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Locally Reinforcement TiC-Fe Type Produced in Situ in Castings

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Abstract

Refinement is one of the most energy consuming technological process, aimed at obtaining mineral raw materials of the proper grain size. Cast structural elements such as jaws or hammers in crushing machines operate under conditions of an intensive wear. The data indicate that 80 % of failures of machines and devices is caused by wearing of rubbing surfaces. This problem became the subject of several scientific and industrial investigations carried out in the whole world in order to produce materials ultra- wear resistant. Methods allowing to obtain wear resistant composite castings are discussed in the hereby paper. Within the performed research microstructures of the produced composite zones were presented and the comparative analysis with regard to mechanical and functional properties of local composite reinforcements in relation to the commercial alloys of increased wear resistance was performed. The results show almost twenty five times increase in wear resistance compared to manganese cast steel containing 18 % Mn.

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

1. Introduction

From the point of view of designing products all engineering materials are having equal rights. Multi-criteria optimization constitutes the base of the selection of materials of the best technological and functional properties and the lowest production and processing costs, and the maintenance of the product [1]. The development of industry and - in consequence - of machines and devices, contributed to designing new casting materials of unavailable so far properties. This concerns both the new materials of predicted properties and production methods. Despite constantly raising levels of production technologies, the foundry practice was not eliminated as the production technique.

On the contrary, its meaning is growing and it is still important and stable element of the economic development.

A demand for elements not undergoing damages, as a result of grinding, grows by the year. The abrasive wear is understood as undesired changes of dimensions of machines and devices elements being the effects of: micromachining, micro crushing, grooving, scratching or spalling. The wearing process of functional objects depends mainly on particle dimensions, their velocity, striking energy, pressure and density [2].

Out of abrasion resistant casting alloys some grades of cast irons and cast steels can be singled out [3,4]. However, on account of a constant tendency to lowering production costs related to replacements of elements of machines and devices, new solutions are searched for. To this end, more and more often functional elements are designed.

An wear process of elements occurs first of all on work surfaces, which inclines to designing locally reinforced castings. Producing an element on the base of only one material causes obtaining the same properties in the whole casting volume. In that case joining two materials of different properties, seems to be a positive solution. The first one, constituting the core, should warrant obtaining the large plasticity and ability to transfer dynamic loads. The second, being the work surface, should be increasing the wear resistance [5]. Achieving the described above correlation between a high hardness of the work area and the core plasticity can be obtained by: performing heat treatment, applying hard-facing or alloying, as well as by producing locally reinforced in casting [6-8].

In forming composite zones in castings the ex situ [9,10] and in situ [11-14] methods can be applied. A reinforcing phase in case of in situ method is formed directly during the metallurgical process. This process is based on chemical reactions occurring between substrates of the ceramic phase, which are placed in a casting mould cavity. The synthesis reaction is initiated by energy supplied in a thermal way by a liquid casting alloy. This method constitutes a modification of the classic SHS method applied in the powder metallurgy [15,16].

The methods of obtaining in situ cast composites and castings locally reinforced by hard ceramic phases will be presented in this paper.

2. Methods of obtaining in situ composites in castings

Methods of obtaining composites in situ in castings enable designing of castings strengthened on surfaces, in zones or within the whole volume. They allow obtaining products joining properties of the selected casting alloy with highly abrasion resistant ceramic phases of TiC type. Due to such solution, it is possible to design elements of machines and devices - operating under conditions of high abrasive wear - reinforced, either locally or in the whole volume, by the selected ceramic phase. An advantage of the described method is limiting the production costs resulting from an application of a few technologies in order to obtain the product, e.g. sinters soldering in, or hard-facing of semi-finished products.

Depending on operating conditions of the given structural detail and its wearing intensity there is a possibility of formation in castings three composite forms.

The process of the in situ formation in the casting the composite layer 1D, is presented in Figure 1. This process is based on covering the mould cavity by emulsion (suspension) containing substrates needed for the singled out ceramic phase formation. Obtaining the layer of a thickness up to 2 mm and the reinforcing phase volume fraction up to 50%, is possible. This warrants obtaining the hardness of the casting surface at the level of 1000 HV and a high abrasion resistance [17-20].

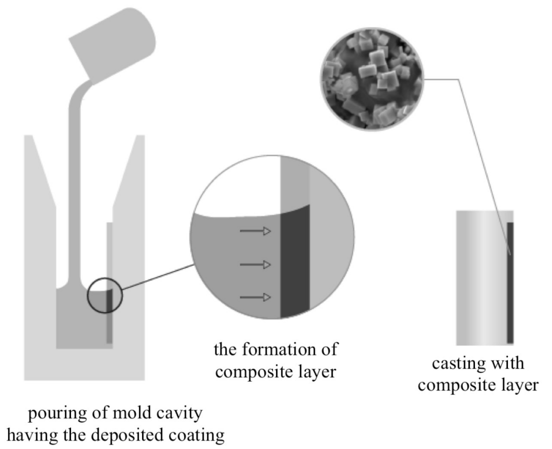

Fig. 1. Schematic presentation of the formation of the composite layer 1D in situ in the casting

Figure 2 presents the process of producing in situ in the casting the composite zone 2D. It allows local reinforcing of the selected work surface of the casting, based on the work conditions analysis and the maximum wear areas. There is a possibility of controlling the ceramic phase fraction, which can constitute even 90 %. The obtained hardness can reach 1500 HV30 [5].

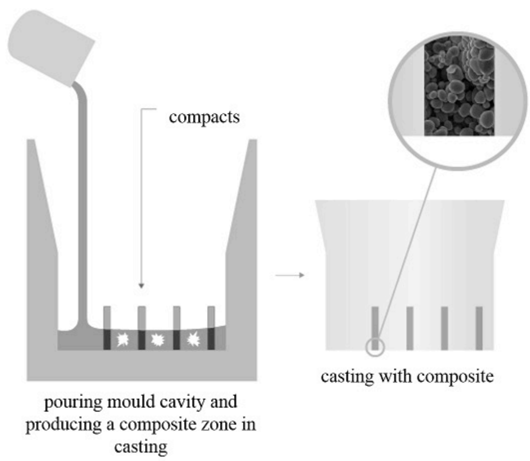

Fig. 2. Schematic presentation of the process of the composite zone 2D formation in situ in the casting

The example of the macrostructure casting reinforced locally by composite zones $TiC/Al_2O_3/FeCr$ is presented in Figure 3.

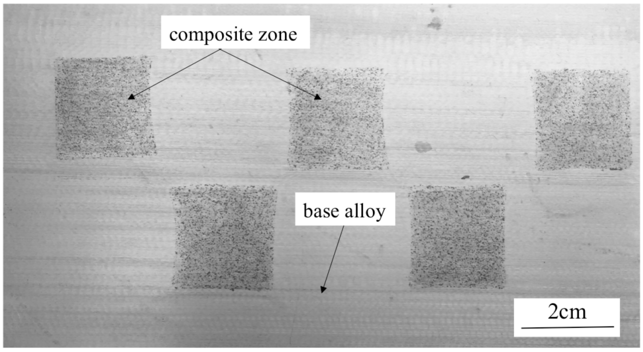

Fig. 3. Casting with locally reinforcement produced in situ in steel casting $TiC/Al_2O_3/FeCr$ type

The last method allows producing the so-called cast composites 3D type, in which the ceramic phase fraction equals app. 6 vol. %. The reinforcing phase produced in situ is equally distributed in the whole casting volume in Fig. 4.

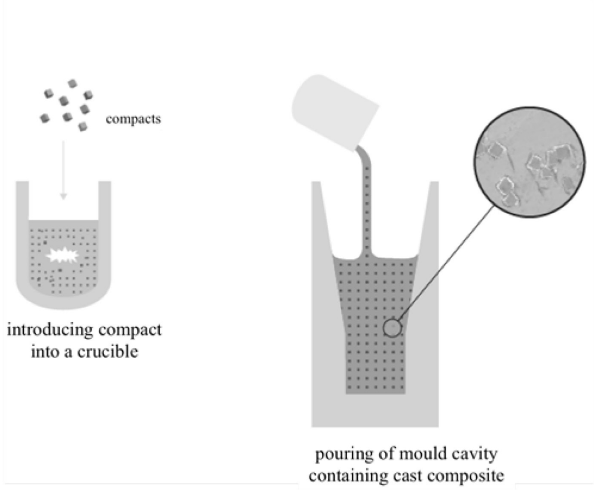

Fig. 4. Schematic presentation of the process of in situ production of the cast composite 3D

The performed investigations indicated its increased concentration in matrix grain boundary. In metal matrix composite (MMCs), the distribution and the kind of particles i.e. size and shape as well as interface between reinforcing particle and matrix has very important effect on the utilization mechanical properties of materials such as: Al/TiC, Ni_3Al/WC, Ni_3Al/ZrC, Ni_3Al/NbC, Ni_3Al/TaC, Ni_3Al/TaB or A339/SiC [12,21]. Transmission electron microscopy (TEM) is very useful tool for microstructural investigations of interfaces between particles and matrix in the MMC. An example of TEM microstructure investigations of interface between TiC and Fe matrix is presented in Fig. 5. One can see STEM-HAADF microstructure of interface where contrast is associated with atomic number of elements (Fig.5a). There is flat boundary between TiC and Fe matrix and without additional intermetallic or carbides phases. The line scan analyze performed along indicated line confirms this assumption.

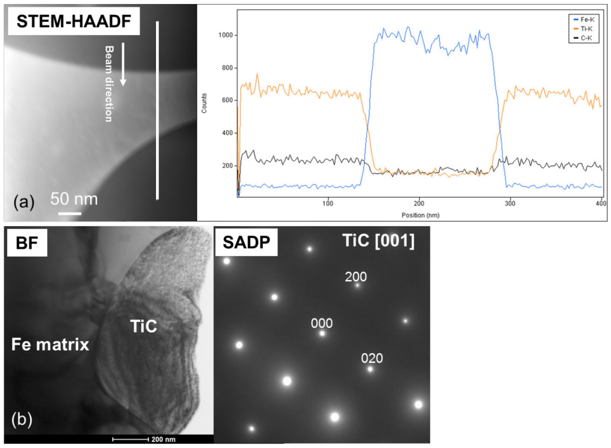

Fig. 5. STEM-HAADF image and result of line scan analyze (a) and BF image and corresponding SADP image (b) of interfaces in TiC-Fe MMCs.

Also bright filed (BF) image presented in Fig. 5b shows the clean and continuous boundary between matrix and TiC particle with the f.c.c structure according to the diffraction pattern.

Composites of 3D type have better mechanical properties than the applied base alloy. However, their hardness was increased only to a small degree which was a result of a relatively small fraction of the distributed ceramic phase [22].

3. Joining composite zones and layers with the casting and their homogeneity and dimensional stability

An essential advantage of composites produced in situ from ceramic phases is good joining with the matrix due to a relative pure boundary: reinforcing phase – matrix. The example of the microstructure of the transition area between the composite zone and the casting core, is presented in Fig. 6. The smooth joining is an effect of a reactive infiltration accompanying the ceramic synthesis reaction in the liquid casting alloy.

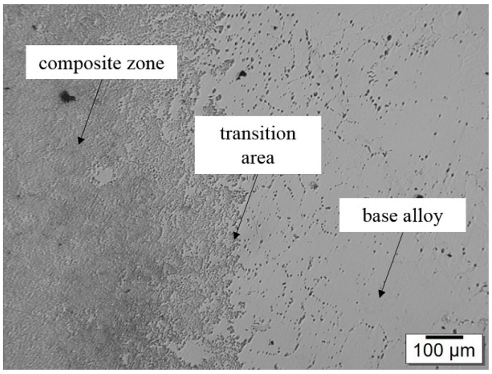

Fig. 6. Transition region between the composite zone TiC – Fe-Cr type and the casting core of cast steel

The homogeneous distribution of the ceramic phase is generated by durable binding between particles of this phase synthesised in the liquid alloy. When there is a lack of such bonds a ceramic phase can be torn off during the mould pouring with liquid metal, during conventional motions or as a result of gravitational segregation. Thus, obtaining information on the spatial character of ceramic particles bonds is very important. Examples of reconstruction and visualisation of the fragment of the composite zone are shown in Fig. 7 and 8. The spatial distribution of the marked TiC particles indicates their bonding, which warrants the dimensional stability and homogeneity of the local composite reinforcement.

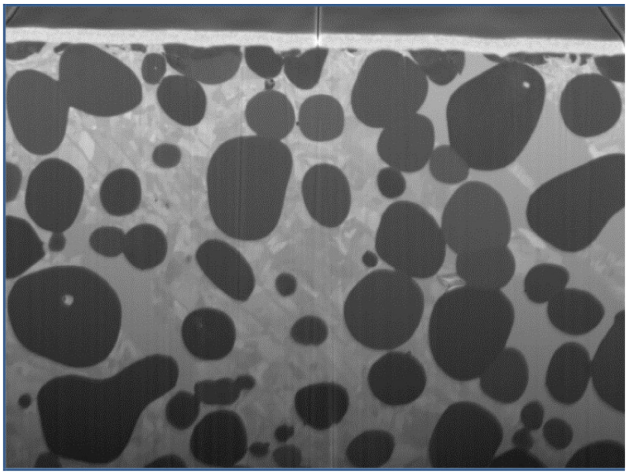
Fig. 7. Microstructure of the cross-section surface of the TiC-Fe composite zone produced in the casting of nodular cast iron

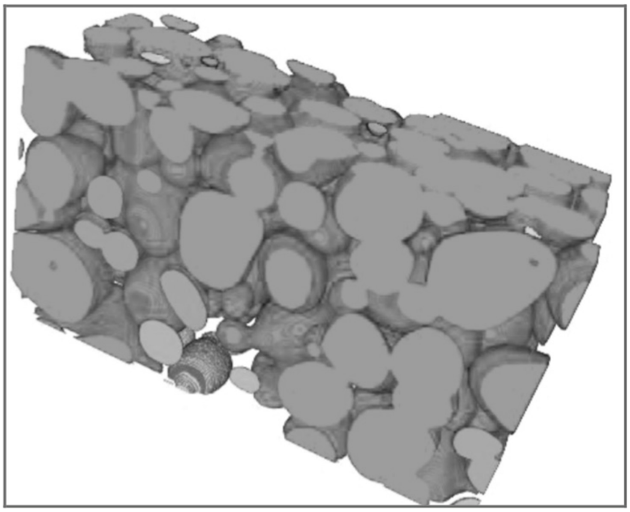
Fig. 8. Distribution of TiC particles of the tomographically reconstructed the composite fragment of zone TiC/Fe type produced in nodular cast iron

4. Mechanical and functional properties of composite zones produced in castings

Composite castings of the ultra-high abrasion resistance have better mechanical and functional properties than the applied, up to the present, commercial abrasion-resisting casting alloys. The example of the microstructure of the composite zone, TiC-Fe-Cr type, is presented in Fig. 9. Precipitates of a high dispersion TiC are seen in the composite zone matrix.

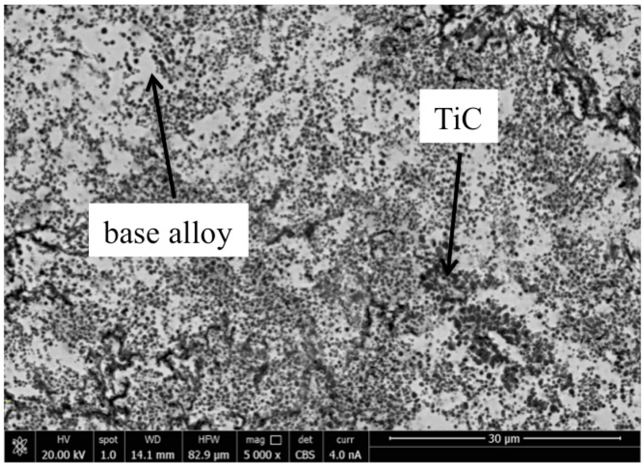

Fig. 9. Microstructure of the composite zone, TiC – FeCr type, obtained in situ in the cast steel casting

The ceramic phase morphology, obtained in the casting, influences mechanical and plastic properties of the composite zone. A possibility of controlling their mechanical and functional properties allows to produce materials adjusted to the requirements of the given application. Literature data indicates that the best mechanical properties are obtained with zones of the composite with a high volume fraction of particles oval forming a coagulated form TiC [23].

Elements intended for operations under significant dynamic loads and abrasion wear mechanisms should not be characterised by a high hardness. That is why the solution for such work conditions is producing the composite zones of mechanical properties, mainly impact toughness, at the level close to the base alloy resistant to dynamic loads. Such effect is possible due to producing the zone of a microstructure containing dispersive precipitates of ceramic phases.

The comparison of the hardness results of composite zones produced in situ in castings with abrasive-resistant casting alloys is presented in Fig. 10 [24,25].

Prepared in situ in the composite casting zone having a lower hardness than the cermet. However, compared to the commonly used alloys based on Fe can be observed hardness increase of more than 200 HV30 units in the case of high chromium cast iron and almost doubled in relation to cast steel containing 18 % manganese.

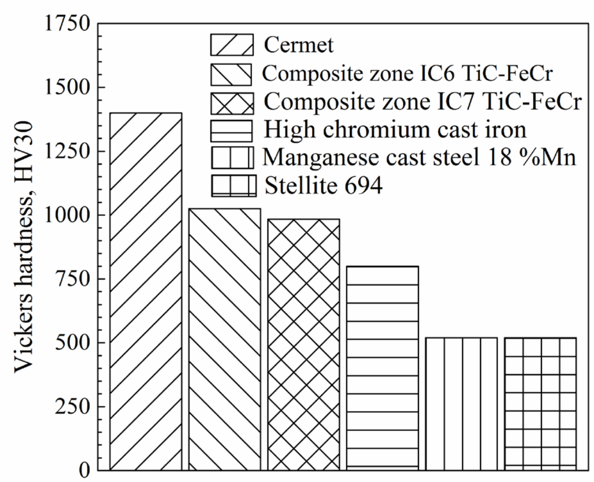

Fig. 10. Comparison of the Vickers hardness of the selected engineering materials with locally formed composite zones in castings

The diagram shown in Fig. 11 presents the comparison of abrasive wear indices of the selected abrasive-resistant casting alloys and composite zones obtained in situ. Tests were performed by the ball-on-disc method. Produced zone composites TiC-Cr and TiC/Fe-Cr/Al_2O_3 have wear rate of less than 2 × 10^{-6} [mm^3/Nm]. Comparing this value with the wear rate for the manganese cast steel containing 18% Mn, almost twenty five times lower wear rate is observed for the composite zone. In the case of chromium white cast iron content of 20 % Cr composite zone have nearly six times lower wear rate.

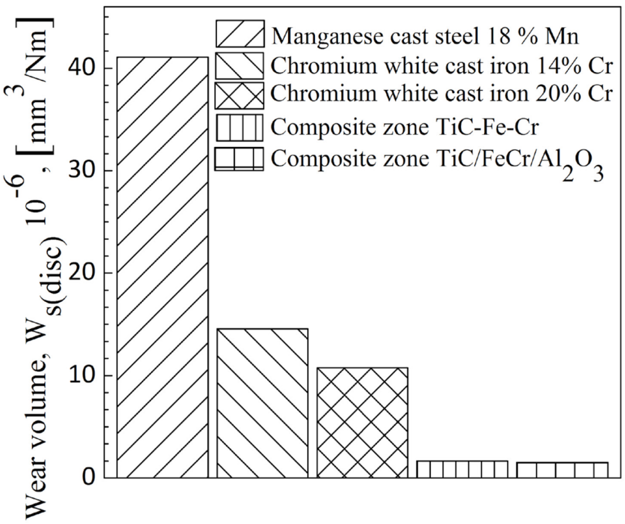

Fig. 11. Comparison of wear rate determined by the ball-on-disc method for the selected abrasive-resistant casting alloys with in situ produced composite zones

Preparation of the functional elements of machines and of local reinforcements in composites containing TiC -type phase microstructure results in a significant increase in hardness and resistance with respect to the applied base alloy. The results also show that the wear indicator zones formed composite is significantly reduced compared to currently use commercial -resistant alloys.

5. Conclusions

Discussed in this article methods of preparation of composite castings allow to obtain functional materials reinforced ceramics based on Fe - C (cast iron, cast steel) or superalloys. Produced by the process in situ TiC ceramic phase has a high hardness which is reflected in the mechanical properties and performance of castings local areas reinforced composite. This method makes it possible to obtain a favorable correlation between the ductile alloys casting wear resistant and high-hardness ceramic phases.

Acknowledgements

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