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Morphology and Material Properties of Carbides in High (24%) Chromium Cast Iron

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Abstract

The present paper is a presentation of results of a study on morphology, chemical composition, material properties (HV_{IT} , H_{IT} , E_{IT}), and nanoindentation elastic and plastic work for carbide precipitates in chromium cast iron containing 24% Cr. It has been found that the carbides differ in chemical composition, as well as in morphology and values characterizing their material properties. The carbides containing the most chromium which had the shape of thick and long needles were characterized with highest values of the analyzed material properties.

Keywords: High-chromium cast iron, Microstructure, Nanoindentation test

1. Introduction

High-chromium cast iron is typically used for components operated in conditions characterized with intensive abrasive wear in power, mining, ceramic, cement, and aggregate supplying industries [1, 2]. High resistance of chromium cast iron castings to abrasive wear results from presence of carbide precipitates in microstructure of the material.

According to [3], to have a chromium cast iron with high resistance to abrasive wear, the volume fraction of carbides should be about 27%. The authors of [4] propose a relationship formula from which it follows that volume fraction of carbides in chromium cast iron depends on carbon and chromium content.

Results of studies on carbon and chromium content on microstructure of high-chromium cast iron were published by, among others, authors of papers [5]. In [5], the effect of carbon (2.72–4.28% C) and chromium (19.39–21.45% Cr) content on resistance to abrasive wear and hardness of chromium cast iron was discussed. The highest values of the analyzed quantities were observed in cast iron containing 4.28% C and 21.45% Cr ($Cr/C =$

5). However, the study did not cover morphology, volume fraction, and material properties of carbides.

From the point of view of resistance of high-chromium cast iron to abrasive resistance, the parameters of interest are values of material properties of carbides and matrix. One tool offering precision measurements of these properties is the nanoindentation test. Results of such tests were presented by Chen *et al.* in [3] who used the nanoindentation method to test both the matrix and carbides in a cast iron with 25% content of chromium and varying content of silicon and carbon, in as-cast condition and after heat treatment. The authors conclude that increased content of carbon and silicon results in an increase of volume fraction of carbides and contributes to origination of bainitic matrix characterized with lower hardness. On the other hand, less content of carbon and silicon favors development of martensitic matrix. However, the quoted paper does not discuss the issue of the effect of carbon and silicon content on chemical composition of carbides and matrix.

In the opinion of authors of the present paper, to be able to shape microstructure of a high-chromium cast iron with

diversified chemistry, obtained in different conditions of primary and secondary solidification with the purpose to obtain a desired combination of service properties, it would be necessary to create a database containing material properties of carbides and alloy matrix.

The objective of the study was to examine and describe morphology, chemistry, and material properties of carbide precipitates in chromium cast iron containing 24% Cr, cast into a sand mould, in condition without heat treatment.

2. The material and methodology

The research material were plates with dimensions 150 mm × 80 mm × 20 mm, cast of iron alloy containing 24% Cr.

The liquid metal was prepared in an induction furnace. The furnace mix for 7 kg alloy contained: 4 kg L210H21S grade cast steel, 1.5 kg special LS pig iron, 0.2 kg FeCr, 1.0 kg steel, 0.08 kg carburizer, 0.05 kg FeMo, 0.03 kg FeB, 0.05 kg FeMn, 0.04 kg FeSi. Carbon and manganese content was adjusted by means of the carburizer and ferromanganese.

The moulds for place castings were made of bentonite clay. The pouring temperature was 1450°C.

Analysis of the alloy chemistry was carried out with the use of Q4 Tasman emission spectrometer (Bruker). The cast iron turned out to contain: 3.66% C, 1.23% Si, 0.51% Mn, 0.029% P, 0.031% S, 23.72% Cr, 0.41% Mo, 0.31% Ni, 0.030% Cu, 0.02% B, and Fe to balance.

Morphology and distribution of carbides was examined with the use of Neophot 2 optical microscope equipped with Videotronic CC20P camera and Multiscan v08 advanced image analysis system. Measurements were taken on metallographic sections cut out in the plane perpendicular to casting surfaces. In view of the fact that the high-chromium iron castings demonstrated a gradient structure along their thickness, whereas properties of microstructure in regions close to the casting surface are the most interesting from the point of view of abrasive wear resistance, examination of the microstructure was carried out on a 5-mm thick material layer adjacent to the surface and the following parameters were determined:

- volume fraction of carbide precipitates V_V , %;
- length of precipitates L , μm ;
- width of precipitates B , μm .

Chemical composition of carbides was determined with the use of VEGA XMH scanning electron microscope (Tescan) integrated with INCA x-Act electron back scattered diffraction system (Oxford Instruments).

Nanoindentation tests aimed at determination of material properties of carbides were carried out per PN-EN ISO 14577-1 standard, with the use of Nanoindentation Tester NHT (CSM Instruments). A diamond indenter B-L 32 with Berkovich tip geometry (apex angle 65.3°, radius < 50 nm) was employed. The tests were carried out at constant load force value of 20 mN, with indenter loading and unloading rate of 40 mN/min. The maximum load force application time was 15 s. Ten carbide precipitates were tested in each group characterized with similar morphology.

Results of the nanoindentation test allowed to determine:

- Vickers' hardness (H_{IT});

- instrumented indentation hardness (H_{IT});
- instrumented indentation elastic modulus (E_{IT});
- indentation elastic deformation work (W_{elast});
- indentation plastic deformation work (W_{plast});
- the elastic work component in the total indenter indentation work (η_{IT}) defined as the ratio of the elastic deformation work to the total mechanical indentation work.

3. Research results and analysis

Metallographic examination of the casting material in the superficial region allowed to identify areas with diversified precipitate development directions which evidences existence of local differences in temperature gradient directions occurring in the course of crystallization (Fig. 1).

The obtained results reveal existence of large, thick, and long carbide precipitates which came out of the matrix in a certain phase of development; further, small, and thin needles; and lastly, small needles with complex shapes of cross-sections perpendicular to their longitudinal axes.

Results of assessment of morphology of carbides in 24%-chromium cast iron are presented in Table 1.

Table 1.
Morphology of carbide precipitates in 24% Cr cast iron

Carbide precipitates	Volume fraction V_V , %	Length L , μm	Width B , μm
Large	14.1	113.0–380.0	15.0–42.5
Small	12.3	5.0–60.0	1.3–8.3
Combined fraction of large and small carbide precipitates: $V_V = 26.4\%$			

In case of chromium cast iron with 24%-Cr content, a characteristic feature was the absence of clearly distinguishable areas of occurrence of only small or only large carbide precipitates. Small and large carbides occurred next to each other. The volume share of small carbide precipitates was estimated to be at level of 12.3%, compared to 14.1% for large carbides. The combined volume fraction for all carbide types was therefore found to be about 26.4%.

Example results of point-like quantitative microanalysis of chemical composition for small and large carbide precipitates and for matrix of 24%-Cr cast iron are presented in Figure 2.

The obtained results indicate that carbides differing in morphology differ also in their chemical composition, especially as far as chromium content is considered. Large, thick, and long carbides are richest in chromium (55.39–56.35% Cr) and contain the least iron (32.95–33.36% Fe), manganese (0.60–0.73% Mn), and molybdenum (0.32–0.41% Mo). Small, thin, and long carbides contain less chromium (52.94–53.92% Cr), but are richer in iron (35.33–35.79% Fe) as well as in manganese (0.64–0.73% Mn) and molybdenum (0.35–0.40% Mo). Small, long, and thin carbides with complex shapes of their cross-sections contain the least chromium (43.95–53.70% Cr), but the most iron (34.92–42.47% Fe) and, additionally, molybdenum (0.59–2.13% Mo), manganese (0.65–0.78% Mn), and silicon (0.06–0.23% Si).

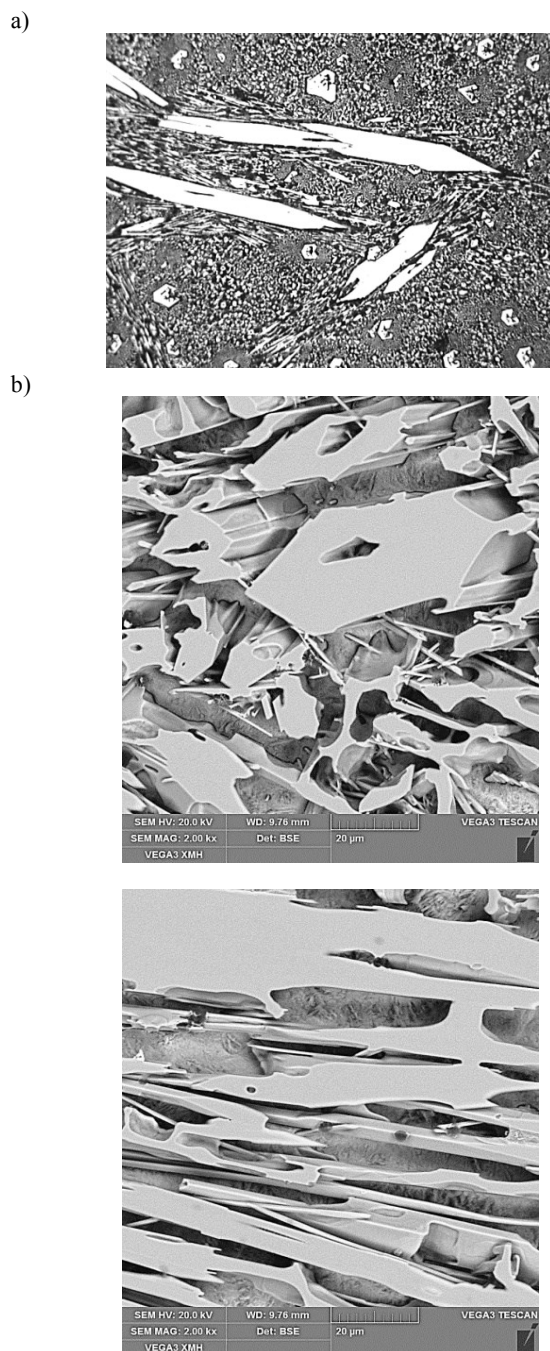


Fig. 1. (a) Microstructure of the casting material at distance of 5 mm from surface. Note two carbide precipitation areas characterized with different directions of their longitudinal axes. Magnification 100 \times . (b) A view of similar areas after deep etching



Point	Element content, wt%							
	C	Si	Cr	Mn	Fe	Ni	Cu	Mo
1	9.72	0.06	56.35	0.60	32.95	0.00	0.00	0.32
2	9.99	0.07	55.39	0.73	33.36	0.00	0.08	0.41
3	9.68	0.07	53.92	0.64	35.33	0.04	0.00	0.40
4	10.16	0.08	52.94	0.73	35.79	0.00	0.00	0.35
5	10.49	0.23	43.95	0.65	42.47	0.00	0.09	2.13
6	10.00	0.06	53.70	0.78	34.92	0.00	0.06	0.59
7	5.38	1.48	14.58	0.55	77.00	0.26	0.31	0.44
8	6.21	1.42	15.13	0.50	75.89	0.30	0.23	0.31
9	9.07	1.42	14.90	0.51	72.74	0.30	0.43	0.63
10	4.80	1.48	14.24	0.53	77.78	0.28	0.30	0.60
11	9.35	1.36	14.78	0.59	72.65	0.27	0.49	0.51

Fig. 2. Results of point-like quantitative chemistry microanalysis for small and large carbide precipitates and matrix of 24%-Cr cast iron

The matrix of the examined cast iron, rich in chromium (14.58–15.13% Cr) and iron (72.65–77.78% Fe), contained also silicon (1.36–1.48% Si), manganese (0.50–0.59% Mn), nickel (0.26–0.30% Ni), copper (0.23–0.49% Cu), and molybdenum (0.31–0.60% Mo).

Example plots representing displacement of the indenter face corresponding to loading and unloading phase in the course of indentation-testing of 24%-Cr cast iron microstructure components are presented in Figure 3.

Results of measurements of material properties specific for individual components of 24%-Cr cast iron microstructure are summarized in Table 2.

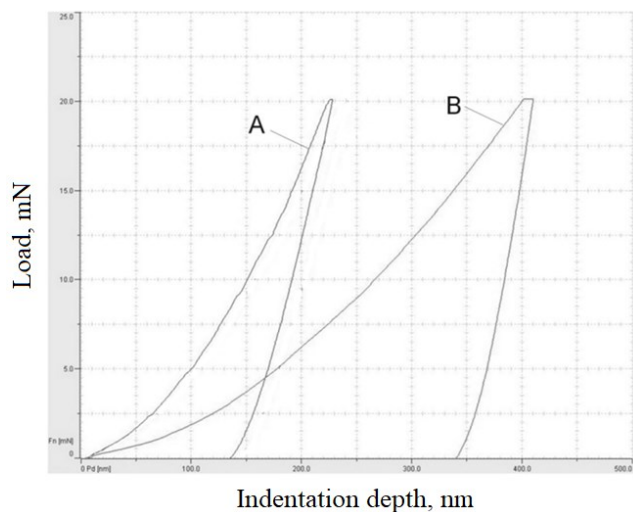


Fig. 3. Example plots of the indenter face displacement during the load application and release in the course of nanoindentation testing of 24%-Cr cast iron microstructure components; A — carbide, B — matrix

Table 2.

Averaged values of material properties for 24%-Cr cast iron microstructure components

Microstructure component	Material parameters		
	HV_{IT} , kG/mm ²	H_{IT} , GPa	E_{IT} , GPa
Large, long, & thick carbides	2110	22,728	336
Small, thin, & long carbides	1910	20,621	291
Matrix	437	4,720	199
	$W_{elast.}$, pJ	$W_{plast.}$, pJ	η_{IT} , %
Large, long, & thick carbides	778	948	45.1
Small, thin, & long carbides	827	1 024	44.7
Matrix	550	2 463	18.2

Due to small dimensions, it was impracticable to determine material properties of small, thin, and long carbides with complex shapes of their cross-sections

The obtained results indicate that the highest values of hardness HV_{IT} , instrumented indentation hardness H_{IT} , and instrumented

indentation elastic modulus E_{IT} are observed for large, thick, and long carbides richest in chromium (55.39–56.35% Cr) and containing the least iron (32.95–33.36% Fe) as well as manganese (0.60–0.73% Mn) and molybdenum (0.32–0.41% Mo). The carbides less rich in chromium were characterized with lower values of material properties. Higher values of the elastic component in the total indentation work η_{IT} were observed in large, thick, and long carbides richest in chromium.

4. Conclusions

The obtained results indicate that values of material properties characterizing carbides in high chromium cast iron depend on morphologies of the precipitates and their chemical composition. It has been found that the highest values of material properties (HV_{IT} , H_{IT} , E_{IT}) and the highest value of the elastic component in the total indentation work (η_{IT}) were demonstrated by large, thick, and long carbides containing the most chromium.

The obtained results represent a contribution to knowledge necessary to be able to shape microstructure of high chromium cast iron obtained in conditions of primary crystallization.

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