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RESEARCH ON 16Mo3 (16M) STEEL PIPES OVERLAID WITH HAYNES NiCro625 ALLOY USING MIG (131) METHOD

BADANIA RUR ZE STALI 16Mo3 (16M) NAPAWANYCH METODĄ MIG (131) STOPEM HAYNES NiCro625

The paper presents the research on the microstructure and mechanical properties of a pipe made of 16Mo3 steel, overlaid with superalloy based on Haynes NiCro625 nickel. The overlay weld was overlaid using the MIG (131) method. The performed macro – and microscopic tests have shown the correct structure of the overlay weld without any welding unconformities. The examined overlay weld was characterized by a dendritic structure of the primary crystals accumulating towards the heat removal. It has been proved that the content of iron in the surface zone does not exceed 7%, and the steel–superalloy joint shows the highest properties in comparison with the materials joined.

W pracy przedstawiono badania mikrostruktury i właściwości mechanicznych napawanej rury ze stali 16Mo3 nadstopem na bazie niklu Haynes NiCro625. Napoina napawana była metodą MIG (131). Przeprowadzone badania makro – i mikroskopowe wykazały prawidłową budowę napoiny bez niezgodności spawalniczych. Badana napoina charakteryzowała się budową dendrytyczną o kryształach pierwotnych narastających w kierunku odprowadzania ciepła. Wykazano, że zawartość żelaza w strefie przypowierzchniowej nie przekracza 7%, a samo połączenie stal/nadstop wykazuje najwyższe właściwości w porównaniu do łączonych materiałów.

1. Introduction

The energy security requirements and the economic issues of generating power energy (decreasing the generating costs) not only involve using new grades of high-temeperature creep resisiting steels/cast steels, but also require introducing alternative fuels; in the power industry, such as biomass, garbage, wastes, etc. [1-3]. The application of new fuels is also connected with limiting the emission of CO_2 into the atmosphere, with the aim of maintaining high efficiency of power units. As a result of the co-combustion of coal from the biomass with wastes or garbage in the industrial boilers, very aggressive chlorides or fluorides are formed in the combustion gases, which leads to a very intense high-temperature corrosion [4, 5]. High temperature and chemically aggressive combustion gases make it necessary to provide appropriate protection of the boiler elements being in contact with these gases. Some of the elements which are the most liable to the aggressive effect of corrosion environment are the pipes of heat exchangers.

One of the method of extending the life of boiler elements most subject to corrosion is overlaying with layers based on nickel alloys (superalloys). The superalloys of nickel are characterized by very high functional properties in extremely difficult operating conditions, such as for example: capability to work continuously at the temperature up to 1250°C, with the changing and dynamic loads, and in a very aggressive corrosion environment of gases, compouns of sulphur, nitrogen, and carbon [5, 6].

The technology of overlaying boiler elements with nickel superalloys on an industrial scale is a relatively new one, and it requires performing a comprehensive research to be able to assess the influence of the above process on the obtaining of high quality overlay welds, meeting the consumer requirements. The paper presents the assessment of microstructure and mechanical properties of an overlay weld – superalloy of Haynes NiCro625 nickel, overlaid on 16Mo3 (16M) steel.

2. Material and methodology of research

The research was carried out on a pipe section of 16Mo3 (16M) steel overlaid with Haynes NiCro625 alloy, following the MIG method (131). The required chemical composition

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and mechanical properties of the overlay nickel superalloy are presented in Tables 1 and 2, respectively.

TABLE 1
Required chemical composition of Haynes NiCro625 superalloy, %mass.

Co	Fe	Cr	Mo	Nb+Ta	Mn	Si	Al	Ti	C
max 1	max 5	21	9	3.7	0.5	0.5	0.4	max 0.4	max 0.10

TABLE 2
Required minimum mechanical properties of Haynes NiCro625* superalloy at room temperature and at 650°C

Temperature °C	UTS MPa	YS MPa	El. %
room	905	490	48.5
650	760	370	55.6

* – alloy after cold working and annealing at the temperature of 1050°C

The microscopic tests were performed on the conventionally prepared metallographic specimens. The metallographic specimens were itched in two steps: basic steel material – etched with nital (Mi19Fe), overlay weld – electrolytic etching in the ML3 reagent. The parameters of current and voltage of the electrolytic etching of the overlay weld are presented inter alia in the work [7, 8]. The observation and record of microstructure images was performed using an optical microscope, Axiovert 25 (LM), and a scanning electron microscope, JOEL JSM 5800LV (SEM). The measurement of microhardness was taken with the Vickers method, using a microhardness tester, Future-Tech FM-7, applying the microindenter load of 100 g (0.91N).

The analysis of iron content on the surface of the overlay weld was made using a scanning electron microscope, JOEL JSM 6610LV, compatible with an X-ray spectrometer, EDS Oxford Instruments X – Max.

The test of adherence of the overlaid layer was carried out by meas of the Revetest XPress Plus device (Scratch Test), using the Rockwell diamond indenter. The test was performed applying the following parameters: the load of 20, 35, and 50 N; the scratch lenght of 3 mm; the scratch speed of 1 mm/min.

3. Macroscopic tests

Performed macroscopic tests of the overlay weld did not reveal any unconformities in the weld line, neither any incomplete fusion, blowholes or any other discontinuities. The lack of welding unconformities on the surface proves maintaining the purity of the overlaid pipe surface.

The macrostructure of the examined overlay weld is presented in Fig. 1. The determined thickness of the overlay weld (of the layer overlaid on the pipe surface) did not exceed 3 mm. It is a value insignificantly higher than the value accepted as an optimum – 2.5 mm [6], which is connected with the price of nickel alloys, and on the other hand, with the difference in the heat conductivity of nickel and iron alloys. The overlay weld was overlaid to a single layer.

Fig. 1. Macroscopic metallographic specimen of the examined element

4. Microscopic tests

The basic material, 16Mo3 steel, was characterized by a ferritic – pearlitic microstructure, typical for this grade of steel (Fig. 2a). In the heat-affected zone (HAZ), however, a diverse microstructure was observed: from martensitic, through martensitic – bainitic, to ferritic – bainitic microstructure – Fig. 2b. Narrow HAZ in the basic material indicates the application of an internal blast cooling of a pipe.

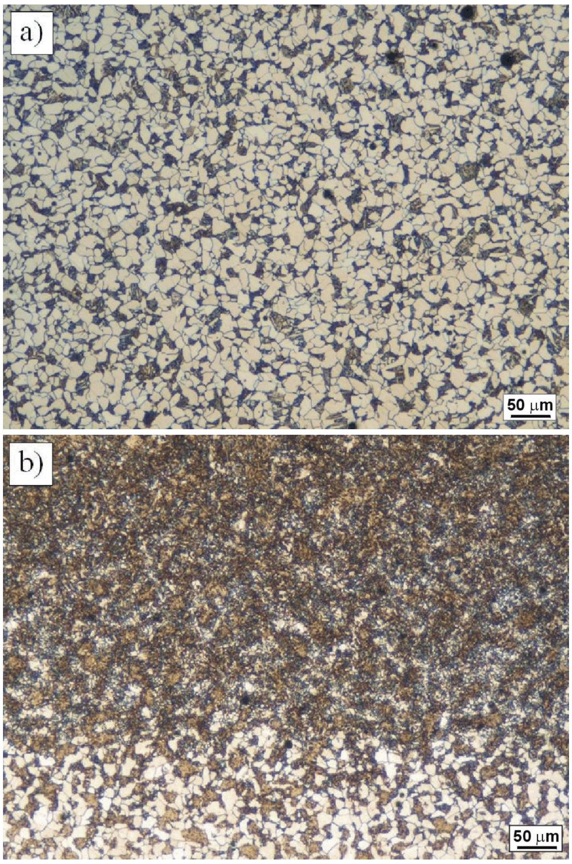

Fig. 2. Microstructure of 16Mo3 steel: a) parent material, b) heat-affected zone

The overlay weld was characterized by an accurate basic material joint. Primary crystals with their typical dendritic structure were observed, accumulating towards the heat removal surface (Fig. 3).

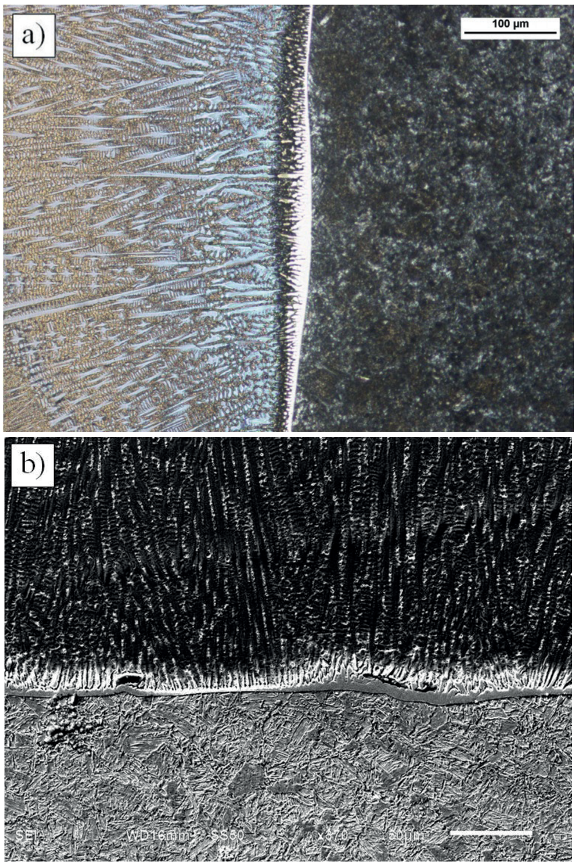

Fig. 3. Microstructure of overlaid layer in the weld line: a) LM; b) SEM

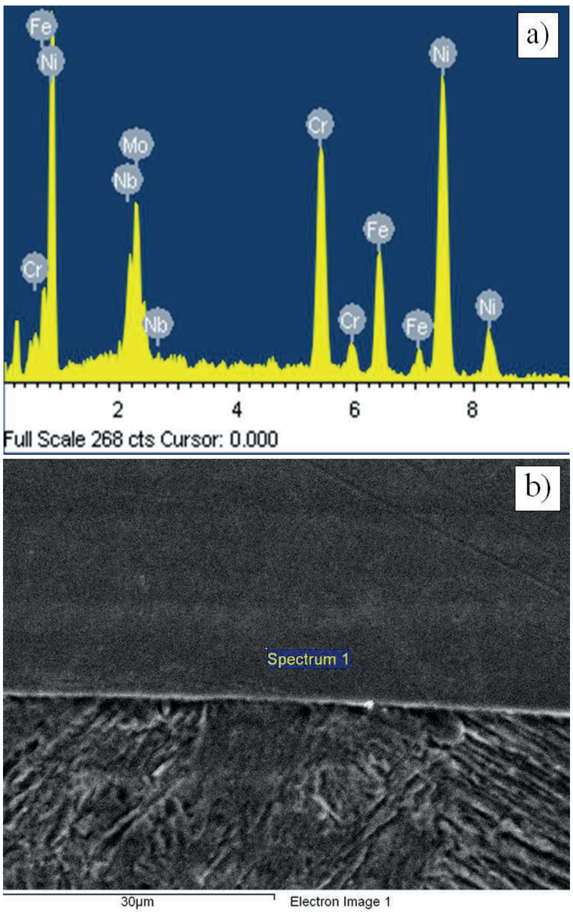

Fig. 4. Examples of X-ray spectrum of overlay weld in the surface layer (a); area of performed analysis (b)

One of the admission conditions for the technology of overlaying pipes of heat exchangers in waste incineration plants is the assessment of the iron content in the surface layer of an overlay weld [8]. It is recommended that the iron content in the automatic overlay welding should not exceed 7%, whilst for manual welding – 10%. Higher content of iron can cause the formation of iron oxides, Fe_2O_3, characterized by a layered and discontinuous structure, which favors their crumbling during the service [8, 9]. The performed tests have shown the average content of iron in the examined overlay weld on the level of 3.7 ÷ 6.4%. The examples of X-ray spectrum of the overlay weld in the surface layer is presented in Fig. 4.

One of the significant factors that have an influence on the required iron content in the surface layer is the linear arc energy which should not exceed 3 kJ/cm, as well as the internal blast cooling that ensures appropriate heat removal [10-12].

5. Microhardness test

The distribution of microhardness in the cross-section of the overlaid pipe is presented in Fig. 5. It is visible that the steel – basic material is characterized by hardness on the level of around 210 ÷ 220 HV0.1; the presence of martensite in the HAZ resulted in a growth of hardness to the value of around 360 HV0.1; the value of microhardness of the overlay weld amounted to around 260 HV0.1.

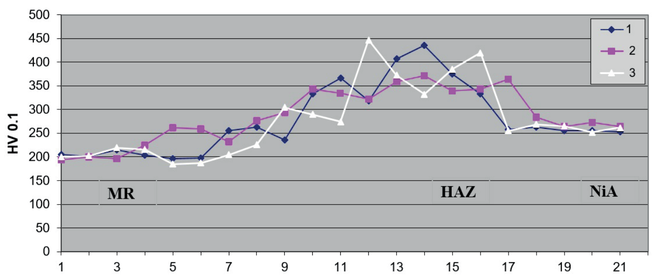

Fig. 5. Distribution of microhardness HV0.1 in the cross-section of overlaid element, where: MR – parent material, HAZ – heat-affected zone, NiA – nickel alloy

6. Scratch test

The study performed by means of a Scratch Test made it possible to determine the coefficient of friction, the scratch depth and the forces of friction on the overlay weld and basic material (steel). Moreover, it revealed that the steel–nickel superalloy joint had the highest properties compared to the materials joined.

7. Summary

The research scope included the microstructure and mechanical properties of the overlay weld of Haynes NiCro625 nickel superalloy overlaid with the MIG method on the surface of a pipe of 16Mo3 steel. It has been proved that the applied parameters of overlaying welding ensure obtaining the superalloy–steel joint without any welding unconformities, with the required iron content (not exceeding 7%) on the overlay weld surface, narrow HAZ and high properties determined by means of the Scratch Test. The only stated reservation was about the thickness of the overlay weld, higher by around 20% than the recommended one. However, it has been declared that there is a possibility of making an overlay weld of the expected quality on the heat exchanger pipe.

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