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Determining the Diffusion Coefficient in Practice of Nitrogen and Carbon for Nitro-Carburizing High Alloy Steel

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Abstract
Through concomitant diffusion of carbon and nitrogen it is aimed the obtaining of superior characteristics of layer and the increasing of efficiency of diffusion process, compared with the simple nitriding. The phenomena of wear, fatigue and corrosion are the main factors that lead to out of use of a tool. All these unwanted phenomena have a common feature: they preponderant occur or in exclusiveness in the superficial layer of the tool. From these considerations appears special significance that is giving researching the physical -chemical processes which occur in superficial layers, as well technologies of obtaining of these layers. Hardness, wear, and fatigue problems are resolved by using in majority of cases of some thermo-chemical and heat treatments, which allow the obtaining of the necessary proprieties of exploitation due to transformations that occur in steel at heating-cooling it.

Keywords
diffusion process, thermo-chemical and heat treatments, superficial layer, X-ray spectra

1. Introduction

In order to determine the coefficient of diffusion for speed steel nitro-carburizing, it has been considered practically data on my research, according to Table 1 and Figure 1. Table presents the calculated value of diffusion coefficient for speed steel Rp3 at two temperatures in nitro-carburizing regime.

The data practically obtained at thermo-chemical treatment of nitro-carburizing and utilized at diffusion coefficient calculation.

Table 1. Value of diffusion coefficient

Nr. crt	Steel type	t [°C]	T [K]	[cm]	τ [s]	D·10^{-7} [cm^2/s]	D·10^{-7} [cm^2/s]
1.	Rp3	570	843	0.048	7200	1.600	2.674
				0.080	14400	2.222	
				0.125	21600	3.617	
				0.137	28800	3.259	
2.		560	834	0.044	7200	1.344	2.176
				0.075	14400	1.953	
				0.107	21600	2.650	
				0.126	28800	2.756	

The average diffusion coefficients for each x and τ were calculated using the Fick's Law I (taking into consideration the useful diffusion depth), as follows [3]:

$$\overline{D} = \frac{x^2}{2\tau} \tag{1}$$

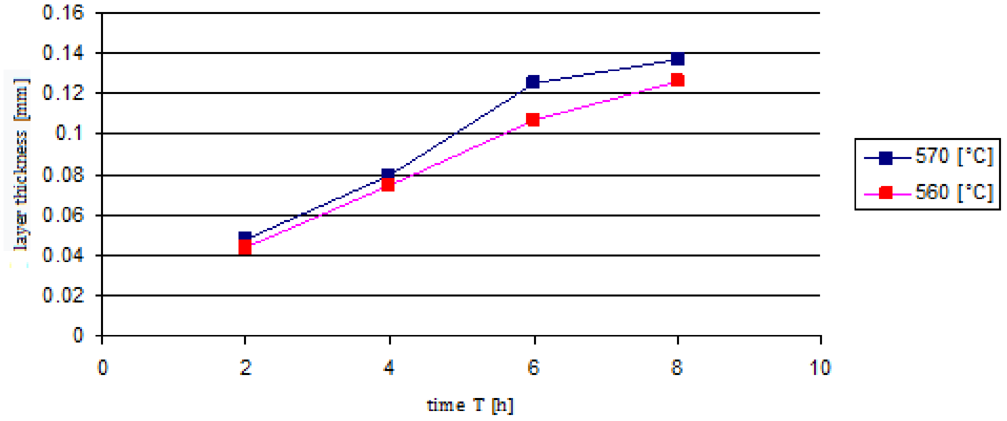

Fig 1. The influence of temperature and the maintaining duration
upon the thickness of nitro-carburizing layer

Knowing the general relation of the diffusion coefficient:

$$D = A \cdot e^{-\frac{Q}{RT}} \tag{2}$$

and looking for a relation between D and T is utilized a dependency of form:

$$\overline{D} = A \cdot e^{-\frac{B}{T}}, \qquad B = \frac{Q}{R}. \tag{3}$$

To calculate the coefficients A and B we used the logarithmic form of the above relation:

$$\lg D = \lg A - \frac{B}{T} \lg e, \tag{4}$$

and making the substitutions:

$$\frac{1}{T} = X \tag{5}$$

a linear equation is obtained

$$Y = -BX \lg e + \lg A \tag{6}$$

and consequently

$$-B \lg e = m \quad \text{and} \quad \lg A = n \cdot B = -\frac{m}{\lg e} \quad \text{and} \quad A = 10^n \tag{7}$$

result

$$Y = mX + n. \tag{8}$$

Using the method of the smallest squares, it determined the values of *m* and *n.* This method appreciated the line that cross through the two points experimentally determinate (Table 1 and Figure 1) by coordinate X_i and Y_i.

The equation of the line that crosses through the points X_i and Y_i is:

$$D = A \cdot e^{-\frac{B}{T}} \tag{9}$$

and calculating the diffusion coefficient for diverse regime temperature at nitro-carburizing, it results

$$D_i = 7.727 \cdot e^{\frac{14526.4975}{T_i}} \tag{10}$$

2. Applied Thermo-Chemical Treatments

Nitro-carburizing has been effectuated in gas mixture containing 50% CO + 25% NH_3 + 25% N_2, at regime temperature of 570 °C, the temperature corresponding to drawback temperature of speed steel.

Nitro-carburizing has been effectuated on sample of speed steel Rp3 and Rp5 that had final thermal treatment previously.

This heat treatment consisted of oil hardening from 1260 °C for Rp3 and 1190 °C for Rp5 and two consecutively drawback of 1.5 hour each (Table 2).

Table 2. The technological parameters of the thermo-chemical nitro-carburizing treatment in plasma

Steel type	Heat treatment	Thremo-chemical treatment	Atmosphere	Pressure [torr]	Temp [°C]
Rp3	Oil hardening from 1260 °C and two drawback 1.5 h	Nitro-carburizing in plasma	50%CO + 25%NH_3 + + 25%N_2	1.5	570
Rp5	Oil hardening from 1190°C and two drawback 1.5 h				

In Table 3 is presented the thickness of the layer obtained during the nitro-carburizing treatment in plasma during different time duration.

Table 3. The thickness of the layer obtained during the nitro-carburizing treatment in plasma during different time duration

Steel type	Thermo-chemical treatment of nitro-carburizing in plasma			
	Layer thickness [mm]			
	2h	4h	6h	8h
Rp3	0.0048	0.0080	0.125	0.137
Rp5	0.0039	0.0074	0.0101	0.124

The surface hardness was evaluated after performing the nitro-carburizing thermo-chemical treatment in plasma. The data were centralized in Table 4.

Table 4. The values of the hardness of the surface for samples of Rp3 and Rp5 nitro-carburized in plasma for 6 hours at the temperature of 570 °C

Steel type nitro-carburized in plasma at 570°C, 6h	Hardness of the surface (Vickers, 500 p / HV0.5)										Average
Rp3	1219	1409	1256	1303	1192	1228	1333	1294	1274	1228	1274
Rp5	1303	1334	1323	1293	1323	1344	1294	1293	1304	1303	1311

As it can be seen from microstructures previously shown (Figures 2 and 3), the nitro-carburized layer is clearly contoured. It is made of diffusion zone of dark color. For a duration time equal with 6 hours the combinations zone barely begins to take shape, in the experimental conditions applied, it gradually grows after this time interval.

Practically, the combination zone must be very narrow or it should be missing, because it is very fragile, being able to create difficulties in the use of the tools.

The higher hardness of the nitro-carburized layer (of 1400-1500 HV) ensures a very good resistance during usage and in the same time it increases the resistance to the fatigue [6, 7]. The increasing resistance to fatigue is due to compression tension that are being generated in layer by the formation of secondary phases and the diffusion of carbon and nitrogen in matrix layer [1, 3, 4].

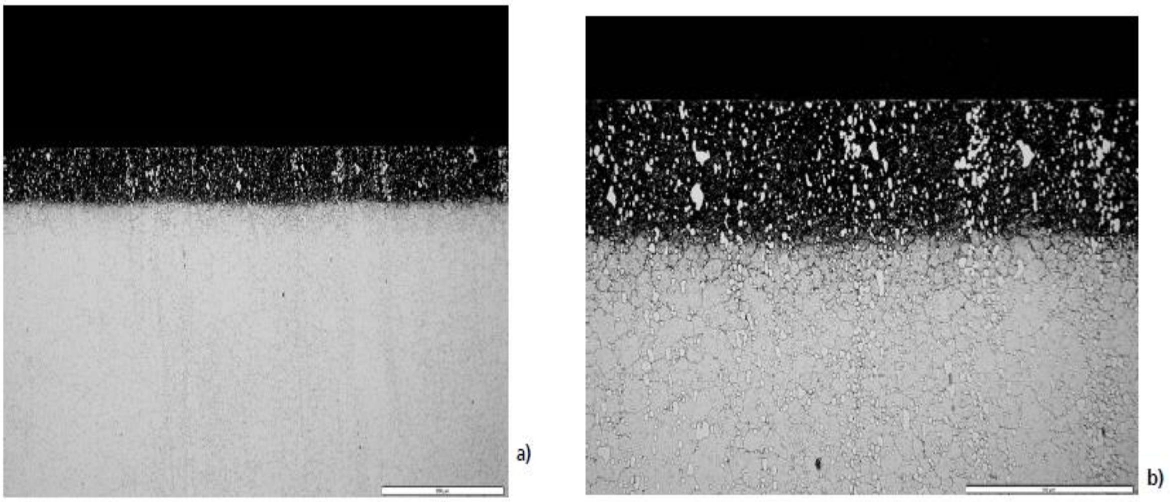

Fig. 2. Steel Rp3 nitro-carburized in plasma, cross section
a) - overview 200μm; b) - detail 100 μm

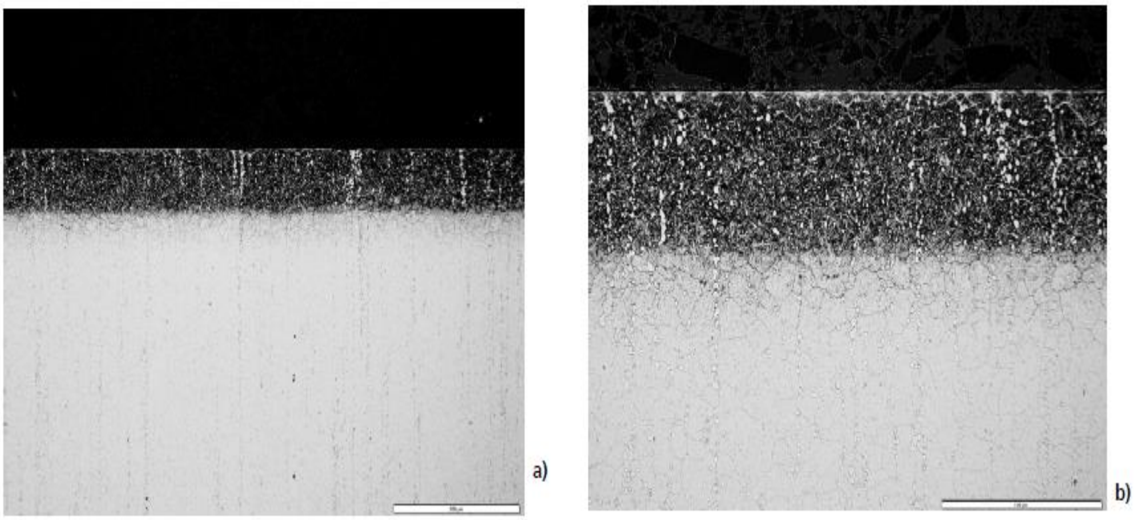

Fig. 3. Steel Rp5 nitro-carburized in plasma, cross section
a) - overview 200μm; b) - detail 100 μm

3. The Results of Analysis X-rays

The electronic microscopy of the basic material also points out the softer structure of the steel Rp5 in comparison with Rp3. The metallographic components are martensite and carbides. The analysis with X-rays (Figures 4 and 5) shows major differences between the diffusion layer and the core.

In the core, the main materials is martensite (α - Fe) in which are dissolved the alloy elements (Cr, W, Mo, V). Also, it is evident the presence of the carbides and the allied cementites. In the diffusion layer the structure is more complex. The nitrides are there besides the components of the core; the carbon share from the layer lead to the diversification of the complex wolfram carbides (Fe_2W_2C, Fe_4W_2C).

The wear resistance is given by the un-metallic characteristics of the layer which hampers the formation of the micro-welding points of the surfaces in contact, having a reduced coefficient of friction and a higher grinding capacity [2, 5]. The way the hardness is distributed generates compression tensions in the nitrocarburate layer. These tensions increase the resistance to fatigue.

4. Conclusions

The kinetics of growth layer that had been nitro-carburized in plasma depends on the thermal and temporal parameters of the process and the chemical composition of the steel.

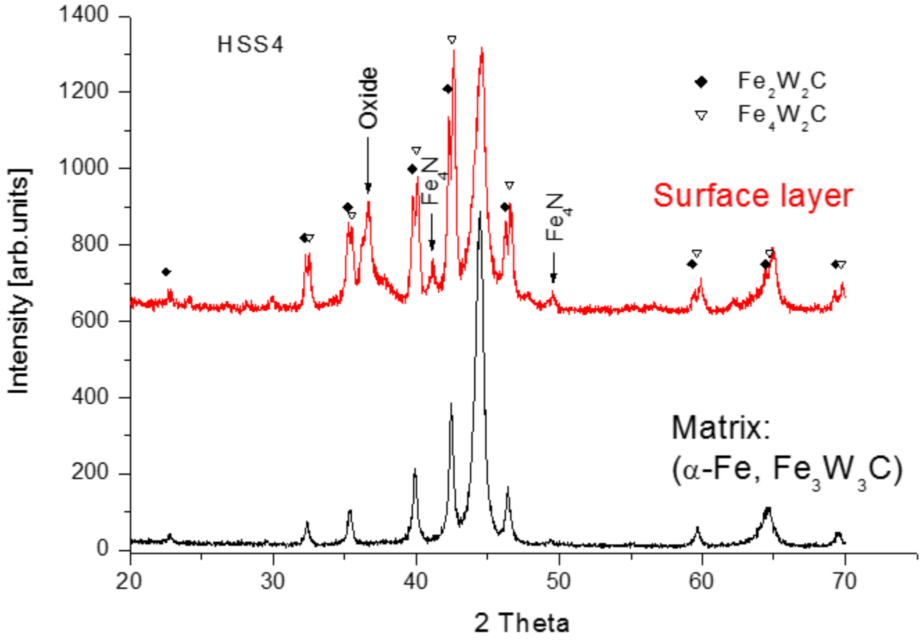

Fig. 4. Steel Rp3 nitro-carburized for 6 hours at 560 °C. Diffraction of X-rays

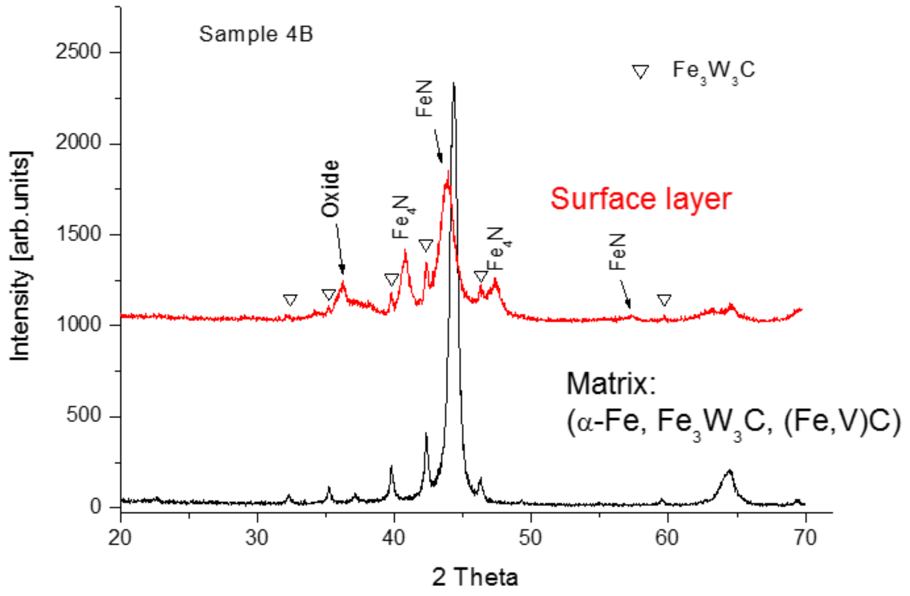

Fig. 5. Steel Rp5 nitro-carburized for 6 hours at 560 °C. Diffraction of X-rays

If the nitrogen diffuses in steel, the carbides will be converted in nitrides or carbo-nitrides because it is known that the alloying elements have a greater affinity for nitrogen than for the carbon.

The alloying elements do not favor the growth of nitro-carburized layer. The hardness of the combination layer and that of diffusion increases proportional to the content of the alloying elements, which in general have a hardness effect on the matrix of the nitro-carburized layer.

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