

IMPROVING TRIBOLOGICAL BEHAVIOUR IN THE CASE OF A NON-CONVENTIONAL TREATED STEEL FOR INDUSTRIAL GEARINGS

Carmen-Penelopi PAPADATU¹

¹*Dunarea de Jos University of Galati, Faculty of Engineering, Mechanical Engineering Department, Romania, papadatu.carmen@yahoo.com*

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Abstract

A thermo-magnetic treatment applied before plasma nitriding modifies the characteristics of the mechanical resistance of the steel, the hardness and the resistance of the material during corrosion process. A non-conventional treatment applied to steel for industrial gearings have been studied in this paper. It have been demonstrated that the energy of the magnetic field conduct to the mechanical oscillations of micro-areas in material and intervenes in the balance of the global power of the phase transformations in solid state changing the thermodynamics, kinetics and the mechanisms of the processes, the microstructures and properties of the steel. The wear tests (dry friction) have been realized using an Amsler stand. The plasma nitriding plant used was the INI 150 which was made by the Institute of Radiation Physics and Technology in collaboration with the "Electrotechnics" Enterprise and the Nuclear Apparatus from Romania, used for industrial nitriding of small pieces. INI 150 was based on the physical phenomenon of a double cathode at plasma (ion) nitriding. This work is a review of my researches from the last years.

Keywords: Steel, properties, thermo-magnetic treatment, plasma nitriding, wear tests

1. INTRODUCTION

The structural aspects into superficial layer of the steel are studied during friction process by using of an Amsler machine, taking two sliding degrees, different contact pressures, and testing time. By X-ray diffractometry the changes regarding the austenite residual, IFe_4N and the degree of the tetragonality of martensite during friction process are carried out. Fe_4N phase being a "hard" phase, increasing the amount of this phase in the thermochemically treated surface layer involves the increasing of the hardness and wear resistance of the surface layer [1,2]. The loss of mass, the intensity of the wear (dry friction) and micro-hardness in the superficial layer at different stage of friction have been monitored. The performed tests allowed establishing the influence of the thermal, magnetic and mechanical parameters on behaviour of the steel taking in study during friction process [3].

The properties of the nitrided layer depend on the nature of the nitride phases. As the nitriding temperature increases, the nitriding duration decreases, but the hardness of the nitrided layer decreases due to the coalescence of the nitrides of the alloying elements. It should be noted that the Fe_2N (ξ) phase - which has a rhombic structure (deformed structure of the ϵ phase) and a low hardness, does not appear in the structure of the researched steels. Within the accuracy limits of the DRON3 diffractometer, the existence of this phase was not highlighted [1,4-8]. The superficial layer of a nitrided steel has a thickness of 0.2–0.35 mm, and it is 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 [8 -10]. Tribological properties during friction and wear processes are determined by the compound layer (the superficial white layer) [2,4,9,10].

2. EXPERIMENTAL PROCEDURE AND RESULTS

The samples have been realized as rollers from a steel grade for improvement treatment for machine parts construction with the following principal content: 0.42 % C, 0.02% Al, 1.02 % Cr, 0.68 % Mn, 0.17 % Mo, 0.33 % Si, 0.26 % Ni, 0.22 % Cu, 0.030 % P, 0.026 % S. Molybdenum content exists in the composition of the steel and this chemical element decreases the stiffening phenomenon.

The first part from the complex experimental program 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 treatment t2 represents a complete martensitic hardening process in weak alternative magnetic field (with cooling in water) and high tempering treatment (with cooling in water, in strong magnetic field - Alternative Current (A.C.)). In this case, the samples have been introduced in the centre of the electrical coil located in the walls of a cylindrical oven [2]. The treatment t3 represents a thermo-magnetic treatment corresponding to the treatment with cooling in water in magnetic field- Alternative Current (A.C.). After thermo-magnetic treatments, a thermochemical treatment as plasma nitriding at 530 °C have been applied. The final treatments have been noted: T1 = t1 followed by plasma nitriding at 530 °C (8h, duration depends on the dimensions of the samples); T2 = t2 followed by plasma nitriding at 530 °C, and T3 = t3 followed by plasma nitriding at 530 °C.

In **Table 1** have been presented the micro-hardness values $\mu\text{HV}_{0.1}$ obtained after thermo-magnetic treatment, comparing with the results obtained through the classic treatment. Mass loss (Δm) and the intensity of the wear (I_u) have been presented too. There are considered samples different treated. Distance from the superficial layer until the experimental **trace** was measured and the value was 0.05 mm. In this point, the Vickers micro-hardness had the values introduced in the following table:

Table 1 Results corresponding to classic treatment (T1) and non-conventional treatments (T2 and T3)

Treatment Code	Normal Load Q [daN]	Sliding degrees ξ [%]	Mass loss Δm (dm) [g]	The depth of the worn layer U_h' [mm]	The intensity of the wear I_u'	Δt [h]	μ (Friction coefficient)	I Fe ₄ N ~ %	$\mu\text{HV}_{0.1}$ [daN/mm ²]
T ₁ (Classic)	75	10	-	0.100	-	0	0.133	18	1159
			0.025		5.89	1		22	
			0.035		4.42	2		14	
T ₂	75		-	0.070	-	0	0.133	14	1513.8
			0.020		2.95	1		22	
			0.020		1.47	2		22	
T ₁	150		-	0.120	-	0	0.116	23	1159
			0.035		5.89	1		25	
			0.040		5.89	2		19	
T ₂	150	-	0.090	-	0	0.116	14	1513.8	
		0.035		4.42	1		14		
		0.025		4.42	2		15		
T _{CA} (T ₃)	150	20	-	0.095	-	0	0.121	24	1354.5
			0.030		4.42	1		36	
			0.030		3.68	2		38	
T ₁ (Classic)	150	20	-	0.135	-	0	0.121	17	1159
			0.040		5.89	1		14	
			0.055		6.70	2		19	
			0.050		6.70	3		26	

The wear tests have been made on Amsler machine, type roller on roller, with different diameters to obtain different sliding degrees (for example, for $\xi = 20\%$, the outer diameter of the conducting roller had 43.9 mm and the second roller had 40 mm. Rollers width was 10 mm. The wear moment $M_f = 40 \text{ daN}\cdot\text{cm}$, the normal load (Q) was 150 daN, the friction coefficient (μ) was 0.121, the length of friction zone of the rollers (L_f) was 74.606 m).

In **Figure 1** have been presented the mass loss ($dm1''$ and $dm2''$) corresponding to the treatment T1 and T2, for a normal load $Q = 75 \text{ daN}$ and a sliding degrees $\xi = 10\%$.

In **Figure 2** have been presented the mass loss ($dm1'$ and $dm2'$) corresponding to the treatment T1 and T2, for a normal load $Q = 150 \text{ daN}$ and a sliding degrees $\xi = 10\%$.

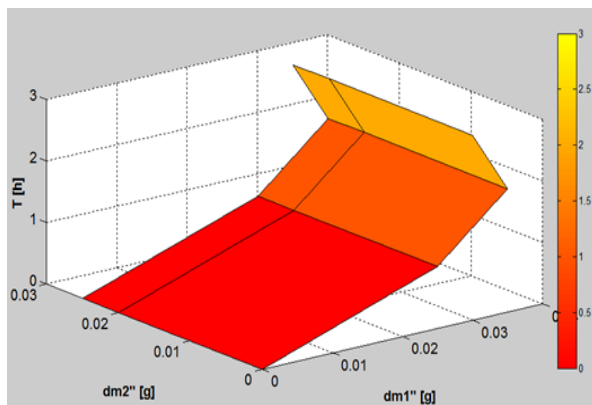


Figure 1 Mass loss during wear tests, for T1 and T2, $Q=75 \text{ daN}$, (10%)

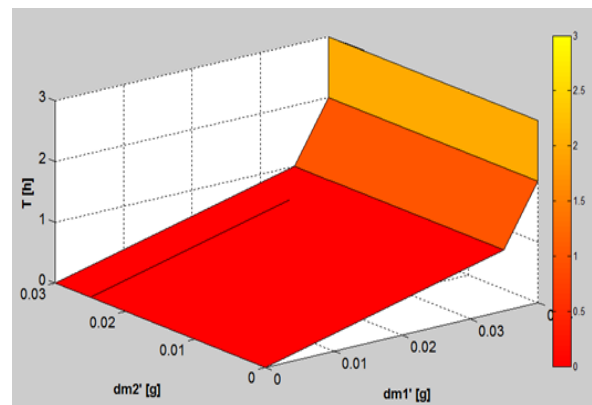


Figure 2 Mass loss during wear tests, for T1 and T2, $Q=150 \text{ daN}$, (10%)

In **Figure 3** have been presented the mass loss ($dm1$ and $dm2$) corresponding to the treatment T1 and T_{CA} (A.C.), for a normal load $Q = 150 \text{ daN}$ and a sliding degrees $\xi = 20\%$.

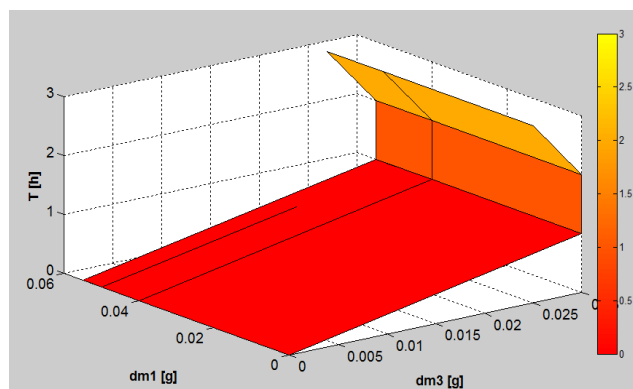


Figure 3 Mass loss during wear tests, for T1 and T_{CA} , $Q=150 \text{ daN}$, (20%)

In **Figure 4**, the Intensities of the wear ($Iu1'$, $Iu2'$) corresponding to the treatment T1 and T2, for a normal load $Q = 75 \text{ daN}$ and a sliding degrees $\xi = 10\%$, have been presented.

In **Figure 5**, the Intensities of the wear ($Iu1$, $Iu2$) corresponding to the treatment T1 and to the treatment T2, for a normal load $Q = 150 \text{ daN}$ and a sliding degrees $\xi = 10\%$, have been presented.

In **Figure 6** have been presented the Intensity of the wear corresponding to the treatment T1 and to the treatment T_{CA} , for a normal load $Q = 150 \text{ daN}$ and a sliding degrees $\xi = 20\%$.

In **Figures 7, 8 and 9** the evolution of the phase Fe_4N have been presented, in three cases: on classic

treatment case as landmark – taking in consideration the different values for the Normal Load Q and sliding degrees ξ - and considering non-conventional treatment cases T2 and T3.

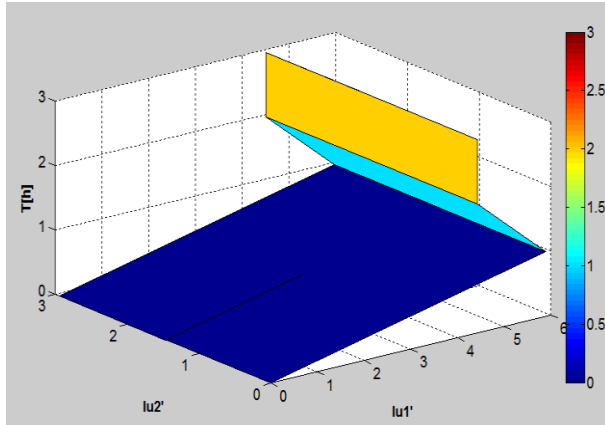


Figure 4 The Intensity of the wear (lu_1' , lu_2') corresponding to the treatment T1 and T2, for a normal load $Q = 75$ daN ($\xi = 10\%$).

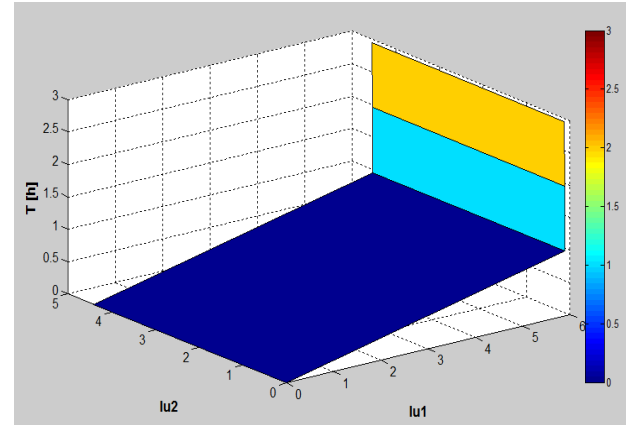


Figure 5 The Intensity of the wear (lu_1 , lu_2) corresponding to the treatment T1 and T2, for a normal load $Q = 150$ daN ($\xi = 10\%$).

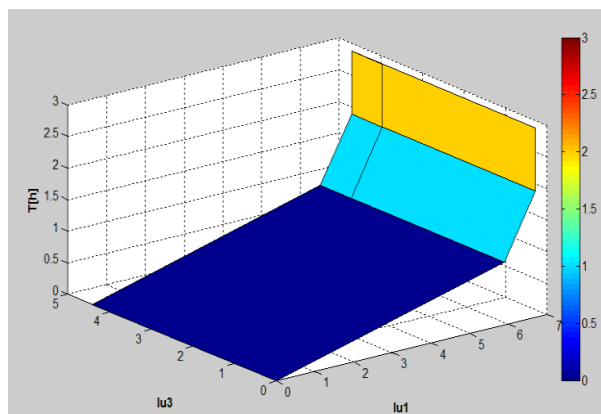


Figure 6 Intensity of the wear (lu_1') corresponding to the treatment T1 and T_{CA} , for $Q = 150$ daN, $\xi = 20\%$.

The amount of Fe_4N phase has a maximum in the case of applying the T3 treatment both before the wear process and after the friction wear tests (see **Table 1**). This situation can be explained by the fact that, Fe_4N being a harder phase, it "stays" in the composition of the surface layer longer in the process of frictional wear. The intensity of the wear due to appreciates the depth of the worn layer, in different cases of the treatments. Because of that, the depth of the worn layer by dry friction had been found in the case of the non-conventional treatments T2 and T3. Hence, the depth of the worn layers is smaller in the case of non-conventional treatment comparing to classic treatment T1.

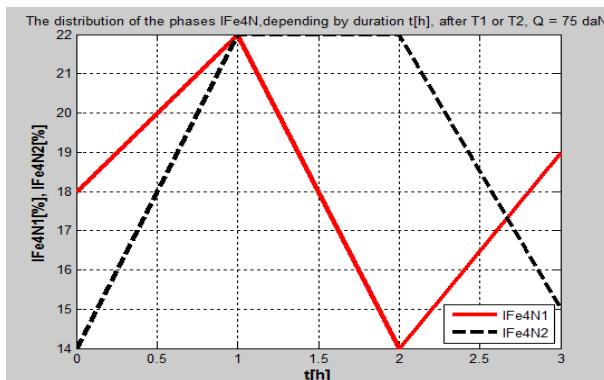


Figure 7 The distribution of the phase IFe_4N , depending by duration t [h], after T1 or T2 treatment, $Q = 75$ daN, $\xi = 10\%$.

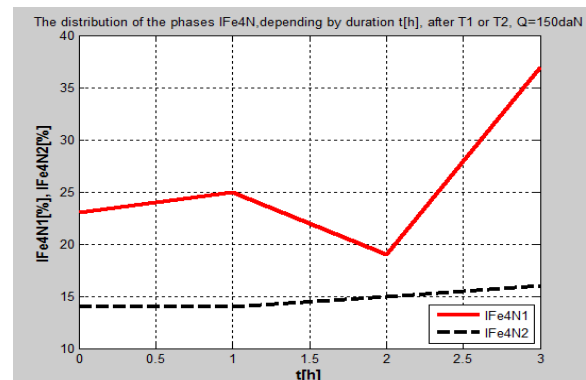


Figure 8 The distribution of the phase IFe_4N depending by duration t [h], after T1 or T2, $Q = 150$ daN, $\xi = 10\%$

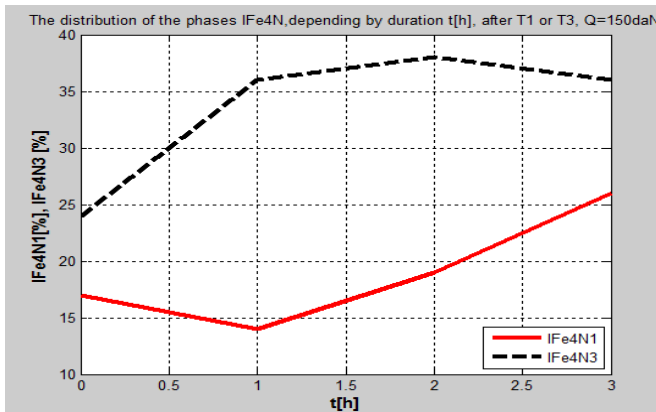


Figure 9 The distribution of the phase IFe₄N depending by duration t[h], after T1 or T3 treatment, Q=150daN, $\xi = 20\%$

In **Figures 7 and 8**, IFe₄N corresponding to T1 treatment had a cyclical evolution and in the case of the non-conventional treatment, the evolution was ascending. In **Figure 9**, upon frictional wear with the same Normal load Q = 150 daN and at the same sliding degree of 20%, an increase in the amount of Fe₄N was observed on the diffractograms.

The highest amount of Fe₄N phase is observed in the situation of applying the T3 treatment (the improvement treatment with cooling in magnetic field-alternating current A.C., H = 1300 A / m, treatment followed by ionic nitriding at 530 °C). In microvolume, after thermomagnetic treatment, the amount of Martensite (M) increased very much [2].

By the action of the magnetic field, the number of martensite germs increases in the same volume, resulting in a finer-finer martensite than in the conditions of classical heat treatment. Martensite increases the hardness of steel. Due to the internal magnetostrictive forces, the conditions for the diffusion of carbon atoms within the elementary cells are created. As a result, the degree of tetragonality of martensite decreases and the fragility of the material decreases. Each of the phases of the magnetic field heat treatment influences the durability differently: the hardening in the magnetic field leads to a 49% increase in durability compared to the classic hardening. The return in the magnetic field determines an increase in durability of only 40% compared to the classic treatment.

At the low recovery of classical hardened steel, the magnetic field slows down the decomposition process of martensite (M), and if the steel has been hardened in magnetic field, the decomposition process of martensite is much slower, there is a tendency to increase the stability of martensite. At the same time, the magnetic field also influences the kinetics of the decomposition of the residual austenite by isotherm, on the heat treatment of tempering, but in the sense of accelerating the transformation. The main cause of these phenomena is the effect of magnetostriction that produces stresses in the microvolumes of the solid solution - stresses that interact with the elastic stress field of dislocations. Magnetostriction represents the dimensional variation of a ferromagnetic material under the action of a magnetic field also called the Joule effect, which depends on the size and direction of the outer magnetic field, the material and the heat treatment previously applied to this material.

3. CONCLUSION

Overlapping a magnetic field - alternative current - in special conditions, on the improvement treatment applied to steel before the plasma nitriding process, it was observed that the quantity of the Fe₄N phase increased in the plasma nitrided layer and the distribution of this phase during wear tests on Amsler stand and implies an increasing of the wear resistance and an improvement of the mechanical properties of the superficial layer of the steel. Also, after thermo-magnetic treatment applied initially, the hardness of the steel increased with 40% in the case of the non-conventional treatment T3 and the micro-hardness of the superficial layer of steel increased with approx. 20 - 30% after thermo-magnetic treatment, depending on the treatment regime applied, comparing to the classic treatment applied. From the diffractometric point of view, the samples had changes of the content of Fe₄N phase in the superficial layer thermo-chemically treated. So, the magnetic field influences positively the mechanical properties of the steel.

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