

The Effect of Addition of Titanium on The Structure and Properties of High Chromium Cast Iron

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Abstract

The paper presents results of Ti-addition to High Chromium Cast Iron (HCCI) on the structure and selected mechanical properties. For this study casted two sets of cylinders with dimensions $\varnothing 20$ mm, $\varnothing 15$ mm x 250 mm, for the High Chromium Cast Iron (HCCI) and with the 4% by mass Ti-addition. Melts were performed in the induction furnace crucible capacity of 15 kg. During the heats the cup with installed S type thermocouple was poured to record the cooling curves. The cylinders were subjected to the static bending strength test. Samples for the test microstructure and Rockwell hardness were cut from the cylinders. The study shows that the addition of titanium had an impact on the structure and thus the properties of High Chromium Cast Iron (HCCI). In subsequent studies, through an appropriate choice of chemical composition and proper process control, it is planned to obtain in the structure the titanium carbides TiC and chromium carbides with type $(Cr, Fe)_7C_3$.

Keywords: High Chromium Cast Iron (HCCI), Titanium, Bending strength, Hardness, Microstructure

1. Introduction

Cast iron has long been well known and esteemed engineering material, which is still subject to many studies. High Chromium Cast Iron (HCCI) belongs to one of the groups of cast alloys, which through continuous improvement of functional properties increase the applications. It can be obtained through the introduction of alloying agents that affect the structure, and thus on the properties of the material.

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-packed structure: carbides of the MC and of the M_2C ;
- interstitial carbides with complex hexagonal, close-packed structure: M_3C , M_7C_3 and $M_{23}C_6$, 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 [1-2].

Table 1.
Comparison of the hardness of the phases occurring in the chromium cast iron [1-2]

Phase	Crystal type	Hardness, max. HV
$(Cr,Fe)_3C$	Orthorhombic	900
$(Cr,Fe)_7C_3$	Hexagonal	1800
$(Cr,Fe)_{23}C_6$	Complex cubic	1650
TiC	Regular spatial	2035
Austenite	Face-centered cubic	210
Ferrite	Regular space-centered	90
Pearlite	Face-centered cubic - Orthorhombic	265
Martensite	Tetragonal	940
Bainite	Regular space-centered - Face-centered cubic	660

Formation of the structure, in particular the carbide phase is formed primarily during the solidification process. For the correct interpretation of the changes that occur in the structure of high chromium cast iron during self-cooling, it is necessary to analyze the triple phase system Fe-C-Cr alloys (Fig. 1). However it should be noted, that the other elements that occur in the high chromium cast iron, has also the influence on the structure. Phase equilibrium systems are the basis for the interpretation of the structure of all alloys. They illustrate the phase composition of alloys and phase transitions as a function of the chemical composition of the alloy and temperature [3-10].

Table 2.
The chemical composition of the High Chromium Cast Iron

Element	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
% mass	71	3.23	0.519	0.646	0.0384	0.0259	23.8	0.119	0.34	0.108

Melts were carried out in an induction furnace with a capacity of 15 kg located in the Department of Engineering of Cast Alloys and Composites in Foundry Engineering of AGH. Performed two melts. The first melt for High Chromium Cast Iron (HCCI) with chemical composition shown in Table 1 and the casting temperature of 1490°C. During the second melt the liquid metal was overheated to the temperature above 1500°C, then added the 4% mass of titanium, the metal held for 5 minutes and poured molds. For each melts casted 2 sets of cylinders with dimensions $\varnothing 20$ mm, $\varnothing 15$ mm x 250 mm. Separately molded the cups with S-type thermocouple to measure the cooling curves using a recorder AGILENT. The cylinders were subjected static bending strength test. Then samples for the microstructure and hardness were cut from the cylinders. The study of hardness was performed using Rockwell method. The samples for microstructure 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, in 300 rpm and pressure 30N. Then specimens were polished with diamond suspension (size 9 and 3 microns) and STRUERS lubricant. Samples were rinsed in anhydrous ethyl alcohol (ethanol 99.8%) and dried in a stream of

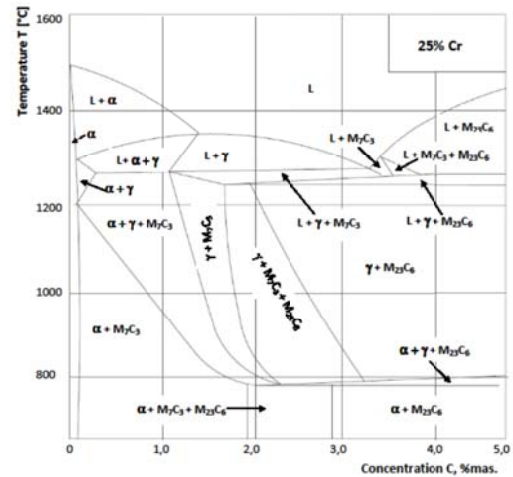


Fig. 1. The phase equilibrium diagram of alloy Fe-C-Cr containing 25% Cr [1]

2. Methodology

The aim of this work is to determine the effect of addition of 4% mass of titanium on the structure and selected mechanical properties of cast iron. The tests were performed on the High Chromium Cast Iron (HCCI) with the chemical composition shown in Table 2.

hot air. Microsections were etched in Vilella reagent. Metallographic analysis was performed using an optical microscope MEF-4M LEICA, aided with automatic image analysis LEICA Qwin.

3. Results and discussions

3.1. Cooling curves

Each cooling curve has characteristic points corresponding to the extending phase crystallization processes in the field of solidification and cooling of the casting. Hence, it is important to do the thermal analysis during every melt [3-6].

Figures 2 and 3 show a cooling curves, and the first derivative, respectively for the High Chromium Cast Iron (HCCI), and after the titanium addition. Provided in Fig. 4 crystallization and cooling curves for the two melts, it can be seen that the crystallization time after the addition of titanium decreases. This is due to the

formation of titanium carbide TiC , which saturate the carbon with the liquid, and thus the actual phase system of Fe-C-Cr alloy shift to the left. Moreover, alloying treatment increase the temperature of crystallization and reduces the theoretical eutectic crystallization temperature (Fig. 1).

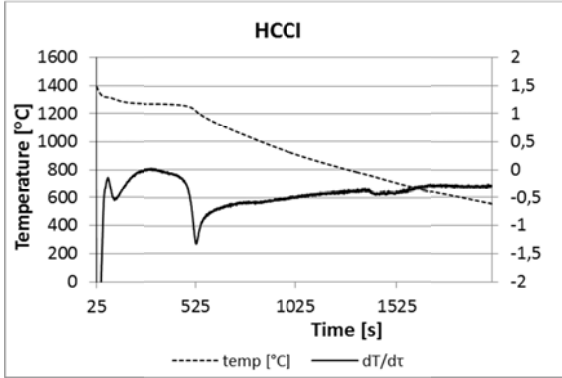


Fig. 2. Crystallization and cooling curve, and the first derivative of cooling curve for High Chromium Cast Iron (HCCI)

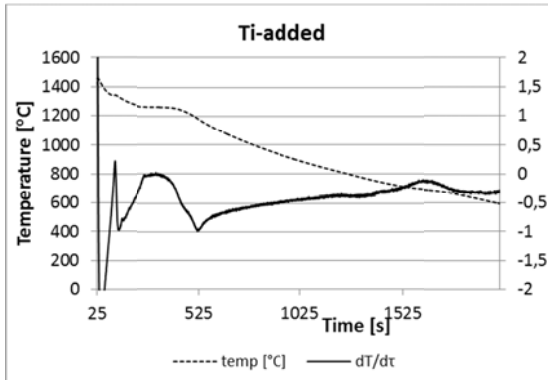


Fig. 3. Crystallization and cooling curve, and the first derivative of cooling curve for Ti-added

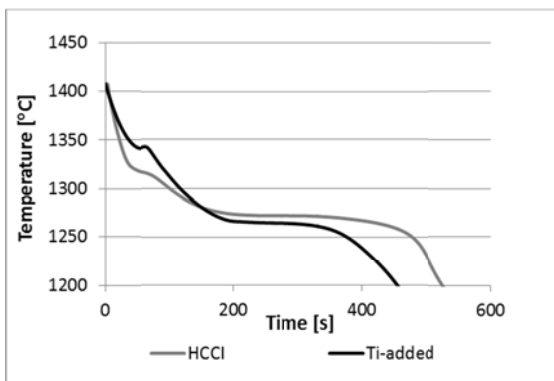


Fig. 4. Crystallization and cooling curve for two melts - High Chromium Cast Iron (HCCI) and Ti-added

3.2. Bending strength

The cast cylinders sample were subjected to the static bending strength. Figure 5 shows the results. Figure 6 shows the breakthroughs of cylinders with $\varnothing 20$ mm diameter for two melts - High Chromium Cast Iron (HCCI) and Ti-added.

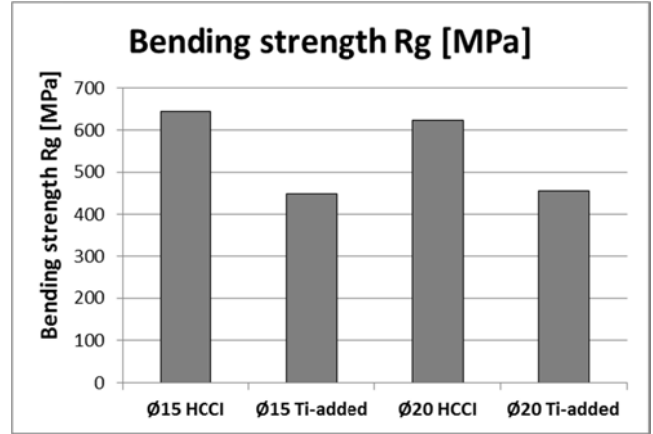


Fig. 5. The bending strength of the cylinders with a diameter $\varnothing 15$ mm and $\varnothing 20$ mm for two melts - High Chromium Cast Iron (HCCI) and Ti-added

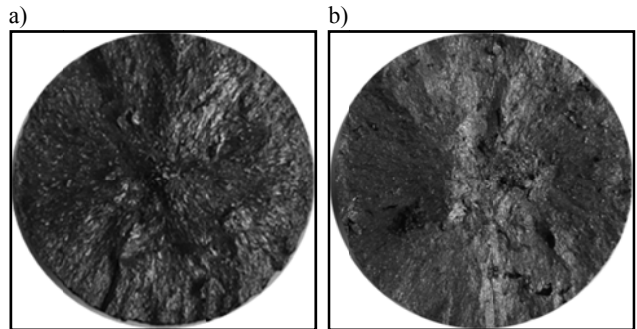


Fig. 6. Fracture of sample with $\varnothing 20$ mm diameter for two melts: a) - High Chromium Cast Iron (HCCI) and b) - Ti-added, after the test for bending strength

From Figure 5 it follows that the addition of the titanium decreased the bending strength. This is due to the transition type of crystallization from exogenous to endogenous and refinement of primary grains by the alloying treatment of 4% mass of titanium.

3.3. Hardness

From cylinders with a diameter of $\varnothing 20$ mm cut the samples with dimensions of $20 \text{ mm} \times \varnothing 20 \text{ mm}$ for hardness test. The study was performed by Rockwell hardness method. Hardness was measured at three points – two in the middle of the sample, and one at the edge. Fig. 7 shows a graph of averaged hardness values for the High Chromium Cast Iron (HCCI) and after titanium addition.

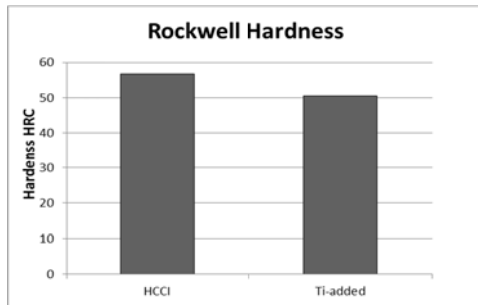


Fig. 7. Graph of averaged Rockwell hardness values for the High Chromium Cast Iron (HCCI) and Ti-added

Addition of titanium decreased hardness of the tested material. The reduction of hardness was due to the saturation of carbon by titanium carbides. This resulted in the formation of chromium carbides M_3C type of lower hardness, next to existing carbides of M_7C_3 type.

3.4. Microstructure

Figures 8 and 9 show pictures of the microstructure respectively, for the High Chromium Cast Iron (HCCI) and after the titanium addition.

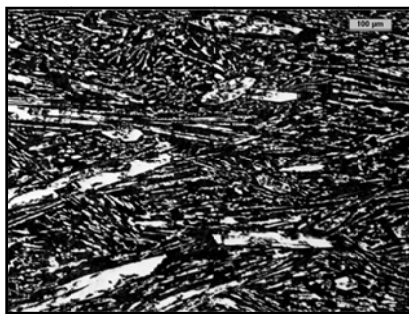


Fig. 8. Microstructure of High Chromium Cast Iron (HCCI), magnification 100x

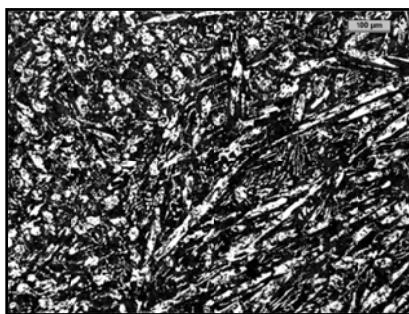


Fig. 9. Microstructure of Ti-added, magnification 100x

Analyzing these microstructures can be seen that the addition of titanium influenced the fragmentation of the structure. The microstructure of the high chromium cast iron after the addition of titanium consists mostly of carbides.

4. Conclusion

The study shows that the addition of titanium in the amount of 4% by mass to high chromium cast iron affects on fragmentation the structure. The addition of titanium results in the formation of titanium carbides and carbon saturation. This resulted in the formation of chromium carbides M_3C -type of lower hardness, next to existing carbides of M_7C_3 -type. As a consequence after the addition of the titanium the lower tensile properties were obtained. To improve these properties, the structure should be controlled by increasing the carbon content to obtain carbides of M_7C_3 -type. In subsequent studies, through an appropriate choice of chemical composition and proper process control, it is planned to obtain in the structure, the titanium carbides TiC and chromium carbides $(Cr, Fe)_7C_3$ -type.

Acknowledgements

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