ARCHIVES
of
FOUNDRY ENGINEERING

ISSN (1897-3310)
Volume 14
Issue 3/2014

43 – 46

9/3

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

Analysis of the High Chromium Cast Iron Microstructure after the Heat Treatment

D. Kopyciński, E. Guzik, D. Siekaniec *, A. Szczęsny
AGH University of Science and Technology, Mickiewicza 30, 30-059 Kraków, Poland
*Corresponding author. E-mail address: dsiek@agh.edu.pl

Received 30.04.2014; accepted in revised form 09.05.2014

Abstract

The article presents results of heat treatment on the high chromium cast iron. The study was carrying out on samples cut from the casting made from chromium cast iron. Those were hardened at different temperatures, then tempered and soft annealed. The heat treatment was performed in a laboratory chamber furnace in the Department of Engineering Alloys and Composites at Faculty of Foundry Engineering AGH. At each stage of the heat treatment the hardness was measured by Vickers and Rockwell methods, and the microscope images were done. Additionally based on images from the optical microscope the microstructure was assessed. Based on these results, the effect of hardening, tempering and soft annealing on the microstructure and hardness of high chromium cast iron was studied. Next the effects of different hardening temperatures on the properties of high chromium cast iron were compared. The study led to systemize the literature data of the parameters of heat treatment of high chromium cast iron, and optimal conditions for heat treatment was proposed for casts of similar properties and parameters.

Keywords: High chromium cast iron, Heat treatment, Hardening, Tempering, Soft annealing

1. Introduction

White cast iron, especially chromium cast iron belongs to one of the groups of cast alloys, which through continuous improvement of functional properties increase the applications.

Microstructure of chromium cast iron (particularly structure-oriented – after unidirectional crystallization) can be perceived as a composite *in situ*, in which the hard carbides are distributed in a metal matrix as a structural component. The effects on the properties of the carbide phase of white cast iron, are well-known (wear resistance, toughness or hardness). White cast iron carbides can be divided into two groups:

- interstitial carbide with a simple, close-packet structure: carbides of the MC type e.g. TiC, and of the M_2C type e.g. W_2C;
- interstitial carbides with complex hexagonal, close-packed structure: M_3C – $(Cr,Fe)_3C$ type, of the M_7C_3-$(Cr,Fe)_7C_3$ type, and of the $M_{23}C_6$ - $(Cr,Fe)_{23}C_6$, as well as $(Cr,Fe)_6C$ types.

Very characteristic property of the carbides is their hardness, which is associated with crystal structure. Table 1 shows the hardness of the iron carbides in the chromium cast iron, and hardness of the metal matrix.

Table 1.
Comparison of the hardness of the phases occurring in the chromium cast iron

Phase	Crystal type	Hardness, max. HV
$(Cr,Fe)_7C_3$	Hexagonal	1800
$(Cr,Fe)_{23}C_6$	Complex cubic	1650
Austenite	Face-centered cubic	210
Pearlite	-	265
Martensite	Tetragonal	940
Bainite	-	660

The hardness is one of the parameters that determine the resistance to abrasion; therefore the optimum value should be high and as constant as possible.

Chromium cast iron is wildly used as a material for machine elements, which are characterized by good mechanical properties, with simultaneous resistance to high temperatures.

Heat treatment allows to significant improvement in the mechanical and technological properties of alloys. The purpose of the heat treatment is primarily elimination or reductions of the casting stresses reduction of the hardness and increase the machinability, also enlarge the mechanical index and abrasive resistance.

The heat treatment of chromium cast iron is carried out using special precautions. Chromium cast iron belongs to the group of white cast iron, therefore is sensitive to the cooling rate, which may result in formation of cracks in castings [1-11].

Currently, in the literature there is a lot of information on heat treatment of chromium cast iron, but it appears that sometimes they conflict with each other. Therefore, a series of tests must be performed to systematize the information above.

2. Methodology

The samples were cut from the casting made from chromium cast iron, with the chemical composition shown in Table 2.

Table 2.
The chemical composition of chromium cast iron

Chemical element	% mass
Fe	rest
C	3.23
Si	0.52
Mn	0.65
P	0.04
S	0.026
Cr	23.8
Mo	0.12
Ni	0.34
Cu	0.11

Five samples with dimensions ø15 × 15 mm were cut from the casting. They were subjected to hardened treatment in different temperatures, and then tempered and soft annealed. The parameters of heat treatment are shown in Table 3. The heat treatment was performed in a laboratory chamber furnace located in the Department of Engineering of Cast Alloys and Composites at Faculty of Foundry Engineering AGH.

At each stage of the heat treatment hardness of each sample was measured by Rockwell and Vickers method. Moreover based on images from the optical microscope (LM) rated their microstructure.

Table 3.
Heat treatment parameters for individual samples

No.	Sample name	Hardening	Tempering	Soft annealing
0	Beta	As cast		
1	Beta1	930°C/ 7h/ air	500°C/ 3h/ air	950°C 1h/ cooling to temp 810°C during 1h/ cooling to temp 600°C for 2h/ air cooling
2	Beta2	950°C/ 7h/ air		
3	Beta3	970°C/ 7h/ air		
4	Beta4	1000°C/ 7h/ air		
5	Beta5	1050°C/ 7h/ air		
Comments		According to [12]		

3. Results and discussion

3.1. Hardness test of alloys

Hardness was measured at three points – one in the middle of the sample, and two at the edges. Figures 1 and 2 shows graphs with the results of hardness after hardening, tempering and soft annealing the Vickers and Rockwell method respectively, compared with the hardness of as-cast sample.

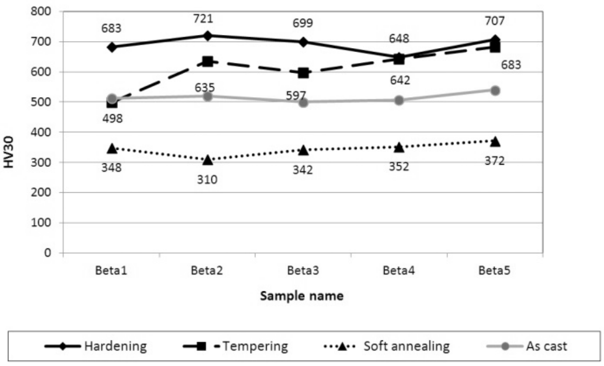


Fig. 1. The Vickers hardness of the samples after hardening, tempering and soft annealing, and as-cast

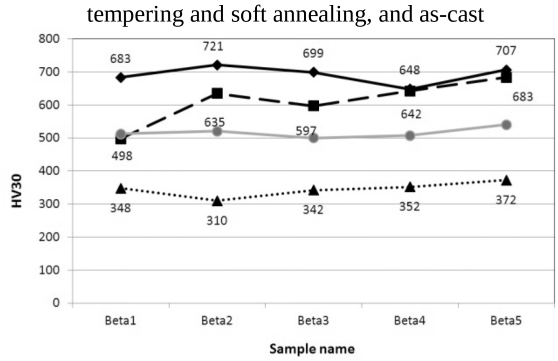


Fig. 2. The Rockwell hardness of the samples after hardening, tempering and soft annealing, and as-cast

From the graphs it can be seen that the highest value of the hardness after hardening was achieved for the sample which was hardened at a temperature of 950°C, both in the HV and HRC method. For each sample there is substantial improvement compared to the value of hardness of the as-cast sample.

Tempering and soft annealing treatment for each sample was carried out under the same conditions. The highest value of hardness after tempering had the Beta5 sample (the sample with the highest temperature of hardening). The largest decrease of the hardness after tempering was achieved for the sample Beta1 - the lowest temperature of hardening. Soft annealing treatment resulted in lower values of hardness. For this treatment also the highest value of hardness was obtained for the sample Beta5, and the biggest differences for sample Beta2. Results shows that each sample, after each heat treatment had similar hardness (60 HRC ±2 units).

3.2. Microstructure of alloys

At each stage of the heat treatment the microstructure of the samples was examined. The samples were mounted in the acrylic resin, followed by the rough grinding discs of diamond grit 120, 220, 600, and 1200 in a forced stream of water, the speed of the wheel - 300 rpm and pressure 30N. Then microsections were polished on the face of the cloth polishing using a slurry with particles of diamond size 9 and 3 microns and lubricant STRUERS. Samples were rinsed in anhydrous ethyl alcohol (ethanol 99.8%) and dried in a stream of hot blow in the oven. Microsections were etched in Vilella reagent.

Metallographic analysis was performed using an optical microscope MEF-4M LEICA, aided with automatic image analysis LEICA Qwin and of the Joel 5500LU Scanning Electron Microscopy (SEM).

Figure 3 shows a metallographic microstructure of the Beta sample (as-cast) and Fig. 4 - microstructure SEM image of carbide. The metallographic microstructure after each heat treatment step for Beta2 sample is given in Fig. 5.

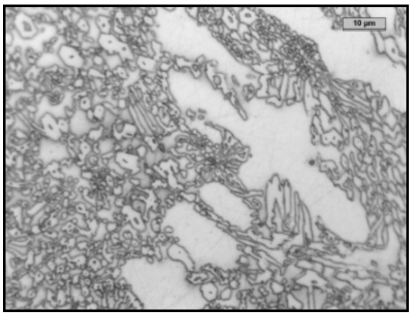


Fig. 3. Metallographic microstructure, Beta sample (as-cast), magnification 1000x

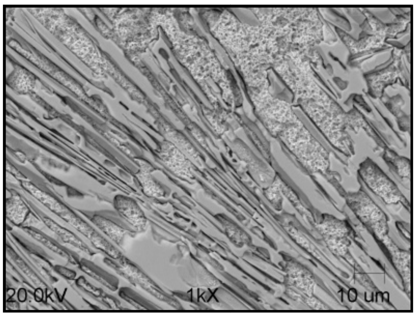
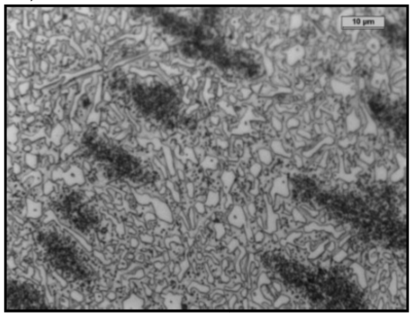
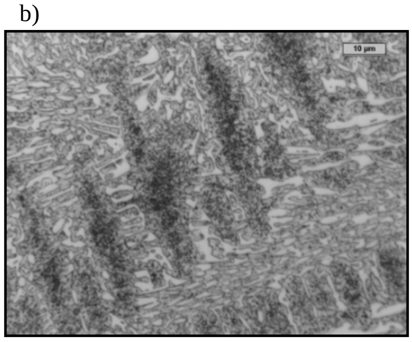


Fig. 4. SEM image of carbide in chromium cast iron, Beta sample (as-cast), magnification 1000x

a)



b)



c)

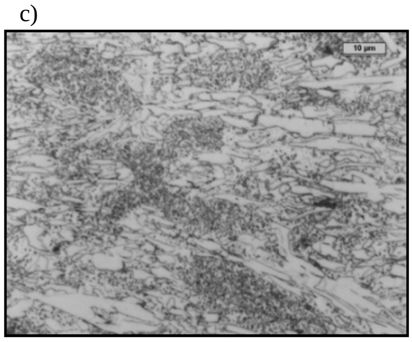


Fig. 5. Metallographic microstructure of Beta2 sample after hardening in temperature 950°C – a), tempering – b), and soft annealing – c), magnification 1000x

Comparing the microstructure of the as-cast sample (Fig. 3) and the microstructure after heat treatment (Fig. 5), the separation of martensite in the matrix can be seen for the samples after heat treatment.

The amount of carbide precipitations (L) was measured by linear intercepts method; the results are shown in the Fig. 6. The number of carbides precipitation is in the range between 1500 and 2700 1/cm.

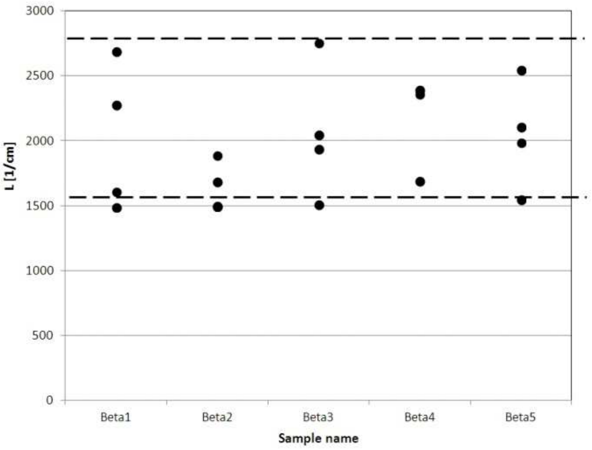


Fig. 6. The number of carbides precipitations (L) after hardening, tempering, soft annealing and as-cast sample

Additionally the distance between carbides (l) was measured; the results are shown in Fig. 7. Distances between carbides are in the range between 2.0 and 4.5 µm.

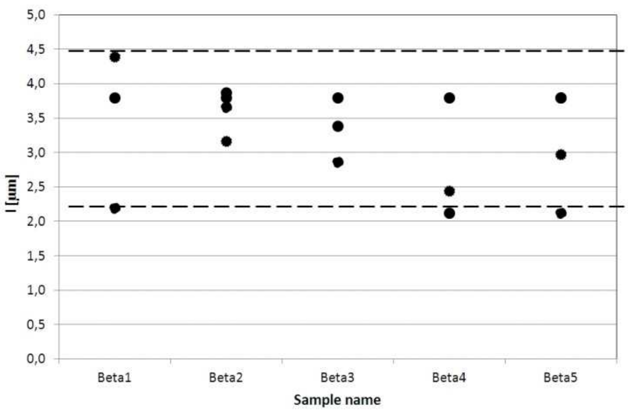


Fig. 7. Distances between carbides (l) after hardening, tempering, soft annealing and as-cast sample

From the figures 6 and 7 and from the metallographic microstructures it can be notice that microstructure of chromium cast iron is composed mostly of precipitation carbides. They affect the strength parameters such as, hardness.

4. Conclusions

Test results indicate that with proper selection of heat treatment parameters the hardness and composition of phase microstructure of chromium cast iron can be controlled. Hardening affects positively the hardness of castings, whereas tempering and soft annealing improves ductile properties of chromium cast iron. By adjusting the heat treatment parameters, the material properties can be customized for a particular application.

The studies let to determinate the optimum heat treatment for this type of cast iron. The best properties were obtained for hardening at 950°C, for other temperature of heat treatments the hardness increased and exceeded 60 HRC units.

Acknowledgements

The study was co-financed by NCBiR in the years 2012-2015 as a targeted project No. IN/150421/U.

References

[1] Podrzucki, Cz. (1991). *Cast Iron*. Krakow: ZG STOP Publication.

[2] Kosowski, A., Podrzucki, Cz. (1981). *Alloy cast iron.* Krakow: University scripts.

[3] Studnicki, A. (2013). *Role of selected modifiers in the crystallization of wear resistant chromium cast iron*. Katowice-Gliwice: Ed. Commission Foundry PAN.

[4] Xiang, Ch. & Yanxiang, L. (2010). Effect of heat treatment on microstructure and mechanical properties of high boron white cast iron. *Materials Science and Engineering.* A 528, 770-775. DOI:10.1016/j.msea.2010.09.092.

[5] Kopyciński, D. & Piasny, S. (2012). Influence of tungsten and titanium on the structure of chromium cast iron. *Archives of Foundry Engineering.* 12(1), 57-60.

[6] Studnicki, A. (2009). Influence of selected modifiers on crystallization curve of chromium cast iron. *Archives of Foundry Engineering.* 9(3), 181-188.

[7] Studnicki, A., Jura, S. & Suchoń, J. (1998). The influence of chemical composition of chromiun cast iron on distribution of carbides size. *Solidification of Metals and Alloys*. 37, 17-37.

[8] Kopyciński, D. (2009). Analysis of the structure of castings made from chromium white cast iron resistant to abrasive wear. *Archives of Foundry Engineering.* 9(4), 109-112.

[9] Kilarski, J., Studnicki, A. & Przybył, M. (2003). Distribution of hardness and microhardness of matrix of chromium cast iron on section casting. *Archives of Foundry Engineering.* 3, 274-279.

[10] Kopyciński, D., Guzik, E. & Piasny, S. (2011). The structure of abrasion-resisting castings made of chromium cast iron. *Archives of Foundry Engineering.* 11(3), 61-64.

[11] Kawalec, M. (2014). Microstructure control of high-alloyed white cast iron. *Archives of Foundry Engineering.* 14(1), 49-54.

[12] EN12513:2011 (E). Founding - Abrasion Resistant Cast Iron.