THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE IX METALLURGY AND MATERIALS SCIENCE, ISSN 1453 – 083X. N^0. 2 – 2006

TRIBOLOGICAL BEHAVIOUR OF NITROCARBURIZED SUPERFICIAL LAYER AFTER THERMO-MAGNETIC TREATMENTS APPLIED TO STEELS, DURING FRICTION PROCESS

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ABSTRACT

Two types of steels subjected to a nitrocarburized thermo-chemical treatment after thermomagnetic treatments. The contact problems are studied employing the concept of tribosystem and tribomodel. The structural aspects into superficial layer of these steels are studied during friction process by using of an Amsler machine, taking two sliding degrees, different contact pressures and testing time. I tried to determine the durability of these materials, the surface structure evolution at different tests after thermomagnetic treatments. The performed tests allowed establishing the influence of the thermal, magnetic and mechanical parameters on behaviour of these two steels taking in study during friction process.

KEYWORDS: thermomagnetic treatments, tribosystem, tribomodel, superficial layer

1. Introduction

Improved steels mean highly tempering steels. By superimposing a magnetic field over a thermal one, structure modifications and implicitly properties modifications are generated.

Under the influence of the magnetic field, theoretically it is possible [B1], [B2], to modify the material state. The energy state of the ferrous-magnetic material is modified due to a certain magnetic moment, its free energy is increased. This may be a first cause which, under the effect of the magnetic filed, induces structure and physical-mechanical properties modifications in the material (steel). Martensite is decomposed upon tempering (annealing), and the intensity of this process depends on both temperature and duration of the tempering. In addition to the martensite decomposition stages (M), other processes take place upon tempering: transformation of the residual Austenite (Arez.), globalization of Troostite, e.t.c.

According to [B1], [C1], with low tempering of the conventionally tempered steel, the magnetic field slows down the martensite decomposition process, and , if the steel has been tempered in magnetic field, the martensite decomposition is even slower, thus tending to increase the martensite stability. At the same time the magnetic field influences the kinetics of the residual austenite decomposition isothermally upon tempering, accelerating the transformation process. The main cause of the above phenomena is the MAGNETOSTRICTION which causes strains in the microvolumes of the solid solutions – strains that interact with the field of elastic strains characteristic to dislocations.

Magnetostriction is defined as a dimensional variation of a 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 previously applied to this material (temperature) [S1], [V1], [S2]. The effect of the magnetostriction decreases with higher temperatures and disappears at the Curie temperature.

Magnetostriction is determined by the influence of the external magnetic field which generates the orientation of the elementary magnetic moments, modifying the balance conditions among the nodes of the crystalline mesh, inclosing variation of the ferrous-magnetic material sample lengths. Under these conditions, the magnetostriction curves can be a result of having measured the ferrous-magnetic sample lengths along the external magnetic field.

In addition to the linear magnetostriction, considered above for plotting the magnetostriction curves with ferrous magnetic materials, it can also be noted a volume magnetostriction which depends on the shape of the piece concerned as well.

Consequences of magnetostriction are:

- - applying alternative magnetic fields causes mechanical oscillations [V1], [B1], [B2] and in the diffusion processes, these (magnetic) mechanical oscillations are quite important because, the strains which are generated by these mechanical oscillations along with the magnetostrictive volume modifications lead to a higher diffusion coefficient;
- of special importance are the local strains in the area of the ferrous-magnetic boundaries. Gradients of the magnetostriction strains occur which further cause higher diffusion coefficients inside the material. They come into contact with the internal strains redistributed by diffusion thus causing a new diffusion influencing factor to appear.

The mechanical oscillations produced by the alternative magnetic fields change the recrystallization conditions especially the germination velocity.

The strains caused by magnetostriction cause elastic and plastic deformations which in turn result in a magnetic texture, thus improving the magnetic and mechanical properties in the direction of the external field ($H_{ext.}$). From this viewpoint the effect of the thermal-magnetic treatment is maximum in the stages of the solid solution decomposition and, especially, upon cooling in magnetic (alternative) field from temperatures higher than Curie point (when orientation of ferrous-magnetic phase particles takes place) [P2], [S1], [V1].

Analysis of the iron-monocrystal magnetostriction [V1],[S1] shows that its sized vary unevenly in different crystallographic directions. Relative elongations $\lambda=\Delta l/l$ have been found as follows: $\lambda_{[100]}= 1{,}9\ 10^{-5}$, $\lambda_{[110]}= -\ 10^{-5}$, $\lambda_{[111]}= -3{,}1\ 10^{-5}$, the cube getting deformed into a romboedru (Fig.1).

In spite of these deformations being very small, mentions must be made that the deformations of the martensite crystal upon magnetization in direction [111] cause its rotation inside plan [110] by an angle β=6°.

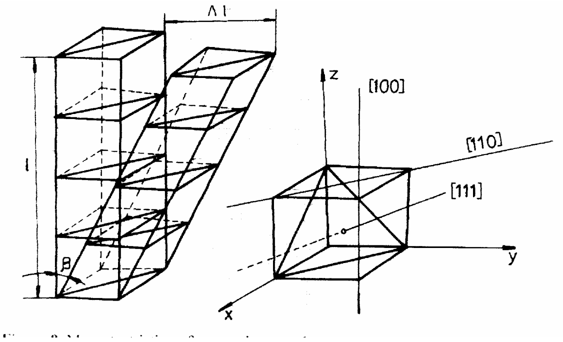

Fig. 1. The iron-monocrystal sized vary unevenly in different crystallographic directions because of magnetic field applied [S1].

Magnetostriction may cause local plastic deformations thus determining ecruisation of the residual austenite. This further implies higher material hardness/endurance.

2. Experimental researches

The steels analyzed in this paper are improved steels which should undergo high local variable strains: traction, compression, shearing and therefore certain properties are imperious:

- Higher hardness and homogeneity of the hardness values;
- elimination, if is possible, of the residual austenite ($A_{rez.}$);
- good tenacity;
- high elasticity point, so as to keep the plastic deformations within small limits.

The chemical composition of the materials analyzed according to STAS 791-88, is presented in Table 1.

The chemical compositions of their material samples, according to the lab bulletins, has been established by: spectral analysis, chemical and quantitative analysis presented vs the standards in force, according to Table 2.

Table 1

Steel grade	C	Mn	Si	P	S	Cr	Cu	Mo	Al
	[%]								
42MoCr11	0,38- 0,45	0,60- 0,90	0,17- 0,37	Max. 0,03	0,02- 0,04	0,90- 1,20	Max 0,30	0,15- 0,30	0,02
38MoCrAl09	0,35- 0,42	0,30- 0,60	0,20- 0,45	Max. 0,03	0,02- 0,035	1,35- 1,65	Max 0,30	0,15- 0,25	0,70- 1,10

Table 2

Steel grade	C	Mn	Si	P	S	Cr	Cu	Mo	Al
	[%]								
42MoCr11	0,42	0,68	0,33	0,030	0,026	1,02	0,220	0,17	0,02
38MoCrAl09	0,38	0,50	0,25	0,026	0,020	1,38	0,058	0,17	1,18

The content of Ni with steel 38MoCrAl09 is 0,26 %, and with steel 42MoCrV11 is 0,32 %. It is stated that, according to the chemical composition, these steels are in compliance with the prescriptions STAS 329-83 and norms API –Spec 11B-1982. The steels analyzed reach a max score 4,5 from inclusions and a fine grain (score 8-9).

The heat/magnetic treatments applied are:

t1, t1’= quenching (850 ˚C) and high tempering (580 ˚C) applied to steel 42MoCr11 (code V) and quenching (hardening) (920 ˚C) and high tempering (620˚C) applied to steel 38MoCrAl09 (code R);

t3, t3’ = quenching (hardening) (850 ˚C) and high tempering (580 ˚C) applied to steel 42MoCr11 (code V) , quenching (hardening) (920 ˚C) and high tempering (620˚C) applied to steel 38MoCrAl09 (cod R), cooling being performed in alternative current magnetic field (H=1300A/m);

t4, t4’= quenching (850 ˚C) and high tempering (580˚C) applied to 42MoCr11 (code V), quenching (920˚C) and high tempering (620˚C) applied to 38MoCrAl09 (code R), cooling being performed in dc magnetic field (H=1300A/m);

T9 = t1(classic)+ plasma nitrocarburation with 42MoCr11 (code V);

T10 = t4+ plasma nitrocarburation with 42MoCr11 (code V);

T11 =t 3 + plasma nitrocarburation with 42MoCr11 (cod V);

T12 = t1’(classic) + plasma nitrocarburation with 38MoCrAl09 (code R);

T13 = t3’+ plasma nitrocarburation with, code R;

T14 = t4’+ plasma nitrocarburation , code R.

Plasma nitrocarburation was performed to treatment temperature of 530 ˚C.

The wear –tests (friction process) were carried out on an Amsler bench from the machine design department „Dunarea de Jos” University of Galați, and the diffractometric analysis were performed by means of a Dron 3 from the same institution.

The curves of variation for phasis distribution and other characteristics in superficial layers because the magnetic field applied before plasma nitrocarburized, function by wear –tests period, are presented in figures: 2 ÷ 19.

Microstructures achieved on heat/magnetic/chemical and plasma nitrocarburation treated samples show that the thickness of the heat/chemically treated surface layer is higher when applying the heat/magnetic treatment (for example, a.c. magnetic field) with steel 38MoCrAl09 (code R), vs. the conventional treatment case- magnetic field -free treatment [3].

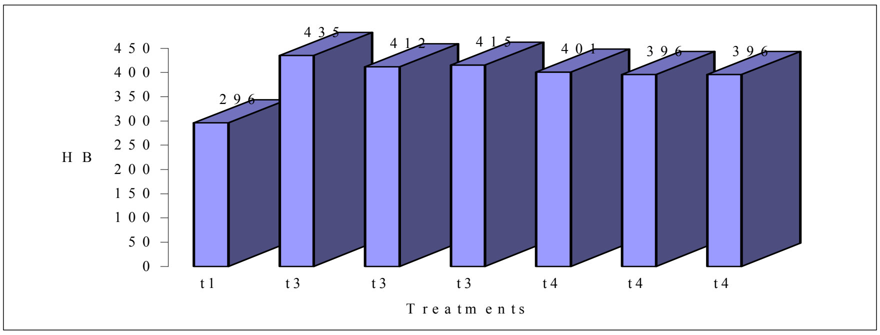

Fig. 2. *The influence of the magnetic field applied at the cooling regime- before nitrocarburation treatment, on the hardness number, in case of 42MoCr11 steel grade (code V)*

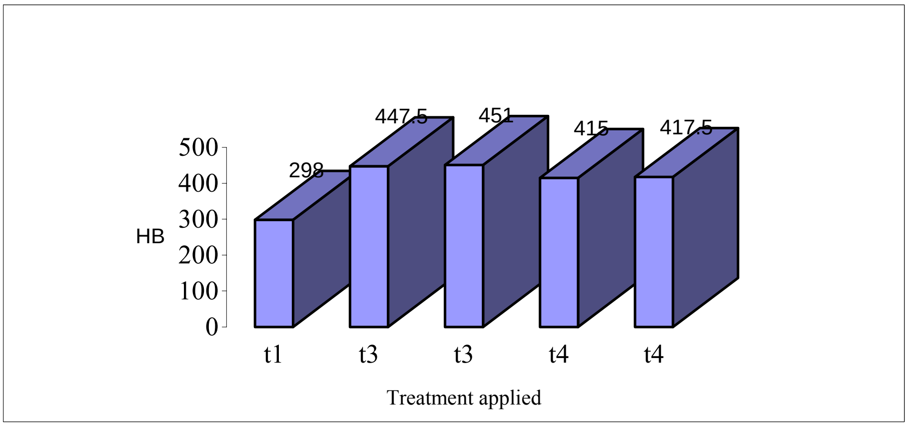

Fig. 3. *The influence of the magnetic field applied at the cooling regime- before nitrocarburation treatment, on the hardness number, in case of 38MoCrAl09 steel grade (code R)*

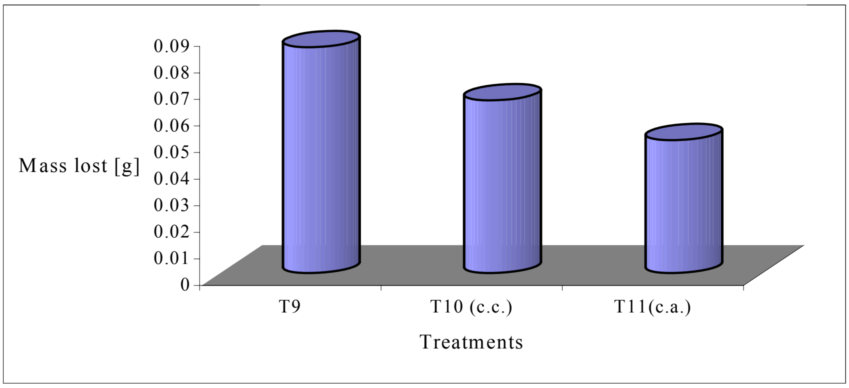

Fig. 4. *The influence of the magnetic field on the average mass loss after 3 hours of wear friction process, strain corresponding to one degree of sliding (by 10%) and the value of the strain are corresponding to Q=150 daN, in case of 42MoCr11 (code V) steel grade (after nitrocarburation treatment) [P1].*

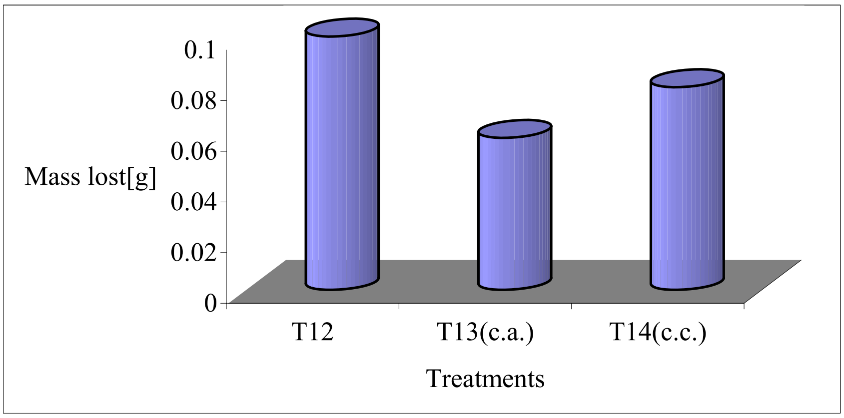

Fig. 5. *The influence of the magnetic field on the average mass loss after 3 hours of wear friction process, which corresponds to a degree of sliding by 10% and the value of the strain are corresponding to Q=150 daN, in case of 38MoCrAl09 (code R) steel grade (after nitrocarburation treatment) [P1].*

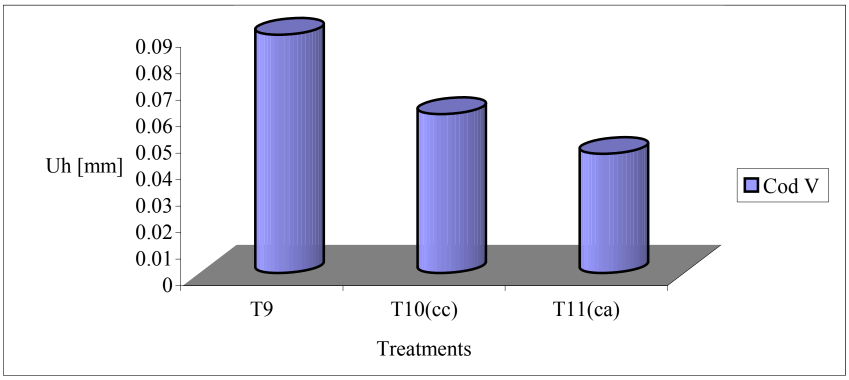

Fig.6. *The influence of the magnetic field on the worn layer depth, after 3 hours of wear friction process, which corresponds to a sliding degree (10%) and the value of the strain are corresponding to Q=150 daN, in case of 42MoCr11 (code V) steel grade (after nitrocarburation treatment) [P1].*

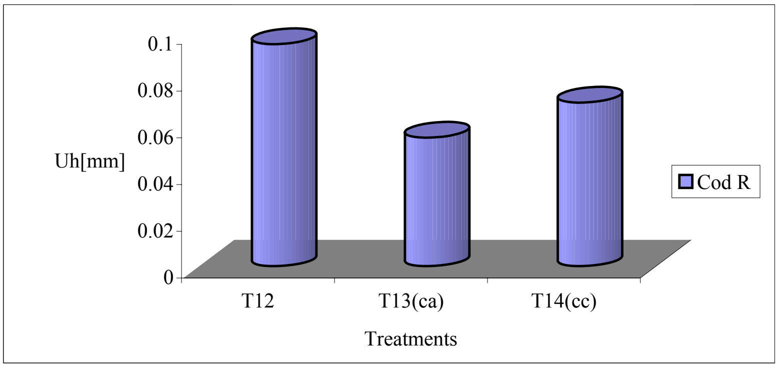

Fig.7. *The influence of the magnetic field on the worn layer depth, after 3 hours of wear friction process, which corresponds to a sliding degree by 10% and the value of the strain are corresponding to Q=150 daN, in case of 38MoCrAl09 (code R) steel grade (after nitrocarburation treatment) [P1].*

Microstructures (figures: 8, 9, 10) achieved on heat/magnetic/chemical and plasma nitrocarburation treated samples show that the thickness of the heat/chemically treated surface layer is higher when applying the heat/magnetic treatment (for example, a.c. magnetic field) with steel 38MoCrAl09 (code R), vs. the conventional treatment case - magnetic field - free treatment

Fig. 8. *Nitrocarburized surface layer on the sample R5 (code R), before wear process tests. Treatment: quenching (t=920˚C) and high tempering (t=620˚C) followed by water cooling in (dc)continuous current magnetic field and plasma nitrocarburation at 530 ºC (7 h)*
(x100)
Nital attack 2%

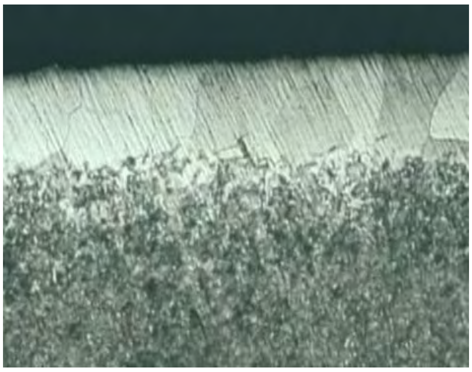

Fig. 9. *Nitrocarburized surface layer on the sample R3 (code R), before of wear process tests. Treatment: quenching (t=920˚C) and high tempering (t=620˚C) followed by water cooling in (ac) alternative current magnetic field and plasma nitrocarburation at 530 ºC (7 h)*
(x100)
Nital attack 2%

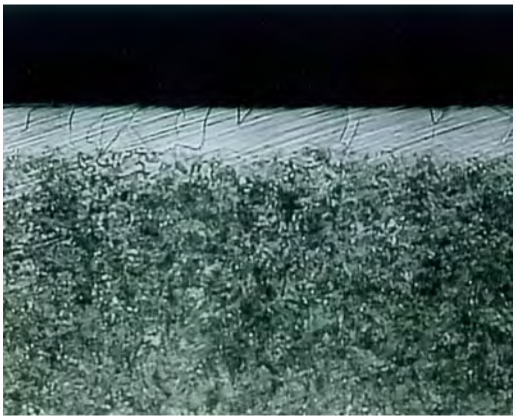

Fig. 10. *Nitrocarburized surface layer on the sample R2 (code R), before wear process tests. Treatment (classic): quenching (t=920˚C) and high tempering (t=620˚C) followed by water cooling - without magnetic field and plasma nitrocarburation at 530 ºC (7 h)*
(x100)
Nital attack 2%

3. Conclusions

For a deeper insight into this theme, the research is focused on pieces from the metallurgical industry (rollers, gears etc.) and on the materials they are made from. At the same time the results achieved under laboratory conditions were used to choose the optimum treatment regimes; depending on the strain conditions the metallurgical pieces are working in, a selection is attempted so that those pieces may be manufactured from the steels investigated and unconventionally treated in this paper. Applying the thermal-chemical treatment implies to make a hard layer into a heat treated (improved) core of a relatively low hardness as compared with the hardness obtained after the thermal-chemical treatment. A first research direction was the improvement of the mechanical characteristics (hardness) in thermo- magnetic treated steels for further applying the diffusion thermo-chemical treatment under the thermo-magnetic treatment

This research is focused on:

a). Improving the wear resistance characteristics of the thermo –magnetic treated surface layer by applying the thermo –magnetic *treatment to the piece core*. The modifications induced by the magnetic field to improve the core, have triggered the modifications of the mechanical and structure properties of the thermo-chemical treated layer. There is an obvious influence of the thermo- magnetic treatment applied to the core on the structure of the thermo-chemical treated surface layer [P1].

b).Continuity of the thermo-chemical treated layer tested to wear resistance and checking the results on three roller-type samples obtained under the same manufacturing and treatment conditions and tested in the same strain conditions for each thermo-chemical-magnetic treatment. Another research direction was the study of the influence of the thermo- magnetic treatment applied before the thermo-chemical treated surface layer when applying plasma nitrocarburation. In a first stage, the samples of microstructures were analyzed after applying the thermo-magnetic treatment and, in the second stage, the microstructures after applying the thermo-chemical treatment of ion nitruration and plasma nitrocarburation, respectively.

It has been shown that, when applying an alternative current magnetic field treatment (for example H=1300A/m), the thickness of the thermo-chemical treated layer increased up to 25% as compared to the conventional thermal, thermo-chemical treatment (H=0 A/m) without a magnetic field. The results from these researches have been compared with those obtained on the classically treated (without magnetic field) samples, while complying with the technological parameters used with the thermal and thermo-chemical treatments in S.C. MITTAL STEEL S.A. Galati.

The novelty of the present paper involves the application of the diffusion thermo - chemical treatment after the thermo-magnetic one, the temperature of the former being lower than that of the latter, except that the thermo-chemical treatment applied after the thermo-magnetic treatment should not modify – due to the high temperature - the improvements of the mechanical properties by the thermo-magnetic treatment.

The positive influence of the volume thermo-magnetic treatment on the surface layer treated thermo-chemically resulted in a higher hardness (see [P1]-subchap.6.1.1.) and the wear resistance by the decreasing the depth of the used layer (see [P1]-subchap.6.4) by approx. 50% - in case of steel 38MoCrAl09 and by 40% - in case of the steel 42MoCr11, which has been proved by the wear tests and the evolution of the mass loss through wear and wet friction.

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