 14(M)-97 ER NiCr-3, EN 18274-01, S Ni 6082, Lincoln	0.03	0.2	3.0	20 (Cr)	bal.	2.5	0.1	1.0
LNT/LNM NiTi, AWS A5.14(M)-97: ERNi-1 ISC 18274-01: S Ni2061, Lincoln	0.02	0.2	0.4	3.1 (Ti)	96.2	-	-	0.06

Table 2. Welding process parameters

Spec. no.	Preheating temperature, °C	Current, A	Voltage, V	Shielding gas flow rate, l/min	Welding rate, cm/min
I-1	not applied	140-155	16-17	12	2.83
I-2	600	140-155	16-17	12	2.57
I-3	650	145-160	16-18	12	2.63
II-1	600	140-160	16-17	12	2.52
II-2	650	145-165	16-18	12	2.62

standard. The element made of copper were prepared without the technological phase. The analysis revealed that the preheating of the copper element to temperature restricted within the range of 600°C to 650°C positively affected the welding process (by providing higher arc stability and the better wetting of the base material with the liquid metal).

The research work involved the making of five TIG-welded joints in the following configuration:

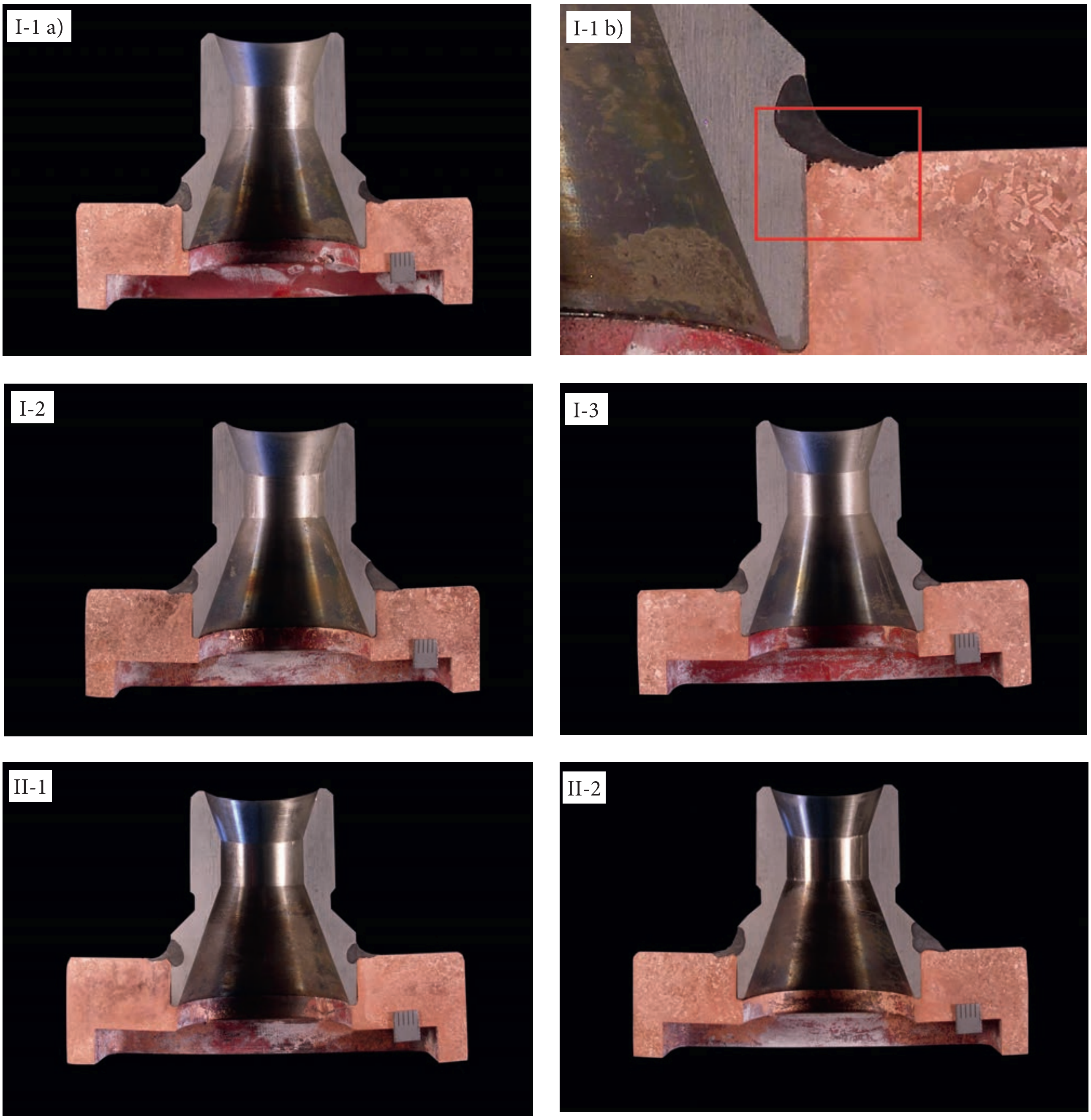

Fig. 3. Macrostructures of the welded joints made using two types of filler metals: I-1 (a, b), I-2, I-3 –NiCro and II-1, II-2 – Ni-Ti

- 3 joints made using filler metal LNT NiCro 70/19 (1.2 mm) – designated I-1, I-2 and I-3
- 2 joints made using filler metal LNT/LNM NiTi (2 mm) – designated II-1 and II-2.

The technological welding parameters are presented in Table 2.

All the joints were held at a temperature of 670°C for 30 minutes.

Macro and microscopic metallographic tests

The joints were sampled for metallographic specimens used in subsequently performed macro and microscopic tests. Figure 3 presents the macrostructure of the welded joints made using the parameters presented in Table 2.

The macroscopic test results revealed that the lack of copper preheating resulted in the lack of

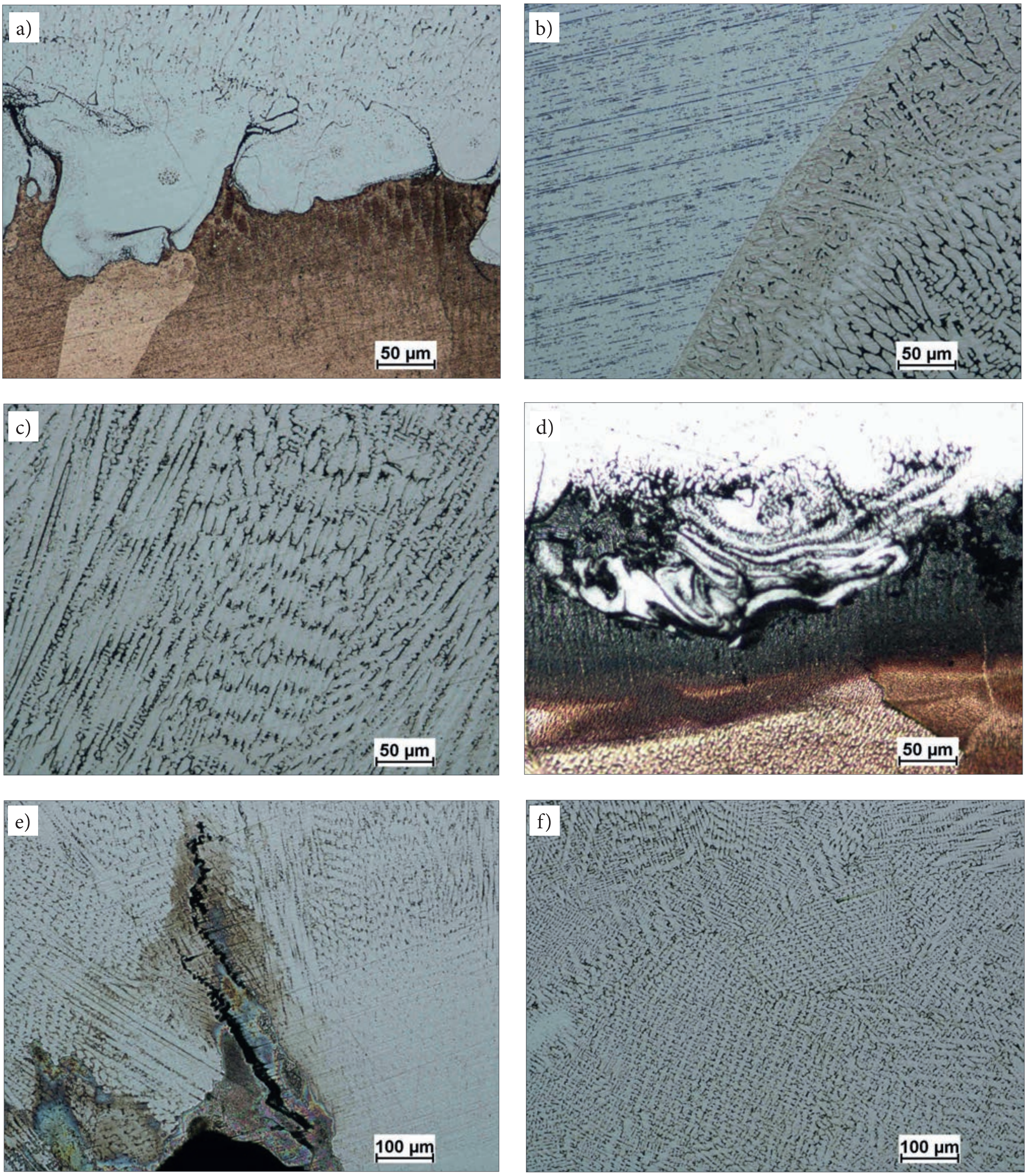

Fig. 4. Microscopic test results – fusion line on the copper side of the weld made using filler metal NiTi (a), filler metal fusion line on the austenitic steel side (b), structure of the weld made using filler metal LNT NiCro (c), structure of the fusion line in the copper material (d), fusion line in the austenitic steel material (e) and structure of the weld made using filler metal LNT NiTi (f)

penetration on the weld root side. The macroscopic analysis of the joints made under conditions and using parameters presented in items 2-5 of Table 2 revealed (both in relation to filler metal NiCro and NiTi) that the application of preheating performed at temperature restricted within the range of 600°C to 650°C enabled the obtainment of proper metallurgical joints of copper and austenitic steel.

The subsequent stage involved the performance of microscopic metallographic tests aimed to identify the structure of the joints and determine whether the interphase boundary contained (if any) intercrystalline phase precipitates, inclusions or cracks. The above-named tests involved the use of an Eclipse MA-200 optical microscope (Nikon). The specimens were subjected to etching in Nital. The structural observations included the weld, base material and the fusion line.

The microscopic tests of joint II-2 (LNT NiTi) did not reveal the presence of imperfections in the welded joints of austenitic steel and copper. The structures of the individual areas were typical of the material configuration subjected to the tests. The grain boundary did not contain precipitates of intermetallic phases. The weld structure did not contain any porosity or traces of material discontinuity, which indicated the appropriate performance of the test as well as the proper adjustment of process parameters and the selection of technological welding conditions.

In the welded joints made using filler metal LNT NiCro 70/19, the HAZ of the copper element contained dark phase precipitates. In turn, the above-named precipitates contained numerous microcracks, which, when triggered by thermal stresses, could propagate and eventually lead to the joint failure (Fig. 4d). In addition, the weld made using the above-named filler metal contained cracks disqualifying the welded joint (Fig. 4e).

Summary

The above-presented tests and results revealed that the key operation during the welding of copper and stainless steel was the preheating of stainless steel up to temperature restricted within the range of 600°C to 650°C. Such preheating aimed to reduce the rate of heat discharge from the material, which enabled the obtainment of proper penetration in the copper material.

In order to minimise the formation of such imperfections as the lack of penetration in the weld root it is recommended to minimise the height of the phase of copper elements.

The filler metal appropriate for the joints made of austenitic steel and copper was filler metal LNT NiTi. The use of filler metal LNT NiCro 70/19 was responsible for the formation of precipitates in the fusion line of the copper material (Fig. 4d).

The technologies developed in order to weld the nozzles (provided by the manufacturer) enabled the making of 10 test elements (5 in each technology), which were subsequently transferred for further tests under production conditions.

Conclusions

1. The tests revealed that the welding of deoxidised copper with steel X3CrNiMo17-12-2 required a special approach to the welding technology as regards the selection of filler metals and the adjustment of preheating temperature.
2. The obtainment of appropriate penetration required the preheating of the copper elements up to a temperature of approximately 600°C.
3. The test materials discussed in the article could be welded using the TIG method, yet the process must be performed under rigorous and repeatable welding conditions.

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