TRIBOLOGICAL BEHAVIOR OF REINFORCED AND UNREINFORCED HIGH CHROMIUM CAST IRON

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Abstract In this paper, the metal matrix composites containing 22 wt % Cr, 2.5 wt % C and 2 to 16 volume percent TiC were processed by solidifying Fe-Cr-Ti-C in which precipitation of titanium carbide and chromium carbide occurred. The microstructure and abrasion resistance of in-situ synthesized composites were compared with the unreinforced high chromium white cast iron (HCWCI) containing 22 w. t. % Cr and 2.5 w. t. % C. SEM, OM as well as abrasion machine test methods which were used for microstructure and wear evaluation of the matrix and reinforcement. As a result, an increase in Ti content, increased the hard TiC volume percent besides the coarse $(Fe,Cr)_7C_3$ in the ferrous matrix. The increase of the TiC content led to an increase in wear resistance, without any considerable increase in macro hardness.

Key Words High Chromium White Cast Iron (HCWCI), Composite, Abrasion Resistance, Titanium Carbide

چکیده در این پژوهش کامپوزیت زمینه فلزی حاوی ۲۲ درصد وزنی کروم، ۲/۵ درصد وزنی کربن و ۲ تا ۱۶ درصد حجمی کاربید تیتانیم مورد بررسی قرار گرفت. این کامپوزیت به روش درجا طی انجماد مذاب حاوی Fe-Cr-Ti-C که در نتیجه آن کاربید تیتانیم و کاربید کروم رسوب می‌کند، ساخته شد. ریز ساختار و مقاومت سایشی کامپوزیت ساخته شده به روش درجا با چدن سفید پرکروم (HCWCI) حاوی ۲۲ درصد وزنی کروم و ۲/۵ درصد وزنی کربن مقایسه گردید. از آزمایشهای OM و SEM و XRD برای بررسی ریز ساختار زمینه و ذرات مقاوم کننده و همچنین از آزمایش سایش به روش پین بر روی دیسک برای بررسی رفتار سایشی نمونه ها استفاده شد. نتایج آزمایشها نشان داد که افزایش میزان تیتانیم موجب افزایش درصد حجمی TiC در کنار $(Fe, Cr)_7C_3$ خشن گردید. افزایش کاربید تیتانیم موجب افزایش مقاومت سایشی چدن سفید پرکروم بدون افزایش قابل توجه در ماکرو سختی آن شد.

1. INTRODUCTION

Each application of cast grinding balls requires a different material specification. During the last 15 years, the Iranian mining industry has experienced an increasing in the use of HCWCI grinding media in dry grinding applications. In these markets, single mills containing 250,000 kg of grinding balls are not uncommon, and hence the economic potential with respect to lower wear rates can be significant [1]. Laboratory scale investigations suggest that former materials can be replaced successfully by ferrotic composites.

Wear in mineral processing equipment is a complex system of material destruction composed of three major components: Abrasion, corrosion and high energy impact [2].

During the rotating or stirring movement of the mill, size reduction takes place through the impact of the material with the grinding media and through abrasion between the media and mill wall. Abrasion in crushers and grinding mills is the cutting away of metal surfaces by ore fragments. Energy is absorbed when force is applied to ore fragments driving them into and along metal surfaces [2].

For decades white cast irons have been the work horse of wear protection in the mining and cement industry, as well as in road construction. Recently, wear resistance metal matrix composites have been developed, including hard particles, such as carbides, borides, and nitrides and a metal (matrix independently of each other) and the design microstructures of superior properties.

Since the primary chemical composition affects the microstructure, the author has investigated Ti and C content effects on the microstructure of Fe-Ti-C systems [3]. The aim of the present study is to compare the microstructure and resulting properties of HCWCI and HCWCI reinforced by various amounts of TiC particles to cover the optimization of the grinding media and to introduce ferrotic composites as a relatively good media.

Tribological properties of the composites have been investigated using a standard test method for wear testing with a pin-on-disk apparatus (ASTM G 99-90) which employed a sintered alumina disk rotating against the test pin held by a load applied by a lever mechanism. Prior to testing the samples the disks were ultrasonically cleaned and washed in acetone. The tests were done by rotating the disk at a speed of 70 rpm with a normal load of 30 N and a distance of up to 1000 meters. Wear behavior was studied by determining the weight loss and scanning electron microscopy.

2. EXPERIMENTAL PROCEDURE

Four ferrotic composites were synthesized in an insitu method by adding different amounts of titanium and graphite to a cast iron melt containing 4 w. t. % C and 22 w. t. % Cr in a high frequency furnace at 1600℃ Due to the stoichiometry of Ti and C in the TiC and their atomic weights for producing 1mole TiC it is necessary to add 1mole Ti (49 gr.) and 1mole C (12 gr.), therefore, the weight ratio of Ti/C was 4/1.

It is our notion that the formation of the carbide occurs through diffusion of titanium to a carbon site where it precipitates as carbide by a chemical reaction. Thermodynamic considerations indicate that TiC is stable during solidification. The melt containing carbide particles was cast into ceramic (zirconia) molds with a size of ϕ 10 [mm] x 50 [mm]. In the following heat treatment the composites were quenched for 10 minutes in cool air.

Metallographic specimens of size ϕ x 10 [mm] x 10 [mm] were prepared from the composites and their surfaces were ground with silicon carbide papers up to 1000 mesh and were polished with cloth containing alumina dispersion up to 1 micron. The microstructures were examined under a scanning electron microscope and an optical microscope Determination of volume fraction, particle size, the shape and distribution of TiC particles were carried out as well as matrix microstructure and chromium carbides. The micro hardness of carbides was measured by a Leitz micro hardness tester under a load of 10 g. Vickers hardness of composites was determined under a load of 30 kg.

3. RESULTS AND DISCUSSION

3.1. Microstructure Addition of various amounts of Ti and Gr into the HCWCI melt resulted in about 2, 6, 12 and 16 volume percent TiC particles in the ferrous metal matrix.

Figure 1 shows the microstructure of HCWCI and reinforced HCWCI. Two distinct morphologies were observed, depending on the chemical composition of the matrix alloys while some parts of the microstructure contain primary TiC particles in the HCWCI matrix as shown in Figure 1-b. Other regions of the microstructure consist of primary TiC particles along with a eutectic phase composed of TiC and ferrite. In this material it is apparent that the primary TiC particles were formed from the melt during cooling [4]. The remaining liquid solidifies in a manner similar to a HCWCI.

The addition of Ti to the Fe-Cr-C alloy does not change the solidification microstructure remarkably, as it is apparent in Figure 1-b. Arjomand et al [5] indicated that the microstructure consists of primary TiC particles, primary austenitic dendrites and a $(Fe,Cr)_7$ C_3 austenite eutectic network. These results could be confirmed with the ASM review committee on cast iron [6]. The results of constituent analysis, EDAX and line scanning of the microstructure, as shown in Figure 2, confirm the existence of TiC. As cooling takes place and the solid state progresses, some of the austenite phase transforms into martensite.

The resulting M_7C_3 carbides stem from hexagonal Cr_7C_3 but may actually contain more Fe

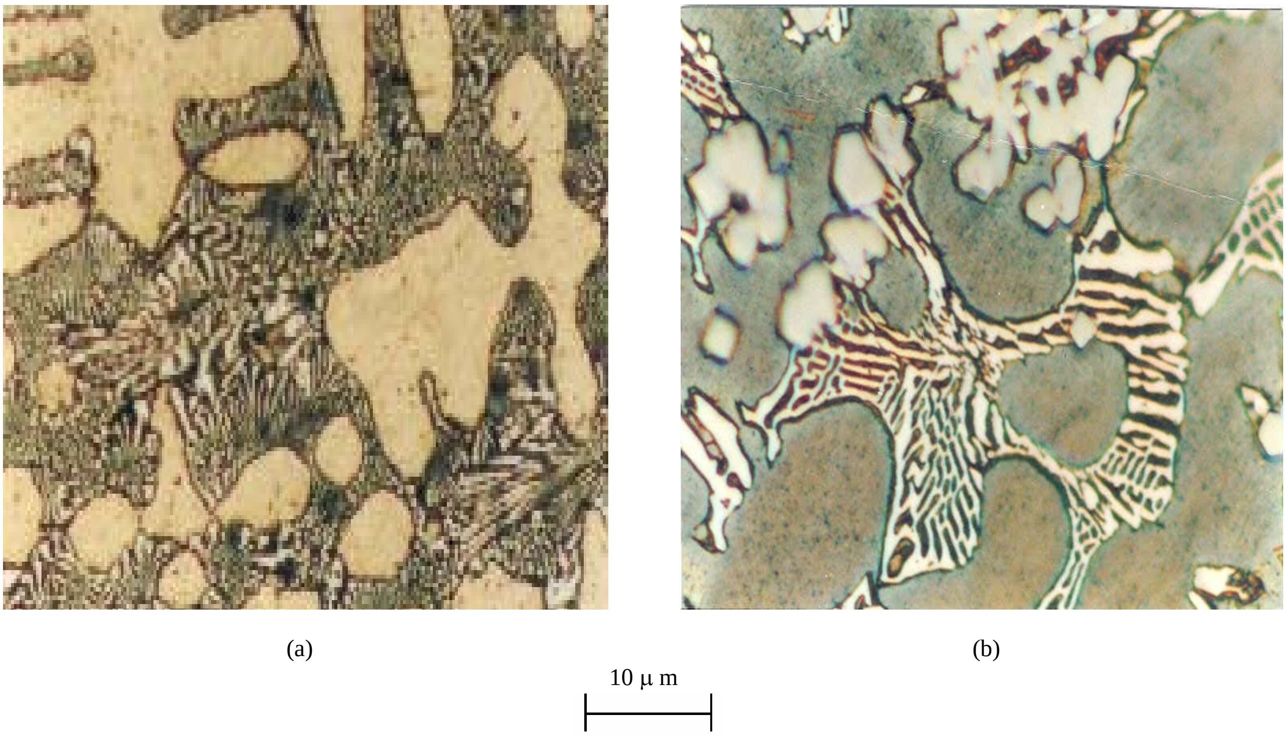

Figure 1. OM micrograph of a: HCWCI, b: reinforced HCWCI.

than Cr which lowers their hardness to the range of 1250 - 1650 $HV_{0.05}$ [5]. In contrast to the eutectic Fe_3C skeleton, the M_7C_3 eutectic consists of individual hard particles embedded in a continuous metal matrix. This change in morphology improves the ductility of the alloys on the low carbon side and resistance to crack initiation in service at all carbon levels [7]. Because of high Cr - C content the as-cast HCWCI consists of about 50 % austenite, which could be decomposed by annealing before hardening and tempering [5]. These HCWCIs were improved by adding Ti to the precipitate primary cubic TiC of superior hardness (2900-3300 HV. 05).

The solidification microstructure of composites is mostly homogeneous. Although almost ideal precipitate distribution was achieved at low volume fraction of TiC, at higher volume fraction, a tendency toward clustering was present. Figure 3 illustrates the distribution of TiC within the reinforced specimens in unetched condition. As expected, by increasing the amount of Ti content volume fraction of TiC particles increases and a decrease in eutectic carbides takes place.

3.2. Wear Resistance Wear rates of the unreinforced HCWCI and reinforced HCWCI are listed in Table 1. The addition of approximately 2 vol. % TiC particles to the iron matrix reduces the mass loss about 8 x 10^{-4} mg, from 45 × 10^{-4} mg to 37 x 10^{-4} mg. Presence of more TiC in the matrix (6 vol. %) decreases the mass loss to about 25 x 10^{-4} mg. Although the volume fraction of chromium carbides in the reinforced alloy is approximately the same as that in the HCWCI alloy, extra wear resistance is gained from the presence of the TiC phase.

The virtual unique wear - resistance of HCWCI mainly contributed to the very hard chromium carbides and TiC particles which could effectively reinforce the matrix and protect it from serious abrasion.

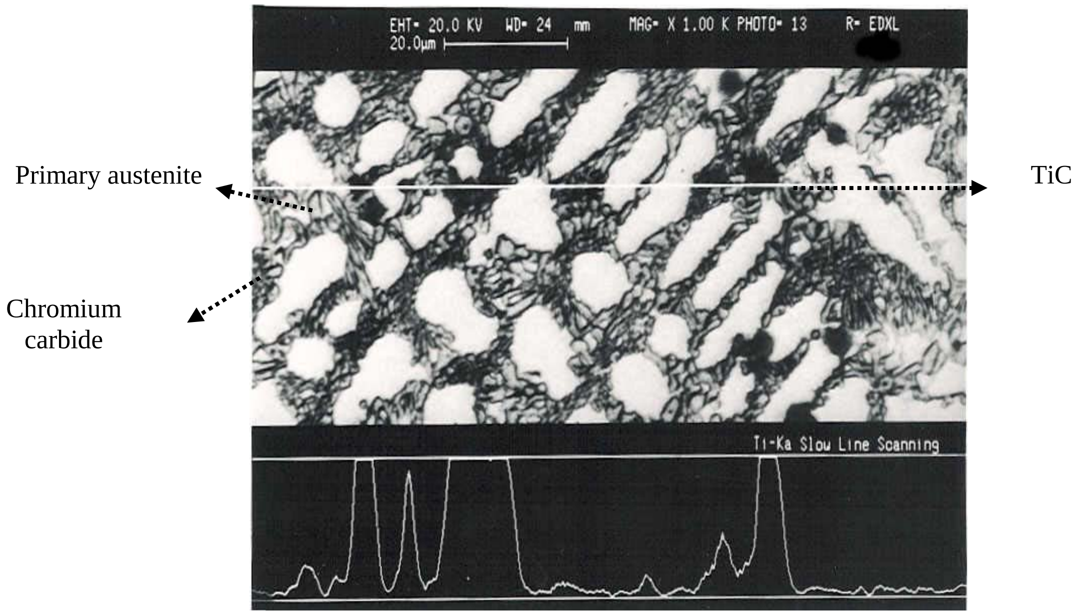

Figure 2. SEM structure of Fe-Cr-C-Ti, Line scanning of Ti.

As indicated in Table 1, macro hardness of the specimens was not significantly affected by the addition of Ti, although the quenching process resulted in an increase it. On the other hand the quenching process caused a considerable increase in the macro hardness due to the transformation of the remained austenite to martensite.

As indicated in Figure 4, an addition of TiC particles into the matrix caused a decrease of weight loss in the wear test. Wear resistance of HCWCI after the quenching process improved due to the transformation of its hard martensitic structure. The amount of weight loss decreased until a critical point (wt % $\approx$ 6); after that, it was raised by the increasing volume fraction of particles. The increase of wear rate after this critical limit of reinforced volume fraction was related to the increase of particles in the composite matrix which was involved by the rough sintered alumina disk, as a result of that, they were forced and broken. This value can be compared with Pagounis et al. [8] results. They have reported 10 Vol % for this critical amount of TiC particles in the white cast iron.

The next heat treatment of these composites contain two opposite effects, 1- to raise the wear resistance due to the presence of hard phases in the hard matrix (chromium carbide and martensite) and 2- to decrease of the wear resistance because of the induced stresses in the interface of TiC particles and the matrix. There is a significant difference between thermal expansion coefficient of carbides and the ferrous matrix. Finally these opposite effects determine the real wear properties.

The as - cast HCWI has the best abrasive wear resistance when the eutectic cells (austenite + M_7C_3) are oriented randomly in the pin abrasion specimen. By comparison, the Fe-Ti-Cr-C alloy produced in this study contains approximately the same volume fraction of hard carbide phases as the white cast iron, but its weight loss is dependent on the characteristics of both the TiC and the M_7C_3 phases.

As expected, up to a volume percent of TiC $\approx$6, as the hardness of these materials increase, the abrasion resistance also increases due to the hard particles dispersion in a relatively soft matrix, the micro hardness varies from one point to another

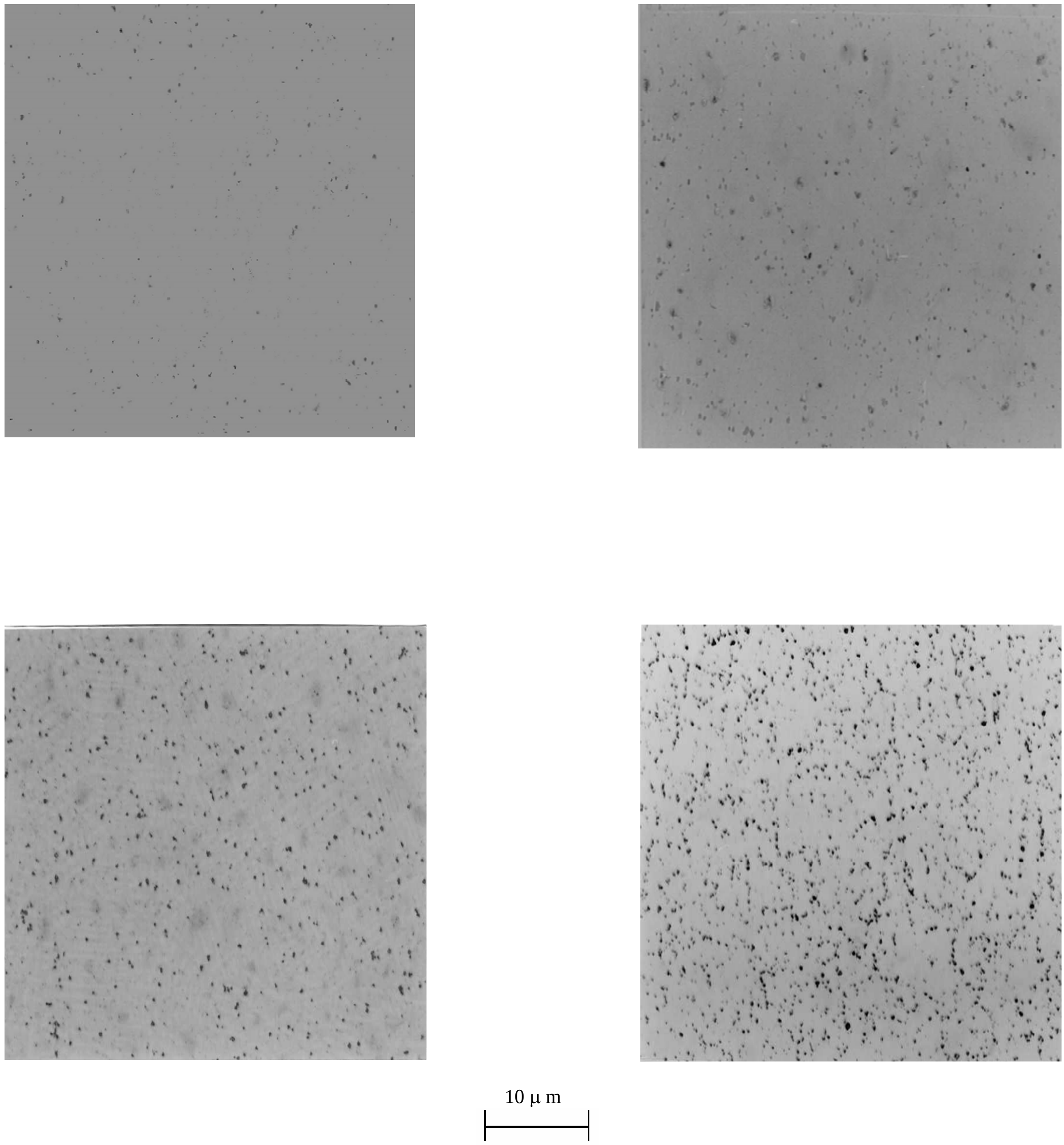

Figure 3. Optical micrograph of matrix in un - etched and vol. % of TiC is: (a) 2, (b) 6, (c) 12 and (d) 16.

especially in the Fe-Ti-Cr-C alloy .

For a material of fixed composition with geometrically variable microstructure, the hardness may be the mechanical property which can best be

TABLE 1. Volume Fraction of TiC, Hardness and Mass Loss of Specimens in as Cast and Quenched Condition.

Alloy composites	Hardness (HRC)		Vol. % of TiC	Mass loss (mg) x 10^{-4}	
	As cast	Quench		As cast	Quenched
HCWCI	50	60	—	45	35
HCWCI + 2 % TiC	51	61	2	37	30
HCWCI + 6 % TiC	51	62	6	25	20
HCWCI + 12 % TiC	52	61	12	27	35
HCWCI + 16 % TiC	50	58	16	35	42

related to abrasive wear resistance [3,7,9].

4. CONCLUSIONS

1. The microstructure of composites processed by precipitating particulate TiC from a Fe-Ti-Cr-C melt can be controlled by controlling melt composition, uniformity and cooling rates.
2. Metal matrix composites containing TiC and $(Cr,Fe)_7C_3$ can be produced insitu utilizing a solidification processing technique.
3. The abrasion resistance of the resulting reinforced HCWI increased up to a volume percent of TiC ≈ 6.
4. The macro hardness of the specimens was not significantly affected by the addition of Ti.
5. The quenching process caused an increase in hardness and abrasion resistance of all the specimens.

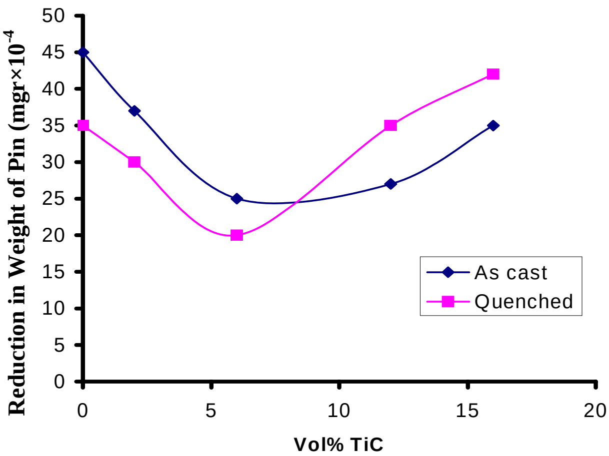

Figure 4. Effect of volume fraction of TiC on reduction in weight of pin.

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