Investigating the Effect of Titanium Addition on the Microstructure and Mechanical Properties of Ni-Hard 4 Cast Iron

Masoud Bahrami Alamdarlo[1], Kamran Amini[2*], Vahid Nemati Najafabadi[1], Mahyar Mohammadnezhad[3]
[1]Young Researchers and Elite Club, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[2]Department of Mechanical Engineering, Tiran Branch, Islamic Azad University, Isfahan, Iran
[3]Department of Materials Engineering, Isfahan University of Technology, Isfahan, Iran
[*]Email of corresponding author: k_amini@iautiran.ac.ir
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Abstract
Ni-Hard4 white cast iron is excellent wear resistant material and has been widely used in wear-affected equipment operated under extreme conditions, such as in mineral processing, cement, copper and iron manufacturing. In this study the effect of titanium addition (1.2, 0.7 and 0.2 wt.%) to the Ni-hard 4 cast iron with the nominal composition of Si= 1.5%, Mn=0.5%, C=3%, P=0.05%, S= 0.05%, Mo= 0.1%, Cr= 8% and Ni= 5.5% was investigated. This study was focused on the hardness, tensile strength, wear resistance and microstructural changes of the Ni-hard 4 cast iron. The results were compared with the Ni-hard 4 titanium free cast iron and demonstrated that the carbide morphology changes from rough plane to the flower leaf due to titanium addition. In addition, results showed that by increasing the percentage of titanium, hardness, strength and wear resistance is improved. In the samples with 1.3% titanium, the hardness, strength and wear resistance improved for 35, 22.5 and 85% respectively as compared with the titanium-free samples. This behavior is a consequence of the chromium carbide replacement with the hard titanium carbides as well as grain refining. Investigating the worn out surface of the samples showed that the predominant wear mechanism is the combination of the adhesive and tibo-chemical.

Keywords
Ni-Hard 4 Cast Iron, Titanium Carbide, Wear Resistance, Hardness

1. Introduction

High chromium cast irons (HCCI) are excellent wearable materials. Their exceptional abrasive and erosive wear resistance result primarily from the emergence of high volume fraction hard (HV 1300–1800) M_7C_3 carbides for the high chromium content (above 12%), although the toughness of the matrix also contributes to the wear resistance [1]. Meanwhile, M7C3 carbides come into being shaft separately in the course of solidification. So HCCI have exceptional mechanical properties due to the improvement of the toughness [2]. Accordingly, HCCI are very suitable for a variety of applications where the stability in an aggressive environment is a principal requirement, including the mineral processing, cement production, electric power and pulp and paper manufacturing industries [1-2]. Ni-hard cast iron (NHWCI) consists of four groups with respect to the ASTM A532 standard (Table 1). The structure of the second type of Ni-hard cast with low nickel content consists of pearlite phase while with increasing the nickel content to higher values; austenite would be the predominant and more stable phase. The most important difference between the Ni- hard cast iron groups are their uses [3]. Impact strength of the D type is higher than the other groups (A to C). The Si content of the D type is high and subsequently the carbide formation accelerated due to a decrease in the carbon, solutionized in the Gama iron (γ) [3]. Ni- hard cast iron vastly uses in powder grinding and materials handling in the cement and mine facilities. The second type of Ni-hard cast iron consists of eutectic ledeburitic carbide (M_3C) and subsequently shows lower toughness. Alternatively, this kind of Ni- hard cast iron is regularly used in the rolling rollers. On the other hand, the fourth type of Ni- hard cast iron consists of non-continuous M_7C_3 carbide, which leads to a higher impact toughness of this type of Ni- hard cast iron [3]. Researchers have re- ported improvements in the wear resistance and mechanical properties of cast iron without reduction in impact toughness by adding strong carbide forming elements, such as vanadium, tungsten, titanium and niobium [4-6]. Ibrahim and etc. shows that adding the titanium up to 1.3% the highest strength and wear and impact resistance is obtained in the white cast iron with chromium and high contents of Molybdenum. This behavior is a consequence of precipitation of the titanium carbides in the austenite matrix [7]. In other study, Chung and etc. revealed that adding the titanium, changing the microstructure of casts iron from hyper eutectic to hypo eutectic in the hypereutectic high chromium cast iron due to decreasing the carbon content of matrix. This behavior is a result of titanium carbide formation. Beyond this, increasing the titanium content to 2%, produced the eutectic microstructure including the titanium and chromium carbides that improves the wear resistance vividly. This behavior is a consequence of microstructure fining as well as replacement of chromium carbides with titanium carbides [5]. In this study titanium is added, where titanium is a strong forming element, since TiC has a high formation temperature and would be the first phase to precipitate during solidification. Therefore, in this study, the effect of different contents of titanium on the micro structural changes and mechanical properties of Ni- hard 4 cast iron was investigated.

2. Experiments

The Ni- hard 4 cast iron was produced with respect to the ASTM A532. The melt was produced in an 800 kg frequency induction furnace (Inducterm). The temperature was controlled via a pyrometer continuously for similar casting situations and the pouring temperature was 1400-1450 ºC for all the samples. Four sand mold Y blocks were prepared with respect to the ASTM E370. The first sample was titanium free and the next three samples have different values of titanium. The chemical composition was evaluated via a quantometer (Fubdry master 2005) with respect to the ASTM E415 standard (table 2). After cooling, the samples were then released from the mold and austenitized at 800 º C for 4 hours. After that, the samples were tempered at 250 º C for 2 hours. The optical micrographs were captured with an Olympus PME3 microscope and with respect to the ASTM E883. Microhardness was evaluated with respect to the Vickers method (applied load of 200 gr) via a KOPA MH2 microhardness tester with respect to the ASTM E-18-03. The hardness was evaluated for at least 6 times for each sample to reach a trustful average. The samples microstructure was also examined via scanning electron microscope (Leo VP436). For more accuracy the samples surface was examined via energy dispersive spectroscopy (EDX). The tensile test was performed with respect to the ASTM 8M-04 for two samples of each group. Wear test was performed with respect to the ASTM G99-05 as the pin- on- disk wear test in the 1000 meter sliding distance, sliding speed of 0.1 m/s and under the applied load of 120 N. The samples weigh lose was evaluated continuously and the abrasive pines were produced form AISI 52100 steel with 63 HRC hardness.

Table1. Structure, chemical composition and uses of NI- Hard cast iron with repect to the ASTM A532 standard

Type	Commercial name	uses	microstructure	%C	%Mn	%Si	%Cr	%Mo	%P&S
A	Ni-Hard 1	Pure wear	Ledeburite carbide M_3C	2.5-3.6	Max 0.2	Max 0.8	1.4-4	Max 1	Max 0.3
B				2.4-3	Max 0.2	Max 0.8	1.4-4	Max1	Max 0.3
C	Ni-Hard 2			2.5-3.7	Max 0.2	Max 0.8	1-2.5	Max 1	Max 0.3
D	Ni-Hard 4	Wear and fluctuating loads	Non-continous carbide M_7C_3	2.5-3.6	Max 0.2	Max2	·7-11	Max 1.5	Max 0.3

Table2. Chemical composition of the solidified samples with respect to the ASTM A532 standard

Samples Number	%C	Mn%	Si%	%Mo	Ni%	Cr%	%P	%S	%Ti
Ti-0	3.1	0.65	1.8	0.15	5.5	8.2	0.06	0.07	-
Ti-2	3.01	0.536	1.81	0.142	5.16	8.6	0.0311	0.0360	0.2
Ti-7	2.96	0.545	2.03	0.178	5.11	8.75	0.0416	·0.0760	0.7
Ti-13	1.88	0.540	2.36	0.179	5.34	8.46	0.0396	0.0508	1.33

3. Results and discussion

3.1 Microstructure

Figure 1 shows the microstructure of the heat-treated samples after etching in Nital 2%. Microstructure of the samples consists of austenite, primary carbide of M_7C_3 and eutectic carbide [8]. Despite the similarity of the phases, the morphology of the samples was completely different. In the free titanium sample, the M_7C_3 primary carbides are thick. The OM micrographs show that with increasing the titanium contents up to 1.3%, the carbide sizes decreases from 37.37 to 12.63 μm (Fig. 1). Moreover, the carbides morphology changes from a thick structures to the thin and leaf sleeves like. This phenomenon makes a more homogenous microstructure in the samples with higher carbides content. Fig. 2 shows that non- homogenous titanium carbides were nucleated in the boundary of M_7C_3 carbide and the matrix. EDX analysis proves that the black particles in the boundary of chromium carbide and the matrix are titanium carbides (Figure 2). The experimental results show that the morphology of primary M7C3 carbides can be improved by adding a suitable amount of Ti. This improvement correlated with the emergence of TiC particles. These particles can act as the substrates for heterogeneous nucleation of primary M7C3 carbides, which results in significant refinement of the final grain size [8].

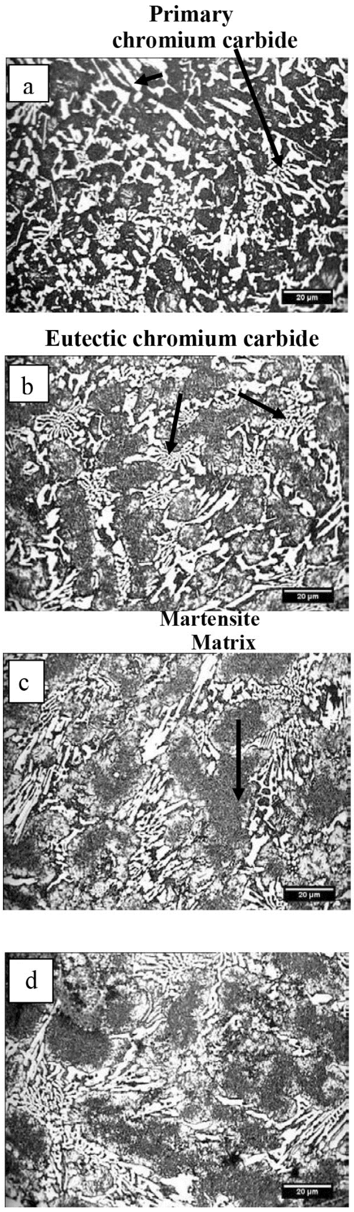

Figure1. OM micrograph of (a) titanium free sample, (b) 0.2 wt.%, (c) 0.7 wt.% and (d) 1.3 wt.% titanium samples

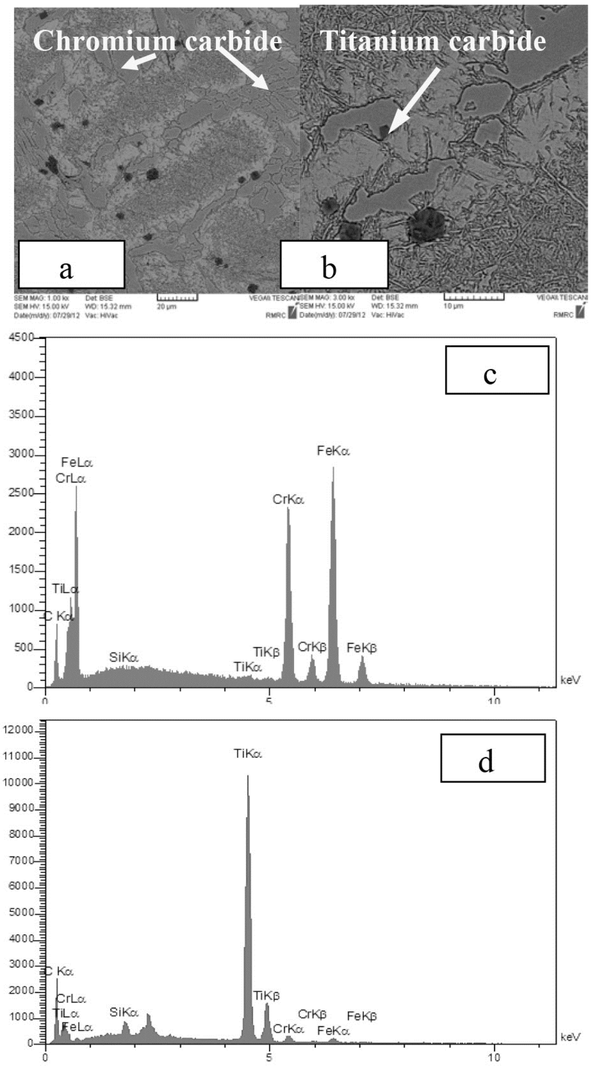

Figure2. SEM micrographs of carbide (a) and (b) and EDX analysis of the carbides (c) and (d)

3.2 Microhardness

With increasing the titanium, the hardness of the carbides increases from 715 to 965 HV (Figure 3). Titanium addition resulted also in decreasing the volume fraction of M7C3 carbides due to migration of a part of carbon to TiC, which indicates that titanium carbides were the first to solidify and may have then acted as nuclei for the proeutectic austenite dendrites, and thereby refining the structure [9]. This phenomenon is a consequence of the titanium carbide formation in the carbide/matrix boundaries, carbides refining and a more homogenous carbides distribution formed due to titanium addition [7-9]. Moreover, the martensite refining increases the hardness for 143 HV from 600 to 742 HV in the samples with higher contents of titanium (Figure 4). Titanium carbide decreases the carbon percentage in the matrix. This phenomenon leads to formation of lateral martensite as an alternative of plate one. Similar studies related to the effect of boron addition on microstructure of white cast iron found that boron refines also the microstructure [10-11].

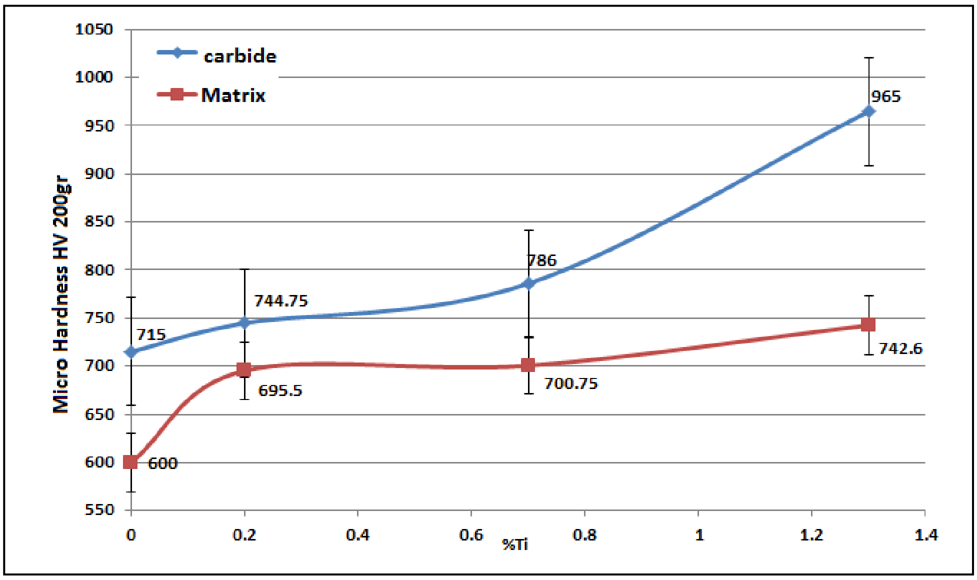

Figure3. Variation of microhardness versus titanium content of the samples

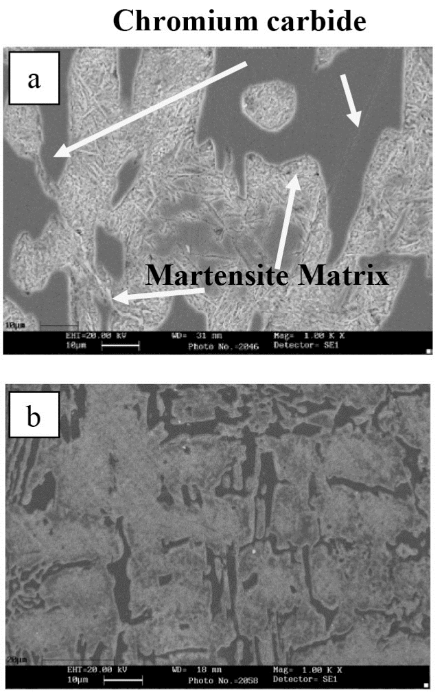

Figure4. SEM micrograph of (a) titanium free sample and (b) sample with 1.3 wt.% titanium content

3.3 Tensile test

With increasing the titanium in the Ni- hard 4 cast iron the ultimate tensile strength increases vividly (Fig. 5). This increase was about 18% for titanium addition up to 1.3 wt.%. Improvement in the hardness and strength with increasing the titanium content is a result of the titanium carbide formation and fragmentation of the chromium carbides network. Also in the presence of titanium in the solution, hardness and strength improves due to the solid solution strengthening phenomenon [7, 9, 12].

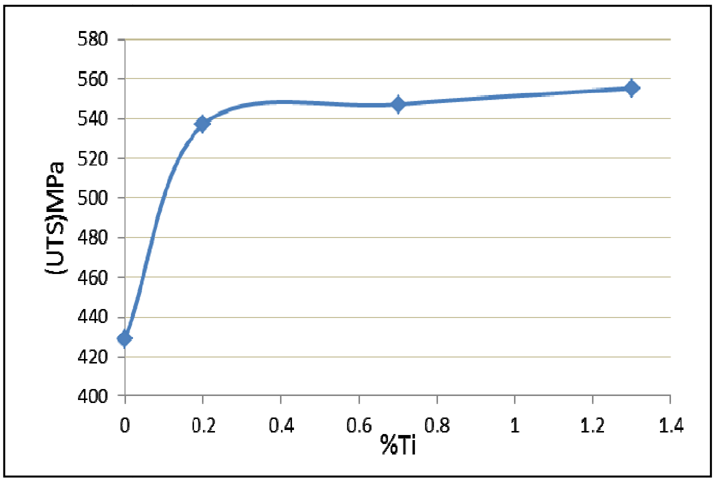

Figure5. Variation of ultimate tensile strengh (UTS) versus titanium content of the samples

3.4 Wear behavior

Titanium addition improves the wear resistance of the Ni- hard 4 cast iron samples (Figure 6). This improvement is a consequence of hardness improvement, carbides homogenous distribution and fine martensitic matrix, produced in the samples with higher contents of titanium (Figure 4) [7, 12-14]. As can be seen, less adhesive wear is observed in the 1.3 wt. % titanium samples. This could be attributed to the structure refinement effect, which is corresponding to eutectic structure with mixed chromium carbides and titanium carbides particles achieved by adding Ti up to 1.3% Ti. This is in a general agreement with the results reported by Chung et al. [5] where they studied the effect of Ti-addition up to 6% Ti on wear resistance of 25% Cr-4% C white cast iron. They noticed that wear rate decreased with increasing the amount of Ti addition due to refining the microstructure by Ti-addition. In addition, chromium carbides were replaced by Ti carbides, which are harder than the former. another study done by Arikan et al. [13] on the effect of Ti-addition up to 0.38% Ti on hardness and wear resistance of heat treated 15% Cr- 3% Mo white iron, they observed that wear resistance can be increased by increasing the amount of Ti-addition due to the structure refinement effect. SEM results show that the predominant wear mechanism is adhesive wear (Figure 7). The worn- out surface of the samples shows different amounts of surface damages as the departed areas. These damages are few and fine in the 1.3 wt.% sample due to the higher hardness of this sample. Alternatively, Adhesive wear was the dominant mechanism, but some degree of tribo-chemical wear was also observed. The tribo-chemical wear was a consequence of a localized high temperature at the contact surface that oxidized the surface of the disk and the pin. also observed (Figure 8). In the studies conducted by Fantalvo [15] on tool steels, increasing the volume fraction and reducing the distance between carbides have reduced the adhesive wear. On the other hand, Yang et al. [16] have considered increasing the hardness of the steel surface as the main actions of the resistance to adhesive wear. Therefore, resistance to adhesive wear increases in the Ti content samples, consequence of hardness improvement, carbides homogenous distribution and fine martensitic matrix.

4. Conclusion

1- Titanium addition changed the carbide morphology from the rough plane to the flower leaf. Moreover, titanium addition increased the homogenous distribution of the carbides in the structure.

2- With increasing the titanium content, the carbide hardness increased from 715 to 965 HV. Moreover, the matrix hardness also improved from 600 to 742.66 HV. It is attributed to the formation of hard TiC particle and fragmentation of chromium carbide network. It is also possible that the titanium dissolved in matrix, may have contributed to the matrix strengthening by solid solution.

3- Titanium addition accelerated the titanium carbide nucleation in the M7C3 carbide and matrix boundaries.

4- Titanium addition up to 1.3 wt.%, increased the ultimate tensile strength from 428.49 to 525.25 MPa in the Ni- hard 4 cast iron samples.

5- Titanium addition, improved the wear resistance of Ni- hard 4 cast iron. It is attributed to the (a) formation of hard TiC ceramic particles and (b) significant refinement of the primary chromium network

6- Wear mechanisms of the samples were adhesive and tribo -chemical.

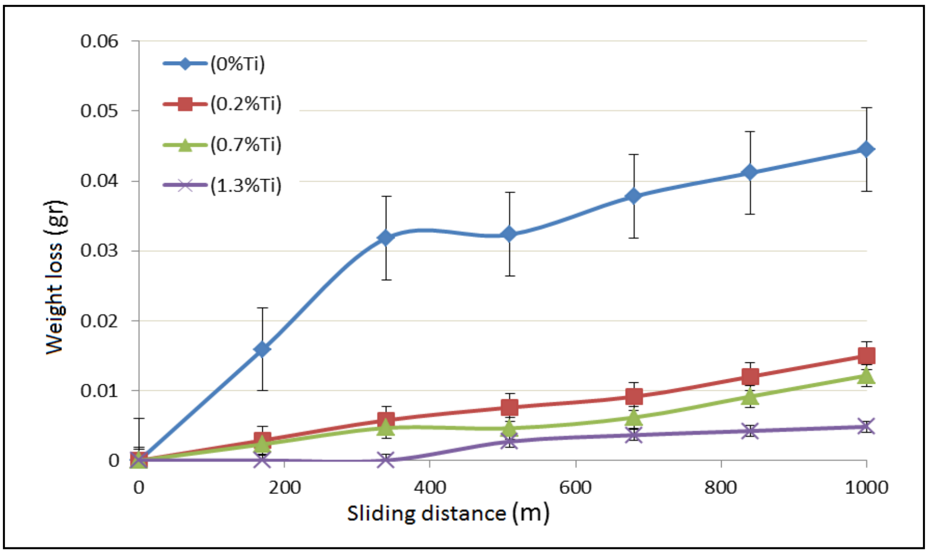

Figure6. Varition of weight loss of the samples versus the sliding distance under the applied load of 100 N and sliding spead of 0.1 m/s

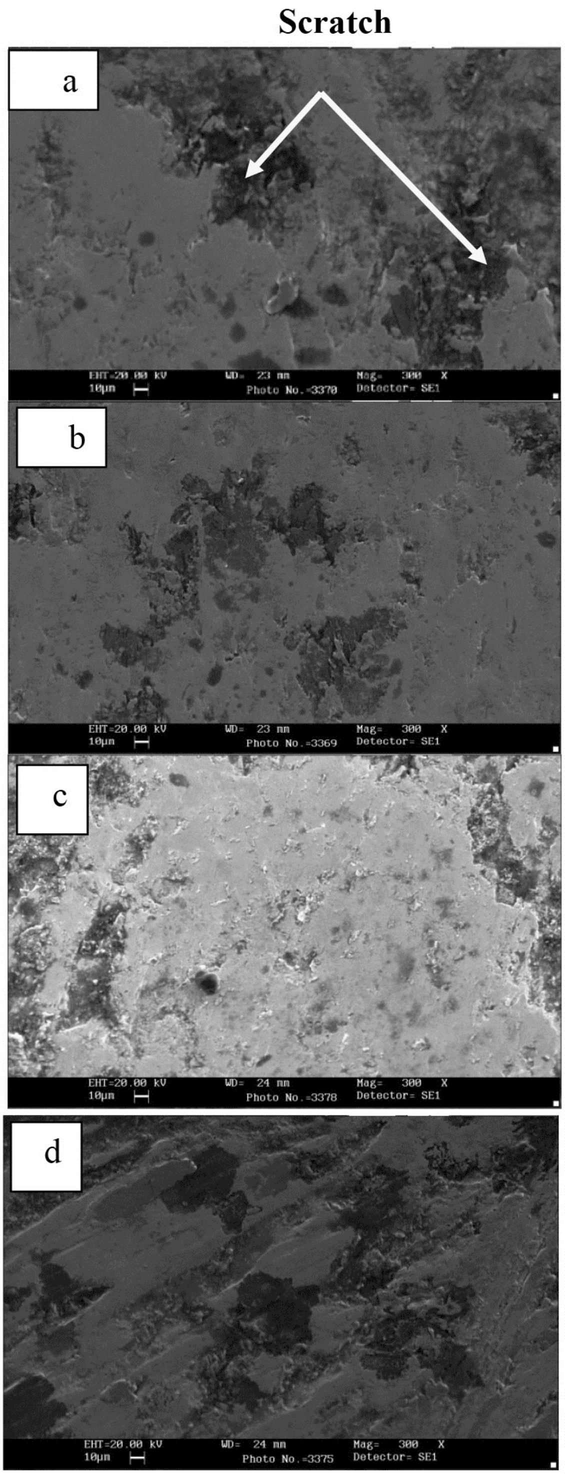

Figure7. SEM micrograph of the worn out surface of the (a) titanium free sample, (b) 0.2 wt.%, (c) 0.7 wt.% and (d) 1.3 wt.% titanium samples

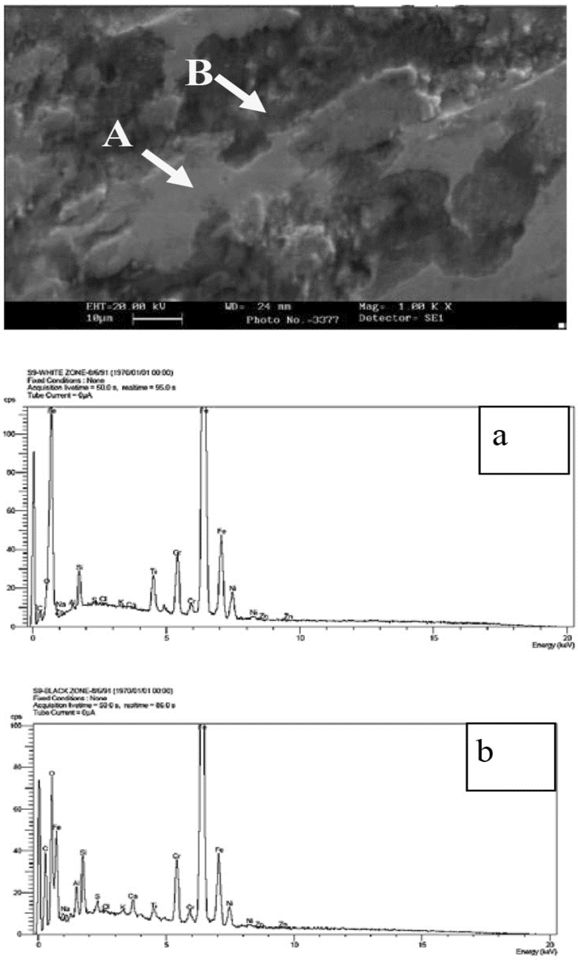

Figure8. SEM micrographs of carbide (a) and EDX analysis of the carbides (b) and (c) of the worn out surface of the 1.3 wt.% titanium smaples

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