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MMA Repair Welding of Nodular Cast Iron GJS 350-22

Abstract: The article presents results of the MMA repair welding of nodular cast iron GJS 350-22. Casting defects were simulated mechanically (through milling), whereas repair welding was performed using selected filler metals (low-carbon filler metal, austenitic filler metal, Monel alloy and nickel alloy) and the manual metal arc welding method (MMAW). Test welds were subjected to visual, penetrant, macro and microscopic tests as well as hardness measurements and were compared in terms of the colour with that of the base material. The tests made it possible to identify the effect of the repair welding process on structural changes in the HAZ area and the susceptibility of the HAZ and the weld to crack formation. The tests also enabled the determination of structures of repair welds and their usability when repairing iron casts. The hardness measurements confirmed effects related to structural changes triggered by repair welding in the HAZ and in the weld. In turn, the comparative tests concerning the colour of the weld and that of the repaired cast iron enabled the selection of a filler metal satisfying the above-named criterion. The tests revealed that the most favourable properties of the repair welds in terms of structural changes were obtained using nickel-based filler metals.

Keywords: nodular cast iron, repair welding, manual metal arc welding, MMAW

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Introduction

Because of its numerous advantageous properties, cast iron is a popular structural material. It is cheap, easy to form through casting, characterised by a relatively low melting point and good mechanical properties, particularly high compressive strength and high vibration damping ability. Because of the above-presented properties, cast irons are the most popular group of ferrous materials used worldwide in the production of various structures. Cast iron is commonly used because of its good workability, high vibration damping ability and high casting properties. As a result, the demand for cast iron products is on the rise. Large casts or single products are sometimes characterised by disturbed material continuity, often as early as at the production stage. In such cases it is possible to apply various repair methods ranging from casting-on, adhesive bonding or bridging to welding-based repairs [1-4]. The primary limitation of cast iron weldability is the formation of white cast iron, characterised by considerable brittleness. Welding repair methods entail a certain heat input to a material during the repair process. The above-named heat

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input may lead to the generation of stresses or the formation of structural changes in the base material, being the primary reason for crack formation. Methods used for the repair welding of casts are the following:

– hot welding, during which an element made of cast iron is heated to a temperature of approximately 700° C. Filler metals used in this repair process usually have the form of bars made of cast iron or covered electrodes, the chemical composition of which is similar to that of a material subjected to welding,
– cold welding, during which a heat input is maintained at the lowest possible level. The process involves the use of low current and short runs, which are additionally peened directly after welding (to minimise welding stresses). Materials used in cold welding vary and include simple low-carbon steels, stainless steels, nickel alloys as well as nickel and copper alloys containing various alloying agents.

Because of a wide range of available and applicable filler metals, cold welding involving the use of covered electrodes offers significant cast repairing possibilities. When repairing iron castings it is necessary to pay attention to several aspects, i.e. to maintain material continuity, tightness and appropriate strength as well as to obtain the colour of a weld similar to that of the base material [5-9].

Individual research

The research work presented in the article aimed to identify the effect of the MMA repair welding of castings made of ferritic-pearlitic nodular cast iron (Fig. 1). The tests involved the use of nodular cast iron GJS-350-22 having tensile strength R_m = 350 N/mm^2 and elongation A = 22%. The chemical composition of the cast iron is presented in Table 1. Specimens subjected to repair (100 mm × 90 mm × 25 mm) were cut out of test plates made of the same heat. On each specimen, a groove having a length of 90 mm, a width of 4 mm and a depth of 8 mm was made using the milling process. The groove simulated a casting defect. Repair welding was performed using filler metals presented in Tables 2 and 3.

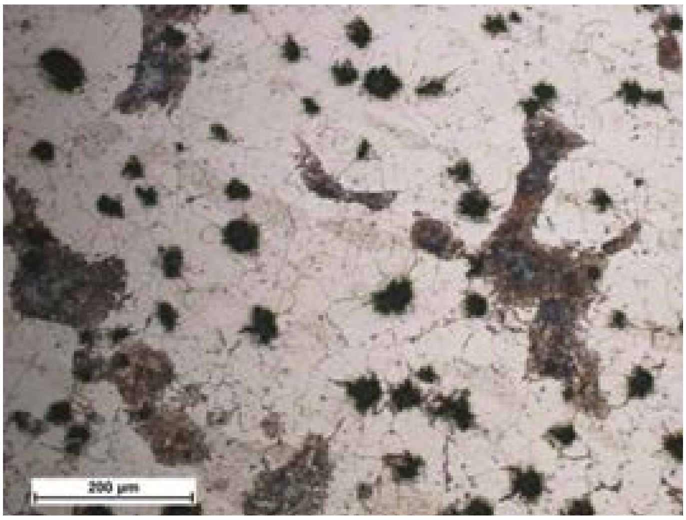


Fig. 1. Microstructure of ferritic-pearlitic nodular cast iron GJS-350-22

Table 1. Chemical composition of cast iron GJS-350-22, (%)

C	Si	Mn	P	S	Cr	Ni
3.37	2.73	0.54	0.06	0.009	0.12	0.04

Table 2. Chemical composition of selected filler metals, %

Electrode type	C	Si	Mn	Fe	Ni	Cu	Cr
EB 150	0.08	0.4	1.1	rest	-	-	-
ES18-8-6B	0.11	0.5	6	rest	8.5	-	18.5
EŻM	<0.7	0.1	0.9	3.0	rest	32	-
NiCl	0.9	0.6	0.6	3.5	>92	-	-
XHD 2230	Nickel alloy, chemical composition withheld by the manufacturer						

Table 3. Mechanical properties of test filler metals

Electrode type	Tensile strength, R_m, MPa	Elongation A_5, %	Toughness KV, J (-40°)	Hardness
EB 150	500-640	>20	>47	-
ES 18-8-6B	605	35	85	190HV
EŻM	300-350	15	-	140-160HB
NiCl	300	-	-	130-170HB
XHD 2230	490	13.5	-	-

Repair welding

The process of welding was performed in the flat position, applying welding parameters recommended by the manufacturers of individual filler metals. In cases of all of the electrodes, the welding current amounted to 100 A. A higher welding current of 130 A was applied only in terms of electrode EB 150. The process of welding was performed using straight polarity DC. Welds were subjected to peening performed using a welding hammer, in the direction opposite to that of welding. Exemplary repair welds are presented in Figure 2.

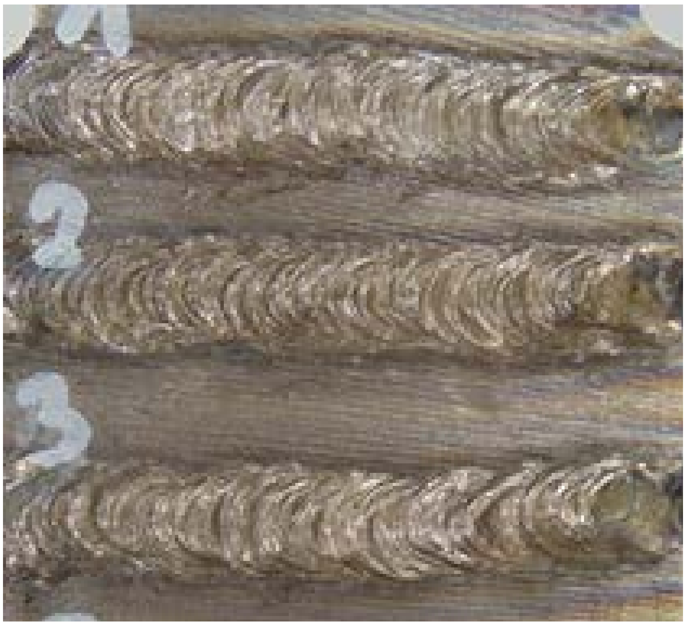


Fig. 2. Repair welds

Tests of repair welds

The repair welds were subjected to visual, penetrant, macro and microstructural tests as well as to hardness measurements. In addition, the colour of the welds was compared with that of the base material.

Analysis of test results

The visual tests did not reveal the presence of welding imperfections on the surface. As regards welding performed using electrodes EB 1.50 and ES 18-8-6B, dye penetrant tests revealed the presence of radial cracks (Fig. 3).

The macroscopic metallographic tests did not reveal cracks in the weld and HAZ areas. In each case, the weld groove was filled properly (Fig. 4).

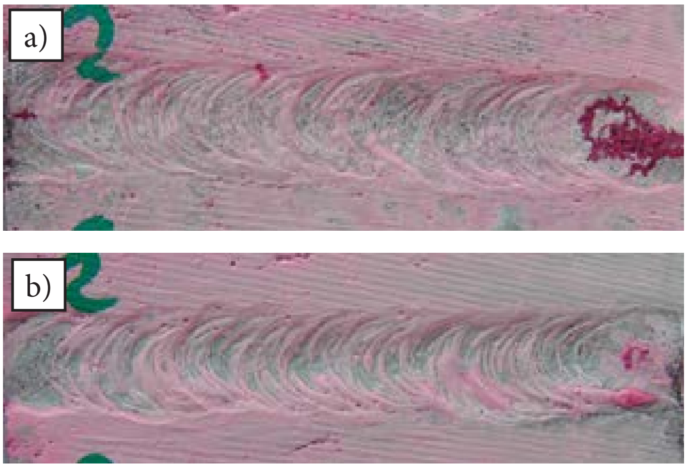


Fig. 3. Cracks present in the repair weld area; a: Electrode EB 1.50; b: Electrode ES 18-8-6B

The microscopic metallographic tests revealed the presence of the martensitic structure in the welds made using electrode EB 1.50. The above-named martensitic structure was formed as a result of the significant diffusion of carbon to the weld area. The structures of the remaining welds were characteristic of the filler metals used in the welding process. The

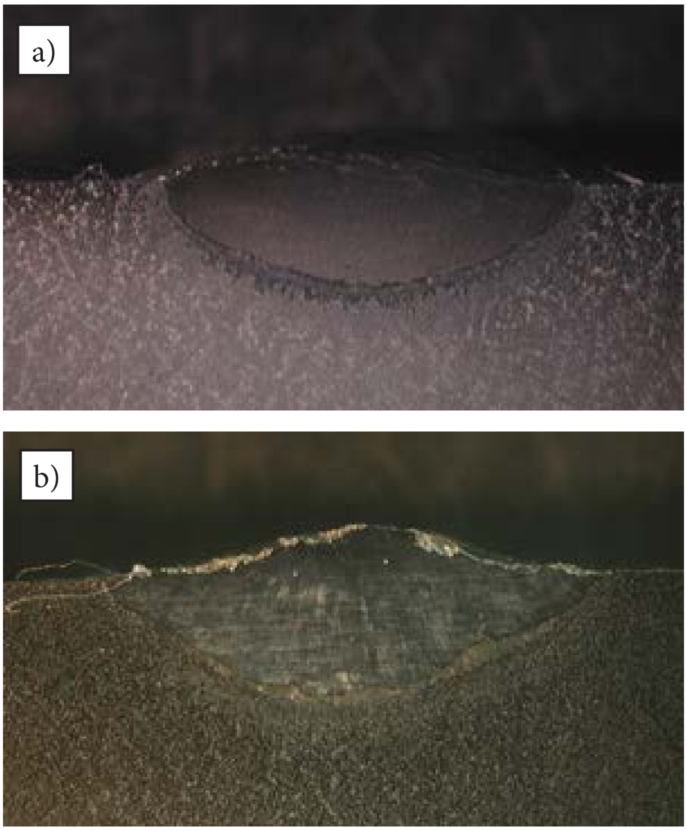
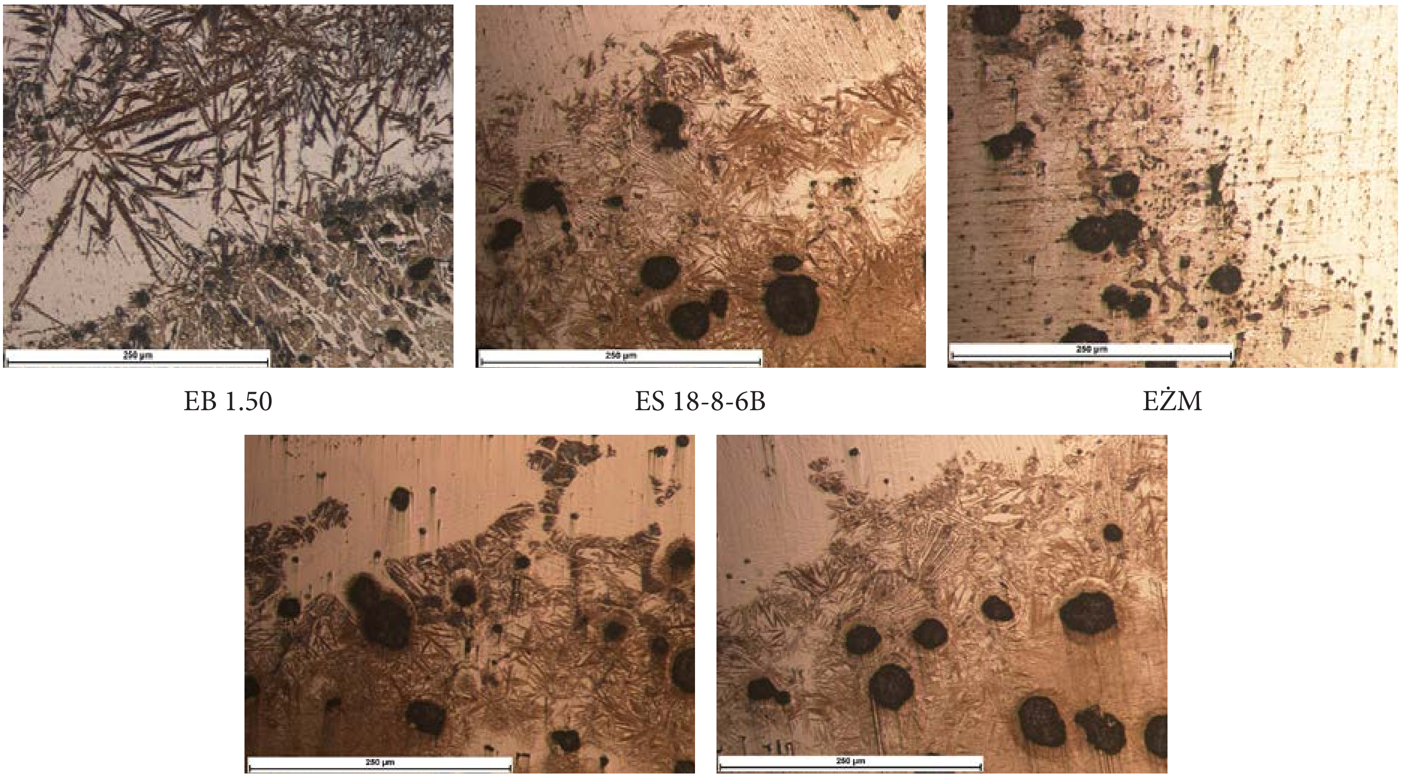


Fig. 4. Macrostructures of the repair welds; a: Electrode NiCl; b: Electrode EŻM



EB 1.50 ES 18-8-6B EŻM

NiCl XHD 2230

Fig. 5. Microstructure of the HAZ of the repair welds

most significant changes in properties of the areas subjected to welding were observed in the fusion line area and in the HAZ (Fig. 5). In terms of the weld made using electrode EB 1.50, the HAZ area contained a white band (i.e. the area having the structure of white cast iron), the martensitic structure and spherical graphite. The HAZ of the weld made using austenitic electrode ES 18-8-6B contained the pearlitic structure and a certain amount of martensite. The HAZ of the weld made using electrode EŻM (Ni/Cu) revealed the presence of the pearlitic structure with martensitic areas and nodular graphite. As regards nickel-based electrodes, i.e. NiCl and XHD 2230, the HAZ area contained fine-acicular martensite with spherical graphite. In addition, the metallographic tests revealed cracks in the area of the weld made using electrode EB 1.50 and in the HAZ area of the weld made using electrode ES 18-8-6B (Fig. 6, 7).

Hardness measurements based on the Vickers hardness test confirmed the results of the microscopic tests. The highest hardness amounting to 700 HV1 was measured in the

Fig. 6. Crack in the weld made using electrode EB 1.50

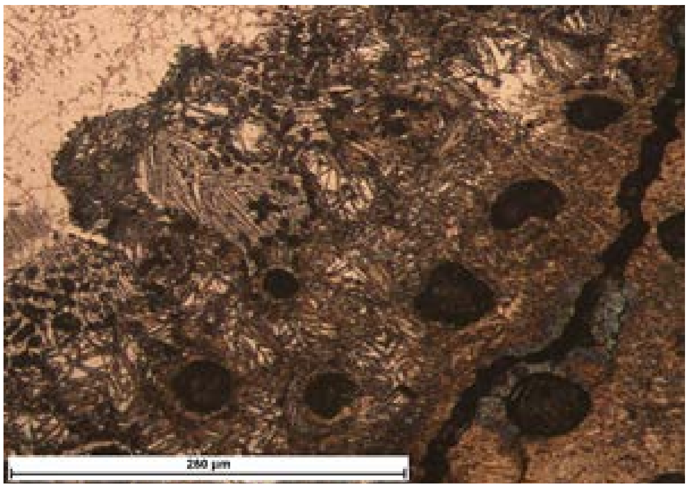


Fig. 7. Crack in the HAZ of the weld made using electrode ES 18-8-6B

weld made using the low-carbon filler metal (EB 1.50). The hardness of the weld made using the austenitic electrode amounted to approximately 350 HV1. In cases of the remaining electrodes, the hardness amounted to approximately 200 HV1. In cases of all of the electrodes used in the tests, the HAZ revealed an increase in hardness, confirmed by the presence of the martensitic structures. The highest value, exceeding 700 HV1, was identified in the HAZ of the weld made using electrode EB 1.50. The hardness in the HAZ area of the weld made using electrode ES 18-8-6B amounted to approximately 600 HV1. In cases of the remaining electrodes, the hardness of the HAZ area was restricted within the range of 450 HV1 to 300 HV1. The lowest hardness values in the HAZ area were identified in the welds made using nickel-based filler metals (NiCl, XHD 2230) (Fig. 8).

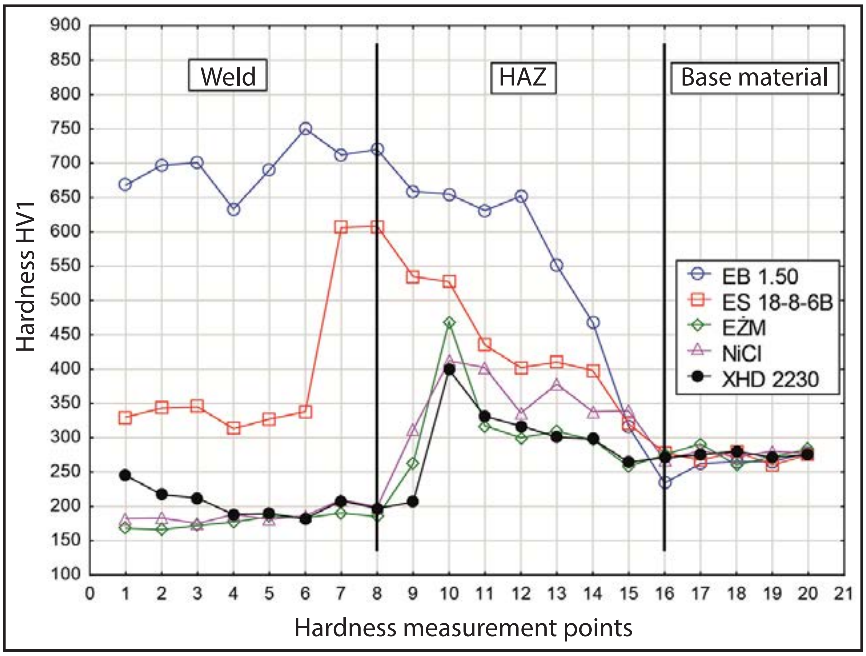


Fig. 8. HV1 hardness distribution in the repair welded cast iron areas


Fig. 9. Surface of the weld made using electrode EB 1.50


Fig. 10. Surface of the weld made using electrode XHD 2230

The comparison of the weld colour with that of the base material required subjecting the weld faces to mechanical treatment. The observations following the mechanical treatment revealed that the weld colour most similar to that of the base material was obtained in the weld made using electrode EB 1.50 (Fig. 9). In cases of the remaining welds, the above-named difference was more visible (Fig. 10).

Summary

The tests concerning the MMA repair welding involving the use of various grades of electrodes revealed the possibility of using the above-named technology when repairing castings made of nodular cast iron GJS 350-22. However, during the repair welding of the aforesaid cast iron it is necessary to pay particular attention to the possible formation of whitened areas (i.e. containing white cast iron) in the HAZ, potentially leading to the formation of cracks. The use of inexpensive low-carbon filler metals enables the obtainment of welds, the colour of which is similar to that of the base material. Unfortunately, martensitic structures formed in the weld and HAZ areas are characterised by a hardness of more than 700 HV1, which combined with a failure to strictly apply the welding technology can lead to the formation of cracks both in the weld and the HAZ area. In terms of structural changes, the most favourable properties of repair welds are obtained using nickel-based filler metals, yet the cost of such repairs is high and it is not possible to obtain a colour similar to that of the base material. Intermediate properties are obtained using austenitic filler metals and Monel alloy-based filler metals.

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