

**TRIBOLOGICAL BEHAVIOR OF 42CrMo4 STEEL NITRIDED BY PLASMA**

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**Abstract**

This paper presents wear behavior of the plasma nitrided 42CrMo4 steel. This steel is used in mechanical industry; it has been assessed by evaluating tribological properties and surface hardness by using a pin-on-disk wear machine and microhardness tester. Experimental results showed that the nitrides  $\epsilon$ -Fe<sub>2-3</sub>N and  $\gamma'$ -Fe<sub>4</sub>N present in the compound layer increase the microhardness. It is found that plasma nitriding improves the wear rate and the presence of a hard and brittle compound layer on the surface causes an increase in wear of the specimen surface.

**Keywords:** Plasma nitriding; Friction; Wear; Steel 42CrMo4

**1 Introduction**

Plasma nitriding is a thermochemical process extensively applied in metallic materials science and surface engineering due to its well-known potential for improving properties such as hardness, wear and corrosion resistance of metallic parts [1,2]. This surface treatment technique consists of the implantation of nitrogen species at low energy into the steel substrate and their subsequent diffusion into the bulk at temperatures above 300 °C. The interaction of nitrogen and steel surface leads to the formation of different types of metallic nitrides, which form the so-called “nitride layer”. Starting from the solid surface, such a modified layer usually comprises an oxide layer, a compound zone and a diffusion zone [3,4]. The resulting structure of these zones depends on several processing parameters such as the concentration of alloying elements, exposure time, substrate temperature and gaseous mixture [5,6]. The presence of a nitride layer obviously changes the mechanisms of interaction between metallic materials and their surroundings, thus affecting their stability in aggressive environments [7–9]. The incorporation of nitrogen imparts better mechanical properties (friction and wear resistance) [10], but the dissolution kinetics (corrosion resistance) remains closely related to the composition of the corrosive medium [11,12].

In this context, the 42CrMo4 steel is largely employed in industrial processes that take place in aggressive environments. Hard iron nitrides are originated during the plasma treatment owing to nitrogen diffusion in the near surface region at temperatures below the eutectic point (593 °C) [13]. Usually, two different phases corresponding to the  $\epsilon$ -Fe<sub>2-3</sub>N and  $\gamma'$ -Fe<sub>4</sub>N nitrides are obtained, whose high hardness improves the strength, friction and wear resistance [14,15]. However, the highest wear resistance is normally achieved when the close-packed hexagonal  $\epsilon$ -

Fe<sub>2,3</sub>N phase is primarily at the surface of the specimens. This is so because the mixed nitride layer of the ε-Fe<sub>2,3</sub>N and γ'-Fe<sub>4</sub>N phases is, in fact, stressed due to a crystal lattice mismatch [16–19].

Recent work have shown that the pitting corrosion resistance of the steel can be significantly improved by nitride layers consisting of ε-Fe<sub>2,3</sub>N and γ'-Fe<sub>4</sub>N phases [20,21]. However, the effect of the nitride layer microstructure on the pitting corrosion behavior of steel is still not fully understood.

In this paper, we address this question by analyzing the influence of plasma processing at optimal parameters (temperature 500 °C, exposure time 4h and gaseous mixture 20 % H<sub>2</sub>, 80 % N<sub>2</sub>) [22] on the corrosion, wear behavior and microstructure of plasma-nitrided 42CrMo4 steel.

## 2 Experimental

42CrMo4 steel samples with nominal composition of 97.027% Fe, 0.40% C; 0.28 % Si; 0.9 % Mn; 1.09% Cr; 0.27 % Mo; 0.015% P; and 0.018 % S (In wt. %) were used in this study. Before plasma nitriding, samples were polished with diamond powder and ultrasonically cleaned in ethanol and during the heating step to reach the processing temperature; the specimens were ion-bombarded for 4 h in Ar/H<sub>2</sub> 80/20 v/v plasma for cleaning purposes. Specimens were nitrided in a vacuum furnace pumped down to low pressure (3 mbar) to minimize the oxygen contamination. The temperature of the samples is measured with the use of a thermocouple. The nitriding parameters were fixed similar to previous works [23]. After processing, the samples were left to cool down slowly (during 8h) inside a vacuum chamber.

The morphology of the samples surfaces was observed by Jeol 5900 Scanning Electron Microscope (SEM). The samples for SEM analyses were mirror-polished with colloidal silica (mesh size = 0.05 μm). The nitrided layers were revealed at room temperature by chemical etching with Nital (2% v/v nitric acid in absolute ethanol). Wear tests were carried out with a pin-on-disk tester, using a 5 mm diameter 100C6 steel ball as the pin. Unlubricated wear tests were performed at room temperature (≈20 °C) with a relative humidity of about 25%, a rotation speed of 60 rpm, a normal load of 5 N and a wear track diameter of 3 mm. The wear rate is determined using the Archard equation (Eq. 1)[24]:

$$Ku = \frac{Vu}{F_N \cdot D} \quad (1)$$

$Ku$ : the wear rate (m<sup>3</sup>N<sup>-1</sup>m<sup>-1</sup>);  $Vu$ : the wear volume (m<sup>3</sup>);  $F_N$ : the applied normal force (N);  $D$ : the sliding distance (m).

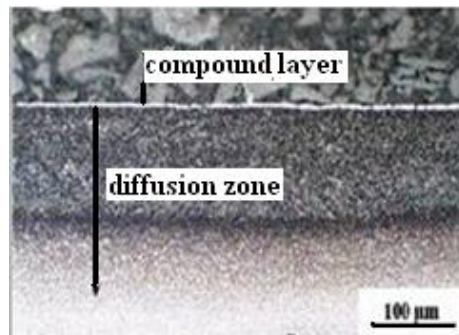
The wear volume was calculated by measuring the mass lost. After the wear tests, the worn regions were examined using a Jeol 5900 SEM.

## 3 Results and discussion

### 3.1 Microstructure of nitrided samples

The morphology and microstructure of nitrided layers produced on near-surface regions of 42CrMo4 steel by plasma treatment at temperature of 500 °C and exposure time 4h and gaseous mixture 20 % H<sub>2</sub>, 80 % N<sub>2</sub> were determined by SEM, respectively. SEM images can reveal up to two distinct types of surface layers. SEM micrograph of cross-sections of sample plasma nitrided in **Fig. 1** shows two distinct layers. One can see an outermost layer well-known as

compound layer or white layer, and below it there is a modified region also known as diffusion layer, as expressed as [23].

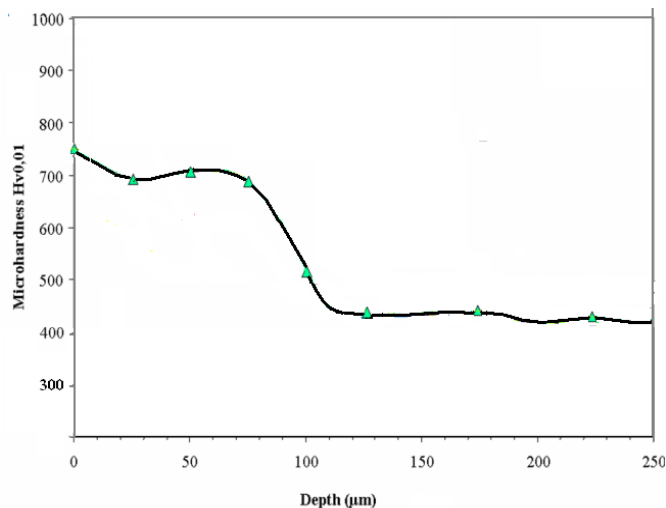


**Fig. 1** SEM micrograph of 42CrMo4 steel surface after plasma nitriding for 4 h at 500 °C in as mixture 20 % H<sub>2</sub>, 80 % N<sub>2</sub>.

### 3.2 Mechanical properties

#### 3.2.1 Microhardness

**Fig. 2** shows microhardness profile of sample treated at 500 °C for 4 h of treatment time at 80/20 of N<sub>2</sub>-H<sub>2</sub> gas mixture. Microhardness profile obtained from cross-section of treated specimen showed the presence of a slope interface between the case (nitrided layer) and the core. Higher surface hardness values and big depth are obtained at these conditions. These results are in good accordance with those of Krishnaraj et al. [25] who studied the mechanical properties of plasma nitrided steel. Priest and al. [26] studied the effect of hydrogen in the case of nitriding to low pressure of steels they showed that hydrogen have an effect on the diffusion of nitrogen. The surface hardness of 42CrMo4 steel was increased up to two times by the plasma nitriding process, as expressed as [27].



**Fig. 2** Course of the microhardness according to the depth

### 3.2.2 Tribological behavior

In this study, the friction reduction and anti-wear properties on the untreated surface were compared with those on the nitrided surface. The friction coefficients measured against a 100C6 steel ball are shown in **Fig. 3a** for the plasma nitrided specimen and untreated one. It was observed in each case that the friction coefficient increased to a steady value during the test time. The steady values of the friction coefficient are approximately between 0.5 for the nitrided sample and 0.7 for the untreated one indicates that the presence of a compound layer with very good friction characteristics caused even lower values of the friction coefficient.

The calculation of wear rate, using the Archard equation (Eq. 1) is given in **Table 1**.

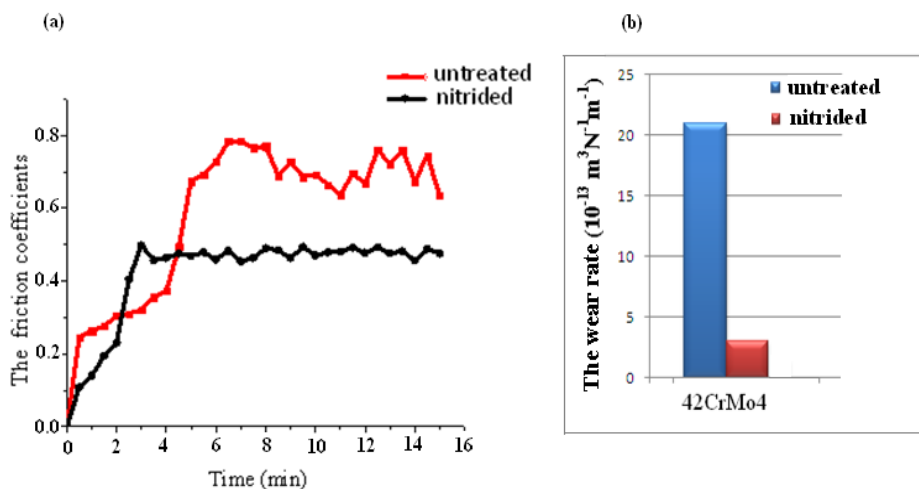
The plasma nitrided steel presents the lowest wear rates (**Fig. 3b**). This behavior could be explained by the hardness of the materials which is 750 HV at the surface. The increase in wear rate is inversely proportional to the decrease in hardness values towards the core.

The presence of a hard and brittle compound layer on the surface caused an increase in the wear of specimen surface due to the fracture of the compound layer with high stress and formation of hard, abrasive particles in the initial stage of sliding.

It can be seen that the prevailing wear mechanism is adhesive wear, which is found for all nitrided specimens. However, the presence of a compound layer causes the appearance of an abrasion wear component because the compound layer breaks down during sliding and forms hard, abrasive particles (**Fig. 4b**). Steel studied has undergone plastic deformation (shear asperities), causing abrasive wear also verified by other authors [28, 29].

**Table 1** Wear rate for untreated and nitrided sample

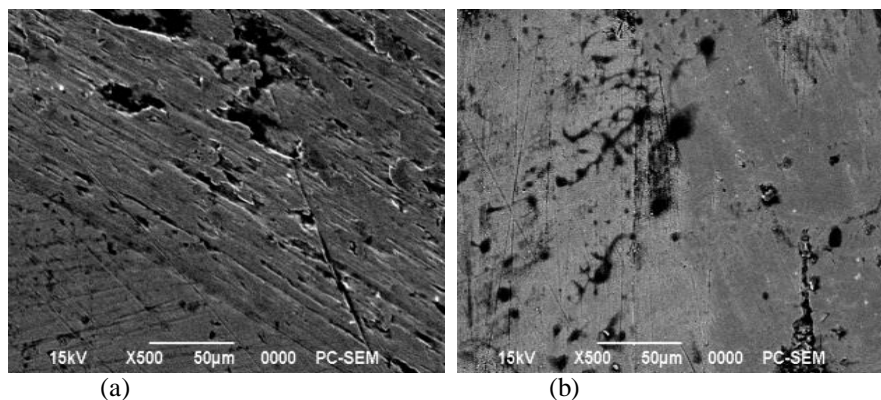
	Untreated	nitrided
wear rate ( $10^{-13} \text{ m}^3 \text{ N}^{-1} \text{ m}^{-1}$ )	21	3



**Fig. 3** a) Friction coefficient patterns and b) Wear rate constant of 42CrMo4 of the untreated and nitrided sample

**Fig. 4a** illustrates the wear track without the compound layer. **Fig. 4b** shows a wear track with a compound layer. In the initial period of sliding, the brittle compound layer with high stress fractured and then transformed abrasive particles. Higher magnification reveals that this layer

initially cracked and then broke into pieces. The wear track is shallower, uniformly stretched along the specimen surface compared to the treated sample and the wear debris is not observed besides the wear track.



**Fig. 4** The SEM morphologies of wear track of: (a) untreated sample, (b) nitrided sample.

#### 4 Conclusions

In this work, it was shown that nitriding treatment applied to carbon steel enriched in chromium is adapted in order to improve the tribological properties of the 42CrMo4 steel. It has been shown that both of the nitrides  $\epsilon$ -Fe<sub>2-3</sub>N and  $\gamma'$ -Fe<sub>4</sub>N are formed after nitriding in optimal plasma treatment conditions (temperature 500 °C, time of treatment 4 h and gas in the mixture 20% H<sub>2</sub> - 80% N<sub>2</sub>). The compound layer increases the wear resistance of steel because the presence of a hard and brittle compound layer on the surface which is due to the fracture of the compound layer with high stress and hard, abrasive particle formation in the initial stage of sliding. However, the wear rate was reduced in the cases that do not include a compound layer.

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