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The Development of a Technology for the Conventional Welding of Butt Joints (of Membrane Walls) of Composite Tubes

Abstract: The article presents results of tests leading to the development of a technology enabling the welding and conventional cladding (methods 141/111) of butt joints of composite tubes made of Sanicro 38/4L7 (nickel alloy/carbon steel) and 3R12/4L7 (stainless steel/carbon steel). In addition, the article discusses process parameters used in the welding of the inner layer and in the cladding of the outer layer of the tube made of Sanicro 38 and 3R12. The article also presents results of macro and microscopic metallographic tests of the joints.

Keywords: butt joints, membrane walls, conventional cladding

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Introduction

The development of industry necessitates the improvement of operating parameters of power equipment and its operational safety. Such a situation imposes the application of new material grades and technological solutions (e.g. joining methods), the use of which was previously uneconomical and, hence, not put in place. Increasingly many companies wishing to remain in the market and participate in new investments pay particular attention to the application and implementation of advanced welding technologies.

Important components of power units such as screens of membrane walls (flat bar – tube – flat bar) are exposed to highly unfavourable operating conditions including erosion, corrosion, high temperature and high pressure. For this reason, the design and construction of new power units involves solutions aimed to extend the permissible operation of power equipment. An important role is played by coatings deposited on the surface of tubes through metallisation, cladding with materials containing nickel (Ni) and chromium (Cr). Another applicable solution involves the use of composite (two-layer) tubing.

Composite tubes 38/4L7 (P265GH/alloy 825) and 3R12/4L7 (P265GH/X2CrNi18-10) are applied in soda recovery boilers (used in papermills), incinerating plants or conventional (coal, gas or biomass-fired) power plants. One of the conditions ensuring the proper operation of such systems involves maintaining the leaktightness of the pressurised part of the boiler as leaks (if any) could lead to explosion and damage affecting power equipment beyond repair. The use of composite tubing reduces the failure frequency of power units, thus enabling the extension of continuous exploitation periods (period between repair downtimes).

The article presents selected results of (destructive and non-destructive) tests performed in order to develop a technology which would enable the conventional welding (methods 141/111 in accordance with EN ISO 4063) of composite tubes made of steel Sanicro38/4L7 and 3R12/4L7, [1–3, 14–16]. The technology was developed in order to fix membrane wall panels in soda recovery boilers.

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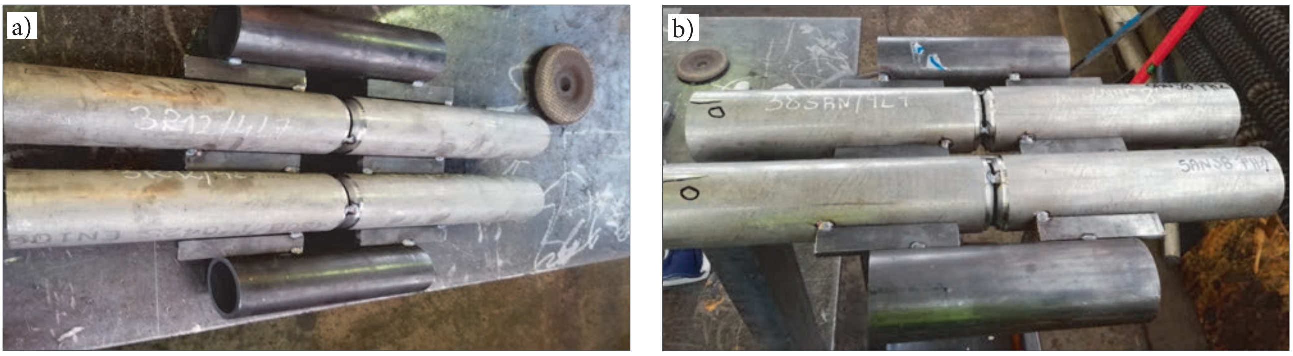

Fig. 1. Preparation of the specimens for welding – butt welds of tubes with flat bars (membrane wall simulation): a) tubes 3R12/4L7 and b) tubes Sanicro 38/4L7

Test materials

The tests involved the use of composite tubes Sanicro 38/4L7 and 3R12/4L7 having dimensions of 63.5 mm (ø) × 6.53 mm (wall thickness) and 150 mm (length) (Sandvik). The manner of pre-weld specimen preparation is presented in Figure 1. The specimens involved the butt welding process (of the tubes) along with additional stiffening (resulting from the presence of flat bars). The chemical composition of the tube material is presented in Tables 1 and 2.

Pre-weld preparation of specimens

The preparation of specimens for the welding process (method 141/111) included the mechanical removal of the outer layer of the coating material (3R12, Sanicro 38) to the substrate surface. The specimens were cut into 150 mm long segments using a band cutting machine (Bianco). The specimens were also subjected to treatment involving the use of a lathe (in order to obtain a total bevel angle of 30° and a groove angle of 60°).

The shape and geometrical dimensions of the joint are presented in Figure 2. The edge preparation manner enabled the making of welds within the area of the material of tube P265GH and the outer layer (3R12 or Sanicro 38).

Testing methodology and test rig

The welding process was performed in two stages. During the first stage, the inner layer of the tube (4L7) was welded using method 141 and filler metal wire DMO-IG (Bohler), obtaining the butt weld with full penetration (Fig. 3a). The second stage involved the cladding of the outer layer performed using method 111 as well as filler metals having the form of rutile electrodes Cromarod 309 MoL (outer layer of tube 3R12/4L7) and Cromarod 383 (outer layer of tube Sanicro38/4L7) (Fig. 3b).

Table 1. Chemical composition of composite tube Sanicro 38/4L7, % by weight [2]

	C	Si	Mn	Cr	Ni	Mo	Cu	Ti
Inner layer 4L7 (P265GH)	0.18	0.30	0.69	0.14	0.25	0.04	0.030	0.005
Outer layer Sanicro 38 (Alloy 825)	0.012	0.15	0.47	19.92	38.24	2.57	1.61	0.75

Table 2. Chemical composition of composite tube 3R12/4L7, % by weight [3]

	C	Si	Mn	Cr	Ni	Mo	Cu	Ti
Inner layer 4L7 (P265GH)	0.18	0.31	0.69	0.13	0.07	0.01	0.022	0.005
Outer layer 3R12 (X2CrNi18-10)	0.008	0.36	1.11	18.22	10.04	0.24	0.26	0.004

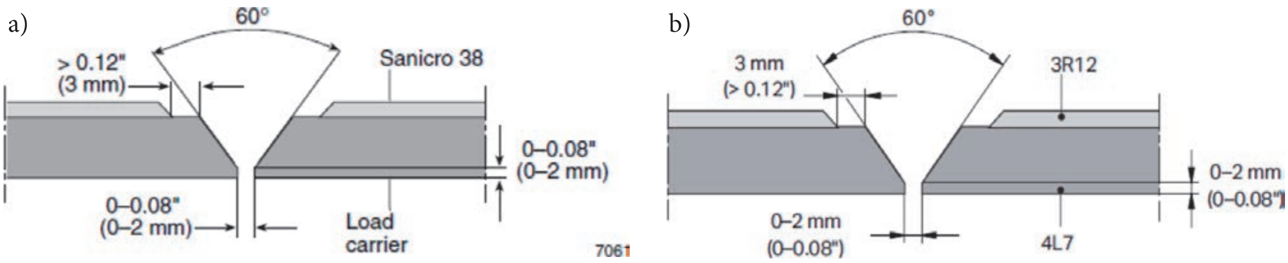

Fig. 2. Preparation of the joint for conventional welding: a) tube Sanicro 38/4L7 and b) tube 3R12/4L7[2, 3]

Fig. 3. Welding of composite tubes: a) melting of the inner layer and the obtainment of the weld using method 141 and b) filling the outer layer using the cladding process (method 111) and the rutile electrode

The test joints were made in the ERBUD Industry company, within a research work aimed to develop a welding technology in accordance with the PN EN ISO 15614-1:2017 [5] and PN EN 15613:2010 standards [6].

The conventional welding tests (methods 141/111) were performed in a workshop of the Erbud Industry company. The tests involved the use of:

- master TIG MLS 3000 welding machine along with fixtures,
- pyrometer (Infrared) having a measurement range of -50°C to ~ +1100°C.

The TIG welding of the inner layer included the following activities:

- use of filler metal wire DMO-IG (Bohler) having a diameter of 2.4 mm [10],
- use of argon (purity 5.0) (PN-EN ISO 14175-I1-Ar) as the shielding gas; the shielding gas flow rate was restricted within the range of 5 l/min to 7 l/min,
- interpass temperature monitoring (max. 300°C)
- lack of preheating,
- value of current used in the horizontal position (PC) was restricted within the range of 115 A to 125 A, whereas the value of current used in position PH (pipe position for welding upwards) was restricted within the range of 110 A to 115 A,
- welding rate was restricted within the range of 0.05 m/min to 0.06 m/min.

The making of the joint of the inner layer was followed by the performance of visual tests (VT) and radiographic tests (RT). The visual and radiographic tests demonstrated the satisfaction of quality level B in accordance with the PN-EN ISO 5817 standard [6, 7]. The subsequent step involved the making of the outer layer by using the cladding process based on method 111. The cladding of outer layer of Sanicro 38 was performed using rutile electrodes Cromarod 383 (having a diameter of 2.5 mm and a length of 300 mm) [8]. The overlay weld of the outer layer of composite tube 3R12/4L7 was made using rutile electrodes Cromarod 309MoL (having a diameter of 2.5 mm and a length of 300 mm) [9] (consistent with recommendations formulated by composite tube manufacturers).

The interpass temperature during the welding of the outer layer of the composite tube could not exceed 150°C. The temperature measurements were performed using a pyrometer (during the welding process). The cladding of the outer layer of tubes 3R12/4L7 and Sanicro38/4L7 was performed using a current of approximately 70 A, a voltage of approximately 24 V and a cladding rate of 0.16 m/min.

All the welding machines and measurement devices used during the welding process had been previously validated and provided with a valid inspection certificate.

Test results

The test joints are presented in Figure 4.

The welded joints were subjected to visual tests and assessment performed in accordance with the requirements of the PN-EN ISO 6520:2009 and PN-EN ISO 5817 standards [6, 7]. The visual tests revealed that the joint of tubes 3R12/4L7 and Sanicro 38/4L7 was characterised by the uniform and spatter-free weld face and the properly shaped weld root around the entire circumference. The joints represented quality level B in accordance the quality requirements of the PN-EN ISO 5817:2014 standard [7].

Subsequently, the joints were subjected to a cladding process involving the use of rutile electrodes and performed to fill the outer layer.

The overlay welds made using welding method 111 are presented in Fig. 5.

The joints made using the conventional cladding method were subjected to visual tests (VT)

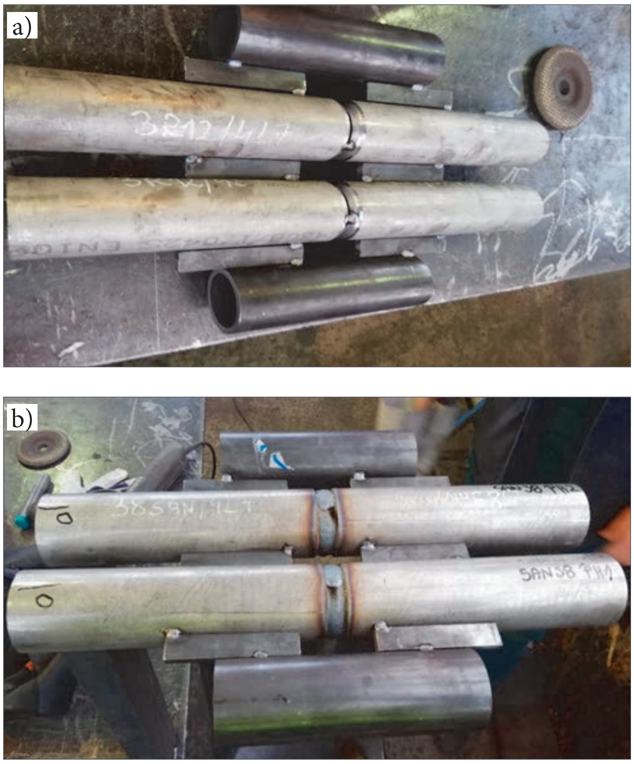

Fig. 4. Weld face view of the joints obtained using the conventional welding process: a) tube 3R12/4L7 and b) tube Sanicro 38/4L7

performed in accordance with the requirements of the PN-EN ISO 6520:2009 and PN-EN ISO 5817 standards [6,7]. The visual tests revealed that the overlay welds were characterised by a proper geometric shape (Fig. 5). The joints represented quality level B in accordance with the quality requirements specified in the PN-EN ISO 5817:2014 standard [7].

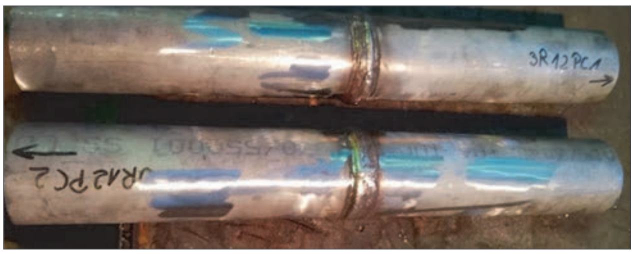

Fig. 5. Weld face view of the joint after the cladding process – tube 3R12/4L7

Figure 6 presents the macrostructure of the joint of tube Sanicro 38/4L7. The macroscopic tests did not reveal the presence of internal welding imperfections.

The microstructural tests of the joint of 3R12/4L7 revealed the presence of the ferritic-pearlitic structure (banded pearlite) in the base material of the outer layer (Fig. 7a). The area between the weld and the base material also contained the ferritic-pearlitic structure (Fig. 7b). In turn, the overlay weld contained the austenitic structure ((outer layer 3R12/4L7) Fig. 7c). It was also possible to notice the clearly visible fusion line (Fig. 7d).

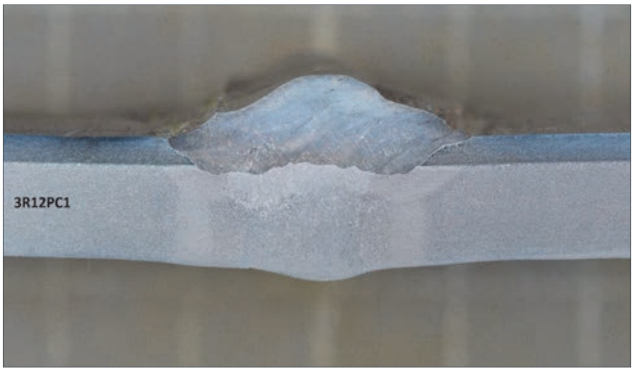

Fig. 6. Macrostructure of the overlay weld of Sanicro 3R12/4L7; external layer was obtained using the cladding process and rutile electrode Cromarod 309MoL

The transverse tensile test (performed in accordance with the requirements of the PN-EN ISO 6892-1: 2010 and PN-EN ISO 4136:2011 standards [11, 12]) as well as the bend test (performed in accordance with the requirements of the PN-EN ISO 5173:2010 standard [13]) confirmed that both the weld and the overlay weld were characterised by required plastic properties (the specimens were free from cracks after the performance of related destructive tests). During the tensile test, the rupture took place outside the joint area (Fig. 8).

Summary

The non-destructive tests did not reveal the presence of surface and internal imperfections. The micrographic tests did not reveal the presence of microcracks; the structure of the material was proper. The macrographic tests confirmed that the joint was made properly. The bend tests revealed that the joints were characterised by appropriate plastic properties [1].

The transverse tensile test revealed the proper mechanical and plastic properties of the joints of the composite tubes.

Both the non-destructive and destructive tests revealed that the welding technology developed within the research work (based on the guidelines contained in the PN EN ISO 15614-1:2017 [4] and PN-EN ISO 15613-5,6:2010 standards [5]) satisfied related requirements concerning welded joints of composite tubes.

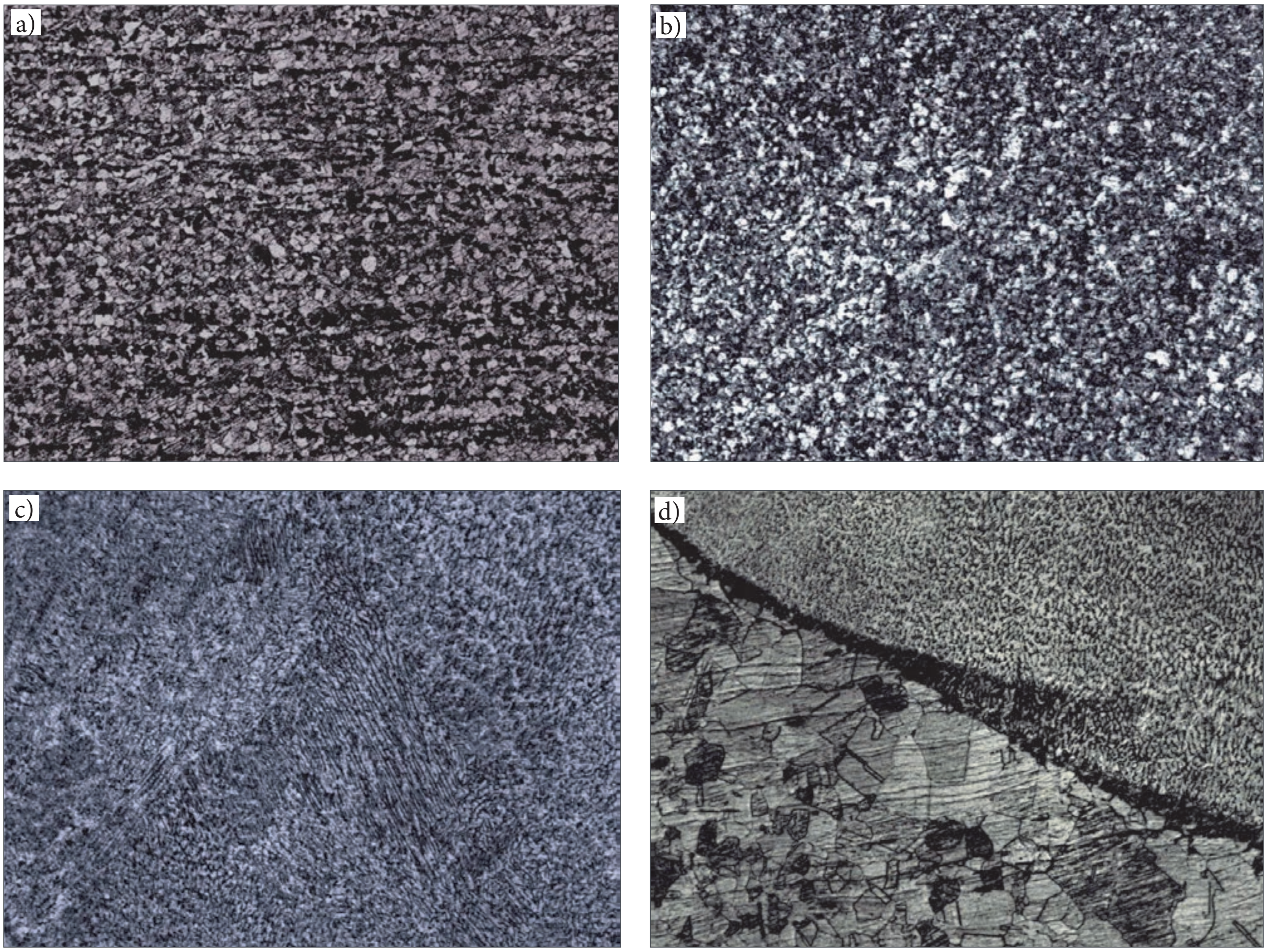

Fig. 7. Microstructure of the joint of Sanicro 3R12/4L7: a) base material 4L7 (P265GH), ferritic-pearlitic structure, b) weld 4L7 (P265GH) – ferritic-pearlitic structure, c) overlay weld, austenitic structure – material 3R12 (X2CrNi18-10) and d) fusion line between the overlay weld and the base material (3R12 (X2CrNi18-10)/ 4L7 (P265GH))

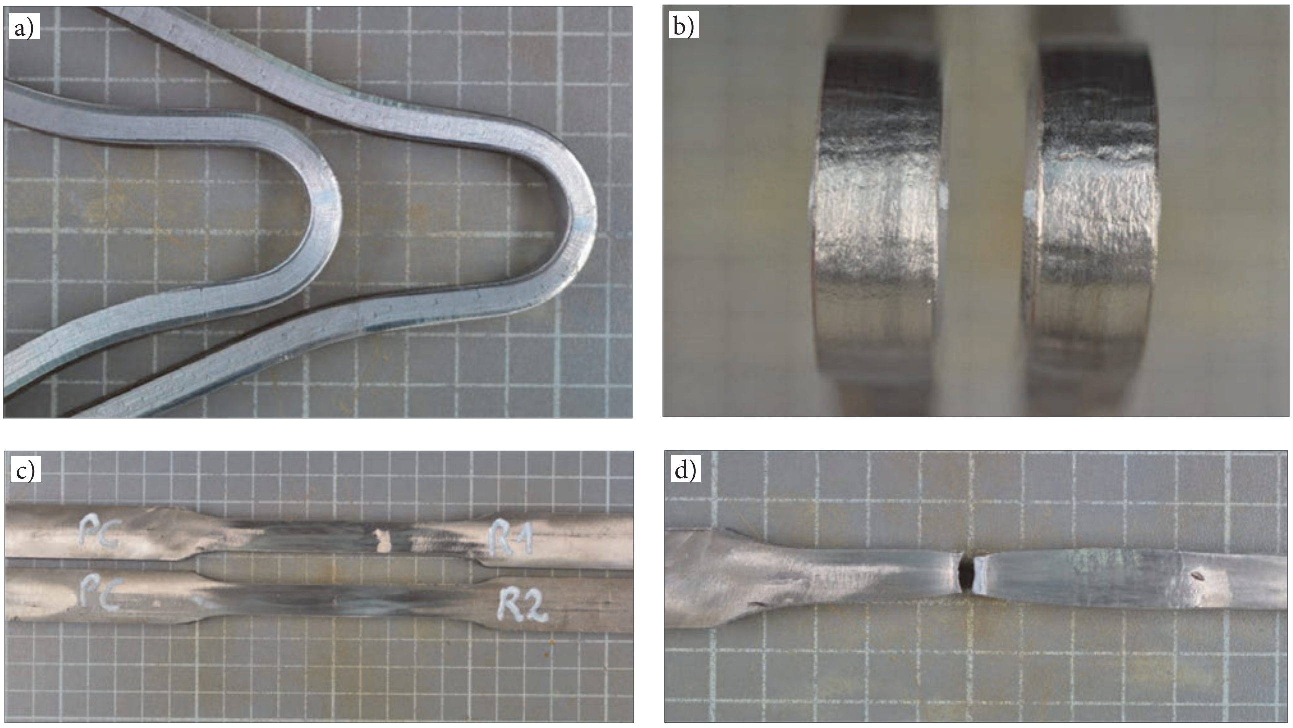

Fig. 8. Destructive tests – composite tube 3R12/4L7 3R12/4L7: a) specimen 3R12PC1 after the bend test, b) bend test – specimen 3R12PC (view from the weld face side), c) specimens 3R12PC1 and 3R12PC2 prepared for the transverse tensile test – view from the weld face side and d) specimen 3R12PC1 after the transverse tensile test

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