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INFLUENCE OF BOILER PIPE CLADDING TECHNIQUES ON THEIR MICROSTRUCTURE AND PROPERTIES

WPŁYW SPOSOBU NAPAWANIA RUR KOTŁOWYCH NA ICH MIKROSTRUKTURĘ I WŁASNOŚCI

The aim of this work was to investigate different weld overlay coating technologies applied to steel boiler pipes and their influence on microstructure and properties of the produced overlays. The investigations were carried out on the boiler pipes weld overlaid by an Inconel 625 and cladded at various conditions (CMT, GMAW and GTAW). The investigations showed that microstructure and mechanical properties of overlaid pipes depend on cladding technology and the chemical composition of the base material.

Keywords: cladding, Cold Metal Transfer (CMT), GMAW, GTAW, microstructure, mechanical properties

Celem pracy była ocena wpływu metody napawania Inconelem 625 rur kotłowych ze stali P235GH i 16Mo3 na mikrostrukturę i własności podłoża i napoiny. Badania prowadzono na odcinkach rur kotłowych napawanych stopem niklu Inconel 625. Rury zostały dostarczone do Fabryki Kotłów SEFAKO S.A. przez czterech dostawców, stosujących różne metody napawania, a mianowicie CMT, GMAW i GTAW.

Badania wykazały, że mikrostruktura i własności mechaniczne rur napawanych istotnie zależą od zastosowanej metody napawania oraz od składu chemicznego materiału podłoża.

1. Introduction

The boiler elements exposed to corrosion and erosion conditions are usually clad by weld overlay of a nickel alloy [1, 2]. The nickel alloys provide a good combination of mechanical strength and resistance to degradation in a chemically-active environment at elevated temperature [3, 4]. However, to ensure an appropriate resistance to corrosion, the chemical composition of coating should be homogenous. Also, the concentration of iron entering from the base material (steel) into the coating should be as low as possible [5, 6].

The application of nickel-based overlay coating technology to protect waterwall tubing in power boilers substantially improves their corrosion and wear resistance. The preferred weld overlaying methods are usually Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW). However, the heat input in these methods is high and excessive dilution with the underlying base material may occur and worsen the protective properties of the layer. Only recently, a novel method, Cold Metal Transfer (CMT), was developed for coating protection of boiler tubes. The CMT technology gives a low thermal input, as compared to the conventional dip arc process, and provides a stable arc no matter what the workpiece surface is like or how fast the welding proceeds. The cold metal transfer process is based on short circuiting transfer, or more accurately, on a deliberate, systematic discontinuing of the arc. The main feature of the CMT process, which distinguishes this process from conventional processes is that wire movement is directly included into the welding process control. In the CMT process the wire is moved towards the work piece until a short circuit occurs. At that moment the wire speed is reversed and the wire is pulled back. When the short circuit opens another time, the wire speed is reversed, the wire moves towards the work piece once again and the process repeats. The metal transfer is almost current-free resulting in substantial reduction in heat generation. This in turn, makes the dissolution of the base metal (steel) in the overlay almost negligible [7, 8].

The aim of this work was to investigate different weld overlay coating technologies applied to steel boiler pipes and their influence on microstructure and properties of the produced overlays.

2. Material and experimental procedure

The investigations were carried out on boiler pipes delivered to the Boilers Factory SEFAKO S.A. by four different suppliers referred to as A, B, C and D. The pipes from suppliers A, B and D were made of the P235GH steel while the pipes from supplier C were made of the 16Mo3 steel. All pipes were weld overlaid by an Inconel 625 alloy. The pipes

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A, C and D were clad by CMT. The pipes B were clad by GMAW followed by remelting of the surface layer of coating by the GTAW method. The investigation comprised metallography as well mechanical testing. The light microscopic examination was performed by an Axio Imager Mat. M1m Carl Zeiss microscope on longitudinal cross-sectioned samples. The samples were subjected to two stage etching: the base metal (steel) was chemically etched in 2% solution of nitric acid in C_2H_5OH and after that the coating was etched in 10% water solution of CrO_3. The Vickers hardness testing was carried out on the same samples at a load of 9.8 N. The measurements were performed along a line perpendicular to the coating. Three series of measurements for each sample were accomplished – the first series started at the distance of 2.1 mm from the fusion line and the following indentations were taken at 0.3 mm intervals; the second one started 2 mm from the fusion line and third one 1.9 mm. Such a procedure permitted to obtain hardness values from points separated by only 0.1 mm.

The tensile tests were performed on the samples cut out from the particular boiler pipes: A, B, C, D as well as from the base material (pipes made of P235GH and 16Mo3 steels). For the testing, the tensile machine Zwick 250 equipped with an electronic extensometer with the base of 80 mm was used. The tests were carried out according to the standard PN-EN10002-1. The following data were acquired from the tensile tests: yield strength $R_{p0.2}$, tensile strength R_m, total elongation A as well as the work-hardening coefficient n. The work hardening coefficient was calculated for the following ranges of deformation: 4÷6%, 10÷15% and 2÷20%. The tensile tests were supplemented by fracture surface examination performed on a Scanning Electron Microscope Hitachi S-3500N.

3. Results and discussion

The microstructures of boilers pipes with the weld overlays are shown in Fig.1. The light microscopic investigations showed that the overlays were free from spatter, porosity, cracking, incomplete fusion or other flaws. The investigations showed that all pipe suppliers applied singular overlays, however, the thicknesses of the clad coatings were different: A – 2.5 mm, B – 2.4 mm, C – 2.3 mm and D – 2.5 mm. The least uniform fusion interface exhibited samples produced by the CMT technology from the suppliers A and D. The average bead slope for these overlays was about 20° and 40°, respectively. On the other hand, the overlays on pipes from the C supplier, produced also by the CMT method, as well as those from the B supplier clad by GMAW and remelted by GTAW methods demonstrated more uniform line of fusion. The average bead slope on pipes from the C supplier was about 20°. The least uniform free surface exhibited the overlays clad by CMT from the supplier A, and the most uniform coating was produced by GMAW and remelted by GTAW (from the supplier B).

The microstructure of the overlays was composed of dendrites whose arms were parallel to the direction of the heat flow. The width of the overlay beads clad by the CMT method, determined from the measurement of distances between the subsequent heat affected zones in the layer, were: for A – 2.5 mm, for C – 3.1 mm and for D – 4.4 mm.

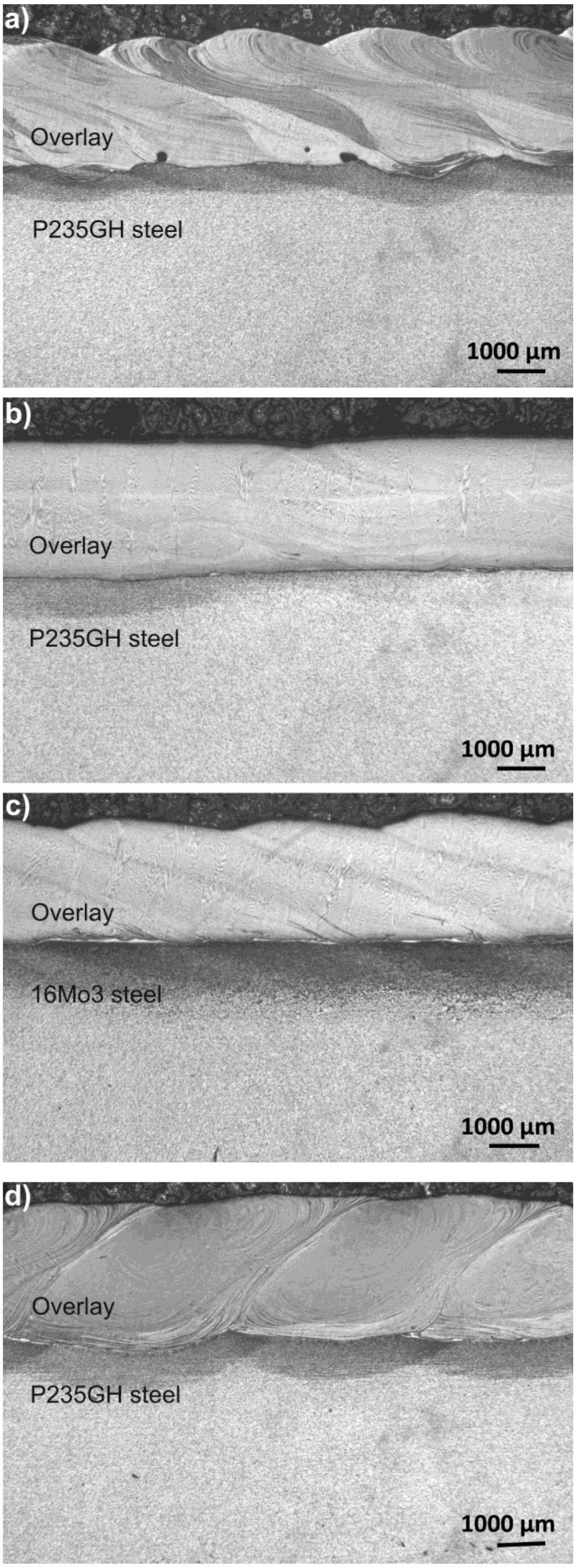

Fig. 1. Microstructure of the clad layer of Inconel 625 alloy; a – supplier A, b – supplier B, c – supplier C, d – supplier D

The microstructure of the base steel in a close vicinity to the fusion line (in the heat affected zone) was in both steels the ferritic-bainitic. Both steels had the ferritic-pearlitic microstructure in areas lying far away from the fusion line.

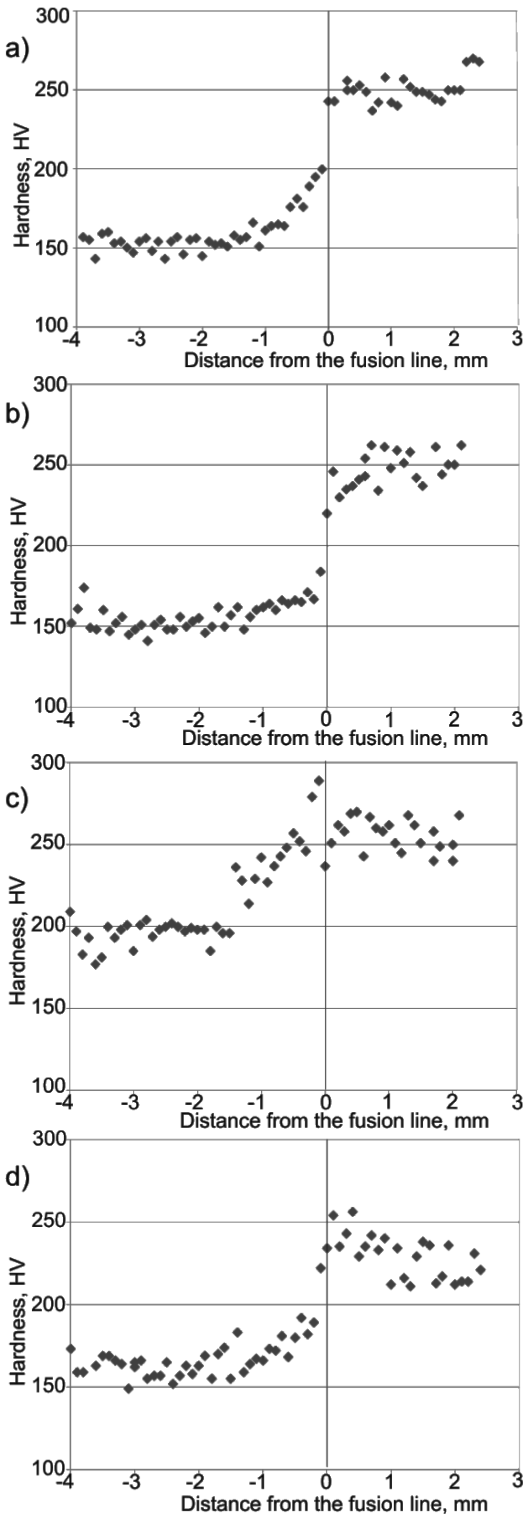

Fig. 2. Hardness profile on the section of the boiler pipes; a – supplier A, b – supplier B, c – supplier C, d – supplier D

The hardness profiles in the direction perpendicular to the fusion line are shown in Fig. 2. The hardness in the heat affected zone, in the case of the steel 16Mo3, was notably higher than that in P235GH steel. The investigations of the microstructure and the hardness showed that the chemical composition of the base metal exerted a considerable influence on the microstructure and the width of the heat affected zones. The largest width of the heat affected zone was found in a pipe made of 16Mo3 steel clad by the CMT method. In the pipes made from steel P235GH, regardless of the cladding method, an abrupt decrease of hardness was observed on the interface between the base metal and overlay.

The hardness of 16Mo3 and P235GH steels were 200 HV1 and 160 HV1, respectively. The average hardness of the overlays of pipes from suppliers A, B and C was approximately 250 HV1, while that from pipes coming from the supplier D was noticeably smaller – it was approximately 230 HV1.

The tensile curves of the P235GH and 16Mo3 steels are shown in the Fig. 3, while the tensile curves for overlaid tubes are shown in Fig. 4. The results of the tensile tests are collected in Table 1. The yield and tensile strengths of the 16Mo3 steel were higher than the corresponding values for the P235GH steel. However, the elongation of the P235GH steel was higher. The samples cut out from a boiler pipe made from the 16Mo3 steel and clad by the CMT method exhibited the highest yield and tensile strength – 462,3 MPa and 645,7 MPa, respectively. Among pipes made from the P235GH steel, the highest yield and tensile strength was found for pipes overlaid by GMAW and remelted by GTAW methods. The mechanical properties of pipes from the suppliers A and D were similar though the sample of the pipe delivered by the supplier D had much smaller elongation.

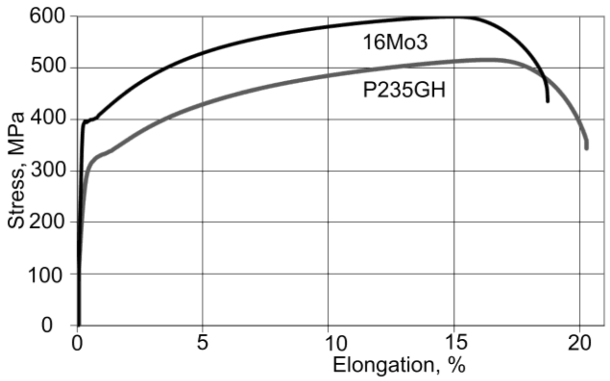

Fig. 3. Tensile curves of the P235GH and 16Mo3 steels

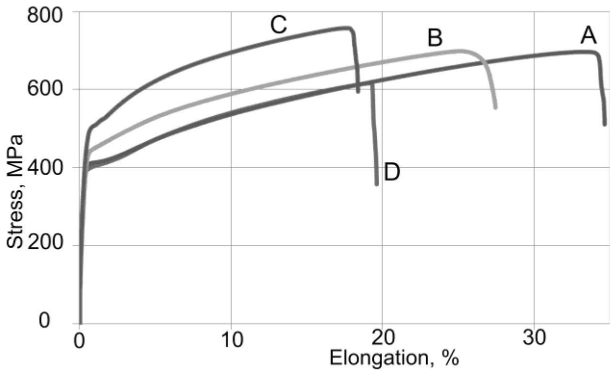

Fig. 4. Tensile curves for overlaid pipes; a – supplier A, b – supplier B, c – supplier C, d – supplier D

TABLE 1
Tensile properties of clad and unclad boiler pipes; a – supplier A, b – supplier B, c – supplier C, d – supplier D

Sample	$R_{p0,2}$, MPa	R_m, MPa	$R_{p0,2}/R_m$, %	A, %	n_{4-6},	n_{10-15},	n_{10-20},	n_{2-20},
A	392,9	529,3	74,2	34,7	0,169	0,220	0,232	0,189
B	426,6	560,4	76,1	27,5	0,142	0,186	0,197	0,159
C	462,3	645,7	71,6	18,4	0,156	0,165	0,165	0,156
D	389,9	517,8	75,3	19,6	0,183	0,214	0,216	0,192
P235GH	307,3	446,2	68,9	20,3	0,181	0,143	0,143	0,172
16Mo3	394,2	527,5	74,7	18,7	0,150	0,104	0,104	0,145

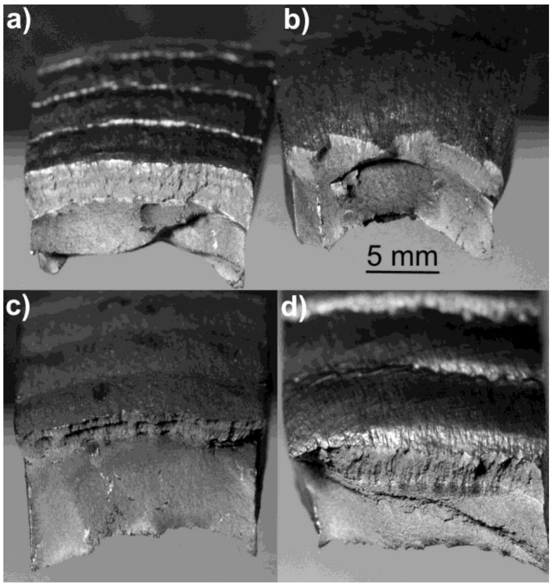

Fig. 5. Fracture surfaces of tensile samples; a – supplier A, b – supplier B, c – supplier C, d – supplier D

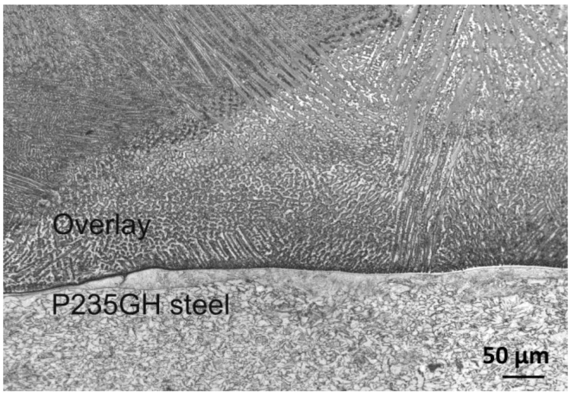

Fig. 6. Microstructure of the sample cut out from the tensile sample portion of the uniform elongation

The thorough examination of fracture surfaces of tensile tested samples showed that the bonding of the overlay with the base steel was strong since no separations of both materials were observed (Fig. 5). Also, the metallographic examinations of the samples cut out from the tensile sample portions of the uniform elongation showed a very good adhesion of all overlays to the base material (Fig. 6). All fracture surfaces had a ductile character. The fracture in samples from the suppliers A, C and D occurred along the borders between neighboring beads. The roughness of the fracture surface in the sample with remelted overlay (from the supplier B) was noticeably greater than in other samples. In all overlays the fracture paths ran through the dendrite interfaces.

4. Conclusions

- Microstructure and mechanical properties of overlaid pipes depend on cladding technology and the chemical composition of the base material.
- Ni-based overlays on pipes from particular suppliers differed in thickness as well as in the inclination and width of weld bead, however, all of them were well bonded to the base material – during tensile tests the overlays did not separate from the steel bed.
- The chemical composition of the base material exerted a significant influence on its microstructure and the width of the heat affected zone; the mainly bainitic microstructure in heat affected zone in the 16Mo3 steel resulted in different hardness profile on the pipe cross section.
- All fracture surfaces of tensile tested pipes exhibited a ductile character. The fracture path in pipes overlaid by the CMT method went through the interface between the neighboring weld beads; the fracture in pipes clad by MIG and remelted by TIG methods proceeded randomly without any dependence on welding history.

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