ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 7
Issue 4/2007

9 – 12

2/4

The heat treatment of Fermanal cast steel

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Received 04.07.2007; accepted in revised form 10.07.2007

Abstract

The study discloses the results of microstructural examinations, testing of magnetic properties and hardness measurements as cast and after heat treatment conducted on the Fermanal cast steel. A characteristic feature of this cast steel is its density lower by about 10% than the density of carbon cast steel [4]. It has been proved that the factor deciding about the composition of microstructure (fraction of ferrite and austenite) is the content of aluminium. The matrix totally austenitic is present in cast steel containing from 0,8 to 0,9% C, from 22 to 24% Mn, and from 4,5 to 5,5% Al. The magnetic properties examined on samples of the Fermanal cast steel were determined by spectroscopy of the Mössbauer effect with isotope ^{57}Fe. The magnetic properties represented by a mean value of the hyperfine magnetic field B_{hf} and relative magnetic permeability □ were determined. It has been stated that the level of magnetic properties of the Fermanal cast steel depends on the content of ferrite. The effect of the parameters of solutioning and ageing on the cast steel microstructure and hardness after modification with additions of B, Ti and Nb was investigated.

Keywords: Cast steel –Fermanal, Hyperfine magnetic field, Relative magnetic permeability, Hardness, Modification

1. Introduction

In years 1977 to 1985, the Institute of Materials Engineering of the Silesian University of Technology in Katowice was conducting studies on the technology of manufacturing the nickel-free, austenitic and austenitic-ferritic cast steels in which the austenite-forming nickel was replaced with an addition of manganese, and the reduced weight of castings was obtained by an addition of aluminium introduced to the cast steel in an amount from 6 to 9% [1]. At present, the studies are continued under a Commissioned Research Project KBN [2, 3].

The microstructure of the Fermanal cast steel is composed of austenite and ferrite, and their content in respect of each other depends on the content of Mn and Al. The matrix totally austenitic is present in cast steel containing from 0,8 to 0,9% C, from 22 to 24% Mn and from 4,5 to 5,5% Al. In cast steel containing over 6% Al., during solidification, the hard and brittle phases of $FeMn_3$, $(Fe, Mn)_3Al$ and $(Fe, Mn)AlC_x$ precipitate [5]. The presence of these phases has an adverse effect on the plastic properties of this cast steel. The Fermanal cast steel of austenitic structure as cast can reach the tensile strength from 700 to 750 MPa and an impact resistance from 0,6 to 0,8 MJ/m^2. The Fermanal cast steel is characterised by good casting properties and paramagnetic behaviour [4]. Therefore it can be used for cast parts of electric motors and generators, specially when reduced weight of the assembly is the main problem.

The aim of the studies carried under the Project was determination of microstructure, magnetic properties and heat treatment effect on microstructure and hardness of the Fermanal cast steel.

2. Materials and methods of investigation

Investigations were made on cast steel of austenitic and austenitic - ferritic matrix, controlled by varying content of manganese and aluminum.

For melting the following charge materials were used: „armco" iron (99,98% Fe), aluminum in grade AR0 (99,95% Al), Fe-Mn (6,67% C, 79,5% Mn, 1,25% Si, 0,21% P), Fe-Mn „affina" (1,33% C, 79,78% Mn, 1,13% Si, 0,18% P). The modifying agents were Ca-Si, Fe-Ti, Fe-Nb and amorphous boron.

Melts were conducted in an induction VSG-02 furnace made by Balzers, in an Al_20_3 crucible. The charge weight was 0,8 kg. After melting of armco iron and FeMn (6,67% Mn), the FeMn „affina" was added and melt surface was covered with cryolite. Next, under thus formed slag coating, aluminum was introduced in several batches (pieces of dimensions from 5 to 10 mm). Before tapping, modification was made, using modifier in a preselected amount (cast steel 4.1-4g CaSi, cast steel 4.2 - 4g CaSi + 8g FeB, cast steel 4.3 - 4g CaSi + 8g FeTi, cast steel 4.4 – 4g CaSi + 8g FeNb), and the cast steel was poured into a graphite mould placed by the side of the crucible, preheated to about 300^oC [6]. The samples for examinations were taken from the cast rods of dimensions ϕ40x100 mm and chemical composition as stated in Table 1 below:

Table 1.
The results of chemical composition analysis

No.	Chemical composition, % wt.					
	C	Mn	Al	Si	P	S
3.1	0,88	23,24	2,69	0,12	0,078	0,022
3.2	0,94	24,12	3,78	0,14	0,083	0,027
3.3	0,89	25,32	5,16	0,21	0,084	0,035
3.4	0,91	23,67	6,56	0,19	0,088	0,023
4.1	0,84	25,21	4,12	0,18	0,087	0,027
4.2	0,82	24,56	5,15	0,23	0,079	0,022
4.3	0,79	25,45	6,02	0,25	0,091	0,028
4.4	0,86	23,76	5,48	0,28	0,084	0,029

3. The results of investigations

The main experimental method used to determine the magnetic properties of the Fermanal cast steel samples was spectroscopy of the Mössbauer effect with isotope^{57}Fe. The Mössbauer effect spectroscopy enables investigating the hyperfine nuclear effects, thus providing numerous valuable pieces of information on the electromagnetic environment of the applied nuclide [5]. The measurements were taken at room temperature on a Polon 2330 spectrometer operating in a system of constant source acceleration in transmission geometry. As a Mössbauer source, the ^{57}Co in Rh matrix of activity of about 50 mCi was used. The analysis of the shape of Mössbauer spectra indicates that samples of cast steel with higher content of Al (melts 3.3 and 3.4) offer much better magnetic properties, represented by the values of magnetic fields and magnetic permeability. The results of these measurements and computations are shown in Fig. 1.

Examples of microstructures as cast, obtained on an optical MiFe2 microscope made by Reichert are shown in Figures 2, 3 and 4.

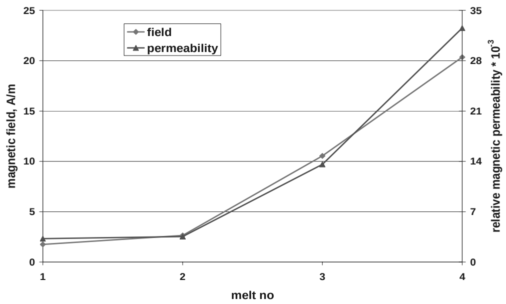

Fig. 1. The results of measurements taken on melts 3.1 to 3.4

In samples from melts 3.1 and 3.2 the microstructure is totally austenitic. Also samples of cast steel from melts 4.1, 4.2 and 4.4 have austenitic microstructure. In these samples one can see the primary precipitates of intermetallic phases, which for indentification should be subjected to either X-ray phase radiography or X-ray microanalysis.

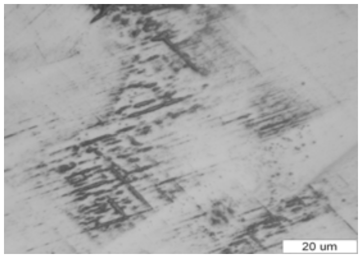

Fig. 2. Microstructure of cast steel from melt 3.1 as cast, 500x

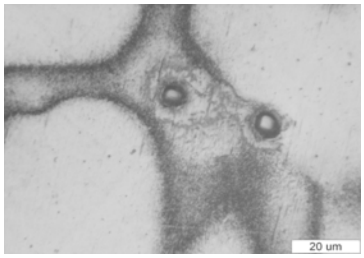

Fig. 3. Microstructure of cast steel from melt 3.4 as cast, 500x

Fig. 4. Microstructure of cast steel from melt 4.4 as cast, 500x

The conducted heat treatment consisted of two operations:

- solutioning at a temperature of 950^oC for a time of 0,5 h followed by cooling in water,
- ageing at three temperatures, viz. 450^oC, 600^oC and 750^oC for a time of 2 h followed by cooling in air.

The treatment covered melts from series 4.1 to 4.4, which contained modifying alloying additives. From the heat treated castings, samples were taken for microstructural examinations. Hardness was also measured as cast, after solutioning, and after final ageing.
Examples of microstructure images after the heat treatment are shown in Figures 5 to 7.

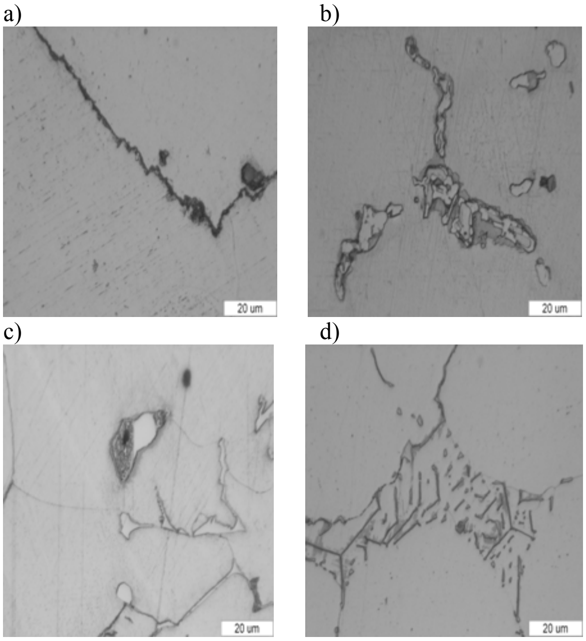

Fig. 5. Microstructure after solutioning at 950°C and ageing at 600°C: a) cast steel 4.1, b) cast steel 4.2, c) cast steel 4.3, d) cast steel 4.4, (100x)

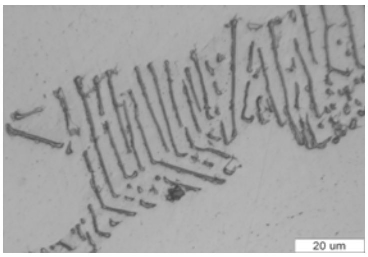

Fig. 6. Microstructure of cast steel 4.4: temperature of solutioning 950°C, temperature of ageing 450°C, 500x

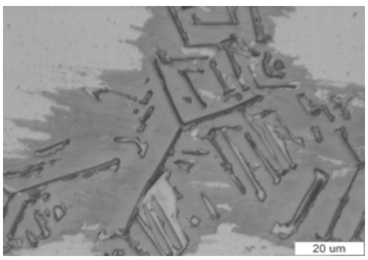

Fig. 7. Microstructure of cast steel 4.4: temperature of solutioning 950°C, temperature of ageing 750°C, 500x

Hardness was measured with Brinell hardness tester using a ball of 5 mm diameter under a load of 750 kg and during the time of 10s. The results of these measurements are shown in Figure 8 - as-cast state, and in Figure 9 - in condition after solutioning and ageing under various heat treatment regimes. The results plotted in the diagram are a mean from five measurements.

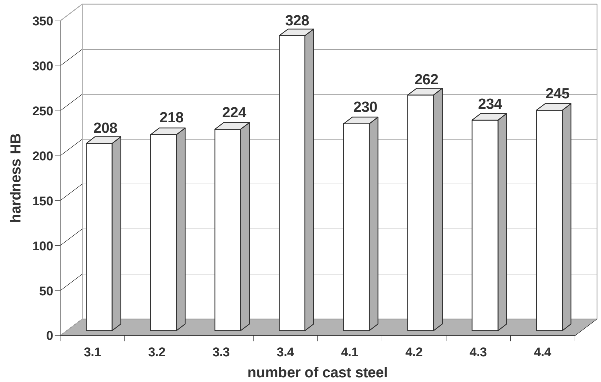

Fig. 8. Results of Brinell hardness measurements as cast

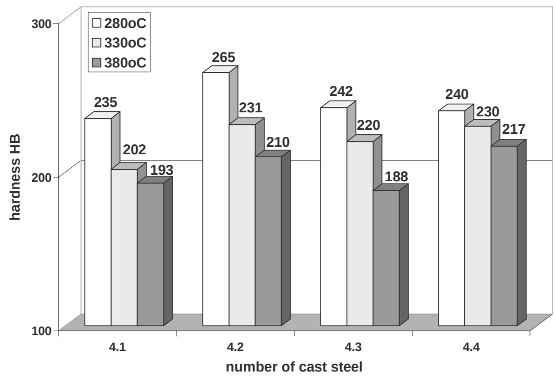

Fig. 9. Results of Brinell hardness measurements after solutioning and ageing

Microhardness HV of microstructural constituents was also measured using a microscope attachment (Reichert Me-F2 metallographic microscope) and applying the load of 50g.
In melt series 3.1 to 3.4, the term „eutectic" means precipitates of magnetic phase, i.e. high-temperature ferrite), while in melt series 4.1 to 4.4 these are the of intermetallic and carbide phases of high melting point. The results are shown in Figures 10.

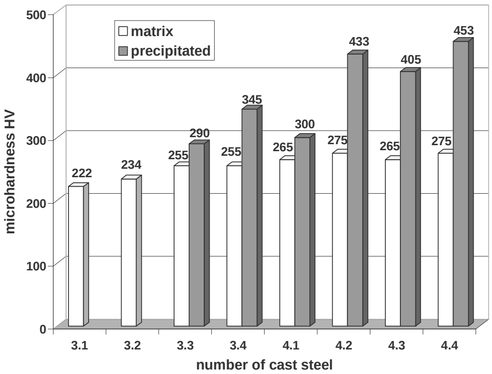

Fig. 10. Microhardness of metallic matrix and as-cast eutectic

4. Analysis of the results

The results obtained during the investigations have proved that the magnetic properties of the Fermanal cast steel depend on microstructure which is determined by the chemical composition and, in particular, by the content of manganese and aluminum. Analysis of the shape of Mössbauer spectra shows that samples of cast steel with high content of aluminum offer much better magnetic properties, represented by the values of magnetic field and magnetic permeability. Increasing manganese content reduces the magnetic properties. On the other hand, they increase with increasing content of aluminium in castings. Data in reference literature indicate that the value of magnetic field (the magnetic coercive force H_c) is about 5200 A/m for carbon steel, whereas the value of relative magnetic permeability ranges to about 30 [6]. These are the values much higher (by one or two orders of magnitude) than the values obtained in the examined materials.

The Fermanal cast steel containing from 4 to 5% Al, from 22 to 25% Mn, and from 0,8 to 0,9% C is austenitic and its properties are fully paramagnetic.

The results of measurements and calculations of magnetic properties have been confirmed by microstructural examinations. Samples which revealed an obvious increase of magnetic field and magnetic permeability revealed also the presence of ferrite precipitates (phase α), whose amount was increasing with increasing content of aluminum. Therefore this cast steel is applicable for cast elements of electric motors and generators, specially when reducing the weight of the whole assembly become the issue of primary importance.

Hardness as cast increases with increasing content of aluminum, which is due to the appearance in matrix of ferrite precipitates (a magnetic phase), when the aluminum solubility limit in austenite is exceeded. Modification slightly raises the hardness of cast steel as cast, the influence on hardness increase being most prominent in the case of boron addition. After heat treatment the alloy hardness is reduced, specially if ageing has been conducted at high temperatures (600^{o}C and 750^{o}C). Yet, it can be expected (though studies of this type have not been included into the scope of this Project) that reduced hardness of Fermanal cast steel will be combined with increase of plastic properties. The highest thermal stablity, i.e. the lowest drop of hardness after heat treatment, has the cast steel modified with niobium.

5. Conclusions

The magnetic properties, represented by the values of magnetic field and magnetic permeability, decrease with increasing content of manganese and decreasing content of aluminum. The as-cast hardness of Fermanal cast steel increases with increasing content of aluminum. The alloy hardness after heat treatment is reduced, specially if ageing has been conducted at high temperatures (600^{o}C and 750^{o}C). The highest thermal stability, that is, the lowest drop of hardness after heat treatment, offers the cast steel modified with niobium.

Acknowledgements

The studies were done under a Commissioned Research Project PBZ/KBN/114/T08/2004 financed by the Ministry of Science and Higher Education.

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