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# Wear Resistance of TiC Reinforced Cast Steel Matrix Composite

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## Abstract

Wear resistance of TiC-cast steel metal matrix composite has been investigated. Composites were obtained with SHSB method known as SHS synthesis during casting. It has been shown the differences in wear between composite and base cast steel. The Miller slurry machine test were used to determine wear loss of the specimens. The slurry was composed of SiC and water. The worn surface of specimens after test, were studied by SEM. Experimental observation has shown that surface of composite zone is not homogenous and consist the matrix lakes. Microscopic observations revealed the long grooves with SiC particles indented in the base alloy area, and spalling pits in the composite area. Due to the presence of TiC carbides on composite layer, specimens with TiC reinforced cast steel exhibited higher abrasion resistance. The wear of TiC reinforced cast steel mechanism was initially by wearing of soft matrix and in second stage by polishing and spalling of TiC. Summary weight loss after 16hr test was  $0,14 \pm 0,23$  g for composite specimens and 0,90 g for base steel

**Keywords:** Metal matrix composites, MMCs, Composite casting, TiC reinforced cast steel, Wear resistance

## 1. Introduction

Modern mining and mineral industry is searching for new materials, which can extend the worktime of crushers, grinding mills and others devices in minerals processing and wastes recycling. Components of these devices works in environments where abrasion often combined with corrosion or impact are prevalent (e.g. impact or cone crushers). Complicated nature of wear often impedes the correct choice of materials which fulfil these criteria. In this type of applications alloyed cast steel and cast iron, are most regularly selected in practice. The high chromium white cast iron is widely used in abrasive wear condition for elements such protective plates for crushers, etc.,

while in impact wear conditions the high manganese cast steel is generally used for hammers, cones, jaws, etc.

The main criterion for choosing an alloy to the wear conditions is hardness which transform into abrasion resistance. Many cast alloys designed to operate under conditions of abrasion characterized a hardness in the range of 500 - 700HV [1-3]. This value is much lower than the hardness of minerals. Therefore, in the last 30-40 - year period wear resistant composite materials have been developed. In general, they are composed of hard ceramic particles in ductile iron alloys matrix. The main advantage of this materials is hardness in the range of 700 - 1600HV [3-6].

This material is known in materials engineering as metal matrix composites (MMC's) and presents an interesting properties for special applications in modern industry, because of their well

combination of hardness and stiffness, reserved for ceramics by now, with ductility and fracture toughness of metallic matrix [7-10]. As the reinforcing phase, the most commonly is used modern engineering ceramics such as carbides, borides, nitrides and others whose hardness reaches even 3200HV [3,4].

The main disadvantage of the technology of metal matrix composites is limited products dimensions, e.g. by powders metallurgy method - they are produced slightly elements such as cemented carbide insert blanks.

Problem of limited dimension of items can be solved by casting technologies in which composite zones are placed in areas exposed to abrasion. For several years in the Department of Engineering of Cast Alloys and Composites at Faculty of Foundry Engineering develops technology to perform composite castings using SHS-B method (SHS synthesis during casting) involving the synthesis of ceramic particles in the presence of liquid alloy casting.

This process involves following stages:

- preparation of compacts from substrates such as titanium powder, graphite powder, and others,
- mounting this compacts in the mould cavity,
- pouring molten alloy into mould.

After filling the mould cavity with molten alloy, high temperature synthesis reaction is initiated by the heat provided via the molten alloy. As a result of this synthesis a composite zone with dispersed particles of carbide ceramics distributed in the matrix can be obtained.

In this paper a wear investigation of TiC/cast steel composites is reported. This composites were tested in Miller machine slurry tester. The results were compared to the wear behaviour of cast steel which was selected as a base alloy.

## 2. Experimental procedure

The mixture of substrates necessary for the synthesis of titanium carbide was prepared in an atomic ratio of 1:1, according to the reaction in equation (1).



For this purpose, the commercial powders of titanium (99.98%, 44  $\mu\text{m}$ ) and graphite (99.99%, 44  $\mu\text{m}$ ) were used. The prepared powders were placed in hermetic container and mixed without the access of air for 24 hours in horizontal axle mixer. After mixing powder was mechanically pressed into rectangular cuboid compacts with dimensions of 10×12×55mm. The pressure used for fabricate of compacts was 250 and 600 MPa.

The base alloy selected for investigations was, low-carbon cast steel. Its chemical composition is shown in Table 1. The charge consisted of an unalloyed steel scrap, grade S235 and Armco iron, was melted in a medium frequency induction furnace with a 20 kg capacity crucible. After the charge was completely melted, the steel was deoxidised with aluminium and FeTi60. Then it was superheated to a temperature of 1600°C and tapped. During tapping, the steel was deoxidised with aluminium and with FeCa30Si.

Table 1.

Chemical composition of the base cast steel, in wt. %

Element	C	Si	Mn	P	S	Fe
L25GS	0.25	1.03	1.14	0.003	0.010	balance

Before pouring of mould, the fabricated compacts with substrates for the TiC synthesis were installed in mould. The steel was next poured into a test mould made of a furan-bonded silica sand mixture. Then the resulting casting was cut, ground and polished to perform metallographic and wear tests.

The structure of the obtained alloy and of the composite zone was measured with Kristalloflex 4H X-ray type diffractometer made by Siemens using CuK $\alpha$  X-rays of the wavelength of 0.15418 nm. The research was carried out at a voltage of 30 kV and a current of 20 mA. Imaging of microstructure produced in the examined materials was done by SEM using an SU-70 Hitachi scanning electron microscope. The wear test was performed in accordance with ASTM G75 Standard Test Method for Determination of Slurry Abrasivity. Summary test period was 16 hours, after each four hours' specimens were cleaned in distilled water, dried and then weighted. Load used in test was of 20N, and slurry is consisted 50 % of SiC.

## 3. Results

Figure 1 shows the results of X-ray diffraction on crystallographic planes of structures obtained in the composite zone produced in experimental steel casting.

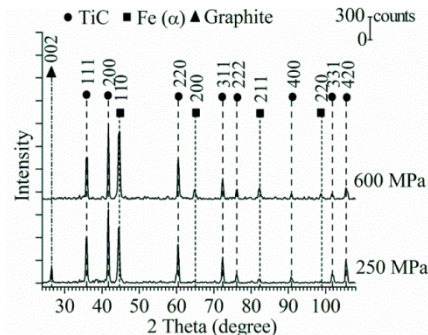


Fig. 1. X-ray diffraction pattern of composite zones and matrix

It can be seen that in the both specimens Fe $\alpha$  and titanium carbide are the main constituents of the composite areas. Additionally, the presence of unreacted graphite has been traced in specimen 250MPa. The microstructure of the examined specimens was detected using scanning microscope. Fig. 2 displays the typical microstructure obtained from the composite zones in as-cast condition. As can be seen in Fig. 2, distribution of titanium carbide particles in matrix is not uniform. In some areas titanium carbide is prevails and in other areas matrix is dominant constituent. In addition, in specimen 250 MPa a small precipitation of graphite has been shown. Distribution of TiC particles like this observed in microstructure of tested material and presence of graphite, may cause irregular wear of castings in macroscopic scale.

The results of the wear test are shown in Fig 3. As expected specimens machined from the composite zone, indicate the less wear rate. High hardness of this specimens (489+/-116 and 1523+/-290 HV respectively for specimens 250MPa and 600MPa) results in small weight loss approximately 0,14±0,23 g after 16hr test.

In per composite specimens, this one machined from base steel matrix result in higher weight loss because of their low hardness (326+/-23HV). Considering the differences in wear rate between specimens compacted at pressure 250 and 600 MPa the mass loss decreased with increasing compaction pressure, which was a consequence of TiC volume fraction.

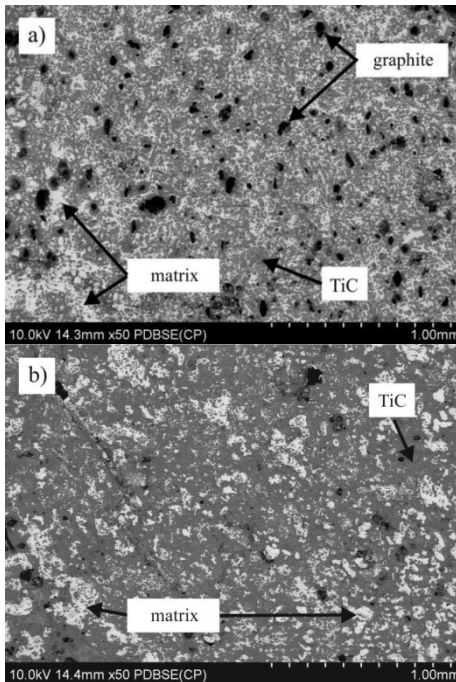


Fig. 2. Typical microstructure of investigated composites  
a) 250MPa, b) 600MPa

As confirmed with the previous observation [11], the content of titanium carbide also increases with increasing compaction pressure. Obtained results indicates that summary weight loss of tested composite specimens are even ten times less than of Hadfield cast steel tested in this same condition [12,13].

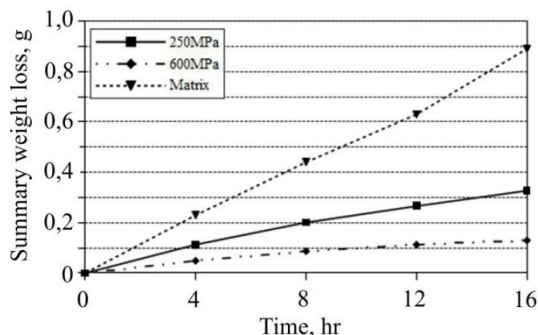


Fig. 3. Summary weight loss of tested materials

Fig. 4 shows the surface of worn specimen machined from base cast steel. The long parallel scratches and grooves are observed on the surface. In some areas, the grooves are deeper than in the other. Additionally, particles of silicon carbide dented into the matrix are observed on the surface. Despite this the matrix surface is worn regularly.

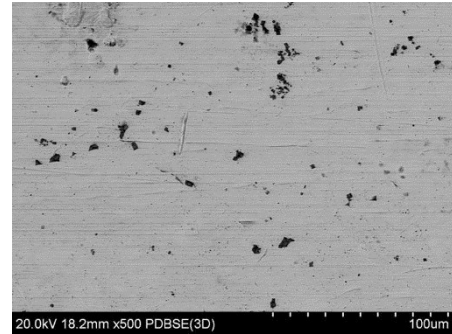


Fig. 4. The base steel surface, after 16 hr Miller slurry test

Composite specimens demonstrate different kind of wear in water slurry. Worn surface of specimens 250 and 600 MPa are shown in Fig. 5 and 6. The first and foremost difference is absence of scratches and grooves on the surface.

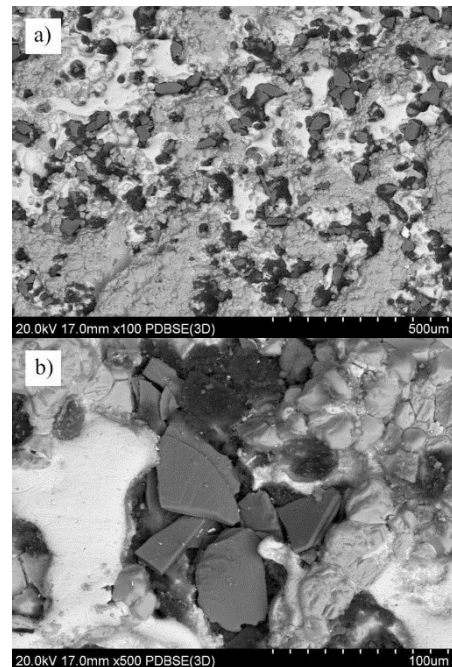


Fig. 5. The surface of specimen 250MPa, after 16hr Miller slurry test

Fig. 5 shows the worn surface of specimen 250MPa. On this surface, some matrix lakes and graphite precipitation are observed. Except that, there are particles of silicon carbide which were embedded between titanium carbide and matrix areas. Abrasive particles of SiC are also revealed on surface of 600MPa specimen (Fig. 6). Because of less amount of soft matrix on the

surface of this specimen, silicon carbide particles quantity is also less.

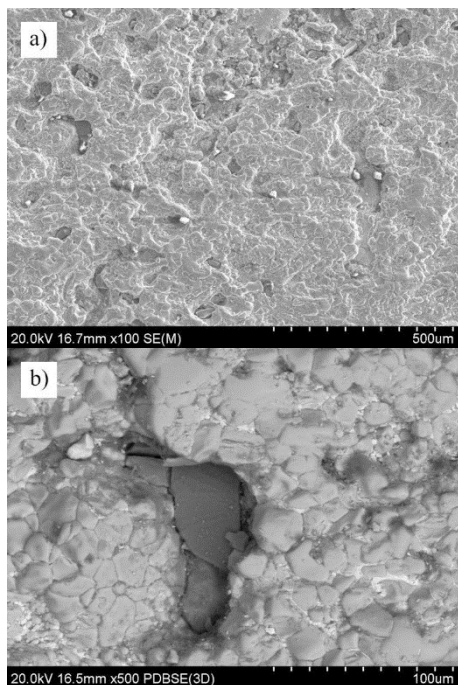


Fig. 6. The surface of specimen 600MPa, after 16hr Miller slurry test

Observing the surface of the composite samples after the abrasion test a following mechanism of wear may be suggested: abrasive wear of composite samples take place in a first stage by wear off the softer matrix. It resulting in, that indentations formed in this way accumulate abrasive particles (Fig. 5b and 6b), which are inhibiting further erosion. Accordingly spalling pits of titanium carbide and a polishing process takes place in the second phase of wear. These observations are also confirmed by the data presented in Fig. 3. The wear rate of composite decrease with the duration of Miller slurry test. After 8 hr summary weight loss were 0.2 g and 0.09g, respectively for a sample of 250 and 600 MPa. After another 8 hr test samples worn out just respectively by 0.10g and 0.04g.

## 4. Conclusions

1. The microstructure of examined composite samples is consisted of TiC, Fe<sub>a</sub> and in addition a small amount of graphite in sample compacted at 250 MPa pressure.
2. The composite zones obtained in low alloy cast steel improved significantly wear resistance of castings. The weight loss of composite specimens were four to six times less than base cast steel.
3. The pressure applied to produce compacts has a fundamental influence on wear resistance. The weight loss has been reduced over twice, from 0,32g/16hr to 0,13g/16hr when the compaction pressure increased from 250MPa to 600MPa.

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