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TRIBOLOGICAL BEHAVIOUR OF NITROCARBURIZED STEELS AFTER THERMO-MAGNETIC TREATMENTS

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ABSTRACT

Two types of steels were subjected to a nitro-carburized thermo-chemical treatment after thermo-magnetic treatments. The structural aspects into the superficial layer of these steels are studied during the friction process using an Amsler machine, taking two sliding degrees, different contact pressures and testing time. It was determined the durability of these materials, the surface structure evolution at different tests after thermo-magnetic treatments.

The performed tests allowed to establish the influence of the thermal, magnetic and mechanical parameters on the behavior of these two steels taken for study during the friction process.

KEYWORDS: thermo-magnetic treatments, nitrocarburation, wear, difractometry

1. Introduction

Under the influence of the magnetic field, theoretically it is possible [1, 2] to modify the material state. The energy state of the ferrous-magnetic material is modified due to a certain magnetic moment, and the free energy is increased. This is possible to be a first cause which, under the effect of the magnetic filed, induces structure and physical-mechanical properties modifications in material (steel).

Martensite is decomposed upon tempering and the intensity of this process depends on both: temperature and time of the tempering. In addition to the martensite decomposition stages, other processes take place upon tempering: transformation of the residual austenite globulization of troostite,…

According to [1,3], with low tempering of the conventionally tempered steel, the magnetic field slows down the martensite decomposition process. 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 cinetics 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. These strains interact with the elastic strains field which corresponds to dislocations.

Magnetostriction is defined as 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 previously applied to this material (temperature) [7,8,9]. 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, inclusing 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.

The consequences of magnetostriction are:

- applying alternative magnetic fields causes mechanical oscillations [1,2,9] and in the diffusion processes, 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 coefficient 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 generated by magnetostriction cause elastic 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) [4, 5, 7, 9].

Analysis of the iron-monocrystal magnetostriction [9, 7] shows that its size 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˚. Magnetostriction may cause local plastic deformations thus determining ecruisation of the residual austenite. This further implies higher material durity/endurance.

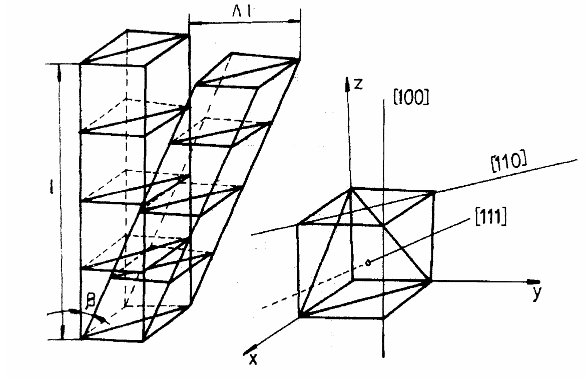

***Fig. 1**: The influence of magnetic field on the size of the iron monocrystal [7].*

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 homogenity of the hardness values;
- elimination, if it is possible, of the residual austenite;
- a good tenacity;
- high elasticity point, so as to keep the plastic deformations within small limits.

The chemical compositions of the investigated samples, have been established by spectral analysis and are presented in Table 1.

***Table 1.** Chemical compositions of material samples*

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 of the steel 38MoCrAl09 samples is 0.26 %, and of the steel 42MoCrV11 samples 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 – Spec11B-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 = t3 + plasma nitrocarburation with 42MoCr11 (cod V);

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

- T13 = t3’ + plasma nitrocarburation with 38MoCrAl09 (code R);
- T14 = t4’+ plasma nitrocarburation, with 38MoCrAl09 (code R).

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

The wear – tests (friction process) were carried out on an Amsler machine, using a wear roles cople which corresponds to a degree of sliding by 10% and the value of the strain are corresponding to Q=150 daN.

In the figures number: 2 ÷ 5 was presented the average mass loss and the worn layer depth, after three hours of wear process for these two steels with or without treatments in magnetic fields- alternative current or continuous current, treated with nitrocarburation treatment.

In both cases we can observe the lawest average mass loss -at T11and T13 treatments, using cooling being performed in alternative current magnetic field and the highest average mass loss -at T9, T12, using a classic treament of the steels.

The continuous magnetic field treatment applied before nitrocarburation treatment (T10. T14) determines intermediare values of average mass loss.

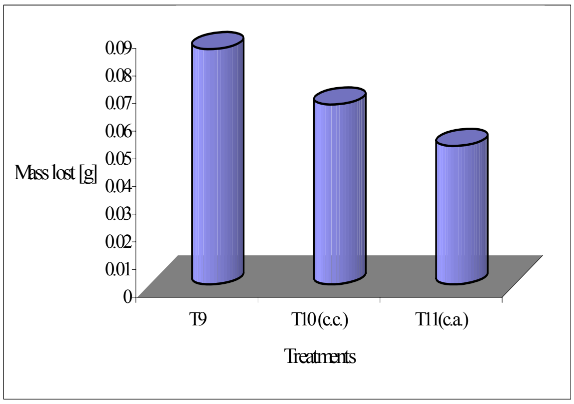

Fig. 2 . *The influence of the magnetic field on the average mass loss after 3 hours of wear friction process, strain corresponding to one degree of sliding by 10% and the value of the strain is corresponding to Q=150 daN, in case of 42MoCr11 (code V) steel grade after nitrocarburation treatment) [4]*

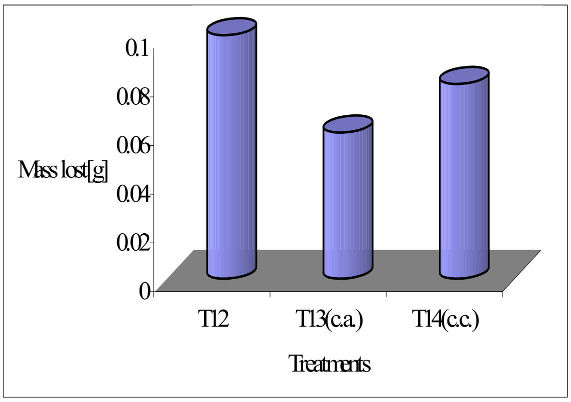

Fig. 3. *The influence of the magnetic field on the average mass loss after 3 hours of wear friction process, which corresponds to a degree of sliding by 10% and the value of the strain is corresponding to Q=150 daN, in case of 38MoCrAl09 (code R) steel grade (after nitrocarburation treatment) [4]*

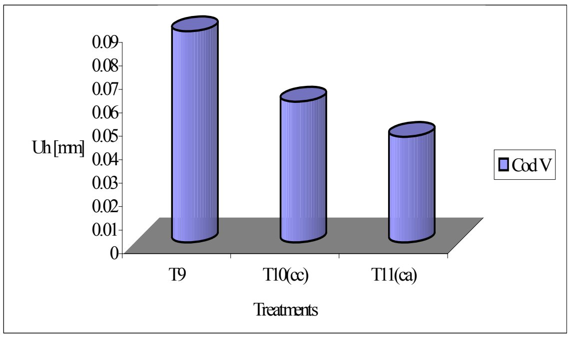

Fig. 4 . *The influence of the magnetic field on the worn layer depth, after 3 hours of wear friction process, which corresponds to a sliding degree by 10% and the value of the strain is corresponding to Q=150 daN, in case of 42MoCr11 (code V) steel grade (after nitrocarburation treatment) [4]*

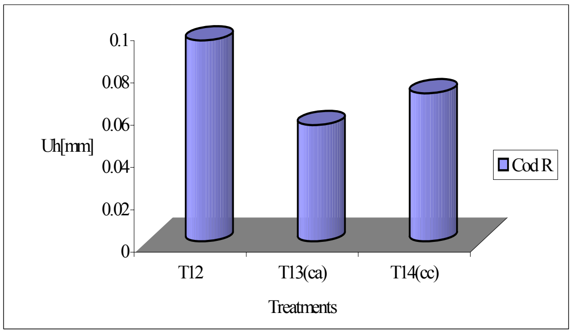

Fig. 5 . *The influence of the magnetic field on the worn layer depth, after 3 hours of wear friction process,which corresponds to a sliding degree by 10% and the value of the strain is corresponding to Q=150 daN, in case of 38MoCrAl09 (code R) steel grade (after nitrocarburation treatment) [4]*

Microstructures (Fig. 6, 7, 8) 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 [6]

Fig. 6. *Nitrocarburized 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%

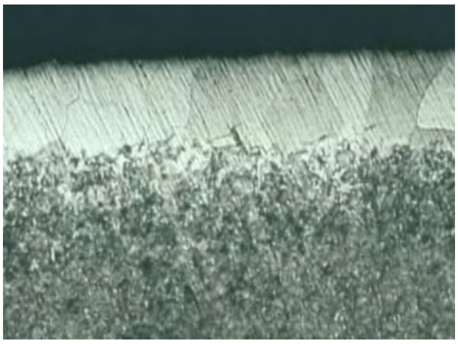

Fig. 7. *Nitrocarburized layer on the sample R3 (code R), before of wear process tests.*
Treatment: quenching (t=920˚C) and high tempering (t=620˚C) followed by water cooling in (ac) alternative current magnetic field and plasma nitrocarburation at 530 ºC (7 h)
(x100)
Nital attack 2%

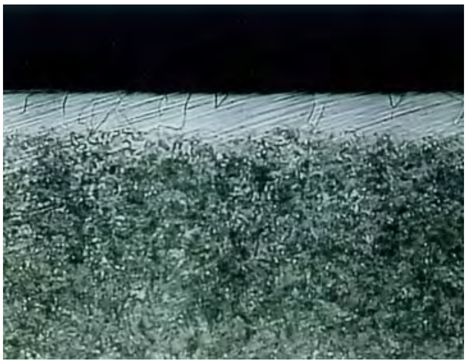

Fig. 8. *Nitrocarburized (surface) layer on the sample R2 (code R), before wear process tests.*
Treatment (classic):quenching(t=920˚C) and high tempering (t=620˚C) followed by water cooling -without magnetic field and plasma nitrocarburation at 530 ºC (7 h)
(x100)
Nital attack 2%

Diffractometric analyses were performed by means of a Dron 3. The curves of variation for phasis distribution and other characteristics in superficial layers because of the magnetic field applied before plasma nitrocarburized, function by wear – tests period, are presented in figures: 9 ÷ 26.

It was made a comparasion between classic treatment (blue lines) and unconventional (magnetic) treatment (red lines). We can observe that for T9 applied to 42MoCr11(cod V) steel (classic treatment), the martensite quantity (Fig 9-12), the nitro-carburs (Fig.13,14) and the internal tensions- II (B 211 ~σ_{II}) function by friction process length (Fig 15,16 from wear layer), are maintained constant during friction (wear) process. In the case of alternative or continuous magnetic field applied to the steels (T10, T11), we can observe a higher initial quantity of martensite and carbo-nitrurs, compared to the classic treatment. During the wear process, the martensite quantity increases and the carburs quantity decrease very rapidly. The internal tensions (II) increase easily according to the lenght of wear tests. This tendency is most important in the case of treatement T10. The martensite thetragonality grade evolution (c/a), function by wear-tests (Fig 17, 18) in the T10 case decreases more rapidly than the classic treatment (T9) and become constan at T11 case.

For 38MoCr Al09 steel, the tendency is the same (Fig 19-2.), but in this case, we can see a little martensite quantity after classic treatment and a higher nitro-carburs quantity, because of the magnetic field applied and because of the alloying elements.

It results a good behaviour of the steels treated with magnetic fields (alternatve current: T11 and T13), during wear tests, comparred to the classic situation (without manetic field treatment: T9, T12) because of the nitrocarburized layer, which has a high depth in magnetic teatment cases and because exists a higher alloyed martensite which determins a special hardness.

An important aspect in this case is that the superficial carbo-nitrurs quantity decreases during wear process.

In the case of magnetic field-continuous current (T10, T14), the nitrocarburized layer is reduced and appear a very important nitro-carburs layer decrease, during wear process. It results, in this case, a very strong wear.

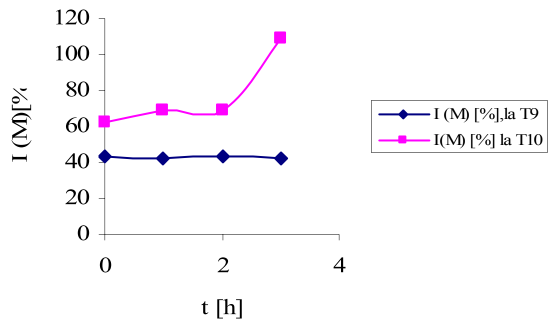

***Fig. 9 .** The influence of magnetic field alternative current, on the Feα(M)-44,98˚phase distribution, function by wear-tests lenght (Q= 150 daN, ξ=10%)-code V*

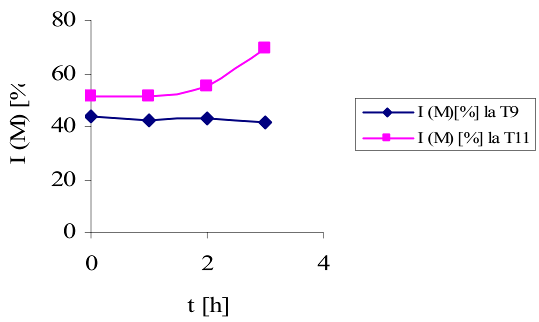

***Fig. 10 .** The influence of magnetic field continuous current, on the Feα(M)-44,98˚phase distribution, function by wear-tests lenght (Q= 150 daN, ξ=10%)-code V*

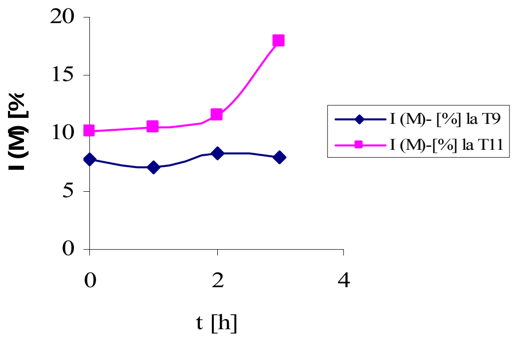

***Fig. 11 .** The influence of magnetic field – alternative current (T11) on the Feα(M)-82,5˚ phase distribution, function by wear-tests length. (Q= 150 daN, ξ=10%)-code V*

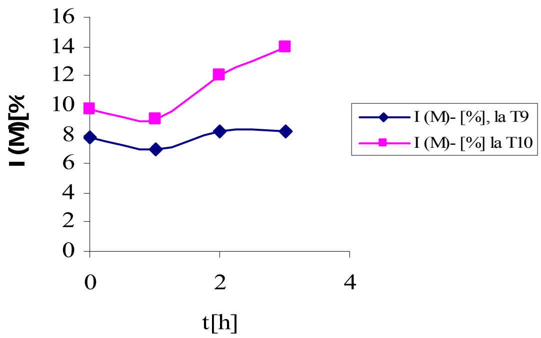

***Fig. 12 .** The influence of magnetic field – continuous current (T10) on the Feα(M)-82,5˚ phase distribution, function by wear-tests length. (Q= 150 daN, ξ=10%)-code V*

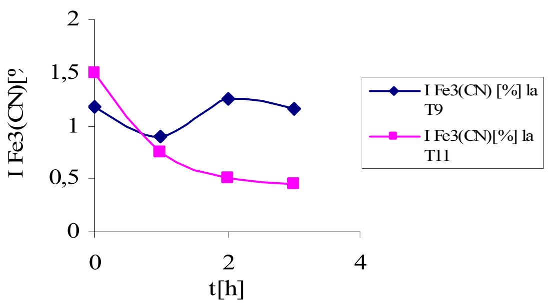

***Fig. 13 .** The influence of magnetic field - current alternative-(T11) on the Fe_3CN) phase distribution, function by the wear-tests length (Q= 150 daN, ξ=10%)-code V*

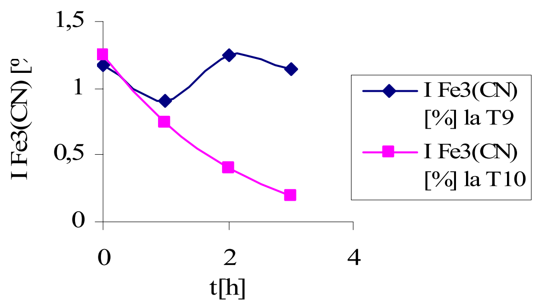

***Fig. 14 .** The influence of magnetic field – continuous current -(T10) on the Fe_3CN)phase distribution, function by the wear-tests length (Q= 150 daN, ξ=10%)-code V*

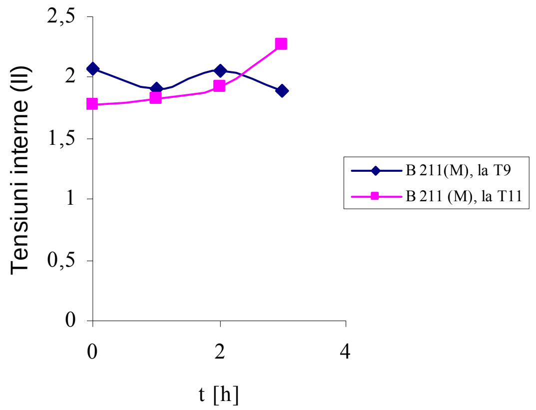

Fig. 15. *The influence of magnetic field (alternative c.)(T11) on the internal tensions- II (B 211 ~σ_{II}), function by friction process length (Q= 150 daN, ξ=10%)- code V*

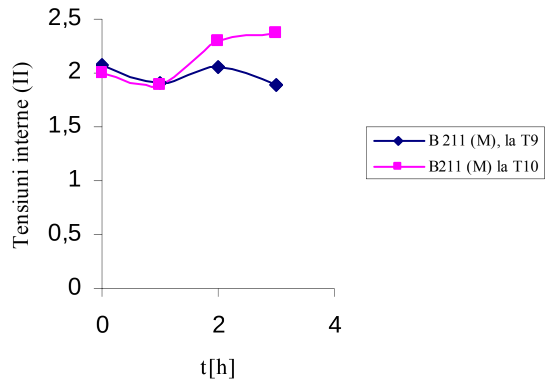

Fig. 16. *The influence of magnetic field (alternative c.)(T10) on the internal tensions- II (B 211 ~σ_{II}), function by friction process length (Q= 150 daN, ξ=10%)- code V*

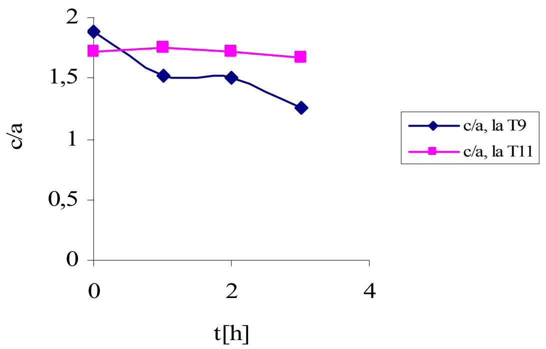

Fig. 17 . *The influence of magnetic field (alternative)-T11 on the martensite thetragonality grade evolution (c/a), function by wear-tests (friction process) duration. (Q= 150 daN, ξ=10%).- code V*

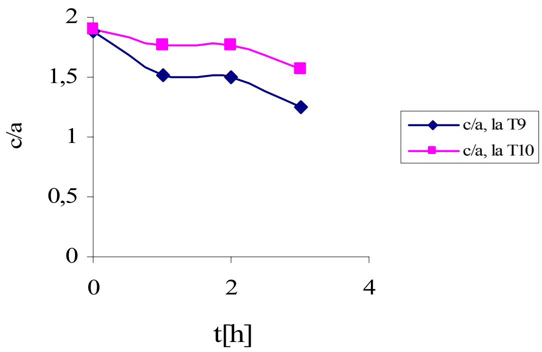

Fig.18. *The influence of magnetic field (continuous)-T10 on the martensite thetragonality grade evolution (c/a), function by wear-tests (friction process) duration. (Q= 150 daN, ξ=10%).- code V*

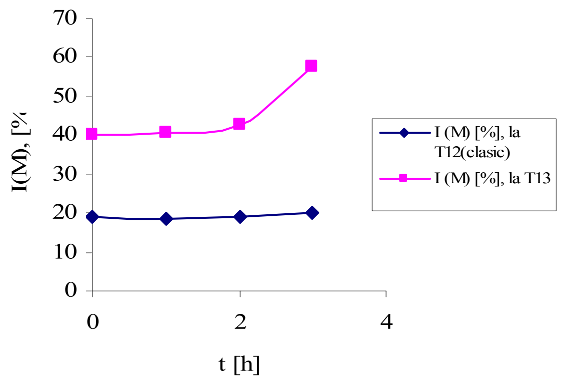

Fig. 19 . *The influence of magnetic field - current alternative (T13) on the Feα(M)-44,98° phase distribution, function by friction process length, (Q= 150 daN, ξ=10%).-code R*

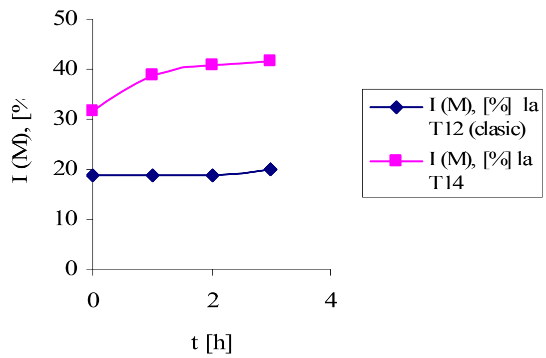

Fig. 20. *The influence of magnetic field - current continuous (T14) on the Feα(M)-44,98° phase distribution, function by friction process length, (Q= 150 daN, ξ=10%).-code R*

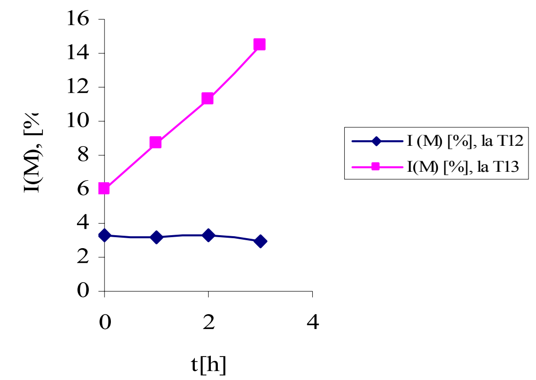

Fig. 21. *The influence of magnetic field -current alternative(T13) on the Feα(M)-82,5˚ phase distribution function by friction process length, (Q= 150 daN, ξ=10%).-code R*

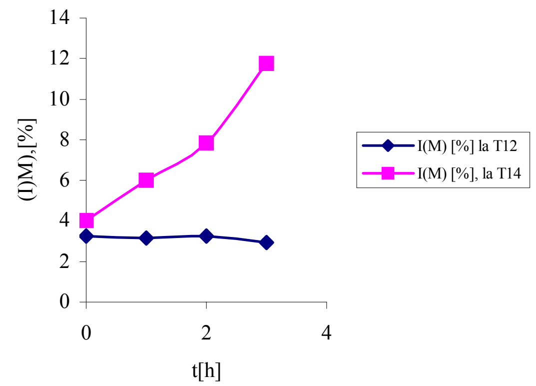

Fig. 22. *The influence of magnetic field -current continuous (T14) on the Feα(M)-82,5˚ phase distribution, function by friction process length, (Q= 150 daN, ξ=10%).-code R*

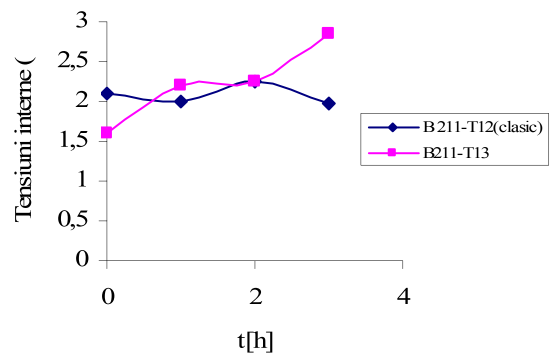

Fig. 23. *The influence of magnetic field (alternative c.)(T13) on the internal tensions- II (B 211 ~σ_{II}), function by friction process lenght (Q= 150 daN, ξ=10%)- code R*

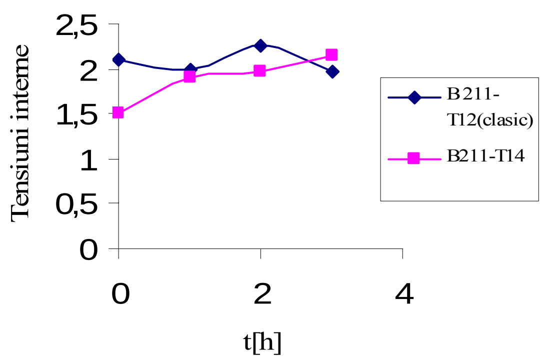

Fig. 24 . *The influence of magnetic field (continuous c.)(T14) on the internal tensions- II (B 211 ~σ_{II}), function by friction process lenght (Q= 150 daN, ξ=10%)- code R*

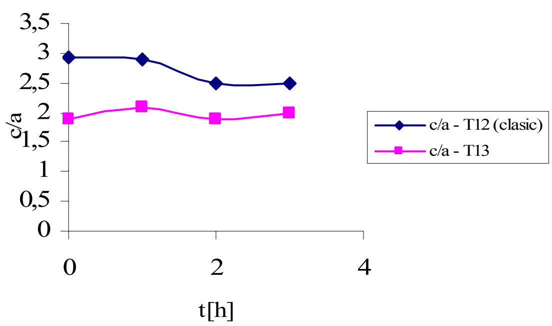

Fig. 25 . *The influence of magnetic field (alternative)-T13 on the martensite thetragonality grade evolution (c/a), function by wear-tests (friction process) duration. (Q= 150 daN, ξ=10%).- code R*

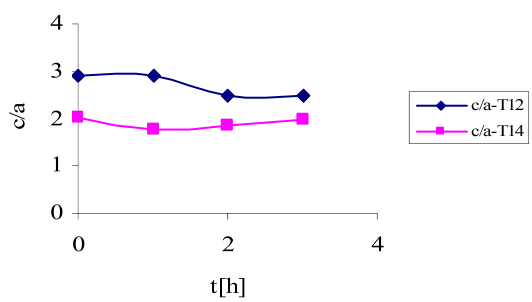

Fig. 26. *The influence of magnetic field (continuos)-T14 on the martensite thetragonality grade evolution (c/a), function by wear-tests (friction process) lenght. (Q= 150 daN, ξ=10%).- code R*

3. Conclusions

Applying the thermal-chemical treatament 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.

This research was 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 therm-magnetic treatment applied to the core on the structure of the thermo-chemical treated surface layer [4,6] (see the figures: 9 -26).

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 (plasma) nitro-carburization.

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-chimical treatment (H=0 A/m) without a magnetic field.

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].

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 [4] and the wear resistance by the decreasing the depth of the used layer [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 (see figures: 6,7,8).

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