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Hardness and Wear Resistance of TiC-Fe-Cr Locally Reinforcement Produced in Cast Steel

E. Olejnik[a,b], Ł. Szymański[b,c], P. Kurtyka[d], T. Tokarski[e], B. Grabowska[c], P. Czapla[c,f]
[a] INNERCO Ltd., Zarzecze 42, 30-134 Cracow, Poland
[b] AGH University of Science and Technology, Department of Engineering of Cast Alloys and Composites
Faculty of Foundry Engineering, Reymonta 23, 30-059 Cracow, Poland
[c] AGH University of Science and Technology, Department of Foundry Processes Engineering
Faculty of Foundry Engineering, Reymonta 23, 30-059 Cracow, Poland
[d] Pedagogical Univeristy of Cracow, Institute of Technology
Faculty of Mathematics, Physics and Technical Science, Podchorazych 2, 30-084 Cracow, Poland
[e] AGH University of Science and Technology
Academic Centre of Materials and Nanotechnology,
al. Mickiewicza 30, 30-059 Cracow, Poland
[f] EUROCAST INDUSTRIES Ltd., Grabowa 21/7, 30- 227 Cracow, Poland
*Corresponding author: e-mail adress: e.olejnik@agh.edu.pl

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Abstract

In order to increase wear resistance cast steel casting the TiC-Fe-Cr type composite zones were fabricated. These zones were obtained by means of in situ synthesis of substrates of the reaction TiC with a moderator of a chemical composition of white cast iron with nickel of the Ni-Hard type 4. The synthesis was carried out directly in the mould cavity. The moderator was applied to control the reactive infiltration occurring during the TiC synthesis. The microstructure of composite zones was investigated by electron scanning microscopy, using the backscattered electron mode. The structure of composite zones was verified by the X-ray diffraction method. The hardness of composite zones, cast steel base alloy and the reference samples such as white chromium cast iron with 14 % Cr and 20 % Cr, manganese cast steel 18 % Mn was measured by Vickers test. The wear resistance of the composite zone and the reference samples examined by ball-on-disc wear test. Dimensionally stable composite zones were obtained containing submicron sizes TiC particles uniformly distributed in the matrix. The macro and microstructure of the composite zone ensured three times hardness increase in comparison to the cast steel base alloy and one and a half times increase in comparison to the white chromium cast iron 20 % Cr. Finally ball-on-disc wear rate of the composite zone was five times lower than chromium white cast iron containing 20 % Cr.

Keywords: MMCs, Locally reinforcement, In situ TiC, Castings, Hardness, Wear resistance, Ball-on-disc

1. Introduction

Abrasive wear is one of the main factors eliminating annually thousands of tons of cast elements of machines and devices. This effect occurs in several industry sectors, mainly in the extractive and power industries.

Ferrous alloys of an increased hardness constitute the largest group of materials used for the production of structure elements resistant to abrasive wear. Among them two groups are distinguished. Martensitic, austenitic, manganese and chromium cast steels can be rated in the first group. The second one constitute less popular martensitic and chromium white cast irons. These materials have different mechanical properties, especially strength and ductility. Cast steels are characterized by a high plasticity and dynamic loads resistance [1,2]. However, cast irons are materials of a high hardness but of a relatively low plasticity. Due to constantly growing work parameters required from machines and devices operating under high wear conditions the mentioned above casting alloys group is currently more and more often substituted by composite materials [3,4].

A solution to the problem of an abrasive over-wearing can become the production of functional elements of machines and devices. A good example are ex situ and in situ methods for fabrication local reinforcements in castings, which will be called, in the further part of this paper, composite zones [5-7]. Due to such approach it is possible to join a potential of plastic and dynamic loads resistant casting alloys with hard ceramics [8].

One of the processes allowing, to obtain composite castings is the Self–propagating High-temperature Synthesis in Bath method (SHSB), which is the modification of the standard Self–propagating High-temperature Synthesis (SHS) reaction, applied in the powder metallurgy [9-12]. To the most popular ceramic phases used for castings reinforcements can be counted: TiC, WC, VC, TiN, Al_2O_3 and ZrO_2 [13-15].

Titanium carbide, as a strengthening phase is characterised by a high: hardness from 3000 to 3200 HV, melting temperature 3067 °C, thermodynamic stability and a relatively good wettability in Fe base alloy [16-18].

Taking into consideration arguments mentioned above, endeavours were undertaken to produce in situ in steel castings of the TiC-Fe-Cr composite zones. In order to ensure the synthesis reaction control and dimensional stability of zones, the moderator of the chemical composition of Ni-Hard type 4 cast iron was introduced into the mixture of TiC substrates. The obtained materials were investigated by analysing their microstructure, structure, hardness and wear resistance.

2. Experimental procedures

The mixture of substrates needed for the in situ TiC synthesis in a liquid casting alloy was prepared in the atomic ratio 1 : 1. Commercially available titanium powders (99,99 %, 45 μm) and graphite (98 %, 10 μm) were applied.

In order to control a reactive infiltration the moderator powder addition was introduced into the substrate mixture. The chemical composition of this moderator is given in Table 1.

Table 1.
Chemical composition of the chromium white cast iron with nickel Ni-Hard type 4 moderator

Chemical composition, [wt %]						
C	Si	Mn	Ni	Cr	Mo	Fe
3.6	2.2	0.8	5.5	10	0.5	rest

The chemical composition of compacts used for local composite reinforcements in a casting is given in Table 2.

Table 2.
Chemical composition of the compacts

Symbol	TiC substrates, [wt %]	Moderator, [wt %]
IC7	30	70

Powders of substrates of the TiC reaction and the moderator were mixed for 6 hours without the air access. Then, the weighted samples of a mass of 165 g were pressed. The prepared compacts were placed in the casting mould cavity by means of fastening elements, according to the scheme presented in Figure 1. Then, the mould was poured with melt of a temperature of 1550 C°. The chemical composition of cast steel - base alloy is presented in Table 3.

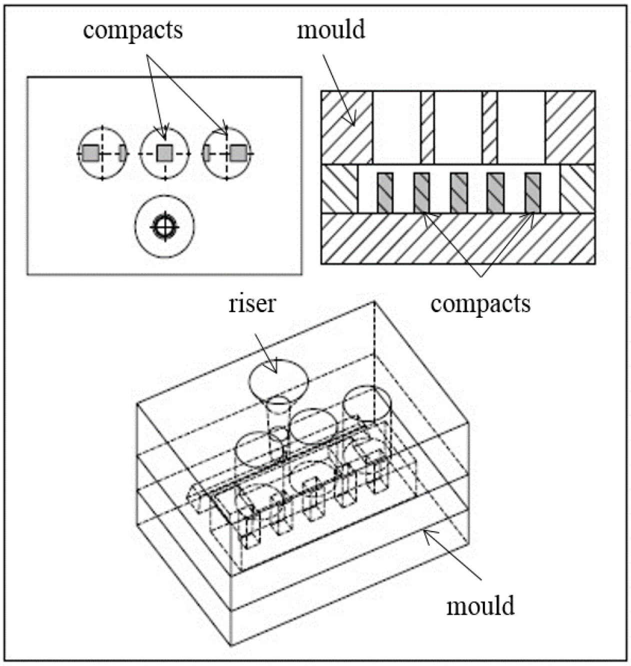

Fig. 1 Scheme of the casting mould with compacts for in situ composite zones production.

Table 3.
Chemical composition of the cast steel - base alloy and reference alloys

Main elements contents [wt %]								
C	Si	Mn	P	S	Ni	Cr	Mo	Cu
Cast steel – base alloy								
0,32	0,6	1,2	0,02	0,01	0,1	0,1	0,3	-
Chromium white cast iron 14% Cr								
1,8	0,6	0,5	0,03	0,02	2	14	0,9	0,8
Chromium white cast iron 20% Cr								
1,8	0,6	0,5	0,03	0,02	2	20	0,9	0,8
Manganese cast steel 18% Mn								
1,1	0,3	18	0,03	0,01	-	-	-	-

The ready casting was cut up in order to take samples containing the composite zone. Before performing metallographic, structural and mechanical tests the samples were grinded and polished. Metallographic investigations were performed by means of the scanning electron microscopy (SEM) on the microscope (Versa 3D, FEI). The phase analysis (XRD) within the composite zone was performed on the X-Ray diffractmeter of the (Kristalloflex 4H, Siemens) type with using the characteristic X-ray radiation of the wavelength 1.5406×10^{-10} m, at a voltage of 30 kV and current of 26 mA. Hardness measurements were performed by means of the Vickers hardness tester of the (Vickers, United). Tests were performed at the load 9,81 N and 10 seconds of pressing. Wear test were made by the ball–on–disc method in the system of the rubbing couple being composite zone – Al_2O_3 ball, at the diameter 3 mm Al_2O_3, friction radius 2,5 mm, rotation speed 192 RPM, 10 N load, test time 10^4 s, in the tribo-tester of the (Ebit).

3. Results and discussion

Figure 2 presents the macrostructure of the casting with locally produced TiC-Fe-Cr composite zones. The introduced moderator allowed obtaining the stable and dimensionally uniform composite zones. The microscopic observations did not indicate casting defects.

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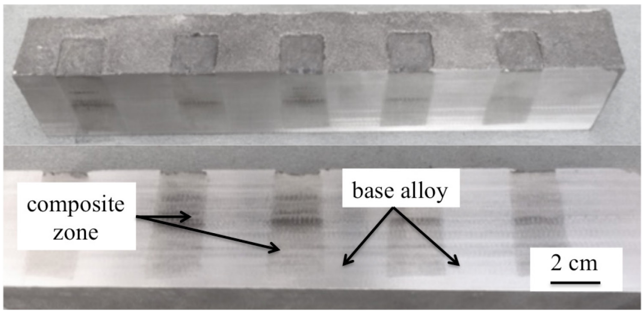

Fig. 2. Macrostructure of the cross section casting with of the TiC – Fe-Cr composite zones

Figure 3 presents the results of the phase XRD analysis of the composite zone. This zone contains carbides of TiC being the consequence of the SHSB synthesis reaction. Visible reflexes from crystallographic planes Feα indicate the zone infiltration by the base alloy. The presence of the Feγ and Cr_7C_3 phases results from the moderator application of the chemical composition shown in Table 1.

Figure 4 presents the transition region between of the TiC-Fe-Cr composite zone and the casting core. The transition area zone is free from the cracks and discontinuities.

Figure 5 shows the microstructure taken on different magnifications of a composite zone produced in steel casting. Figure 5b shows that composite zone is characterized by the big amount of TiC carbides homogeneously distributed in the matrix. Also the shape and size of TiC carbides are homogeneous. One can see in figure 5c that the particles size of rounded TiC particles is about 0.7 micron.

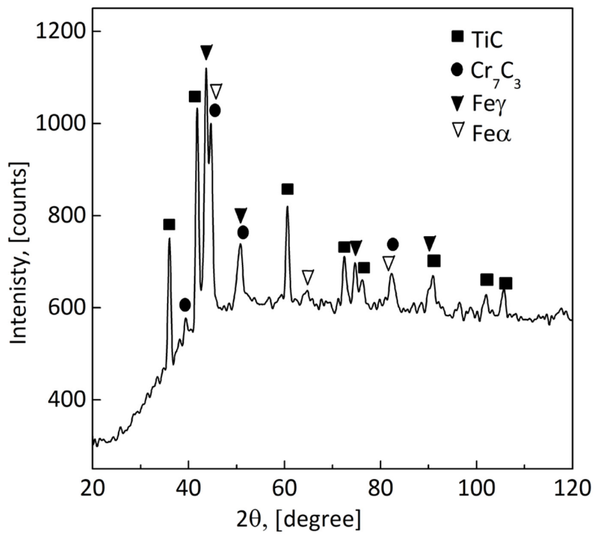

Fig. 3. X-ray diffraction analysis of the TiC-Fe-Cr composite zone

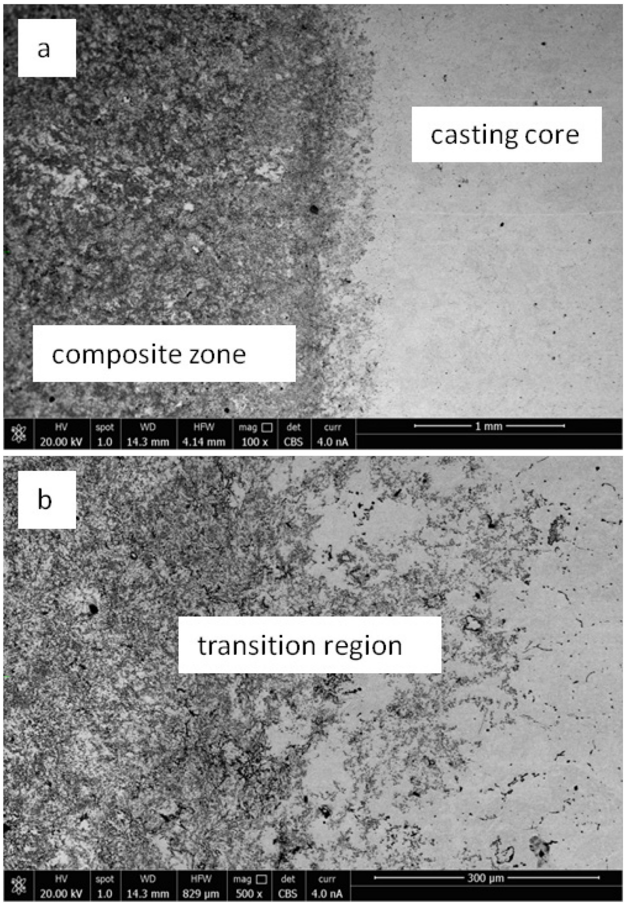

Fig. 4. BSE images of microstructures of the transition region between the TiC-Fe-Cr composite zone and the casting core

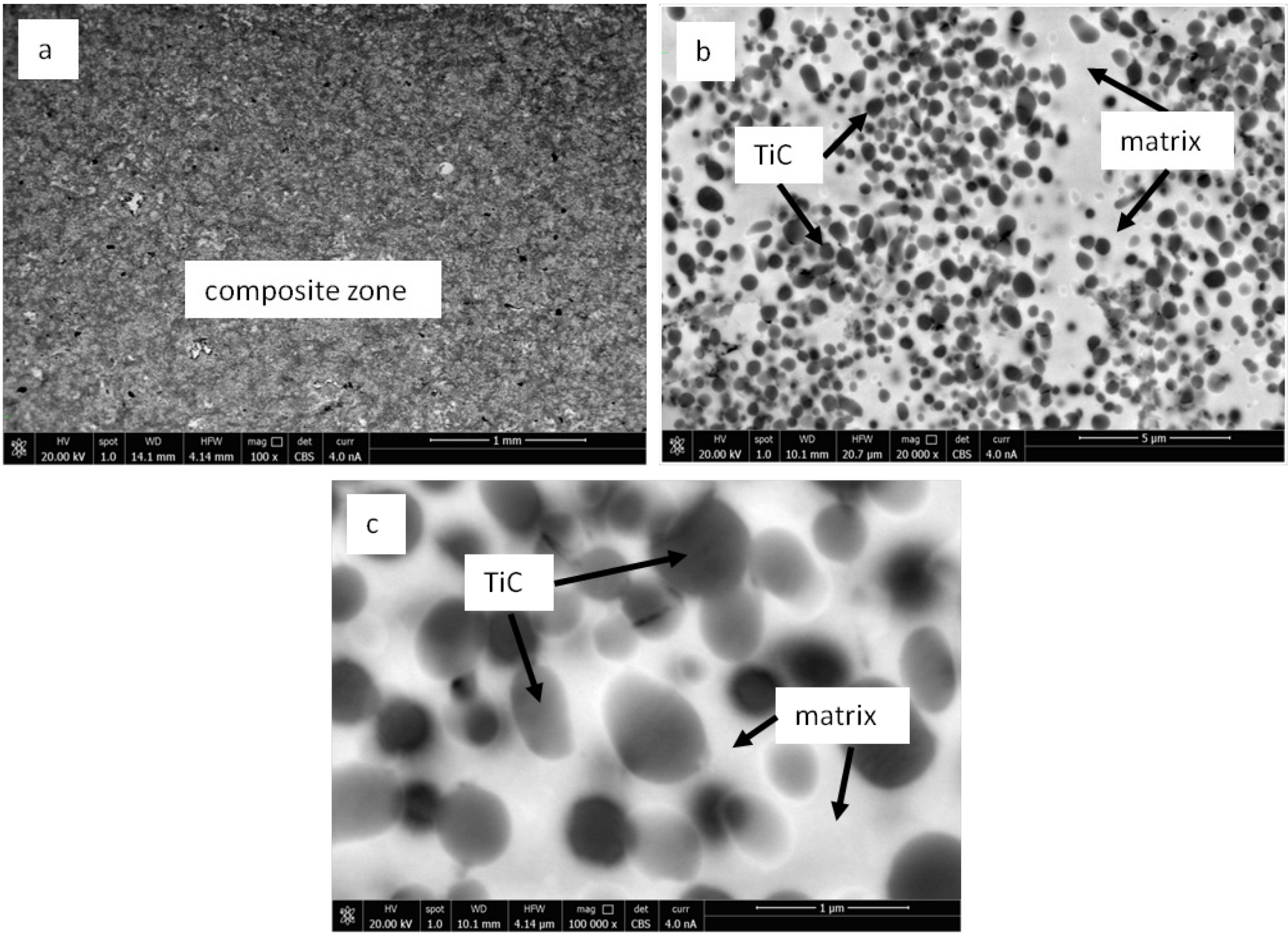

Fig. 5. The microstructure of a TiC-Fe-Cr composite zone produced in cast steel casting.

The results of the hardness of the produced composite zone and base alloy, which average values were 1500 HV1 and 500 HV1 - respectively, are presented in Figure 6. This indicates three times hardness increase of the composite zone as compared to the used base alloy. In the singled out places of the highest concentration of ceramic TiC and Cr_7C_3 phases the results of 2000 HV1 were achieved, which means nearly four times hardness increase.

Figure 7 presents wear indices of the selected abrasion-resisting casting alloys and the produced (within this research) composite zone. The determined wear rate (W_s) of the local composite reinforcement was equal to 2,84 × 10^{-6} [mm^3/Nm]. Comparing this result with the wear rate of the composite zone was nearly fourteen and five times lower than manganese cast steel 18 % Mn and chromium white cast iron containing 20 % Cr, respectively.

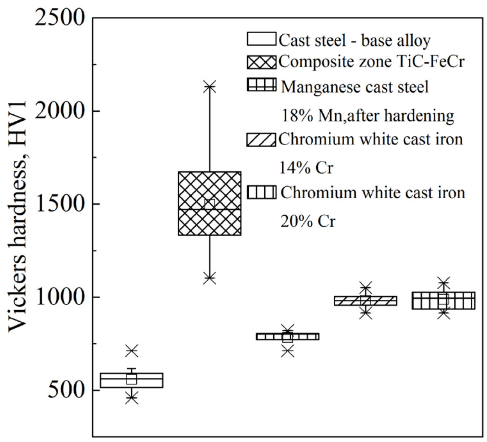

Fig. 6. Vickers hardness HV1 of TiC-Fe-Cr composite zone and the selected reference alloys

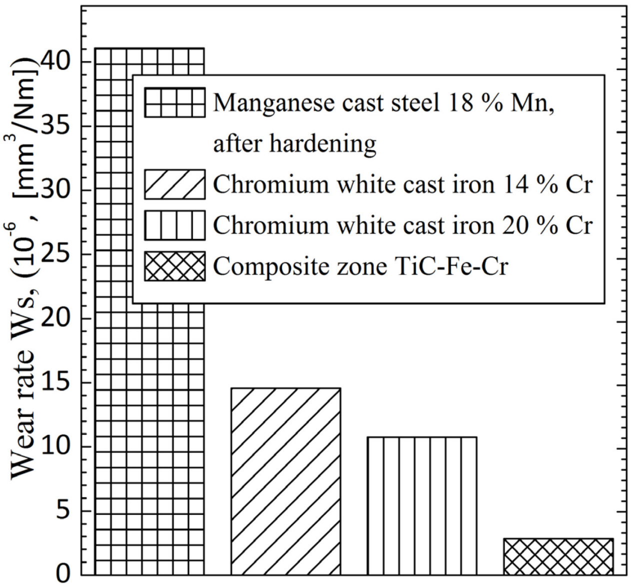

Fig. 7. Ball-on-disc wear rates of the TiC-Fe-Cr composite zone and the selected reference alloys

4. Conclusions

The application of the method of in situ production in the casting the composite zones of the TiC-Fe-Cr type, allows joining potentials of two groups of engineering materials: casting alloys and hard ceramics.

Due to their properties connecting it is possible to achieve five times lower of the ball-on-disc wear rate in relation to the most wear resistant chromium white cast irons. Designing of cast functional machines and devices containing composite zones allows for an abrupt increase of their service life.

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