WEAR BEHAVIOR OF NIOBIUM CARBIDE COATED AISI 52100 STEEL[1]

Frederico Augusto Pires Fernandes[2]
Carlos Kleber Nascimento de Oliveira[3]
Amadeu Lombardi Neto[4]
George Edward Totten[5]
Luiz Carlos Casteletti[6]

Abstract

Bearing steels must have high hardness, good wear resistance and dimensional stability. The aim of this work was to study the effect of NbC coating, produced using the thermo-reactive deposition (TRD) process, on the wear resistance of the AISI 52100 steel. Untreated AISI 52100 samples were ground up to 600 mesh emery paper. The bath was composed of 5wt.% ferro-niobium (65 wt.% Nb), 3wt.% aluminum and ($Na_2B_4O_7$) to 100%. Samples were treated at 1000ºC for 4h and quenched in oil directly from the bath. The resulting layer was characterized by X-ray diffraction, scanning electron microscopy and a micro-abrasive wear testing. The thermo-reactive deposition process in molten borax produced a hard and homogeneous layer composed by NbC, which was confirmed by X-ray diffraction. The NbC coating produced a great increase in the wear resistance of the AISI 52100 steel, decreasing the wear rate by an order of magnitude in relation to the substrate. For coated and uncoated samples the worn volume and wear rate increases with the load.
Key words: AISI 52100; Thermo-reactive deposition; NbC; Wear.

COMPORTAMENTO EM DESGASTE DO AÇO AISI 52100 RECOBERTO COM NbC

Resumo

Aços para rolamentos devem apresentar alta dureza, resistência ao desgaste e estabilidade dimensional. O objetivo deste trabalho foi estudar o efeito de um recobrimento de carboneto de nióbio (NbC), produzido por meio do processo de deposição termo-reativa, na resistência ao desgaste do aço AISI 52100. Amostras não tratadas do aço AISI 52100 foram lixadas até lixa 600 mesh. A composição do banho foi de 5% ferro-nióbio (65% Nb), 3% de alumínio e 92% de bórax ($Na_2B_4O_7$). As amostras foram tratadas a 1000ºC por 4h e resfriadas em óleo diretamente do de bórax. A camada produzida foi caracterizada por difração de raios-X, microscopia eletrônica de varredura e ensaios de desgaste do tipo micro-abrasivo. O processo de deposição termo-reativa em bórax fundido produziu uma camada dura e homogênea, composta por NbC, que foi confirmada por difração de raios-X. O revestimento NbC produziu um grande aumento na resistência ao desgaste do aço AISI 52100, diminuindo a taxa de desgaste por uma ordem de grandeza em relação ao substrato. Para as amostras com e sem revestimento do volume desgastado e a taxa de desgaste aumenta com a carga aplicada.
Palavras chave: Aço AISI 52100; Deposição termo-reativa; NbC; Desgaste.

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2 *Chemical Engineer, Doctoral Student, EESC-USP, São Carlos, Brazil.*
3 *Materials Engineer, Professor, URCA, Juazeiro do Norte, Brazil.*
4 *Engineer, AEROALCOOL, Franca, Brazil.*
5 *Engineer, Professor, Portland State University, Oregon, USA.*
6 *Materials Engineer, Professor, EESC-USP, São Carlos, Brazil.*

1 INTRODUCTION

The coating of surfaces is one of the most versatile ways to enhance the performance of components with respect to wear and/or corrosion. Hard coated surfaces can be produced by several processes, such as Physical Vapor Deposition (PVD), Chemical Vapor Deposition (CVD), nitriding and so on. An alternative method is the thermo-reactive diffusion/deposition (TRD) technique which can be used to obtain niobium carbide coating on iron based alloys.[3,4]

Niobium carbide (NbC) exhibits a number of interesting characteristics for its use in wear applications. Additionally to high hardness, toughness and stiffness, the NbC presents an extremely high melting temperature (3873ºC), which is a good indication for its use in high temperature environments. There are several reports in the literature, concerning niobium carbide coating techniques and properties.[1,2]

The AISI 52100 is one of the most common bearing steels. This material is used in rolling contact and must have high hardness, good wear resistance and dimensional stability.[5]

The aim of this work was to study the effect of NbC coating using the thermo-reactive deposition (TRD) process on the wear resistance of the AISI 52100 steel.

2 MATERIALS AND METHODS

Before the TRD treatments, AISI 52100 samples were ground up to 600 mesh emery paper. The bath was composed of 5wt.% ferro-niobium (65 wt.% Nb), 3wt.% aluminum and (sodium tetraborate - $Na_2B_4O_7.10H_2O$) to 100%. Samples were treated at 1000ºC for 4h and quenched in oil directly from the bath. The resultant layer was characterized by X-ray diffraction, scanning electron microscopy (SEM), Vickers hardness measuring and a micro-abrasive wear testing. Table 1 shows the nominal chemical composition of the AISI 52100 bearing steel used in this work.

Table 1. Nominal chemical composition (weight %) of AISI 52100 steel

	C	Si	Mn	P	S	Cr	Fe
AISI 52100	0.95-1.10	0.15-0.35	0.25-0.45	0.03 max	0.025 max	1.35-1.65	bal.

The measurements of Vickers micro-hardness were performed using a Buehler digital equipment with a load of 300gf and application time of 10s. The X-ray diffraction pattern was obtained on the surface of the sample using a Rigaku Gergerflex equipment with scanning angles ranging from 10 to 100°. The analyses were performed using copper Kα radiation and continuous scanning with a speed of 2°/min.

Electron microscopy was performed using a scanning electron microscope (SEM), LEO 440 model with a tungsten filament.

Micro-wear tests were performed in a fixed ball machine without abrasive and using a 52100 steel sphere of 25.4mm in diameter. The rotation speed and load were 500 rpm and 665, 1459 and 1826g (6.65, 14.59 and 18.26N), respectively. Consecutive wear scars were produced for test times of 5, 10, 15, and 20min in order to obtain the volume loss curve. The removed volume (V) of each wear crater and its depth (h) were calculated according to the following equations:[6,7]

$$V \approx \frac{\pi \cdot d^4}{64 \cdot R}, \text{ for } d << R \qquad (1)$$

$$h \approx \sqrt{\frac{V}{\pi \cdot R}}, \text{ for } h << R \qquad (2)$$

where d is the scar diameter and R the sphere radius.

3 RESULTS AND DISCUSSION

Figure 1 presents a electron micrograph of the cross section of the NbC coated AISI 52100 sample by the TRD process. A continuous and homogeneous layer is observed over the base material surface. The thickness of the NbC layer measured directly from the SEM image was about 6.1±0.1µm. Also, the martensitic structure is verified below the compound layer.

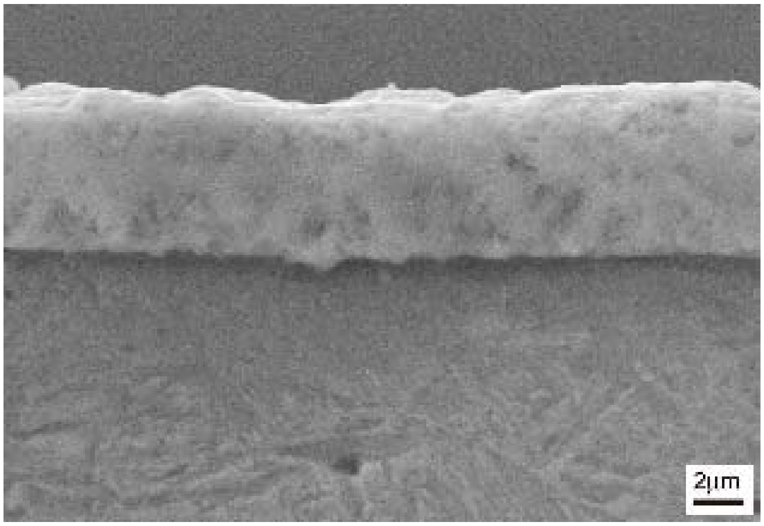

Figure 1. Scanning electron micrograph of a NbC coated AISI 52100 steel.

On Figure 2 the X-ray diffraction pattern of the NbC coated AISI 52100 steel is shown. The narrow peaks confirm the presence of a cubic NbC layer on the surface of the substrate, according to JCPDS card, number 38-1364. Also, some peaks related to the martensitic substrate are detected due to the reduced thickness obtained by the TRD coating process. The surface hardness of NbC the coated alloy was 1992±145HV, which is much higher than the substrate hardness (~700HV).

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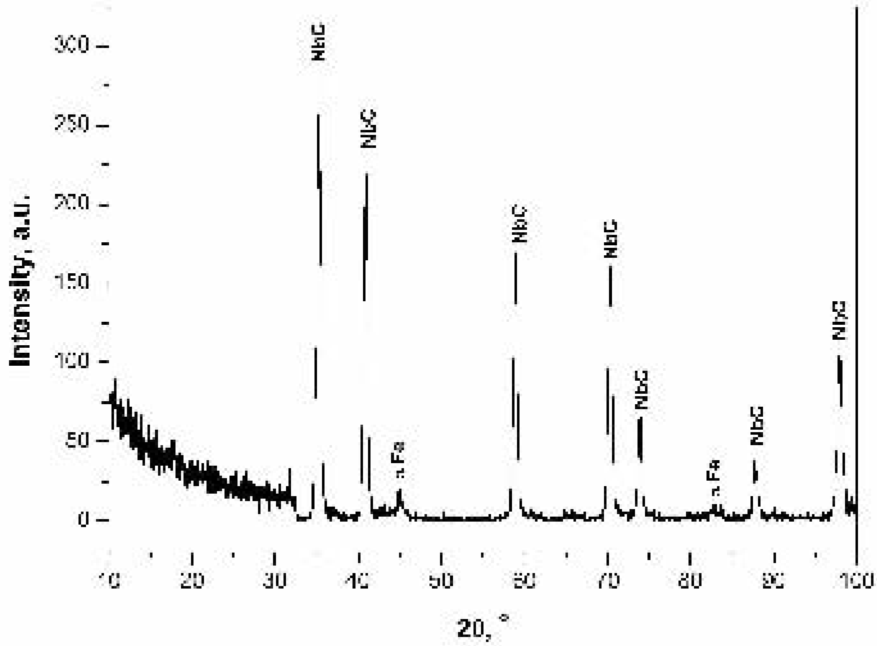

Figure 2. X-ray diffraction pattern of the NbC coated AISI 52100 steel.

3.1 Wear Characterization

Figure 3 shows the volume loss curves versus traveled distance of the AISI 52100 steel substrate (Fig. 3a) and the NbC coated alloy (Fig. 3b). The volumes were calculated using Eq. 1. The worn volume of the AISI 52100 substrate increases as the applied load increase, and shows a tendency of stabilization along the traveled distance, for all applied loads.

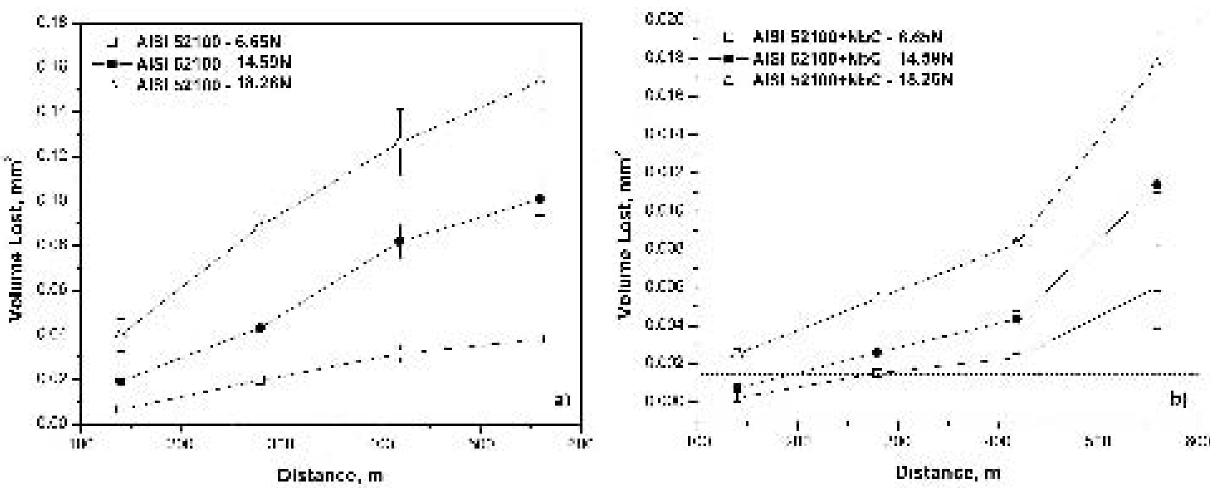

Figure 3. Volume loss curves of the: (a) AISI 52100 substrate and (b) NbC coated AISI 52100, with 6.65, 14.59 and 18.26N of load.

The worn volume curves of the NbC coated bearing steel also presented an increment on the volume lost with the applied load. However the total volume lost, related to the three loads, were about 10 times less than the substrate, indicating a great

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wear reduction. NbC coated AISI 52100 sample did not showed a tendency of volume stabilization along the running distance, which is due to the perforation of the NbC layer reaching the substrate that presents a high wear rate.

Calculations based on the layer thickness and Eqs. 1 and 2 indicates that the maximum crater diameter to layer perforation is 0.787mm or 0.0014846mm^3 of volume. The dashed line on Figure 3b indicates this maximum volume until the layer disruption. Appling 18.26N the layer is broken with the first 5min of wear testing.

Even after the break down of the NbC layer the substrate/layer wear rate remains constant until 15min of wear testing (Fig. 3b) when the substrate starts to loss a significative volume.

Figure 4 plots the wear rate against the applied load of the substrate and the NbC layer. To calculate the wear rate (mm^3.m^{-1}) of the volumetric loss curves for each applied load a linear regression was performed and the slope is the wear rate. The wear coefficients are plotted against load, on Figure 4, of the NbC coated AISI 52100 steel and the substrate itself.

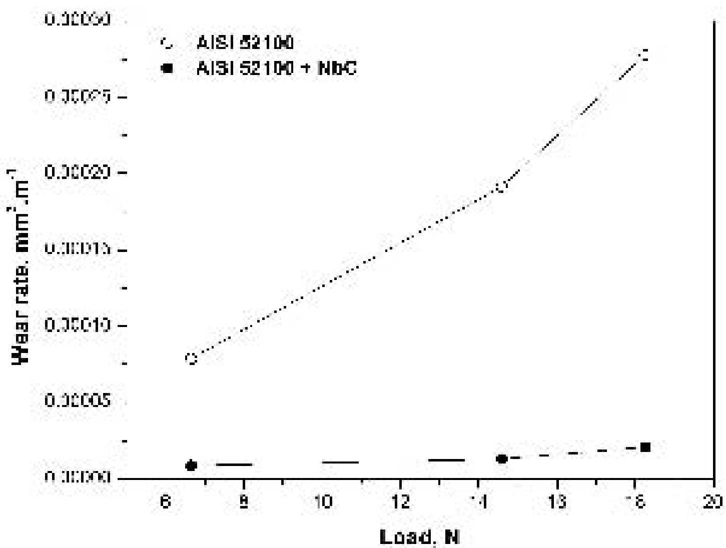

Figure 4. Variation on wear coefficient versus applied load of the substrate and the NbC coated AISI 52100 steel.

The wear rates of the substrate and the NbC coated sample increases almost linearly with load, although the coated alloy yielded small values. This indicates a great enhancement in tribological properties.

4 CONCLUSIONS

The thermo-reactive deposition in a molten borax containing NbC produced a continuous and homogeneous layer on a AISI 52100 steel. The produced layer is composed by NbC, as confirmed by X-ray diffraction. This layer presents a very high hardness (1992HV) and greatly enhances the wear resistance of the substrate.

The worn volume increases as the load was increased, although the wear of the NbC coated alloy was about 10 times smaller than the substrate's wear. The wear rate

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also increases with load and the coated AISI 52100 showed a lower wear rate when comparing the substrate.

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