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Properties of welded joints made of cast steel GX8CrNi12-1

Abstract: The article presents test results concerning welded joints made of cast steel GX8CrNi12-1. The above-named cast steel has a martensitic microstructure and can be used in pressure equipment operated at ambient and high temperature. The test joints were made in the horizontal position and in the vertical up position. The foregoing was dictated by the fact that the above-named positions are used in industrial conditions, e.g. when welding steel castings. The welding process performed in the above-named positions ensured that specimens were sampled from areas exposed to the lowest and highest arc linear energy. The article describes the process of manual metal arc welding (111) and the post-weld heat treatment. The test joints were subjected to destructive tests including transverse tensile tests, impact strength tests, hardness measurements as well as macro and microscopic tests. The test results revealed differences in properties of joints made in different positions, resulting from various heat inputs to joints during welding.

Keywords: Mechanical properties, cast steel, welded joint, post welding heat treatment

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Introduction

In many industry branches cast steels are widely applied for production of rollers, turbine housings, valve chambers, corrosion-resistant elements, turbine shafts, etc. [1-4]. An implementation of as-cast materials may significantly simplify a production process. On the other hand, using of such materials as well as steels intended for work at elevated temperatures is often a challenge for the welding engineer [5-8]. These difficulties comes from macroscopic and microstructural differences between as-cast and wrought materials. As-cast components usually have larger dimensions (thickness) than their wrought counterparts, what is directly reflected by their more problematic weldability.

A thickness of joined elements is one of the most crucial feature that has to be taken into account upon a selection of welding parameters. With increasing a component's thickness, and with raising value of carbon content equivalent, it is necessary to apply a pre-heating and post-welding heat treatments [5-8].

It should be noted that components made of cast steel are subjected to various heat treatment processes in order to obtain pre-assumed set of properties. What is very important, these properties have to be maintained after a welding

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process. The heat treatment is especially important in the case of martensitic cast steels [9-11]. For these materials it is crucial to determine a proper combination of temperature and time that allows receiving optimal performance. In this work, GX8CrNi 12-1 martensitic cast steel was selected as the material investigated. This cast steel is characterized by fracture work of 45 J at room temperature, while at -30°C this value is lowered to only 28 J (the corresponding impact toughness is 35 J/cm^2) [12].

The main purpose of this work was to evaluate the effect of welding position on resulted properties of joints in GX8CrNi 12-1 steel.

Table 1. Chemical compositions of the cast steel and the additional material (wt. %)

	C	Mn	Si	P	S	Cr	Ni	Mo	V
GX8CrNi12-1	0,07	0,63	0,33	0,014	0,005	12,26	0,88	0,03	0,05
13.1 BMP	0,034	0,66	0,32	0,009	0,016	12,9	1,6	0,28	-

Table 2. Basic process parameters applied upon welding in the PC position

Path	Welding process	Weld size [mm]	Welding current [A]	Arc voltage [V]	Heat input/ Linear energy [kJ/mm]
1	111	4	165-180	22-25	0.50-1.08
2-n	111	5	200-220	23-26	0.63-1.37

Table 3. Basic process parameters applied upon welding in the PF position

Path	Welding process	Weld size [mm]	Welding current [A]	Arc voltage [V]	Heat input/ Linear energy [kJ/mm]
1	111	3,2	110-120	22-24	0.90-2.16
2-n	111	4	130-150	22-25	1.14-3.23

Methodology

Two butt welds of GX8CrNi12-1 were prepared by hand with coated electrode, in PC and PF positions, by using an additional material marked as 13.1 BMP Metrode (grade E13 B52 according to PN EN 3581: 2016)[13]. A thickness of joined sheets were equal to 30 mm. Chemical composition of the cast steel and the additional material are listed in Table 1. The joints before welding process were pre-heated up to 150°C, while the maximum interpass temperature was set at 300°C. After the welding process both welds were cooled down below 100°C and then subjected to annealing at 700°C/8 h (Fig. 1).

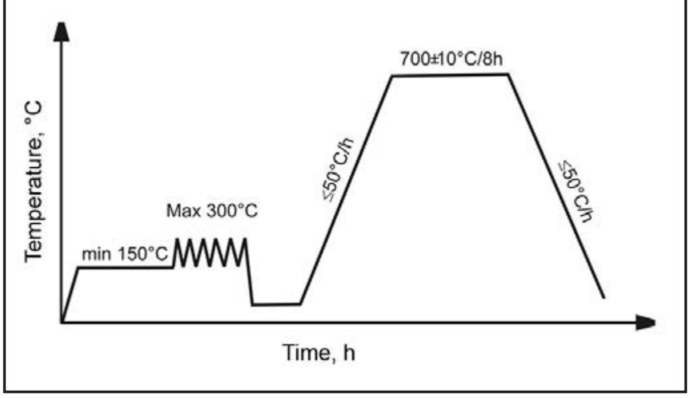

Fig. 1. Scheme of temperature profile applied upon the welding process and the subsequent heat treatment

Basic process parameters applied upon welding in PC and PF positions are shown in Table 2 and Table 3, respectively.

The obtained welds were subjected to destructive evaluations. Samples for tensile tests, impact thouighness tests, macroscopic examinations and microhardness measurements, were cut off. Metallographic analyses were performed on polished surfaces etched by Mi19Fe reagent, by using Olympus GX51 light microscope

Results

Macroscopic images of obtained welds are shown in Figure 2. Additionally, lines for a subsequent microhardness measurements, were also marked. The macroscopic evaluations showed a presence of correct arrangement of welding paths without visible internal welding incompatibilities. The results of microstructural characterization revealed a tempered martensite structure in whole volume of the joint (Fig. 3). Such homogeneous structure originates from the heat-treatment at 700°C applied for both examined welds. The microstructure features observed in various sites of the welds

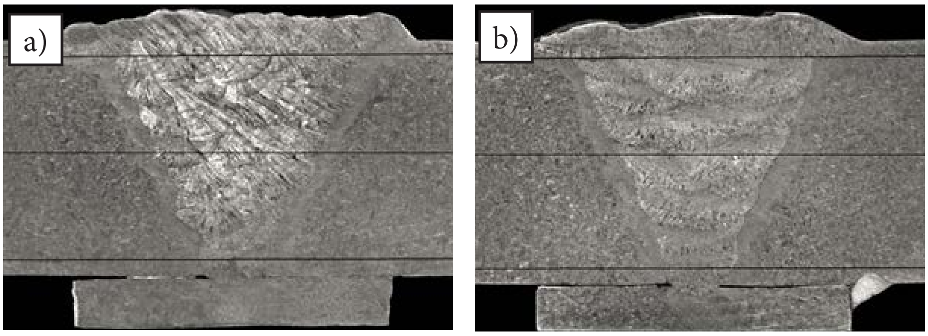

Fig. 2. The macrostructure of welds obtained by using: a) the PC position, b) the PF position

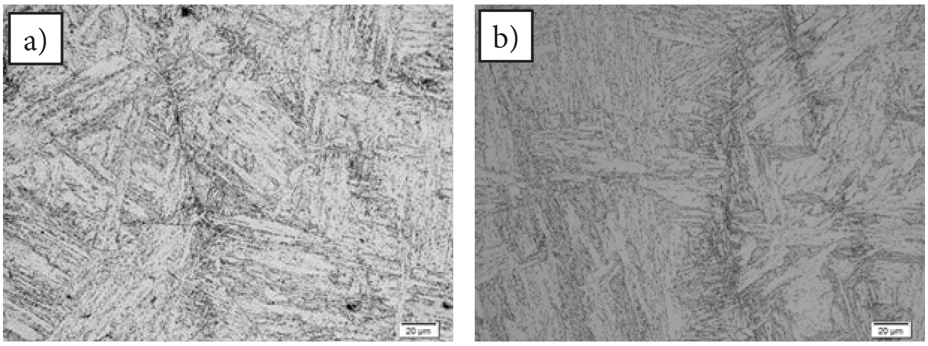

Fig. 3. The microstructure of GX8CrNi12-2 base material obtained by using: a) the PC position, b) the PF position

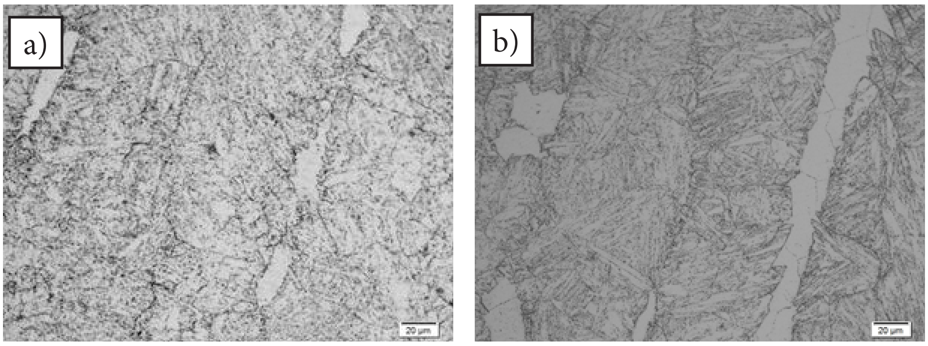

Fig. 4. The microstructure of heat affected zones in GX8CrNi12-2 welds obtained by using: a) the PC position, b) the PF position

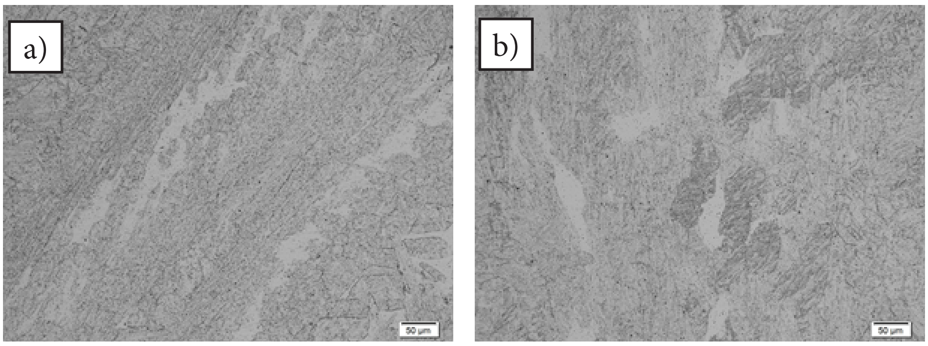

Fig. 5. The microstructure of welds in GX8CrNi12-2 welds obtained by using: a) the PC position, b) the PF position

fabricated by using the PC or the PF position, are compared in Figures 3 to 5.

For both welding positions the base material (Fig. 3) was characterized by tempered martensite microstructure with a number of carbides precipitated upon the post-welding heat treatment. For both welds, some areas near fusion lines were characterized by a peripheral distribution of carbides. Bright regions between crystallites were preliminarily recognized as delta ferrite [14]. However, this identification has to be confirmed by further SEM/EDS or XRD experiments. It should be also noted that these structural features were observed only locally, mostly in the middle part of the welds and in near face regions. The corresponding microhardness measured in these areas was in the range of 250 and 310 HV.

The results of mechanical strength examinations confirmed a proper selection of welding and heat treatment parameters. The ultimate tensile strength of both types of welds, was between 620 and 630 MPa.

Futrthermore, a significant variation of microhardness on the cross-sectioned welds, was noted. In each weld an increase of hardness in heat affected zone (as compared to the base material) was measured. The largest increase of hardness was observed in near fusion line areas (Fig. 6 and Fig.7) – 40-60 HV units more than the hardness of base material. Inside the weld, microhardness values were intermediate between those measured in the base materials and the heat affected zone.

The work of fracture was evaluated at room temperature by using standard Charpy V samples (with dimensions of 10 × 10 × 55 mm). The samples were taken from the weld and the heat

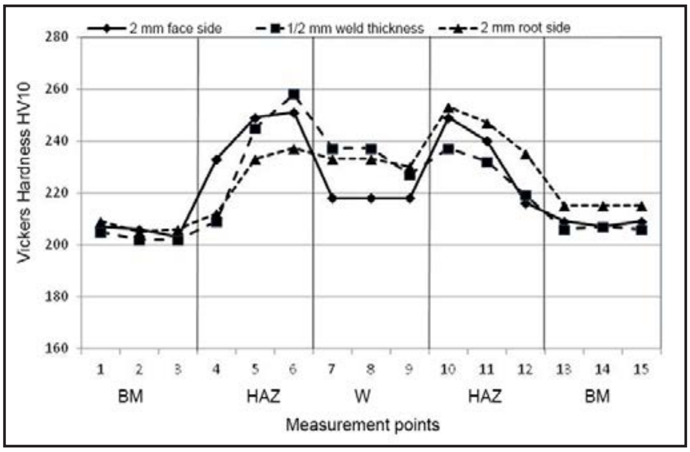

Fig. 6. Distribution of microhardenss in weld in GX-8CrNi12-1 cast steel fabricated by using the PC position

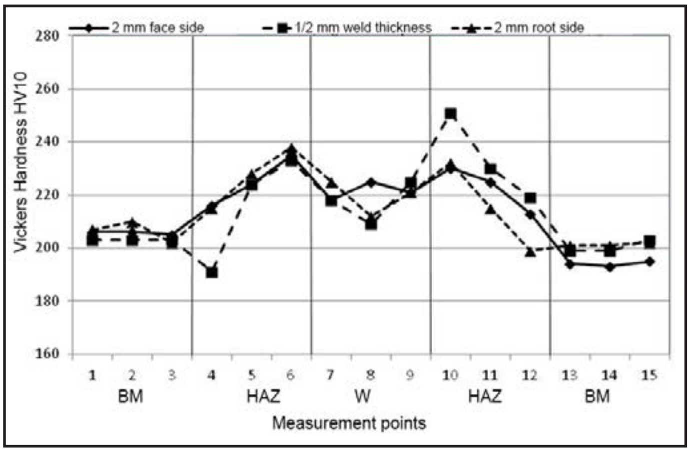

Fig. 7. Distribution of microhardenss in weld in GX-8CrNi12-1 cast steel fabricated by using the PF position

affected zone (three samples from each area). The obtained results are shown in Figure 8. All received values were above the pre-assumed threshold of 45 J. Nevertheless, some differences between the weld and the heat affected zone, might be distinguish. In each case, the work of fracture was lower in heat affected zone, however the differences were also less prominent for welds fabricated by using the PF position.

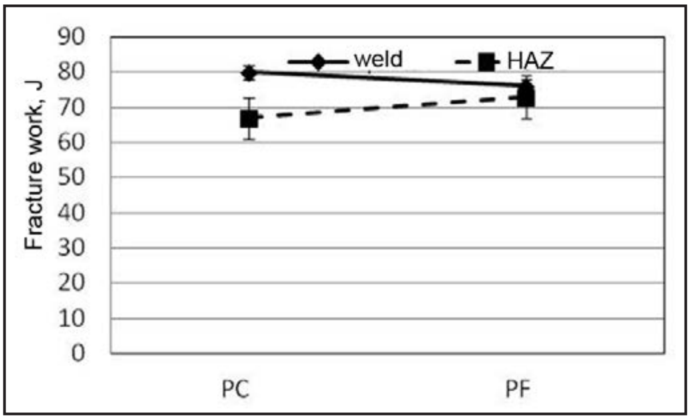

Fig. 8. The work of fracture for examined welds

Discussion

The conducted welding tests of GX8CrNi12-1 cast steel joints in the PC and PF positions allowed determining the appropriate welding technology for the production of this type of joints. Performed microstructural and mechanical properties characterization revealed some differences between joints fabricated by using PC or PF positions, especially regarding a distribution of microhardness in particular weld areas. A high increase of hardness in near fusion-line areas should be justified by the effect coming from mixing the cast iron with additional material. It might be assumed that directly after the welding process, differences in hardness were more prominent, while the additional heat treatment allowed receiving more homogeneous distributions. In the near fusion line, few zones where precipitation at grain boundaries was more intensive (Fig. 4), were observed. In these regions, the applied heat treatment did not result with a full microstructure homogenization. A differentiation of microstructure was also reflected in the results of impact toughness tests. For each sample the heat affected zone was characterized by a lower work of fracture, but every time it was above the pre-assumed threshold of 45 J. The work of fracture was also higher for welds fabricated by using the PF position and subsequent heat treatment, showing also minimal differences between the weld and heat affected zone.

Summary and conlcusions

Based on the results of performed research, the following conclusions are drawn:

– The applied heat treatment at 700°C, intended for lowering of residual stresses inside welds, results in a homogenization of hardness and work of fracture.
– A more beneficial distribution of hardness and work of fracture was obtained for welds fabricated by the PF position and by using a twice higher linear energy than in the case of the PC position.

– The results obtained for welds in GX8CrNi12-1 cast steel fabricated by both welding positions confirm a correct selection of process parameters, and allows recommend them for application in real industrial processes.

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