EXPERIMENTAL RESEARCHES REGARDING THE POSSIBILITY TO INCREASE THE DURABILITY OF A CrMo ALLOYED STEEL SUBJECTED TO SOME NON-CONVENTIONAL TREATMENTS, APPLIED IN MAGNETIC FIELD

PAPADATU Carmen-Penelopi, COTEŢ Adrian, VASILESCU Elisabeta, ANDREI Gabriel

Dunarea de Jos University, Galati, Romania, EU, papadatu.carmen@yahoo.com

Abstract

In the last 20 years, the technical progress made it possible the use of very hard materials in several fields like manufacturing parts for the car industry, the pieces for railroad, for nuclear power, in aeronautics and in the mechanical industries.

In this paper, it was studied the evolution of the superficial layer at the steel subjected to a non-conventional treatment, during the wear tests. It is a rundown of the results obtained. The material was subjected to the thermo-chemical treatment (plasma nitro-carburizing treatment, or ion nitriding, or laser nitriding treatment) applied after thermo-magnetic treatment regimes.

The structural aspects of the superficial layers of the steel are studied before the wear process. The wear process was studied using an Amsler type machine, taking two sliding degrees at a constant contact pressures and the testing was done in time. The tests were done to detect the sustainability to the material, the evolution of the superficial layer characteristics through different of wear tests and to establish the influence of these thermo-magnetic treatments regimes.

Keywords: Durability, thermo-magnetic treatments, thermo-chemical treatment, wear process

1. INTRODUCTION

The superficial layer is defined according to the type of the interaction between the external action and materials. This layer - in our case - was obtained after a surface treatment, a thermo-chemical one.

Introducing a surface treatment as nitro-carburizing process or ion (plasma) nitriding (P.N.), or a laser nitriding, it was obtained an increasing of the wear resistance. The resistance of corrosion also increases.

For example, the diffusion process and the interaction of the nitrogen and carbon with the basic material lead to structural constituents whose nature determines a major hardness of the nitro-carburized layer. In this paper was studied the effect of the magnetic field applied before the Ion nitriding or nitro-carburizing treatments. These thermo-chemical treatments modify the grain limit and the resistance of treated material.

For instance, the mechanical properties of the steel -as the wear resistance- can be significantly improved and the hardness of the tool steels can be double on the surface [2].

Before applying a superficial treatment, it is necessary a basic treatment applied to the steel. During this basic treatment (the improved treatment) it is necessary to apply a magnetic field (A.C. or D.C.). Finally, we had the result of a thermo-magnetic treatment (different regimes) applied before thermo-chemically treatments.

In **figure 1** was presented one of the first model of the superficial layer [2, 3].

A magnetic field which is overlapped during the heat treatment, determine the modification of the structure [1] because the energy of the magnetic field which interferes in the global energy balance of the solid stage transformation. This magnetic field changes the transformation mechanisms and kinetics, resulting the thermo-magnetic treatment. In the end, it can obtained the change of mechanical properties and the change of the structure for this material. Adding a surface treatment (for example, a thermo-chemical treatment), determine the increase of the wear resistance and the corrosion resistance. [1].

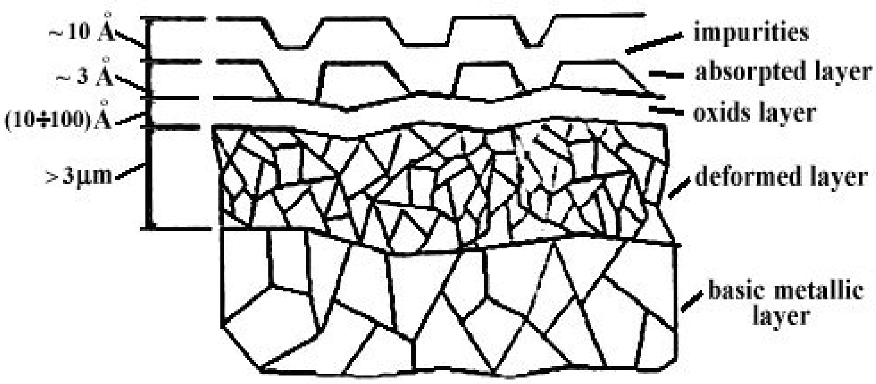

Figure 1 One model for the superficial layer (sourse: J. Caubet)

Magnetostriction determines local oscillations resulting local plastic deformations [1, 4, 6].Magnetostriction determines a reduction of the quantity of the residual austenite. Furthermore, this situation implies a higher hardness of the material and for many applications - good endurance characteristics.

The control of the ion (plasma) nitrided layer using micro-hardness curves, for example, involves the determining of the micro-hardness from the superficial layer on the depth. Following this influence of the magnetic field can be seen the effects of the aluminum (1.18%) and chromium (1.38%) - as alloying elements of the steel - and the influence of the thermo-magnetic treatment on the micro-hardness of the superficial layers obtained through thermo-chemical treatment applied after thermo-magnetic treatments. This influence is determined by the increasing of the thickness of the superficial layer. This superficial layer obtained after unconventional treatment has higher micro-hardness values than the superficial layer classical treated (see **Figure 1**).

In this paper, it was presented a review regarding the advantages and disadvantages between the classic improvement treatment and the treatment realized in magnetic field. It is a rundown of the results obtained in the last years.

2. EXPERIMENTAL PROGRAM

For the experimental program, there have been considered three lots of samples from AISI (SAE) 4038 steel grade. The chemical analysis obtained by atomic absorption primarily revealed a basic composition presented in **Table 1**. The steel analyzed had a max score 4.5 from inclusions and a fine grain (score 8) [2, 6].

The material was subjected to the plasma nitro-carburizing treatment process, or ionic (plasma) nitriding, or laser nitriding treatment, after thermo-magnetic treatment (in D.C. current or in A.C. current).

It is necessary to do a comparison between the classic treatment and the non-conventional one.

Table 1 Chemical composition of the material [2, 6]

Steel grade	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Cu (%)	Mo (%)	Al (%)
AISI(SAE)4038	0.38	0.50	0.25	0.026	0.020	1.38	0.058	0.17	1.18

The tests of wear process through the dry friction are designed to estimate the material resistance. For these tests, it was used an Amsler type machine, taking two degrees of sliding (ξ=10% or, ξ=20%), at a certain contact pressure and the testing was done in time (see **Figure 2**).

The tests were done to detect the evolution of the superficial layer through different wear tests with dry friction. It was established the influence of the tribological factors (operating parameters such as the normal loading Q) on the superficial layers.

Table 2 presents the standard mechanical characteristics of the steel (SAE 4038) [2, 6], corresponding to The Society of Automotive Engineers (SAE) and The American Iron and Steel Institute (AISI).

Table 2 Mechanical characteristics of the steel [2, 6]

Steel grade	$Rp_{0.2}$	R_m	A_5	Z	$KCU_{300/2}$	$KCU_{300/5}$	HB (State of annealing)
	[daN/mm^2]		[%]		[daJ/cm^2]		[daN/mm^2]
AISI(SAE) 4038	85	100	15	50	9	6	229

It were applied the following treatment regimes:

a) a martensitic hardening process at 920°C followed by a treatment of high tempering at 620°C →classic treatment (H =0 A/m), noted with t1

b) a treatment of hardening of steel (at 920°C) followed by a high tempering (at 620°C) applied to steel, cooling being performed in alternative current (a.c.) magnetic field (H = 1300 A/m), noted with t3

c) a treatment of hardening of steel (at 920°C) followed by a high tempering (at 620 °C), cooling being performed in d.c. (direct current) magnetic field, noted with t4

After these basic treatments, one part of the samples of the steel were subjected to a nitro-carburizing process (Tenifer) at 530°C, one part of the samples were subjected to a ion (plasma) nitriding (P.N.) at 530°C and the rest of the samples were subjected to a laser nitriding treatment.

We noted with: T1- a complex classic treatment consisting of the treatment t1 followed by a ion nitriding treatment realized at 530°C; T3 or *Tca* - a complex treatment consisting of the unconventional treatment t3 followed by a ion nitriding treatment realized at 530°C; T4 or *Tcc* - a complex treatment consisting of the unconventional treatment t4 followed by a ion nitriding treatment realized at 530°C.

We noted with: T12 or T1' - a complex classic treatment consisting of the treatment t1 followed by a ionic nitro-carburizing treatment realized at 530°C; T13 - a complex treatment consisting of the unconventional treatment t3 followed by a ion nitro-carburizing treatment realized at 530°C; T14 - a complex treatment consisting of the unconventional treatment t4 followed by a ion nitrocarburizing treatment realized at 530°C.

We noted with: T5' - a complex classic treatment consisting of the treatment t1 followed by a laser nitriding; T7' - a complex treatment consisting of the unconventional treatment t3 followed by a laser nitriding; T8'- a complex treatment consisting of the unconventional treatment t4 followed by a laser nitriding.

The wear tests have been made using an Amsler machine, roller on roller, taking two sliding degrees (ξ= 10% or, 20%), testing in time (3 hours). After each hour of wear tests the external diameter was measured. It were determined the wear resistance of the rollers through dry friction and the surface structure evolution for different parameters of testing regimes. The other factors which influence the wear process are: the contact geometry of the friction couple (roller on roller), the technological parameters (surface quality, heat treatments etc.) and the exploitation conditions (the thermal solicitation, for example).

Wear tests were carried out on an Amsler machine (see **Figure 2**), using several couples of rollers (see **Figure 3**).

Each couple corresponds to different sliding degrees ξ. The contact between roller is *b*=10 mm [6, 8].

Figure 2 Wear tests were carried out on an Amsler machine [6, 8]

Figure 3 Couples of rollers corresponding to different sliding degrees ξ [6], for Amsler machine

The sliding degree (ξ) is defined as [8]:

$$\xi = [(v_1 - v_2) / v_1]\ 100\ [\%], \quad (1)$$

where $v1$ and $v2$ are the peripheral velocities of the rollers in contact, each one having their specific peripheral velocity due to a particular combination of angular speeds (n1, n2) and diameter sizes (d1, d2) [2].

Index 1 or 2 are added for the roller 1 or 2, respectively, both of the same tested friction couple. For instance, ξ=10% is obtained for a pair of tested rollers having d1=40 mm, n1=180 rpm and d2=40 mm, n2=162 rpm; ξ=18% is obtained for a pair of tested rollers having d1=44 mm, n1=180 rpm and d2=40 mm, n2=162 rpm; the level of the stress is corresponding to a specific load of 150 daN (as normal load is *Q*=1.500 N). As we stated above, the Magnetostriction determines a cold hardening of the residual austenite, a higher material hardness and for many applications - good endurance characteristics (see **Figure 4**).

3. RESULTS AND DISCUSSION

In **Figure 4**, was represented the variation of the hardness corresponding with each basic treatment applied [6]. The magnetic field applied influences also the micro-hardness of the steel (see **Figure 5**).

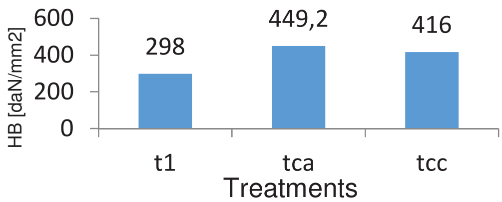

Figure 4 The hardness values, after basic treatment

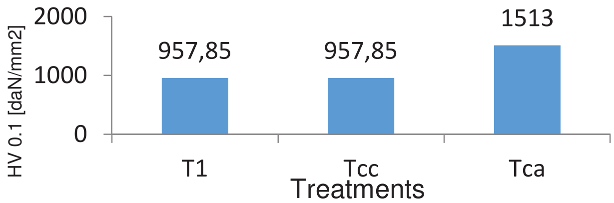

Figure 5 Micro-hardness values in the ion nitrided layer at 0.02 mm distance from the surface of the samples

In **Figure 6**, was presented the influence of the thermo-magnetic treatment on the worn-out layer depth, after 3 hours of wear tests, ξ=20% and Q=150 daN. The thermo-magnetic treatment regimes were applied before thermo-chemical treatment regimes (except the classic treatment T1).

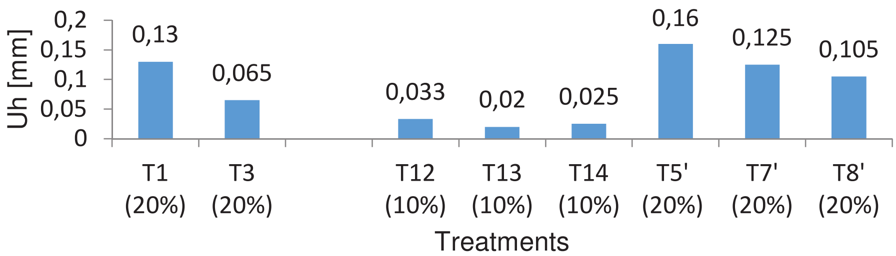

Figure 6 Evolution of the worn-out layer depth (Uh) after three hours of wear tests, for Q=150 daN

The microstructures (see **Figures 7 - 9** [6], and **Figures 10 - 12**) shown that on the case of thermo-magnetic treatments applied before thermo-chemical treatments the thickness of the white superficial layers is higher than in the classic treatment case. The thickness of the superficial layer increases if we apply a thermo-magnetic treatment before the thermo-chemical one [6].

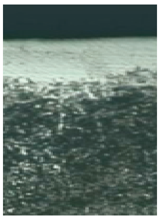

Figure 7 Superficial layer thickness in the case of the treatment T14 (x100). Nital attack 2%

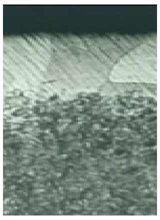

Figure 8 Superficial layer thickness in the case of the treatment T13 (x100). Nital attack 2%

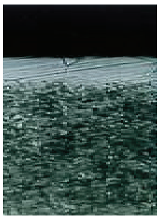

Figure 9 Superficial layer thickness in the case of the treatment T12 (x100). Nital attack 2%

Figure 10 Superficial layer thickness in the case of the treatment T3 (x100). Nital attack 2%

Figure 11 Superficial layer thickness in the case of the treatment T2 (x100).

Figure 12 Superficial layer thickness in the case of the treatment T1 (x200). Nital attack 2%

It was obtained a higher diffusion for thermo-chemical treatments applied after thermo-magnetic treatments regimes [6]. Analyzing the microstructures before the wear tests, it can be observed that every stage of the heat treatment in magnetic field (AC current or DC current in magnetic field) influences the hardness and the thickness of the superficial layers obtained after thermo-chemical treatments. In **Figure 13** is represented the influence of the thermo-magnetic treatment applied before of the ionic nitriding treatment on the evolution of the mass loss (Δ m), after three hours of wear tests. In **Figure 14** is represented the effect of the thermo-magnetic treatment applied before of the laser- nitriding on the average mass loss (Δm), after three hours of wear process through dry friction.

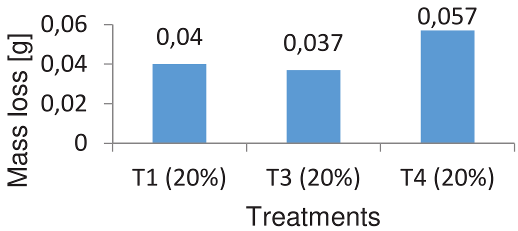

Figure 13 Evolution of the average mass loss (Δm), after three hours of wear tests, for normal loading Q=150 daN, in the case of ionic nitriding

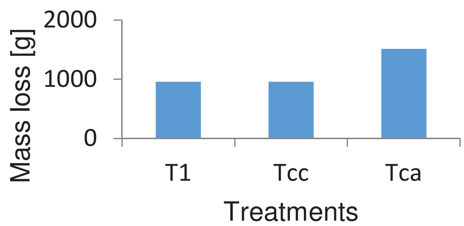

Figure 14 The average mass loss (Δm), after three hours of wear process for normal loading Q=150 daN and ξ = 20% (conducting roller).

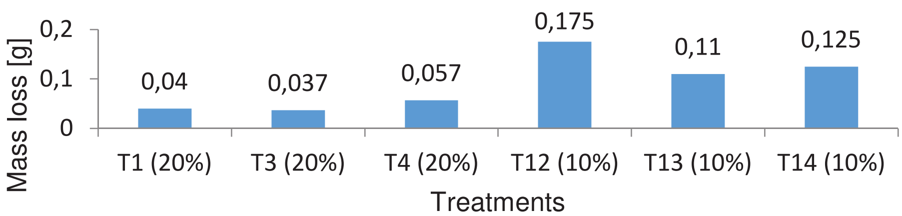

Figure 15 Evolution of the average mass loss (Δm), after three hours of wear tests, for normal loading Q=150 daN, in the case of ionic nitriding and nitrocarburizing applied after thermo-magnetic treatments

The cumulated material weight loss was represented by the values of the parameter notated with *Δm.* It were obtained many values for the mass loss (for example, see **Figure 14**). These values were evaluated using the following expression:

$$\Delta m_i = (m_{i-1} - m_i) + \Delta m_{i-1}, \qquad (2)$$

where Δm_i characterizes the mass loss after three hours of wear process through a dry friction, which results from the contact of the rollers, using an Amsler machine. The measured were taken after each hour of wear process. Wear tests are carried out on a basis of 60 minutes duration, three times.

4. CONCLUSIONS

The positive influence of the thermo-magnetic treatment on the surface layer thermo-chemically treated resulted in a higher hardness of the layer, in the same way as in [2, 5, 6]. The depth of the worn-out layer (Uh) during the wear process decreases if we apply a thermo-magnetic treatment (A.C. current in magnetic field) before the thermo-chemical treatment. The microstructures (**Figures 7 - 12**) achieved with a thermo-magnetic treatment and a thermo-chemical one show that the thickness of the thermo-chemical treated surface layer is higher when we apply the thermo-magnetic treatment (for example, A.C. current in magnetic field), vs. the conventional treatment case, in the same way as in [7, 10].

In conclusion, a thermo-magnetic treatment (alternative current in magnetic field) applied modify the wear resistance. The wear resistance increases, the mass loss (*Δm)* decreases and the worn-out layer depth [2, 6] decreases by approx. 40%.

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