



## OPTIMIZATION OF DEEP CARBURIZING HEAT TREATMENT

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### ABSTRACT

*Optimization of deep carburizing heat treatment is made with integration in heat treatment process, next stages, diffusion and annealing spheroidization that is to transform the residual austenite into ferrite and globular carbides. These steps allowed to bring carburized materials in optimal parameters. In this paper are presented research on the hardness of SAE 3310 and SAE 4320 steels in different moments of deep carburizing, made by the proposed method. This research clearly demonstrate an improvement in outcomes deep carburizing and the application of optimization methods in concrete conditions has an important role, with real benefitts. From the study carburizing treatments can be observed decrease in residual austenite content located on the surface of the piece after diffusion and spheroidization annealing, which leads to increased hardness in the area.*

**Keywords:** deep carburization, diffusion, mass transfer

### INTRODUCTION

Carburizing in a controlled atmosphere uses a gas mixture of a carrier gas, produced in a controlled atmosphere generating and natural gas added in order to ensure a certain amount of carbon potential. [1], [2].

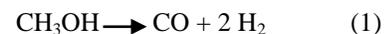
Carburizing heat treatment, defined as a process of heat treatment of metals and alloys, with a succession of heating and cooling operations under specified conditions applied to metal products, in order to bring them into structural and internal stress conditions favorable to use, has in its application to large bearings a few of essential features:

- carburizing in gas medium with controlled carbon potential;
- great carburizing depth (6-8mm);
- great time for keeping in carburizing furnace (80-120 hours);
- achieve of a minimum hardness of 59-60HRC carburated surface;

Knowledge of thermodynamic parameters based on the analysis of independent reactions taking place in the oven workspace. The carburizing process is generally described by the following steps:

- reactions between components of carburizing environment;
- transport and transfer of carbon to carburizing environment - metal surface interface;
- diffusion of carbon into the metal matrix.

The standard approach to providing a controlled atmosphere with a different carbon potential by the introduction of propane is obtained by the furnace preparation, which is purged with inactive gas of nitrogen and methanol. [3] The methanol is in the liquid state up to 65<sup>o</sup>C and then evaporated down. At 750<sup>o</sup>C it behaves according to the following reaction:



The mixture is made of 2/3H<sub>2</sub> + 1/3 CO. Within the mixture occur in very small quantities of carbon dioxide (CO<sub>2</sub>), water vapor (H<sub>2</sub>O) and methane (CH<sub>4</sub>). By introducing an approximately equal volume of nitrogen in the furnace an inert gas is obtained such as:

20% CO, 40% H<sub>2</sub>, 40% N<sub>2</sub>.



This composition corresponds to the composition of an endogaz. Carbon enrichment is done by using propane, reaching that the atmosphere has a carbon potential of  $C_p = 1.1-1.4$

The mass flow unit describes how many grams of carbon reach the surface in a second unit. It is defined by the product of the transfer coefficient  $\beta$  and the potential difference between carburizing environment and the carburized part.

$$\phi = \beta(C_a - C_s) \quad (2)$$

where  $\Phi$  - mass flow unit [ $\text{g}/\text{cm}^2\text{s}$ ]

$\beta$  - transfer coefficient [ $\text{g}/\text{s}$ ]

$C_a$  - carbon potential of carburizing atmosphere [ $\text{g}/\text{cm}^3$ ] [4], [6].

Mass transfer from the carburizing environment on the metallic surface occurs due to the difference between the average concentration ( $C_a$ ) and metal surface ( $C_s$ ).

The phenomenon of adsorption is the process through which the mass transfer at the gas-solid occurs.

The phenomenon of adsorption is the process through which the mass transfer at the gas-solid occurs. By adsorbing a concentration of carbon atoms in the gaseous-medium interface surface is produced. If the connection forces between the metal surface and adsorbed atoms are of physical nature (Van der Waals forces), adsorption is physical, and if connections that are established valence (chemical) bonds chemical adsorption (chemisorbtion) occurs.

During the physical adsorption structural changes do not occur between the adsorbed molecules but there is a slight deformation of the valence electrons orbit.

Adsorption mechanism can be explained by two theories accepted by the researchers:

- Free atomic theory whereby on the surface of the metallic products, dissociation of carburizing environment (gaseous) molecules occurs with release of active atoms that can be adsorbed by the solid; by this theory can not be explained some phenomena occurring during the carburizing such as the favorable influence of water vapors on carbon adsorption.
- Theory of electrostatic forces whereby ions or ionic complexes formation occurs through an ionization process of the environment as a result of electron transfer through thermoelectric emission from the metal surface to gas molecules; electrostatic forces act on the excited gas molecules and thereby determines their adsorption onto the metal surface.

Ionic complexes dissociate in adsorbed state, thus forming active carbon atoms, which then diffuses into the metal.

Diffusion occurs in the metallic material as a result of the appearance on its surface layer of an excess of carbon atoms from the gaseous medium by adsorption mechanisms. Carbon atoms at the metal surface will diffuse into the surface layer with the concentration  $C_s$  to the interior of the solid body with concentration  $C_0$ , which results in the formation of carburized layer.

According to Fick's second law, the solid diffusion process can be described by a differential equation of the type:

$$\frac{\partial c}{\partial \tau} = \frac{\partial}{\partial x} \left( D_{(c)} \frac{\partial(x,t)}{\partial x} \right) \quad (3)$$

$$D_{(c)} \frac{\partial c}{\partial x} = J_i \quad (4)$$

Restrictions consist in carbides formation and residual austenite. These drawbacks can be avoided by low carbon potential closed to the eutectoid content.

The entry data are: chemical composition of steel, carbon potential, mass transfer coefficient of steel, time of maintaining in controlled atmosphere and the temperature of this space. For optimal results, is imposed to obtain a controlled percent of carbon to a certain depth, making allowances for rectification processes so that the carburized pieces must be resistant to the end of heat treatment. [5]

Researches has been done in order to emphasize that the carburizing thermochemical treatment performed on bearing elements generally and on hollow and cylindrical rollers especially, on large bearings can be performed on very large depths (7-8mm) with excellent results in the field of increase bearing life. Such attempts were made on SAE 3310 steel.

## OPTIMIZATION OF CARBURIZING PROCESS

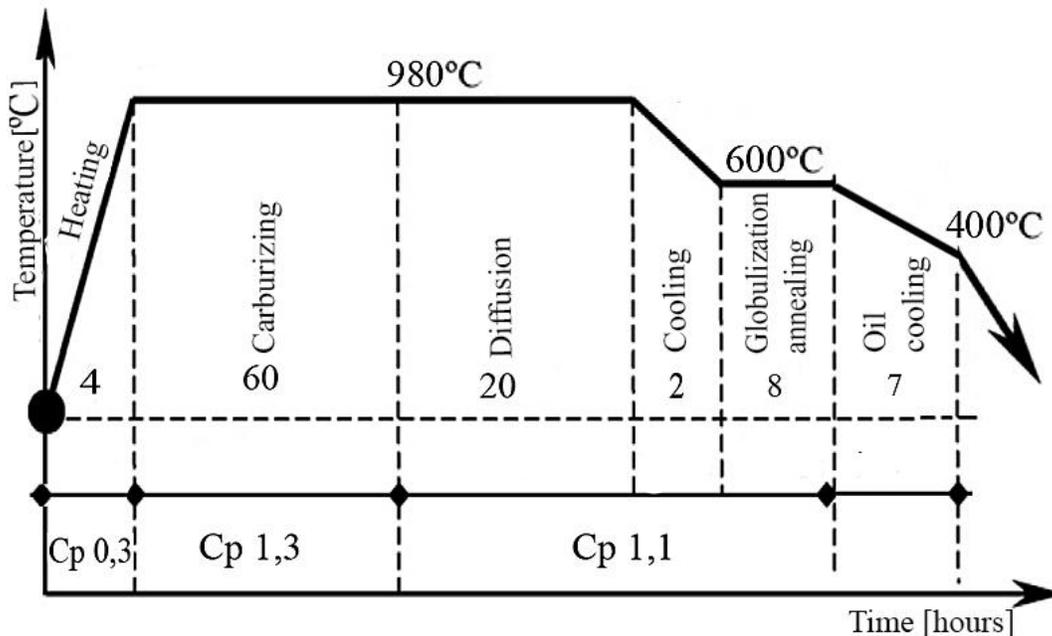
Research carried out and presented below provide theoretical and practical developments towards deep carburizing on very large sizes 6-8mm into the carbon potential atmosphere  $C_p = 1.3-1.4$  specific for large sized bearings. In Fig. 1 it can be seen that during the heating pieces reach from ambient temperature to  $980^\circ\text{C}$ , the carburizing

temperature, followed by combined carburization with diffusion of different carbon potential, cooling, maintain and then again cooling to the ambient temperature. Time for the heating step is different between 3 and 4 hours, depending on the volume of the carburated part and for the diffusion phase it takes 30-35% of carburizing phase. Cooling is done in the furnace. [11]. The formation of a residual austenite amount is almost inevitable in steel layers carbide microstructures containing high levels of carbon. However, excessive residual austenite in amounts of more than 50%, causes a decrease in the level of hardness and a reduction in fatigue strength.

The main cause of residual austenite excess is the existence of an excessive carbon content on the surface layer. This condition lowers  $M_s$  Temperatures and so displaces the equilibrium of martensitic transformation. The most common areas of carbon concentration at the surface are edge and corner areas of the parts because there are areas in which austenite saturates tin carbon- in the first stage of the carburizing cycle. Although carbon has access from both sides of the corner area, it is not able to get inside the sample during the diffusion cycle. As a

result, even though the carbon content gradually drops to the desired level on the flat or curved surface of the workpiece, the carbon content existing at the corners is still much higher than the desired one and therefore a high content of retained austenite, is resulting in a lower level of hardness compared to that existing on flat surfaces.

Another consequence of high carbon content is revealed by the formation of massive carbides. These carbides are formed at the austenite grain boundary and may have different morphologies in interdependence with the degree of alloying of steel subjected to carburizing. Carbon potential, both at carburizing step and the diffusion step is strictly controlled by the sensor, being when it decreased, atmosphere being supplemented again with propane. The subcritical spheroidization annealing is applied after carburizing and diffusion because it still retains an amount of residual austenite during annealing, which undergoes transformation to ferrite and globular carbides. It is made at 600 ° C for approx. during 8 hours with slow cooling to produce the spheroidization of the existing carbides.



**Fig.1** The proposed diagram of deep carburizing heat treatment

In view of quenching (hardening), austenitization is carried out in controlled atmosphere

furnace with carbon potential  $C_p = 0.8\% C$  at 800°C, semi-products being fixed in special devices that



prevent major deformations. Retention time for austenitization is dependent on the thickness of the products, aiming the partial dissolution of the globulizate carbides existing in the carburized layer.

In general, the time required for austenitization is subject to the percentage of carbon, the thickness of the heat-treated layer (2.5 cm / h) and the temperature, heating at a temperature of 55<sup>0</sup>C above the austenitization temperature leading to an optimization of thermal treatment. Bearing carburated elements are austenized at temperatures of approx. 800<sup>0</sup>C. [7]

Cooling for hardening is performed by fast transfer from the austenitization oven (furnace) and immersing the product together with the device, in the salt bath at a temperature of 180<sup>0</sup>-200<sup>0</sup> C.

The formation of martensite hardens steel depending on the proportion of carbon It is noted that the maximum hardness is achieved at a rate of 0.8% carbon. This is explained by the fact that the existence of more than 0.8% residual austenite

decreases the hardness of the steel.. In the salt bath products are held for 6 hours in order to transform hardening martensite into recovery martensite and to reduce the residual austenite content. Relatively high recovery duration aims relaxation and redistribution of residual stresses. [8], [9], [10].

**EXPERIMENTAL RESEARCHES**

Blanks are cylindrical and have the dimensions: D=40 mm și L=30mm.

Carburizing was done in an atmosphere of carbon potential Cp = 1.4Carbon potential was measured every 6 hours and brought to its prescribed value by adding propane. Cooling was done in water.The assessment of hardness was made of the surface of workpiece until core measurements performed at a distance of 0.5 mm pitch.

Time was chosen according to the diagram in Fig. 1. Measurement results are in Table 2.

In Table 1 are shown the used materials.

Table 1 Chemical composition of carburized pieces

Steel	Standard	Chemical composition [%]							
		C	Mn	Si	Cr	Ni	Mo	S	P
3310	SAE	0,08	0,45	0,15	1,40	3,25	0,15	max 0,035	max 0,04
		0,13	0,60	0,35	1,55	3,75			
4320	SAE	0,17	0,45	0,15	0,40	1,65	0,20	max 0,035	max 0,04
		0,22	0,60	0,35	0,60	2,00	0,30		

Table 2 Hardness of steel for different time of carburizing process

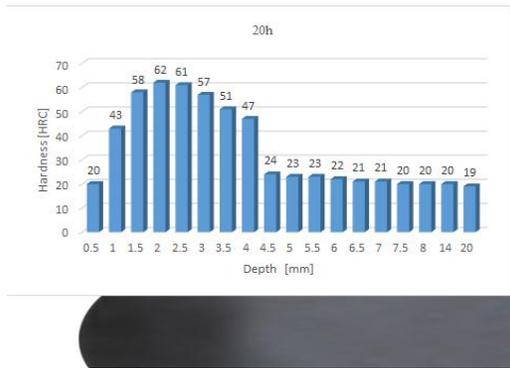
Time [h]	Hardness steel 3310 [HRC]																		
	Depth[mm]	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	14	20
20 h	20	43	58	62	61	57	51	47	24	23	23	22	21	21	20	20	20	19	19
35h	26	45	56	60	62	63	60	57	52	49	25	23	22	21	21	21	20	20	19
50h	21	26	37	49	56	60	61	63	62	60	57	53	50	45	30	25	20	20	20
60 h	37	31	38	47	53	58	61	62	63	63	61	58	55	52	49	43	23	20	20
80 h	39	42	45	50	55	59	60	62	63	63	61	59	56	53	51	48	25	21	21
100 h	60	61	61	61	61	61	60	60	59	58	57	55	54	52	50	48	24	21	21
	Hardness steel 4320 [HRC]																		
20 h	21	41	55	60	61	59	33	48	25	24	23	23	21	21	20	19	19	19	19
35h	26	44	54	57	60	64	61	58	51	47	25	24	22	21	21	20	19	19	19
50h	26	27	35	51	56	61	61	62	61	59	58	51	50	47	31	20	20	20	20
60 h	34	32	38	49	53	60	61	63	63	62	60	58	54	52	47	42	22	20	20
80 h	41	44	49	53	56	60	61	62	63	62	62	59	58	55	54	45	23	21	21
100 h	61	61	61	61	62	62	61	60	60	58	56	55	53	51	49	48	23	21	21



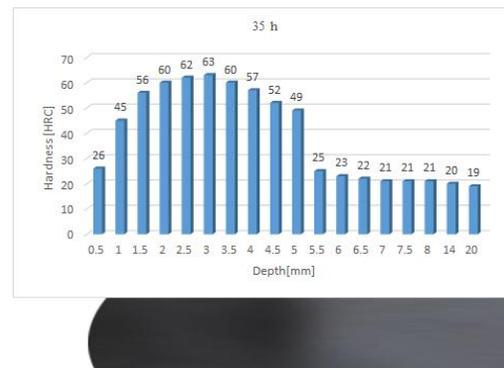
**Interpretation of results**

Measurements show clearly hardness changing with keeping time in the oven (furnace). In Fig.2 diagram it is shown the evolution of hardness after 20 hours of carburizing in controlled environment with  $C_p = 1.4$ . Note that carburized layer is about 4 mm and at the surface appears a significant reduction of hardness due to residual austenite. In Fig.3,4,5, moments 35 h,

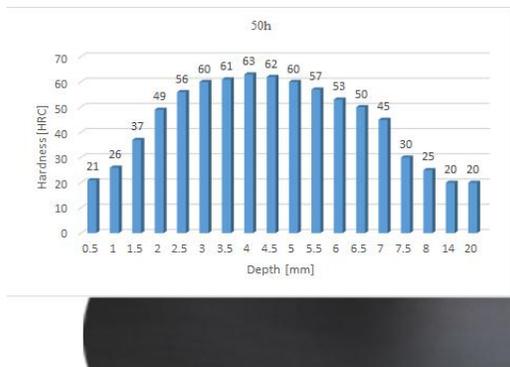
50 h and 60 h are presented, which practically end carburizing stage with  $C_p = 1.4$ . An increase of carburized layer up to 8 mm can be observed. In Fig.6 hardness diagram is shown after diffusion and in Fig.7 diagram is shown after spheroidization annealing.



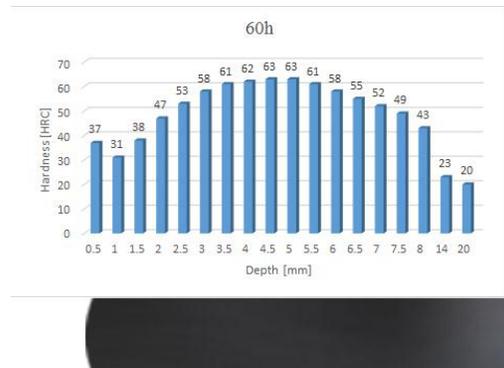
**Fig.2** Diagram of hardness for SAE 3310 after 20 hours



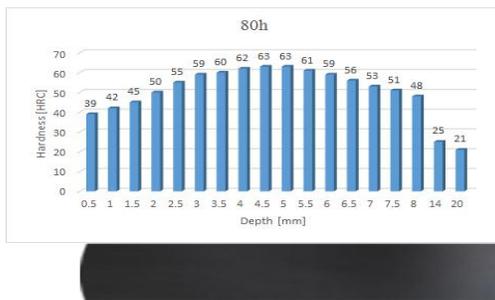
**Fig.3** Diagram of hardness for SAE 3310 after 35 hours



**Fig.4** Diagram of hardness for SAE 3310 after 50 hours



**Fig.5** Diagram of hardness for SAE 3310 after 60 hours



**Fig.6** Diagram of hardness for SAE 3310 after 80 hours



**Fig.7** Diagram of hardness for SAE3310 after 100 hours



## CONCLUSIONS

Hardness graphics were obtained depending on the time of carburizing and carbide layer depth, drawing diagrams that can be used in choosing the carburizing parameters. It is noted the relationship between the average carburizing rate and holding time, noting the decrease of that, with increasing of carburizing time. Considering, in the case of deep carburizing, that occurs inevitably, a hyper-carburization on depth 1-3 [mm], with the effect of obtaining an unacceptable concentration of residual austenite (60-70%), after quenching, was necessary to find a solution to reduce the amount of carbon in the normal. This was done by applying a diffusion treatment after carburizing into the atmosphere of carbon potential decreased. While maintaining the temperature at 980<sup>o</sup>C, for 20 hours into an atmosphere with Cp=1,1 was done redistribution of carbon atoms in the layer, on 7-10 mm from surface. From the study of the diffusion and carburizing treatments can be observed decrease in residual austenite content located on the surface of the piece after diffusion, which leads to increased hardness in the area.

The factors that determine the distribution of carbon in the layer are carburizing temperature, maintaining time in furnace, carburizing environment features, characteristics of the steel subjected to carburizing can be established after determination of hardness curves from materials.

## Acknowledgement

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