RESEARCHES ON THE TRIBOLOGICAL BEHAVIOR OF A NON-CONVENTIONAL TREATED STEEL

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Abstract

This paper aim to be considered a review of the own researches realized in the non-conventional treatments domain in the magnetic field. The magnetic field applied under certain conditions, during the cooling process of the steel samples in the case of the improvement treatments, modifies the mechanical properties of the steel.

It is important to take in consideration the improvement of the mechanical properties of a Cr-Mo alloyed steel used for the construction of the industrial machines parts. In this case, the influence of the magnetic field applied during the improvement treatment on the mechanical properties was considered. A thermo-chemical treatment in plasma completed the treatment program. The structural changes in the superficial layers during the treatment determine the improvement of the mechanical properties of the steel tested during the wear process.

The tribo-models behavior during the dry friction processes was analyzed. This study determines the wear intensity for a certain type of tribo-model and for a certain type of material. An Amsler stand was used for all wear tests. The rollers with different diameters were used in order to obtain different sliding degrees (ξ) and two distinct values of task of loading (Q) were considered.

Keywords: Steel, non-conventional treatment, wear process, mechanical properties.

1. INTRODUCTION

Until 1932, Minkievici, Tarasov, Erahtin, Stark and Zaimovski [1,2] Roentgenographically studied the behavior of the alloyed steels Cr-Mo and they demonstrated that the best magnetic properties of these materials have been obtained as a consequence of their variable structure appeared in the initial level of the atomic ordering processes.

In terms of obtaining a hard magnetic material, the phase transformations can be divided in three groups: the martensitic transformation of the steels, a decomposition of the solid solution and phenomena of the atomic ordering in alloys.

As a consequence of the martensitic transformation of the steel during the heat treatment, the case of the magnetic materials to which the nature of coercive force is explained by internal inhomogeneous tensions and inclusions, can be obtained [1]. To create a stabile magnetic texture, the cooling of the steel samples in magnetic field was adopted as a part of experimental program [2].

The thermo-magnetic effects appear in steels, metals and semiconductors when a magnetic field and a temperature gradient act on these materials and they consist of an existence of a potential difference or, an existence of a temperature difference when the system is crossed by a thermal flow in a magnetic field presence. In the first case, for a potential difference, the effect was called Nernst - Ettingshausen and can be longitudinal or transversal. In the second case, when a temperature difference appears, the effect was called Maggi - Righi - Leduc, longitudinal or transversal, and consists in a temperature difference appearances (ΔT) simultaneously with the thermal flow which cross longitudinal respectively, transversal the system in the presence of the magnetic field (transversal or longitudinal applied) [1,2].

A change of the transformation temperature, in applied magnetic field conditions, occurs if one of the phases is ferromagnetic and a spontaneous magnetization takes place. For example, in the case of the steel, during the martensitic transformation, the Austenite (A) is a paramagnetic phase and the Martensite (M) is a ferromagnetic phase. Experimental was demonstrated [2,3] that the movement of the transformation temperature of the phases depends linear by the intensity of the magnetic field applied during the treatment, in cooling process.

In the case of thermo-magnetic treatment of the steel, Magnetostriction appears and realizes mechanical oscillations which modify the germination speed. The Martensite strips that appear will be oriented along the magnetic field lines and a new texture realized by the magnetic field will appear. The magnetic field applied during the cooling process for the improvement treatment increases the transformation speed. In this case, a finesse of the structure appears and the hardness increases because the quantity of the Martensite (M) increases too, as a consequence of the increasing of the germination speed [1,3,12]. In this paper, a thermo-chemical treatment applied after a thermo-magnetic treatment improves the mechanical characteristics of the superficial layers of the steel considered.

2. MATERIALS AND EXPERIMENT

Nitriding for steels is a thermo-chemical treatment widely employed in the machine components production and metallurgical industry to mitigate any wear or corrosion process and other fatigue damage in these materials. The consequences of this treatment are strongly influenced by many different variables such as: the steel composition, the potential of nitrogen, the temperature (for this case, 530 ˚C) and duration [2,4]. In this study, the influence of such parameters which affect the nitrided layers' thickness and the composition of these layers were assessed.

The superficial layer (the white layer) of a nitrided steel depending on the nitriding duration and consists of the nitrides: ε - phase with variable composition of carbon and nitrogen, depending on the steel grade or the atmosphere type and unstable [8], or γ' - phase (Fe_4N), which depends on the atmosphere and the steel grade [5,6,9,13].

Tribological properties during friction are determined by the compound layer (the white layer). Under the compound layer exists a diffusion area, which reaches deeper into the material, until approximately 0.1 - 0.5 mm. In the case of the wear dry tests the Normal Load (Q) bearing capacity and fatigue strength are largely determined by the micro-hardness (Vickers) and by the depth of the diffusion area, which can be observed by analyzing the microstructural aspects of the steel.

For the experimental program, the samples (rollers) from a steel grade for improvement treatment for machine parts construction have been considered. This material has the following principal content: 0.42 % C, 0.02% Al, **1.02** % Cr, 0.17 % Mo, 0.68 % Mn, 0.22 % Cu, 0.33 % Si, 0.26 % Ni, 0.030 % P, 0.026 % S. The existence of the Molybdenum content in the composition of the steel decreases the stiffening phenomenon.

The first stage from the complex program of treatments consisted of thermo-magnetic treatments. The treatment t1 represents a hardening treatment (at 850 °C) followed by a high tempering (at 580 °C), being a classic improvement treatment. The other treatment, t3, represents a hardening treatment at 850 °C with a cooling in water in strong alternative current (A.C.) in magnetic field followed by a high tempering process at 580 °C (with the cooling in water in strong A.C. in magnetic field). The treatment t4 represents a hardening process at 850 °C (with a cooling in water, in direct current of magnetic field) followed by a high tempering process (with cooling in water, in D.C. of magnetic field) [2], t3 and t4 being two non-conventional treatments.

The second stage from the complex program of treatments consists in applying the thermo-chemical treatment: a plasma (ionic) nitriding at 530 °C (7h), after thermo-magnetic treatment, applied at the different samples from the same steel grade considered or, laser nitriding with some special parameters. The treatments were considered, such as: Tca = T3 = t3 + plasma nitriding; Tcc = T4 = t4 + plasma nitriding; T1 = Tclassic1 = t1 +

plasma nitriding; T5 = Tclassic2 = t1 + laser nitriding; T7 = t3 + laser nitriding; T8 = t4 + laser nitriding; T2 = t2 + plasma nitriding. The treatment t2 represents a complete martensitic hardening process in weak alternative magnetic field (cooling in water) and high recovery process (just cooling in water, in strong Alternative current (A.C.) of magnetic field with H = 1300 A/m). In this case, the sample was introduced in the centre of the electrical coil located in the walls of a cylindrical oven.

The wear tests have been made using an Amsler machine, with couples roller on roller, taking two sliding degrees ($\xi 1$ = 10 % and $\xi 2$ = 20 %), and the measurements were made at each hour. The normal load had the following values: Q1 = 75 daN or Q2 = 150 daN. The Moment of friction was Mf = 45 daN·mm^2, corresponding to Q2. After each hour of wear test, the external diameter was measured and the diffractometric aspects were studied with Dron 3 equipment. The wear resistance of the rollers through dry friction and the surface structure evolution for different parameters of testing regimes were determined.

3. RESULTS AND DISCUSSION

The wear tests, through a dry friction process, have been made using several couples of rollers in contact. Each couple corresponds to a different sliding degree (ξ) which was defined as the relation [2,6,8,11]:

$$\xi = \left(1 - \frac{\nu 2}{\nu 1}\right) . 100, \ (\%) \tag{1}$$

In this case, v_1 and v_2 are the peripheral velocities of the rollers in contact. The rollers had the width (b) by 10 mm [2,6,7], the linear contact having 10 mm. Each case has a specific combination of angular speeds (n_1, n_2) according to the diameter sizes (d_1, d_2). The results were presented in **Table 1** [2].

Table 1 Results obtained after three hours of wear tests

Treatment Code	Sliding degree ξ (%)	Normal load Q (daN)	Mass loss M(g)	Thickness layer loss Uh (mm)	The wear intensity Iu x 10 $^{-4}$ (g/m)	Δt(h)
T1	10	75	0.025		5.890	1
			0.035		4.420	2
			0.030	0.100	4.420	3
T2			0.020		2.950	1
			0.020		1.470	2
			0.025	0.040	1.470	3
T1		150	0.035		5.880	1
			0.040		5.890	2
			0.040	0.120	5.890	3
T2			0.035		4.410	1
			0.025		4.420	2
			0.030	0.090	4.420	3
T1	20		0.040		5.890	1
			0.055		6.700	2
			0.050	0.145	6.040	3
T4			0.040		4.885	1
			0.040		4.885	2
			0.050	0.130	4.885	3
T3			0.030		4.420	1
			0.035		3.680	2
			0.025	0.095	3.680	3
T5			0.045		5.890	1
			0.040		5.160	2
			0.040	0.110	5.160	3
T7			0.040		5.160	1
			0.035		4.420	2
			0.035	0.095	4.420	3
T8			0.030		3.680	1
			0.035		3.680	2
			0.035	0.040	4.420	3

The mass loss evolution and the wear intensity versus time testing, in the case of the classic treatment (T1) and in the case of the non-conventional treatments, have been represented in the following figures:

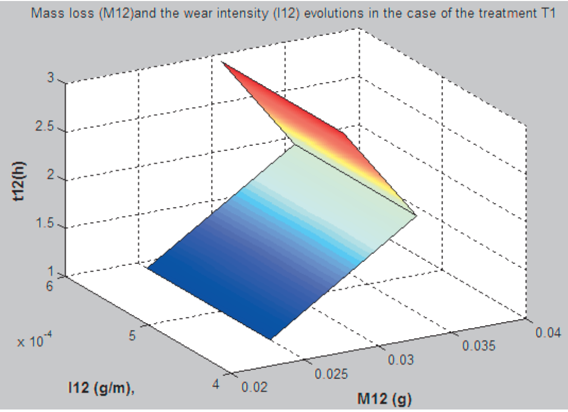

Figure 1 Mass loss (M12) and the wear intensity (I12 x 10^{-4}) evolutions in the case of the treatment T1 (classic), for Q = 75 daN, ξ = 10 %

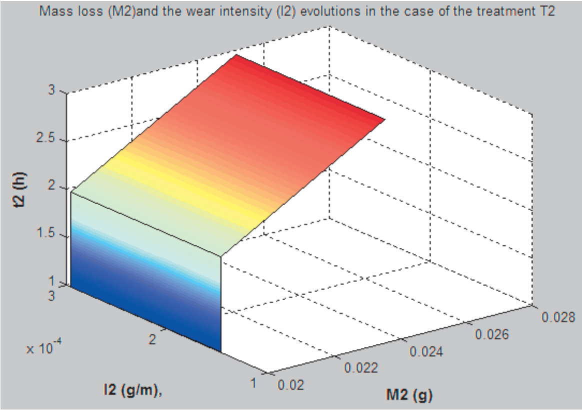

Figure 2 Mass loss (M2) and the wear intensity (I2 x 10 $^{-4}$) evolutions, in the case of the non-conventional treatment T2, for Q = 75 daN and ξ = 10 %

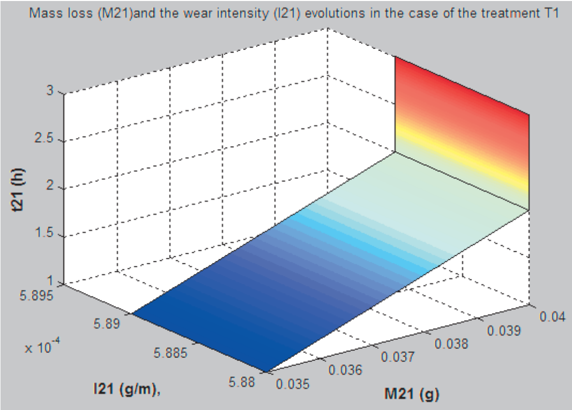

Figure 3 Mass loss (M21) and the wear intensity (I21 x 10 $^{-4}$) evolutions, in the case of the treatment T1, for Q = 150 daN and ξ = 10 %

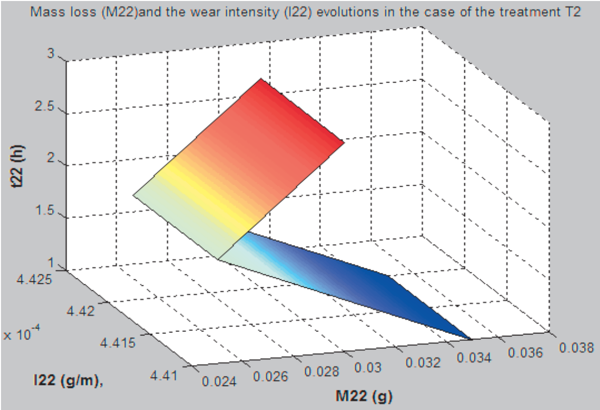

Figure 4 Mass loss (M22) and the wear intensity (I22 x 10 $^{-4}$) evolutions, in the case of a non-conventional treatment T2, for Q = 150 daN and ξ = 10 %

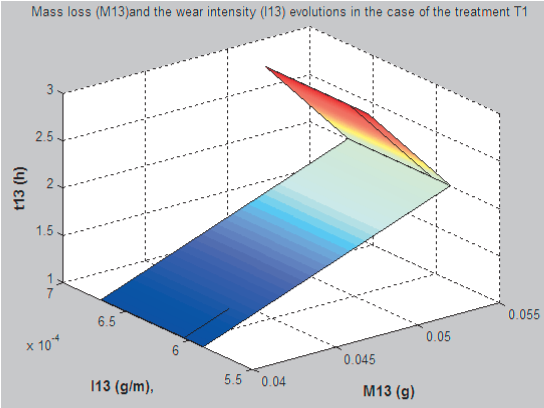

Figure 5 Mass loss (M13) and the wear intensity (I13 x 10 $^{-4}$) evolutions, in the case of the treatment T1, for Q = 150 daN and ξ = 20 %

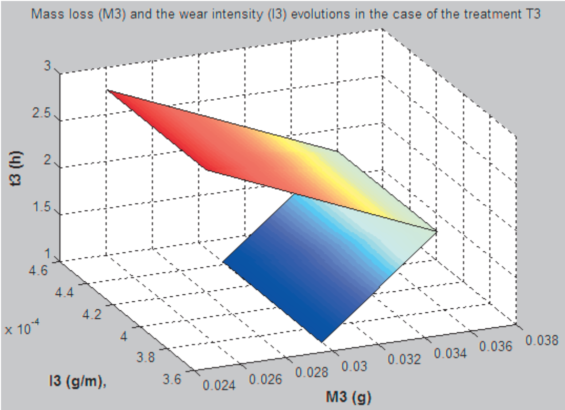

Figure 6 Mass loss (M3) and the wear intensity (I3 x 10 $^{-4}$) evolutions, in the case of a non-conventional treatment T3, for Q = 150 daN and ξ = 20 %

In **Figure 7** was represented the evolution of the worn-out layer depth, after three hours of wear tests, depending by treatments.

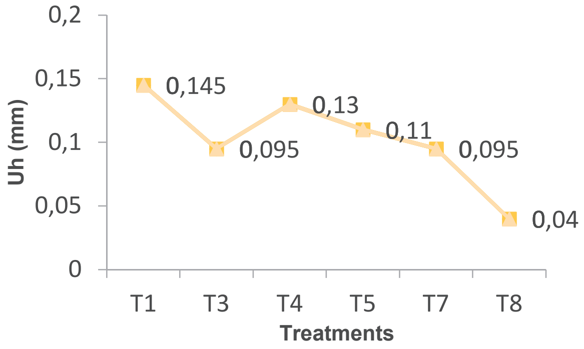

Figure 7 The worn-out layer depth evolution, after three hours of wear tests, corresponding to different treatments, in the following wear conditions: ξ = 20 %, Q = 150 daN

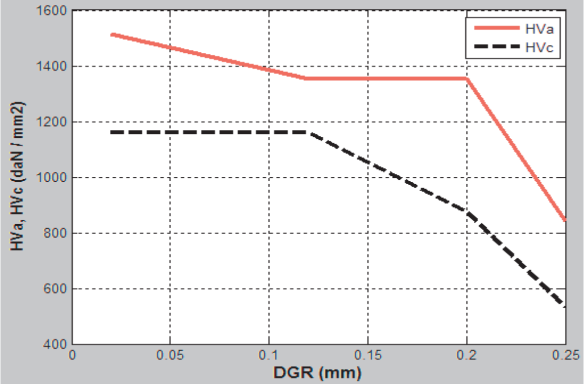

Figure 8 The micro-hardness versus the thickness of the superficial layer (DGR).

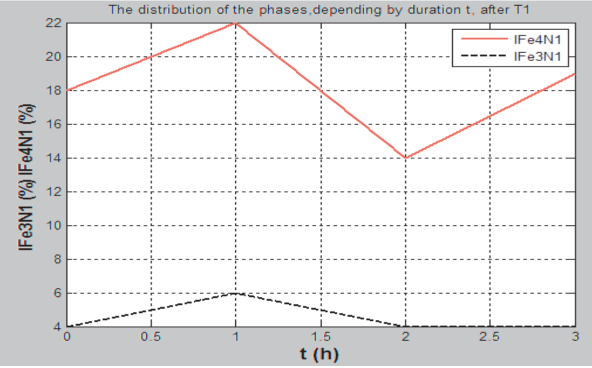

Figure 9 Distribution of the phases on superficial layer, depending on the wear tests duration, for samples treated with T1, tested for Q = 75 daN and ξ = 10 %.

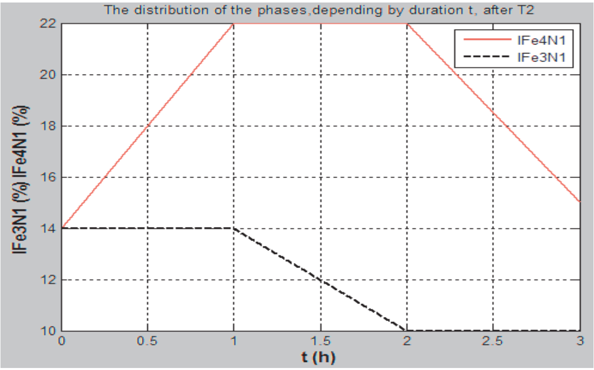

Figure 10 Distribution of the phases on superficial layer, depending on the wear tests duration, for T2 treated samples, tested for Q = 75 daN, ξ = 10 %.

In **Figure 8**, some notes must be mentioned: HVa represents Vickers micro-hardness of the superficial layer in the case of the treatment T3 (A.C.in magnetic field) and HVc represents the Vickers micro-hardness of the superficial layer in the case of the treatment T4 (D.C. in magnetic field). Thermo-magnetic treatments, particularly for alternative current applied before thermo-chemical treatments, produce the increasing of the micro-hardness of the superficial layers, more than in the classic treatment (T1) case. Comparing the **Figures 9** and **10**, it can be observed that the quantity of the Fe_4N phase is the biggest in the case of the non-conventional treatment in magnetic field - Alternative Current (see T2 case).This Fe_4N phase has an oscillated variation of the quantity (see the red diagrams) after every hour of the wear tests. Fe_4N phase has the role to increases the wear resistance [2, 10]. So, in the case of the non-conventional treatment (T2), the resistance of the superficial layers during the wear process is the biggest, comparing with the classic treatment case (T1). After three hours of friction process, the quantity of the Fe_3N phase in the superficial layers decreases more in the case of the non-conventional treatment. It is known that this phase causes the fatigue of the superficial layer and it’s possible to appear cracks. In the **Figure 10**, this phase Fe_3N has a quantity descending. This fact appears due to increase the durability of the superficial layers non-conventional treated in Alternative Current (A.C.) in magnetic field.

4. CONCLUSION

Analyzing the results presented above, the thermo-magnetic treatments - particularly corresponding to magnetic field alternative current (A.C.) applied before the thermo-chemically treatment - modify the mechanical properties of the steel on positively direction. The micro-hardness of the steel increased, the worn - out layer depth (Uh) decreased, the quantities and the distribution of the phases (Fe_4N and Fe_3N) have been modified such that the durability of the steel subjected to a dry wear process, increased.

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