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# ABRASIVE WEAR RESISTANCE OF A QUENCHED AND SUB-ZERO TREATED HIGH-CHROMIUM WHITE CAST IRON

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The study reported in this paper concerned development of such microstructure of high-chromium (24 % Cr) cast iron which could secure high abrasive wear resistance of die inserts used to fabricate stampings from refractory materials. It was found that by increasing the cast iron cooling rate as a result of thermal interaction with the chill, it is possible to obtain fine carbide precipitates with diversified morphology, rich in Cr and Fe, containing Mo and Si. The matrix in the regions of thermal interaction with the chill was enriched in Cr and Mo, but depleted of Fe and Si. The sub-zero treatment process was developed to secure presence of hardening products in the matrix. The obtained structure of high-chromium cast iron has made the inserts more resistant to abrasive wear compared to tool steels after hear treatment used earlier.

*Key words:* high-chromium cast iron, quenched, microstructure, carbide, wear resistance

## INTRODUCTION

Refractory bricks used in the metals producing industries are manufactured with the use of 85 % $Al_2O_3$ – 11 % MgO aggregates, containing also $TiO_2$, $SiO_2$, CaO, $Fe_2O_3$, with the grain size in the range 2,7 – 3,7 mm (Figure 1), which show particularly high mechanical strength and resistance to thermal shock. The bricks are obtained by firing a semi-product called stampings. The particles of mass of which the stampings are formed are characterized with sharp edges and hardness value of 1 746 HV0.5.

In the course of press-moulding, side surfaces of stampings are reproduced by die inserts, while their upper and lower surfaces are formed by lower punch and plunger faces exerting pressure of up to 15 kN. Die inserts are subject to wear caused by scratches made by aggregate grains (Figure 2).

It has been found that in case of insert surface shown in Figure 2, the depth of scratches fell in the range from 0,5 to 2,5 mm. An interesting issue consisted in determination of the force at which the inserts were scratched with aggregate grains. It turned out that to make scratches of that depth using the scratch test apparatus equipped with a diamond indenter with tip radius 200 μm and apex angle 120°, it was necessary to apply the force of 5 N and 20 N, respectively. This suggests that aggregate grains are pressed against the insert surfaces with the force falling within this very range.

For the purpose of long production series, some manufactures cover die inserts with plates made of sintered carbides, typically WC - Co. The main flaw of the solution is high price of the tooling, and for this reason, the inserts are fabricated mainly from tool steels thermally treated to obtain hardness 60 – 61 HRC.

Numerous research centers carry out studies on application of other materials to produce die inserts. The objective of the presents research project was an attempt to use high-chromium cast iron for this purpose, because in view of high volumetric share of carbide precipitates, the material is widely used for parts and tools working in conditions of abrasive wear in the mining and aggregate supplying industries [1,2]. According of [3], the highest abrasion resistance is demonstrated by

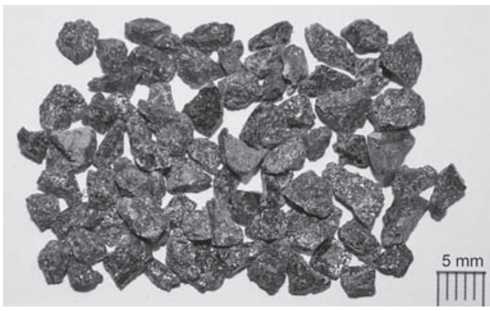


**Figure 1** A view of particles typical for 85 % $Al_2O_3$ – 11 % MgO aggregate

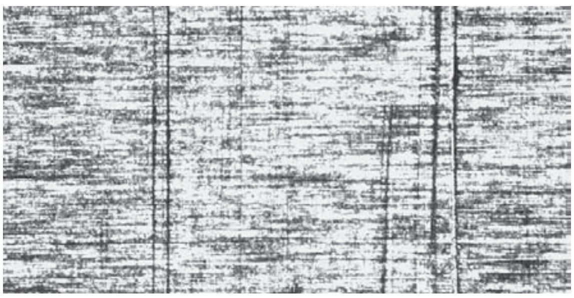

**Figure 2** A view of a fragment of die insert surface after fabrication of a single stamping

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cast irons with chromium content ranging from 12 % to 26 %. Modeling of microstructure of a high-chromium cast iron with the aim to improve its resistance to abrasive wear is oriented at fragmentation of carbides by increased solidification rate [4], increase of hardness through introduction of alloy additions [5], and thermal treatment in order to obtain matrix with martensitic structure [6].

## EXPERIMENTAL MATERIALS AND PROCEDURE

The material for tests was developed in the form of high-chromium cast iron plate castings, representing friction surface of segmented die inserts. Dimensions of the plates were 363 × 99,5 × 15 mm. To create conditions for fast solidification in the plate regions adjacent to the friction surface, the plates were reproduced in a casting mould with the use of chills with dimensions 370 × 110 × 15 mm (Figure 3).

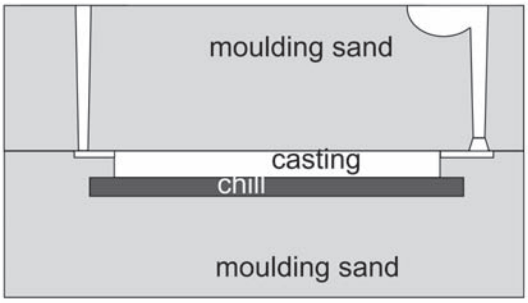


**Figure 3** A schematic drawing of the casting mould

The liquid metal was prepared in a laboratory induction furnace with capacity of 2 liters. The foundry mixture for 7 kg of the alloy included: high-chromium cast steel, straight carbon steel, ferroalloys (FeCr, FeMo, FeMn, FeSi, FeB), and a carburizer. The temperature at which the bentonite moulds with chills and the small chill mould used to cast samples for analysis of chemistry were poured was 1 500 °C.

The chemistry was analyzed with the use of Q4 Tasman emission spectrometer (Bruker). Results of the analysis are given in Table 1.

To determine parameters of thermal treatment aimed at obtaining martensitic structure of the matrix, dilatometric analysis of material samples (Ø 6 × 20 mm) taken from the gating system were carried out. The samples were heated up to temperature 1 000 °C at rate 400 °C / h, austenitized for 2 hours, then cooled in air down to ambient temperature, and finally immersed in liquid nitrogen.

It was found that with the assumed parameters of the thermal treatment ($T_{Ms}$ = 63 °C, $T_{Mf}$ = – 90 °C), a full martensitic transformation had occurred. The obtained results constituted the grounds on which such thermal treatment of the plate castings could be accepted. The treatment has increased hardness of plates on the surface reproduced by the chill (measured after removing a 0,1 mm thick layer of the material) to 65 HRC, compared to 64 HRC on surfaces reproduced by sandmix (after removing a layer of the same thickness).

Table 1 **Chemical composition high-chromium cast iron / wt. %**

| C | Si | Mn | P | S | Cr |
|---|---|---|---|---|---|
| 3,65 | 1,26 | 0,53 | 0,03 | 0,033 | 23,96 |
| Mo | Ni | Cu | B | Fe | |
| 0,44 | 0,30 | 0,03 | 0,02 | to bal. | |

Resistance of the plates to abrasive wear was assessed in actual production conditions. To this end, segmented inserts with thermally treated cast-iron plates were mounted in an experimental three-cavity mould. The remaining inserts were made of material used earlier (1.2379 grade steel) thermally treated to hardness 60 – 61 HRC. After making 3 472 stampings, the mould was disassembled and the inserts examined. On the friction surface, the wear-out depth was estimated.

Microstructure of plates cast out of high-chromium cast iron was examined on metallographic sections cut in the plane perpendicular to the friction surface, in regions located 1 mm and 10 mm from the surface. The examination was carried out with the use of Vega 3 electron microscope (Tescan) equipped with INCA x-act electron back scattered diffraction system (Oxford Instruments).

## RESULTS AND DISCUSSION

A view of the friction surface of the segmented die insert made of high-chromium cast iron with marked region from which samples for metallographic examination were taken is shown in Figure 4. Results of estimation of the insert material wear-out depth after tests performed under production conditions are summarized in Table 2.

The obtained results indicate that the used variant of microstructure of high-chromium cast iron allows to extend service life of the die insert compared to the material variant used earlier.

An example microstructure of a plate casing from the areas distant by 1 mm and 10 mm from the friction surface is presented in Figure 5.

Results of chemistry microanalysis for carbide precipitates with different morphology and the matrix are given in Table 3.

The obtained results indicate that microstructure of plates made of high-chromium cast iron is characterized by presence of carbide precipitates in the form of thin and thick needles, polyhedrons, and polyhedrons with holes. Refinement of carbides in the regions of the material crystallizing in conditions of interaction with a chill is much more prominent than in the regions where such interaction does not occur. Diversified conditions of crystallization were reflected in chemical composition of both carbides and the matrix. In the material crystallizing without thermal interaction with chill, matrix is significantly depleted of Cr and Mo but enriched in iron. One characteristic feature of this area is presence of carbides in the form of thin needles which are much richer in Mo but with Cr content lower compared


**Figure 4** A view of friction surface on a plate made of high-chromium cast iron after tests in production conditions with marked area from which samples for metallographic tests were taken

Table 2 **Results of estimation of the insert wear-out depth after fabrication of 3 472 stampings**

| Die insert material variant | Wear - out depth $h_{max}$ / μm |
|---|---|
| Steel 1.2389 thermally treated to hardness 60 – 61 HRC | 500 |
| 24 % Cr cast iron after sub-zero treatment, hardness 65 HRC | 350 |

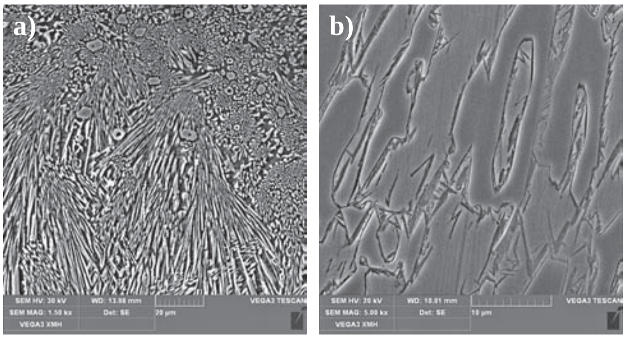


**Figure 5** Microstructure of a high-chromium cast iron plate from the region (a) 1 mm and (b) 10 mm away from the friction surface. Carbides in the form of needles and against the background of hardening products

Table 3 **The effect of solidification conditions on chemistry of carbide precipitates and matrix / wt. %**

| Cr | Mo | Fe | Si | Ni |
|---|---|---|---|---|
| 1 mm from surface (chill interaction effect - Fig. 5a) | | | | |
| Carbides — needles, polyhedrons | | | | |
| 49,4 - 53,5 | 0,4 - 0,8 | 35,0 - 38,4 | 0,1 - 0,2 | — |
| Matrix | | | | |
| 24,7 - 34,2 | 1,0 - 1,7 | 57,6 - 62,8 | 0,4 - 1,4 | 0,2 - 0,3 |
| 10 mm from surface (no chill interaction effect - Figure 5b) | | | | |
| Carbides — thin needles | | | | |
| 45,7 - 46,2 | 1,1 - 1,2 | 40,8 - 41,1 | 0,1 | — |
| Carbides — thicker needles | | | | |
| 55,3 - 56,2 | 0,3 - 0,3 | 32,2 - 34,0 | 0,1 | — |
| Carbides — polyhedrons | | | | |
| 52,3 - 54,3 | 0,3 - 0,5 | 33,9 - 35,5 | 0,1 | — |
| Matrix | | | | |
| 12,0 - 12,2 | 0,3 - 0,4 | 76,7 - 78,4 | 1,42 - 1,46 | 0,3 - 0,4 |

to other carbide forms. The fast solidification conditions resulted in strong refinement of microstructure which made it hard to grasp differences in chemistry of precipitates with different shapes more precisely.

The diversity observed in the microstructure was reflected in value of the measured hardness and the resulting increase of resistance of the die inserts to wearing out of die inserts used to press-mould refractory stampings, compared to material solutions used earlier.

## CONCLUSIONS

A microstructure of high-chromium white cast iron was developed containing carbide precipitates in the form of thin and thick needles, polyhedrons, and polyhedrons with holes, with matrix containing hardening products.

Carbides present in the material are rich in Cr and Fe, and contain also Mo and Si. The fast solidification conditions resulted in high refinement of microstructure which made it difficult to determined differences in chemical composition of precipitates differing in their shapes. Existence of such diversification was found in case of larger carbide precipitates present in the zone where there was no interaction with the chill.

Accelerated solidification resulted in supersaturation of the matrix with chromium and molybdenum and reduction of iron content. The matrix, unlike the carbides, contained nickel.

Microstructure of the high-chromium cast iron (24 % Cr) developed in conditions of fast solidification and cryogenic treatment allowed to increase hardness of inserts up to 65 HRC with resistance to abrasive wear higher than this observed when tool steels heat-treated to hardness 60 – 61 HRC were used.

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**Note:** Jan Snakowski is responsible for English language, Rzeszów, Poland