THE INFLUENCE OF THE NONCONVENTIONAL TREATMENT IN MAGNETIC FIELD ON THE SUPERFICIAL LAYER TREATED IN PLASMA

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Abstract

The paper wants to be a review of the own researches realized in the nonconventional treatments domain, corresponding to the magnetic field treatments applied to a steel of construction for industrial parts, for gears and some parts of industrial machines. The magnetic field applied under certain conditions during the cooling process of the sample in the case of the improvement treatments, modifies the properties of steel, the hardness, the corrosion resistance and the wear resistance increase.

The studies on tribomodels during the dry friction processes determine the wear intensity for a certain type of tribomodel and for a certain type of material. An Amsler stand was used. The experimental study uses two distinct values of task of loading (Q). The rollers with different diameters were used in order to obtain different sliding degrees (ξ). The Diffractometric aspects have completed this study.

A thermo-chemical treatment in plasma with diffusion applied at a temperature under the temperature of the thermo-magnetic treatment leads at high wear resistance and better characteristics of the superficial layers of the steel.

Keywords: Steel, thermo-magnetic treatment, wear process

1. INTRODUCTION

Between the years 1920-1930, Herbert E. showed that when it is used a constant magnetic field intensity, the hardness of the steels increases. The energy of the magnetic field may intervene in the balance of the global power of the phase transformations in solid state altering the thermodynamics, kinetics and the mechanisms, the structures and some properties of the steels.

The magnetic field leads to a decrease of the residual austenite content (Arez) during the annealing/hardening treatment of the tool steels, according to the literature [1, 2, 4]. For example, it was calculated that 30% Arez in a hardened steel that it contains 1.1% C and 8% Ni, is transformed by returning to 360 ˚C in 30 minutes, while the same steel, the same amount of the residual austenite was transformed by the treatment in magnetic field by returning to 360 ˚C in 24 minutes.

Experimentally it was found that the magnetic field reduces the cooling capacity of the quenching medium , being reduced its influence over oil and water cooling during the treatments, while the aqueous salt solutions accentuates the action of the magnetic field.

When the transformation was produced in a magnetic field with a H intensity and the induction I, the thermodynamically calculus shows that the temperature of the transformation - to which attends a magnetic phase - it „moves” with the following value [1]:

$$\Delta T = (T_0 - T_{TR}) \tag{1}$$

It was considered that the temperature of equilibrum is T_0 and the temperature of transformation (A1, M_S,..) is T_{TR}. The variation of the thermodinamically potential of two phases represents the motric force of the transformation (ΔG). In the case of the martensitic transformation, this diferences of the temperature ΔT corresponds of the modification of the temperature Ms with ΔT. This fact influences the transformation A(γ)→M(α) through the variation of the temperature M_S and decreasing the residual Austenite quantity [1, 2].

The cooling in magnetic field during thermo-magnetic treatment regimes modifies the characteristics of the steel, comparing with the classic treatment results [2, 3, 4].

From the literature [2, 3, 4, 5] experimental was found that a large number of steels for bearings (RUL1, RUL2) and tools (CSOs and Rp sites) have an increased durability, a better resistance of corrosion and an increased resistance at dry friction caused by the increasing of the hardness and the decreasing of the amount of the lost material (mass loss) in dry friction process as a consequence of the magnetic field applied during the improvement heat treatment of the steels.

Starting from the fact that the authors and researchers have not addressed the application of the thermo-chemical diffusion treatment after the thermo-magnetic treatment, the research novelty consists precisely in applying of the plasma nitridation (nitriding) after the thermo-magnetic treatment. This nonconventional treatment modifies the characteristics of the resistance of the steel, the hardness and the plasticity of the steels.

The novelty of this study is to apply a thermo-chemical treatment with diffusion (for example, plasma nitriding) at the temperature under the temperature of the thermo-magnetic treatment. Thus leads at high wear resistance, to the improvement steel. These researches were started in the doctoral thesis [6]. This thesis was finalized years ago but the researches continue.

There were considered different thermo-magnetic treatments as improvement treatments with cooling in water in magnetic field applied before ionic nitriding treatment (plasma nitriding) at 530 ° C. This temperature of the thermo-chemical treatment was considered at 530 ° C, being specific for this kind of the improvement steel. The influence of such parameters affecting the nitrided layers' thickness, for example: the hardness, the composition and the residual stress were evaluated. In the Literature, taking into account the nitriding process, at all temperature below 510˚C - 520˚C substantial quantity of the "S-phase" as found to be present, especially in the case of the austenitic stainless steel [2, 10]. In case of the low temperature (100˚C - 510˚C), plasma nitriding produces the expanded austenite (the S-phase) with good behavior at friction. Phase γ (Fe_4N) appears at the higher temperatures than 500˚C and reduces the thickness of the S-phase.

The magnetic field modifies the residual stresses which were obtained by treatment of hardening/tempering. This process depends by the content of the carbon from the structure of the steel. In all the cases, the cooling in magnetic field has been made during the improvement treatment of these steels, the residual stresses by hardening decreases, the residual austenite quantity decreases too and -as a result- the magnetic field has positive effect on the mechanical properties because the hardness of the steels and the wear resistance increase, both of them.

The magnetic field causes the magnetostriction which produces tensions in solid solution microvolumes. Magnetostriction is a dimensional variation of ferrous-magnetic materials under the action of a magnetic field, also called Joule effect, which depends on the size and direction of the external magnetic field, the material and the heat treatment applied to steel [2, 3, 6, 9]. The effect of the magnetostriction consists in local plastic deformations and this effect decreases with the increases of the temperatures and disappears at the Curie temperature. The mechanical oscillations produced by the alternative current in magnetic fields change the re-crystallization conditions, especially the germination velocity.

2. MATERIALS AND EXPERIMENT

For the experimental program, were considered the samples (rollers) from a steel grade of improvement for a machine part construction. 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, 0.32 %Ni, 0.03 % P, *0.026* % S. The existence of the

Molybdenum content in the composition of the steel decreases the stiffening phenomenon. The outer diameter of the rollers has 40 mm, the inner diameter of the rollers has 16 mm and the width b = 10 mm.

The first stage from the complex program of treatments consists in thermo-magnetic treatments.

The treatment t1 represents a Martensitic hardening process (at 850 °C) and a high recovery process (at 580°C), corresponding to a classic treatment of improvement.

The treatment t2 represents a complete martensitic hardening process in a weak alternative magnetic field (cooling in water) and a high recovery process with cooling in water, in strong Alternative current (A.C.) of magnetic field. In this case, the samples were introduced in the centre of the electrical coil which was located in the walls of a cylindrical oven. The samples were introduced in the centre of the coil.

The other treatment, t3, represents a hardening process (just cooling in water in strong alternative current (A.C.) of magnetic field) and a high tempering process (just the cooling in water in strong A.C. magnetic field). The treatment t4 represents a hardening process (just cooling in water, in direct current of magnetic field) and high tempering process (just cooling in water, in D.C. magnetic field).

The samples were cooled in a special recipient "closing" the magnetic field lines.

The second stage from the complex program of the treatments consists in applying the thermo-chemical treatment: a plasma (ion) nitriding at 530 °C, after thermo-magnetic treatment. The treatments were noted: Tca = T3 = t3 + plasma nitriding; Tcc = T4 = t4 + plasma nitriding; T1 = Tclassic = t1 + plasma nitriding; T2 = Tx = t2 + plasma nitriding.

Micro-hardness (Vickers) values were measured on the treated surface layer obtained through thermo-chemical treatment regimes shown above. Were performed a minimum eight determinations for each case.

The wear tests (through a dry friction process) were carried out on an Amsler machine [10], using several couples of rollers, each couple corresponding to different sliding degrees (ξ), defined as the following relation [5, 8, 10, 11]:

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

In this case, v_1 and v_2 are the peripheral velocities of the rollers in contact, each one having their specific peripheral velocity. For this kind of tests there were used rings (rollers) with the width (b) 10 mm [6, 10,11]. Each case has a particular combination of angular speeds (n_1, n_2) according to diameter sizes (d_1, d_2). Index 1 or 2 are added for the roller 1 or 2, respectively, both of the same tested friction couple. For instance, theoretically, ξ=*10 %* corresponds to a pair of tested rollers having the outer diameter of conducting roller d_1= 40 mm, for n_1=180 rpm and the outer diameter of the second roller d_2= 40 mm (k = 0.90) and ξ=*20 %* corresponds to a pair of tested rollers having d_1= 44 mm, n_1=180 rpm and d_2= 40 mm (k = 0.90). It were determined the durability of the rollers and the surface structure evolution for different parameters of testing regimes. Every test of wear/friction had a duration by three hours, for each task loading value [6, 8, 10].

Experimental program continues with diffractometrical aspects of the superficial layer during three hours of wear tests. Diffractometric test was realized using a Dron 3 from the Laboratory of *Dunarea de Jos* University, Galati, Romania.

3. RESULTS AND DISCUSSION

After plasma nitriding the white superficial layers had higher depths in the case of thermomagnetic treatment.

In **Figure 1** was represented the evolution of the hardness v.s. the applied basic treatments.The magnetic field influences (increases) the hardness of the steel. In **Figure 2** was presented the evolution of the micro-hardness values (Vickers) in the ion (plasma) nitrided layer, depending on the treatments, at 0.25 mm distance from the surface of the samples, in depth of the samples (of the leading rollers of wear). In **Figures 3, 4** and **5** the microhardness values after the treatments T1, T2, T3 and T4 were noted with HV1, HV2, HVca respectivelly, HVcc.

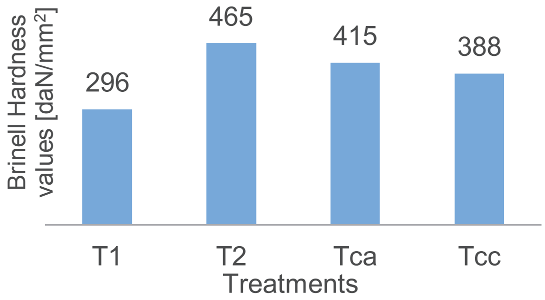

Figure 1 The hardness values after the basic treatments applied before the thermo-chemical treatment.

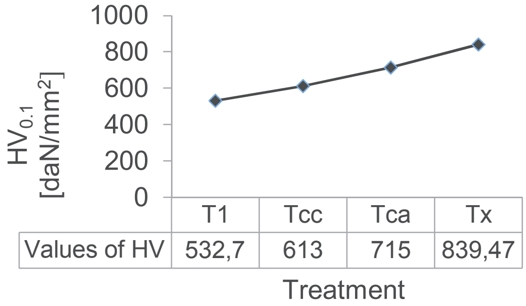

Figure 2 The evolution of the micro-hardness values in the ion nitrided layer, depending on the treatments, at 0.25 mm distance from the surface of the samples

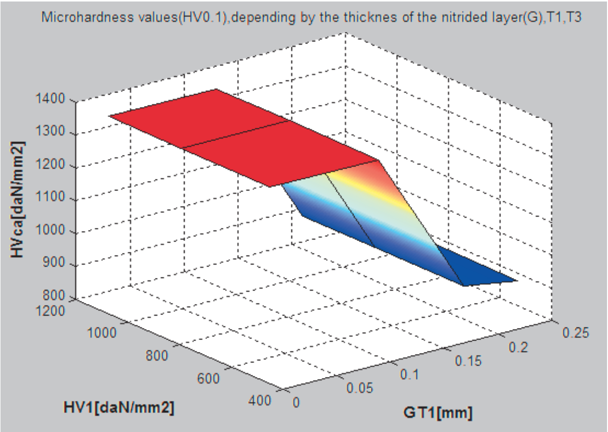

Figure 3 Microhardness values after the treatments T1 and T3 v.s. the thickness of the nitrided layer (GT1), before the wear tests.

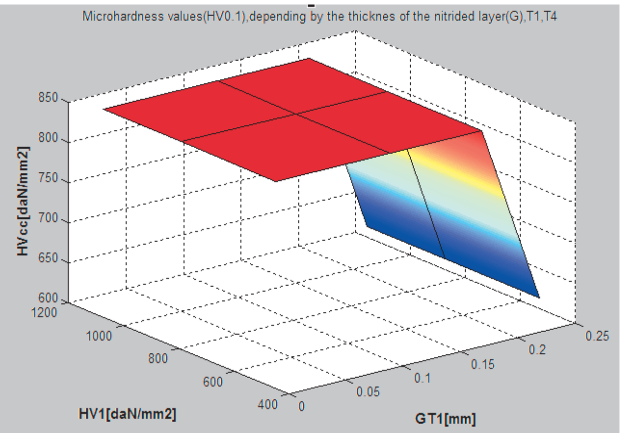

Figure 4 Microhardness values after the treatments T1 and T4 v.s. the thickness of the nitrided layer (GT1), before the wear tests.

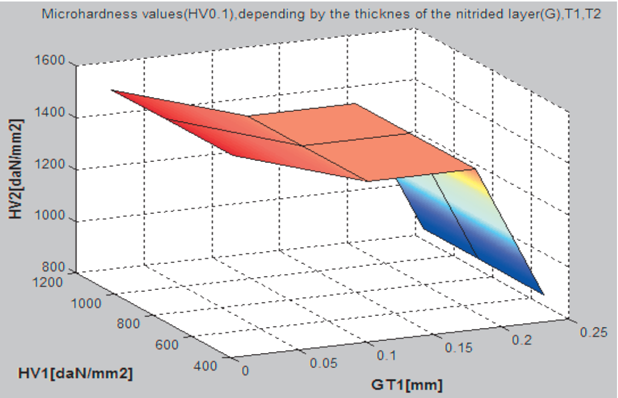

Figure 5 Microhardness values after the treatments T1 and T2 v.s. the thickness of the nitrided layer (GT1), before the wear tests.

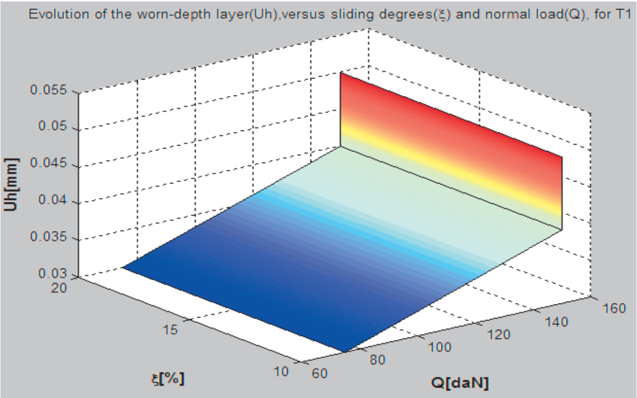

Figure 6 The evolution of the worn-out layer depth (Uh) v. s. the sliding degrees (ξ= 10 % or 20%) and normal load (Q= 75 daN or 150 daN), for the treatment T1, after two hours of wear tests.

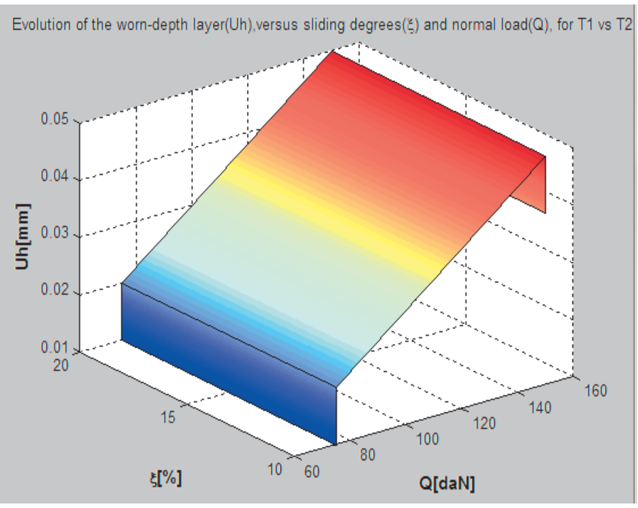

Figure 7 The evolution of the worn-out layer depth (Uh) v.s. the sliding degrees (ξ= 20 % or 10%) and normal load (Q= 150 daN or 75 daN), for the treatments T1 v.s. T2, after 2 hours of wear tests .

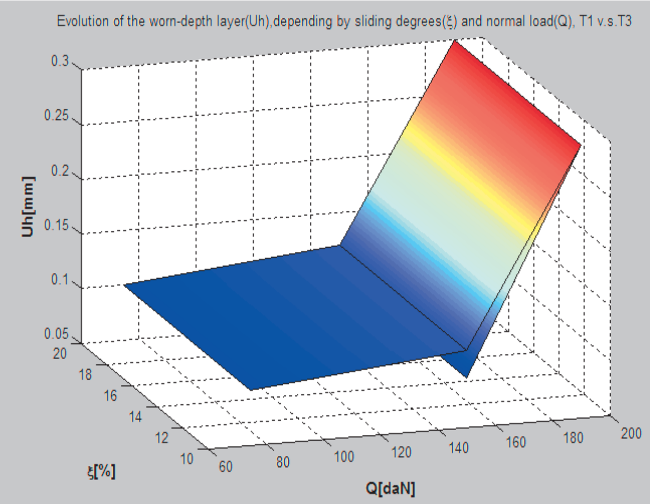

Figure 8 The evolution of the worn-out layer depth (Uh) v.s. sliding degrees (ξ) and normal load (Q), T1 v.s.T3, after two hours of wear tests.

In the case of the thermo-magnetic treatment (A.C. Magnetic field, T3 = Tca) followed by plasma nitriding, the superficial nitrided layer had a higher value of the hardness. In **Figures 6 - 8,** were represented the evolution of the worn-out layer depth (Uh) after two hours of dry wear tests v.s. the sliding degrees (ξ) and normal load (Q), depending by the treatments.

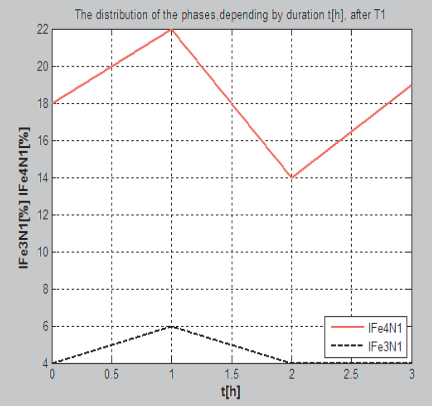

Figure 9 Evolution of the phases distribution in the nitrided layer, after T1, depending by the wear duration, Q=75 daN, ξ=10%.

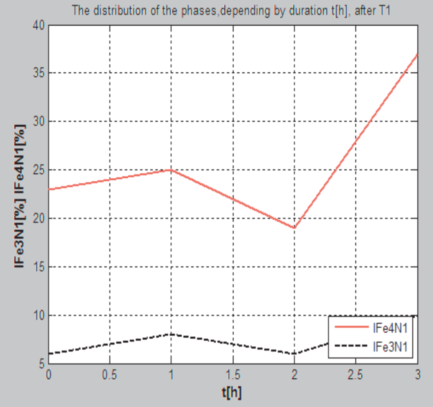

Figure 10 Evolution of the phases distribution in the nitrided layer, after T1 depending by the wear duration, Q=150 daN, ξ=10%.

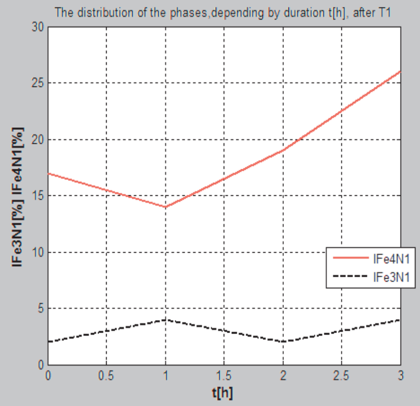

Figure 11 Evolution of the phases distribution in the nitrided layer, depending by the wear duration, Q=150 daN, ξ=20% (after T1).

From diffractometry point of view, in **Figures 9 - 14** were represented the evolution of the distribution of the phases depending by the wear duration corresponding to different normal load values and the evolution of the tetrahedral degree of martensite (B211) in the superficial layer, for every case.

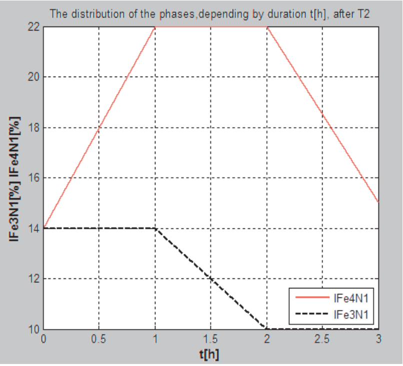

Figure 12 Evolution of the phases distribution in the nitrided layer, depending by the wear duration,in the case of Q=75 daN, ξ=20% (after T2).

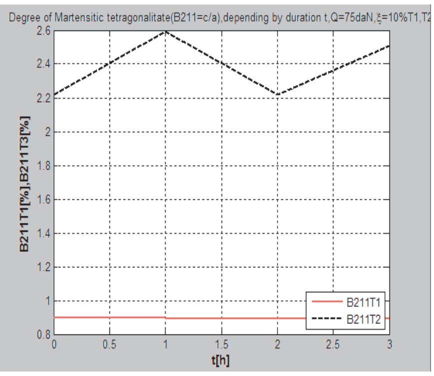

Figure 13 Evolution of the tetrahedral degree of martensite,in the case of T1 v.s. T2, ξ=10%, after three hours of wear tests, Q = 75 daN

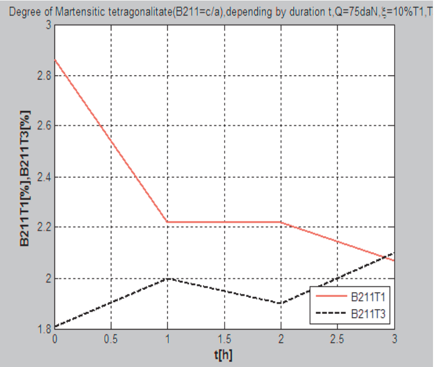

Figure 14 Evolution of the tetrahedral degree of martensite,in the case of T1 v.s. T3, ξ=20%, after three hours of wear tests,
Q = 150 daN

Figure 15 Microstructure after T1, *(x100) Nital Atack 2%*

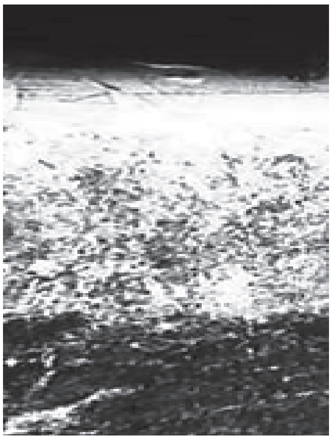

Figure 16 Microstructure after T3, *(x100) Nital Atack 2%*

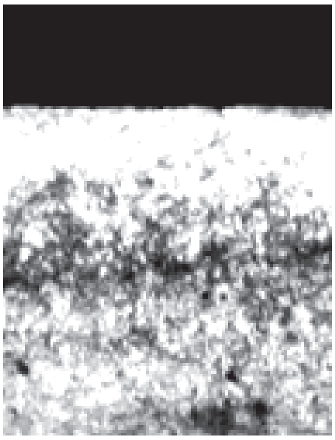

Figure 17 Microstructure after T2, *(x100) Nital Atack 2%*

In **Figure 18** was represented the evolution of the nitrided layers' thickness v.s. the applied treatments.

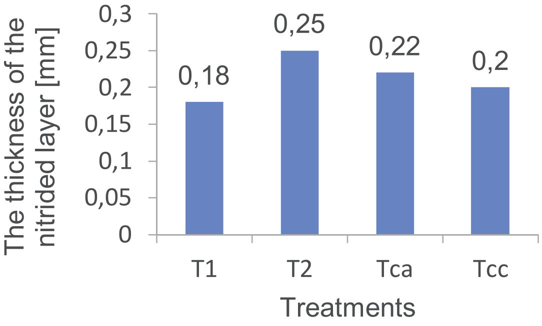

Figure 18 The thickness of the nitrided layer v.s.the applied treatments

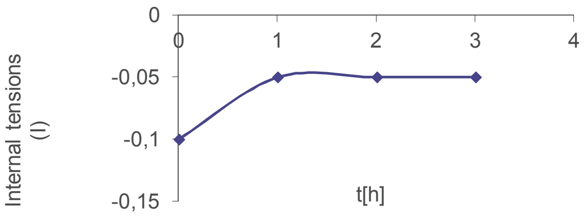

Figure 19 Deviation of the position of the diffraction line (220) corresponding to the first order internal tensions, depending on the duration of wear, after the treatment T2

If the carbon percentage is up to 0.6%, the evolution of the degree of tetragonality (c/a) of the Martensite in the wear process can be controlled by the evolution of the diffraction line.

4. CONCLUSION

Basically, the hardness of the steel increased by approx. 50% for unconventional T2 treatment and approx. 40% for unconventional T3 treatment (alternative current-magnetic field).

After the application of the thermo-chemical treatment, the micro-hardness of the superficial layer increased in the case of application of the magnetic field with approx. 20-30% depending on the treatment regime applied. The thickness of the worn-out layer through friction process has been reduced in the case of unconventional treatment. From the diffractometric point of view, the samples present changes in the content of Fe3N and Fe4N phases in the thermo-chemically treated superficial layer, during the wear process and due to the non-conventional thermo-magnetic treatment applied as a basic treatment.

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