



ARCHIVES  
of  
FOUNDRY ENGINEERING

DOI: 10.2478/afe-2014-0015

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



ISSN (2299-2944)

Volume 14

Issue 1/2014

63 – 66

# The Abrasive Wear Resistance of Chromium Cast Iron

D. Kopyciński<sup>a\*</sup>, S. Piasny<sup>a</sup>, M. Kawalec<sup>a</sup>, A. Madizhanova<sup>b</sup>

<sup>a</sup>AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland

<sup>b</sup>KazNTU Kazakhstan National Technical University, Satpayev Str. 22, Almaty, Kazakhstan

\* Corresponding author. E-mail address: dj@agh.edu.pl

Received 26.06.2013; accepted in revised form 02.09.2013

## Abstract

The resistance of cast iron to abrasive wear depends on the metal abrasive hardness ratio. For example, hardness of the structural constituents of the cast iron metal matrix is lower than the hardness of ordinary silica sand. Also cementite, the basic component of unalloyed white cast iron, has hardness lower than the hardness of silica. Some resistance to the abrasive effect of the aforementioned silica sand can provide the chromium white cast iron containing in its structure a large amount of  $(Cr, Fe)_7C_3$  carbides characterised by hardness higher than the hardness of the silica sand in question. In the present study, it has been anticipated that the white cast iron structure will be changed by changing the type of metal matrix and the type of carbides present in this matrix, which will greatly expand the application area of castings under the harsh operating conditions of abrasive wear. Moreover, the study compares the results of abrasive wear resistance tests performed on the examined types of cast iron. Tests of abrasive wear resistance were carried out on a Miller machine. Samples of standard dimensions were exposed to abrasion in a double to-and-fro movement, sliding against the bottom of a trough filled with an aqueous abrasive mixture containing SiC + distilled water. The obtained results of changes in the sample weight were approximated with a power curve and shown further in the study.

**Keywords:** Abrasive wear resistance, Structure of white cast iron, Type carbides:  $M_3C$ ,  $(Fe,Cr)_7C_3$

## 1. Introduction

Cast iron structure is formed during crystallisation, cooling and heat treatment of this material. During crystallisation process, the final type, content, distribution and geometry of cast iron phases are decided. On the other hand, the appearance of casting fracture depends on the type of high-carbon phases. i.e. graphite and cementite - in plain cast iron, and alloyed cementite and carbides formed in combination with various elements - in alloyed cast iron. Thus, conventionally, based on the appearance of cast iron fracture, grey and white cast irons, or mottled cast iron are distinguished [1-7], and on this division, the classification of cast iron grades currently produced is based. This paper describes the abrasive wear-resistant white cast iron, in the structure of which

there is a high content of carbides. Cast iron of this grade is widely used for parts of devices operating in the mining and construction sectors of the industry, and in milling equipment and machines used by the manufacturing industries, where high resistance to the abrasive effect of minerals and other solid materials is required. Another area of application of this cast iron is for parts of devices operating in the chemical industry, in metallurgy and in the widely understood power industry, i.e. the devices that are expected to offer failure-free operation under the harsh conditions of high (or low) temperatures, combined with resistance to the harmful effect of corrosive environments and acids.

## 2. Methodology

Applying the conditions normally encountered in industry, chromium white cast iron was manufactured. The manufactured cast iron had the following chemical composition is show in table 1.

Table 1.  
The chemical composition chromium cast iron

Melt No.	Chemical compositions % mass.										
	C	Si	Mn	P	S	Cr	Ni	V	W	Ti	Cu
I/1	3.01	1.07	0.6	0.03	0.05	12.9	0.07	0.005	0.031	0.005	0.039
I/2	2.35	0.65	1.06	0.05	0.07	25.6	1.09	0.009	0.065	0.010	0.962
I/3	1.78	0.70	0.33	0.05	0.06	18.3	0.07	0.005	0.055	0.004	0.047
I/4	3.14	0.96	0.54	0.05	0.06	24.6	0.42	0.047	0.047	0.014	0.079
I/5	3.21	0.71	1.36	0.05	0.06	26.6	0.64	0.032	0.025	0.009	0.047
I/6	4.50	1.06	1.04	0.04	0.06	25.2	1.02	0.007	0.025	0.009	1.020
I/7	3.35	1.51	0.63	0.03	0.05	21.2	0.61	0.036	0.062	0.013	0.193
I/8	3.60	0.93	0.27	0.02	0.01	16.1	0.01	-	-	5.04	0.05

Melting was carried out in an induction furnace of 250 kg capacity, applying the following procedure: in the bottom of the crucible, a charge composed of the pig iron and steel scrap, followed by iron scrap, was placed. After melting down the charge, ferrochromium and ferromolybdenum were added. After dissolving of ferrochromium, ferrosilicon was added. The cast iron was next overheated to a temperature of 1500°C and held at that temperature for 5 minutes. As a next step, the content of manganese was made up with ferromanganese, holding the metal for the next 3 minutes. During holding of cast iron and before tapping, the melt temperature was monitored with a thermocouple. Molten cast iron was transferred to a ladle. The ladle was next handled to a pouring stand and moulds prepared previously were poured with molten metal. As a next step, specimens for mechanical tests and polished sections for metallographic examinations were prepared.

Studies of abrasive wear resistance were carried out on a Miller machine. Specimens of a standard size, i.e. 25.4x12, 7x5 ± 9 mm, were charged with the weights and subjected to an abrasive wear test, rubbing in a reciprocating motion against the bottom of a gutter filled with the aqueous mixture of an abrasive medium (SiC + distilled water). The study involved three tests performed in 16-hour series consisting of four-hour shifts each. Then, the respective wear resistance curves were plotted. After each run the specimens were washed, dried and weighed to the nearest 0.1 mg. Based on the results of the measurements, the weight losses and the cumulative weight losses were determined after each test in a given series, enabling the results to be plotted on a time - weight graph. The cumulative (summarised) weight losses (regarded as a total mass loss which has occurred since the beginning of the constant load effect) were recorded after 4, 8, 12 and 16 hours of the test cycle. The obtained results of changes in the specimen weight were approximated with an exponential curve described by the following relationship:

$$W(t) = A \cdot t^B \quad (1)$$

where: W – the weight loss, [g], t – the time, [hours], A, B – the constants determined by the least square method.

Regardless of the number of trials in a series and the duration of a single test, the mass wear rate  $V_w$  determined by the slope of a tangent to the wear curve in the second hour of testing was adopted:

$$V_w = A \cdot B \cdot 2^{(B-1)} \quad (2)$$

where: A, B – the constants from relationship (1) [8].

Tests of abrasive wear resistance conducted on a Miller machine enabled comparing the abrasive wear resistance of the materials tested. In addition, as a reference, the chromium cast steel was tested, which is generally considered a material of high abrasion resistance. The chemical compositions of this material are tabulated in table 2 (compare with the composition of studied chromic cast iron).

Table 2 gives, among others, also chemical composition of the alloyed ductile iron resistant to abrasive wear, used for gears and pulleys, here selected for comparative purposes. Microstructures of the manufactured reference materials are given in Figure 1.

Table 2.  
The chemical composition cast steel and ductile cast iron

Melt No.	Chemical compositions Wt. %										
	C	Si	Mn	P	S	Cr	Ni	V	W	Ti	Cu
CS	0.06	1.08	0.74	0.03	0.05	25.3	5.53	0.014	0.060	0.009	2.84
DCI	3.68	2.41	0.32	0.01	0.01	0.02	0.008	0.009	0.065	0.010	1.04

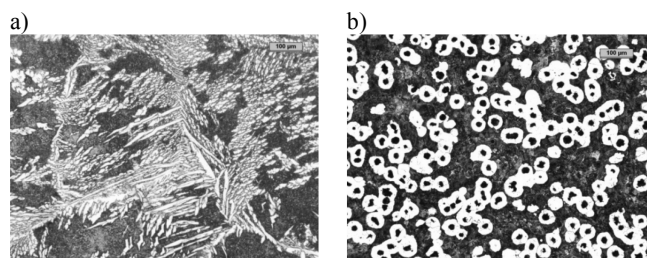


Fig. 1. Microstructures of castings made from cast steel - melt no. CS - (a) and made from ductile cast iron –melt no. DCI – (b)

## 3. Structure high chromium cast iron

Figure 2 and Figure 3 shows the microstructure of high chromium cast iron obtained from a trial melt.

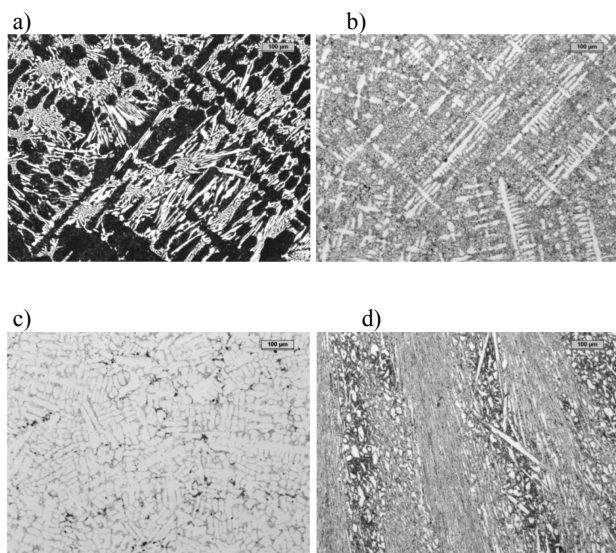


Fig. 2. Microstructures of castings made from high chromium cast iron: melt no. I/1 – (a), melt no. I/2 – (b), melt no. I/3 – (c), melt no. I/4 – (d)

The structure can be defined as hypoeutectic, „slightly” hypoeutectic or eutectic and „slightly” hypereutectic. The spatial arrangement in a structure of this type can be compared to a system of the interpenetrating phases bonded together in eutectic. Model solidification eutectic grains in the high-chromium cast iron shown in Figure 4. One of these phases is formed of the austenite dendrites that are penetrating into another phase, composed of the faceted crystals of chromium carbide  $(Cr,Fe)_7C_3$ .

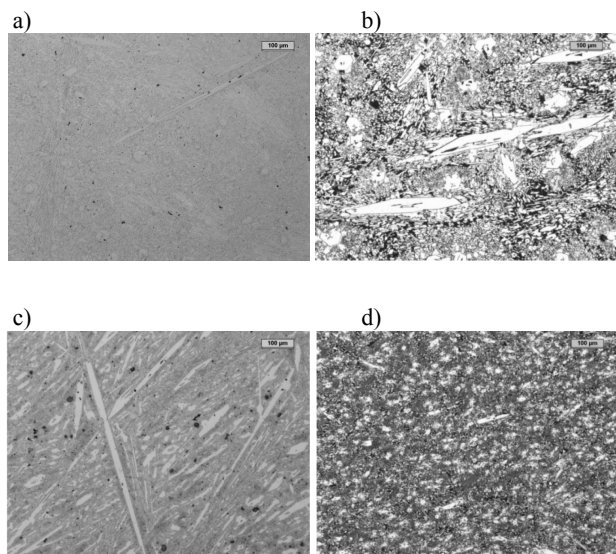


Fig. 3. Microstructures of castings made from high chromium cast iron: melt no. I/5 – (a), melt no. I/6 – (b), melt no. I/7 – (c), melt no. I/8 – (d)

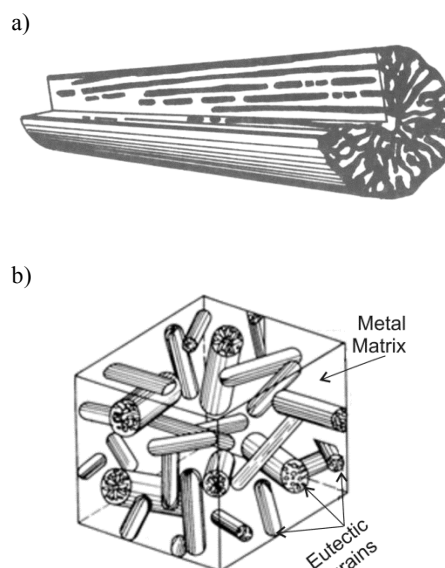


Fig. 4. Model  $\gamma - (Fe,Cr)_7C_3$  eutectic grain – (a) and model of the high-chromium cast iron solidification [9] – (b)

## 4. Results and discussion

In Table 3 compares the resulting loss of weight, the determined parameters A, B, and Vv and hardness HV30. The obtained results are displayed in the form of a collective graph in Figure 5.

Table 3.

Results of abrasive wear resistance measurements

Melt No.	Weight loss g				A	B	V <sub>w</sub>	Hardness HV30
	After 4 hours	After 8 hours	After 12 hours	After 16 hours				
I/1	0.11	0.225	0.375	0.505	0.0233	1.1090	0.028	518
I/2	0.07	0.12	0.2	0.28	0.0166	1.0007	0.017	548
I/3	0.15	0.27	0.39	0.52	0.0431	0.8916	0.036	425
I/4	0.14	0.25	0.37	0.48	0.0402	0.8909	0.033	537
I/5	0.10	0.20	0.30	0.40	0.025	1.0000	0.025	685
I/6	0.14	0.26	0.37	0.48	0.041	0.8872	0.034	514
I/7	0.10	0.17	0.25	0.33	0.0297	0.8591	0.023	792
I/8	0.06	0.11	0.18	0.23	0.015	0.9849	0.015	786
CS	0.235	0.40	0.59	0.85	0.064	0.9102	0.055	290

Also a studies were conducted using a T-01M Tester with a ball-on-disc system, designed to evaluate the tribological properties of materials used for parts of machinery and equipment constituting the friction pairs. With this device it is possible to determine the wear resistance and friction coefficient of the material in sliding pairs, depending on the sliding velocity, surface pressure, presence and type of lubricant contamination and other factors. The study was conducted in accordance with the methods set out in the ASTM G99 and DIN 50324 standards. In studies of the abrasion resistance, chromium cast iron from melt no. I/5 was used

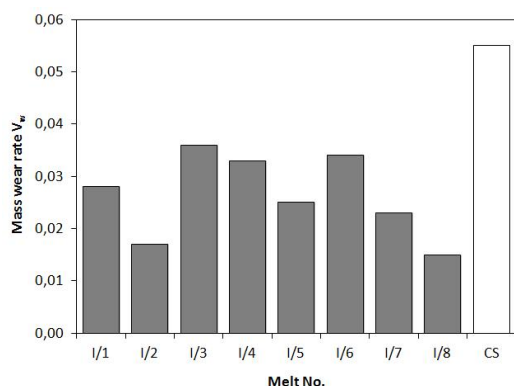


Fig. 5. Comparison of the mass wear rate observed during a 16 hour test cycle in the examined grades of abrasive wear resistant alloyed white cast iron and in the cast steel grade from melt no. CS used as a reference material

The sample in this study was a 6 mm diameter cylinder. It was abraded by an SiO<sub>2</sub> ball pressing it with a preset force (27N). The duration of one test was 2000 min. Figure 6 shows in the form of plotted graphs the abrasive wear behaviour of chromium cast iron and of a reference material, which in this case was low-alloyed ductile iron of the following chemical composition from melt no. DCI in Table 2.

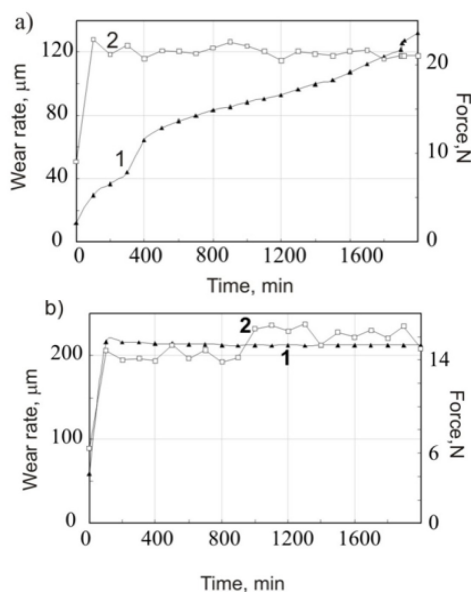


Fig. 6. Linear wear in dry friction: (1) wear rate, (2) force; ductile iron (melt no. DCI)- (a) and the tested chromium cast iron (melt no. I/5) - (b)

Studies showed that in the ductile iron the abrasive wear rate was proportional to the value of force. With time lapse the force of pressure was increasing causing further abrasion of the material. On the other hand in the case of high-chromium cast iron a sudden shift occurred followed by stabilisation of the abrasive process. At a given load no further wear of the material was possible.

## 6. Conclusions

The obtained results show us that titanium added to conventional grades of white cast iron increases quite remarkably both hardness and wear resistance. This study also shows that titanium introduced to chromium cast iron as an additional alloying element exerts a significant effect on the structure of this material. Titanium is a carbide-forming element but, unlike other elements of this type, it does not form complex carbides in the chromium cast iron, but TiC carbide only. This carbide is formed at high temperature in the liquid metal. Introduced to cast iron, titanium has a modifying effect, as revealed by the structure refinement and increased performance characteristics. It turns out that the greatest abrasive properties has a chromium cast iron around the eutectic structure. Compared with alloyed white cast iron, the selected representative grade of cast steel has a definitely inferior resistance to abrasion

## Acknowledgements

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

## References

- [1] Guzik, E. (2001). *Some selected problems concerning the processes of cast iron improvement*. Archives of Foundry Engineering 1M, pp. 1–128. (in Polish)
- [2] David, J. R. (1996). *Cast Irons*. ASM Specialty Handbook, ASM Inter. Mater. Park, OH.
- [3] Studnicki, A. (2013). *The role of selected modifiers in crystallization of chromium cast iron with high wear resistance*. Archives of Foundry Engineering 1M, pp. 1–137. (in Polish)
- [4] Studnicki, A., Kondracki, M., Szajnar, J. & Wróbel, T. (2013). Crystallization of low alloyed construction cast steel modified with V and Ti. *Archives of Foundry Engineering*. 13, pp. 92–96.
- [5] Kopyciński, D., Guzik, E. & Piasny, S. (2011). The structure of abrasion-resisting castings made of chromium cast iron. *Archives of Foundry Engineering*. 11, pp. 61-64.
- [6] Kopyciński, D. (2009). Inoculation of chromium white cast iron. *Archives of Foundry Engineering*. 9, pp. 191-194
- [7] Wołczyński, W., Guzik, E., Wajda, W. & Jędrzejczyk, D. (2012). CET in Solidifying Roll – Thermal Gradient Field Analysis *Archives of Metallurgy and Materials*. 57, pp. 105-117.
- [8] Kalandyk, B. & Głownia, J. (2001): Estimate of mathematical model of weight losses kinetic in Miller apparatus. *Archives of Foundry*. 2(4), pp. 376-383. (in Polish)
- [9] Taran, J.N., Mazur, W.I. (1978). Metallurgija Publications. Moscow