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EXAMPLE OF DECARBURISING PHENOMENA DURING THE CARBURASING HEAT TREATMENT PROCESS

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ABSTRACT

Carburizing is a very popular method of thermochemical treatment to increase the surface hardness of steel parts. It is achived by heating the steel at an austenite temperature in an environment of appropriate carbon source. Carbon sources provide the corresponding so-called a carbon potential (C potential). In the case of equilibrium state, the carbon concentration is the same in a gas atmosphere and steel. However, a nonequilibrium state leads to carburizing or decarburising processes. This paper presents the results of microstructure analysis of the steel 20X after carburizing heat treatment. The microstructure analysis was performed for the initial state of the samples, after carburizing without quenching (cooling on the air) and in the quenched state. After the heat treatment a decarburising area at the surface of the sample is visible.

1. INTRODUCTION

Carburizing is one of the oldest methods used for increasing of the surface hardness of steel parts. Increasing of carbon content at the surface, followed by quenching (to get martensite microstructure) and low temperature tempering leads to very high hardness in the surface layer (in the range of HRC 58–62) while the core stays a tough and ductile. After carburizing the carbon content at the surface is usually in the range of 0.7-0.9 (1.0%) while the carbon content in the core is about 0.15-0.25%. [1, 2, 3]. Carburizing is achieved by heating of steel at the austenitizing temperature (800-1050 ^{o}C) in an environment of appropriate carbon sources. Carbon sources could be in solid, liquid, gaseous and plasma state and it provides the corresponding so-called a carbon potential (C potential) which is higher than the carbon content in the steel. C potential is the maximum carbon content that can be reached during the carburizing on the surface of steel and it is in balance with a gaseous environment at carburazing temperature.

In the nonequilibrium condition the activity of carbon in the carburizing atmosphere ($a_{C(gas)}$) is higher than the activity of carbon in the steel ($a_{C(steel)}$). The difference in the carbon activities leads to the desired carbon transfer into the steel. The flux

m (number of atoms M that penetrate the area F in unit time) is proportional to the carbon activities difference:

$$\vec{m} = \frac{M}{F} dt = -\beta(a_{C(gas)} - a_{C(steel)}) \qquad (1)$$

Where β is the carbon transfer coefficient (which is dependent on the composition of the carburizing atmosphere and the carburizing temperature with value $1.25x10^{-5}$ cm/s for endothermic methane-propane gas). By combining equation of Fick's first law (2) (where D is diffusion coefficient and according to which the variation in time of the concentration depends on the concentration gradient $\frac{\partial c}{\partial x}$ parallel to the x-axis)

$$\frac{\partial c}{\partial t} = -D \frac{\partial c}{\partial x} \qquad (2)$$

and equation (1) a formula for the effect of time on the growth of the carbon diffusion depth can be derived as follows:

$$x = At = \frac{0.79\sqrt{Dt}}{0.24 + \frac{C_{At} - C_0}{C_p - C_0}} - 0.7\frac{D}{\beta} \quad (3)$$

Where the limiting carbon content C_{At} determines the depth At of carbon diffusion [3].

The content of carbon in the surface layer depends on the temperature, time, C potential of the agent for carburasing and the chemical composition of the steel. It generally tends that the carbon content in the surface layer is about 0.8% for non-alloy steels and less for alloy steels [4]. The carbon content in the surface layer should not be higher than 1.1 % because of forming a retained austenite and/or cementite network. The carbon content decreases from surface to center and by measuring of microhardness from the surface to the center is possible to determine the depth of carburized and hardened layer according to the standard BAS EN ISO 2639:2004 [5, 6].

This paper presents the results of microstructure analysis of steel 20X after carburizing heat treatment. The microstructure analysis was performed for the initial state of the samples, after carburizing without quenching (cooling on the air) and in the quenched state.

2. EXPERIMENTAL

Initial material in this experiment was steel 20X according to standard GOST 4543-71. That is a chromium steel with chemical composition given in Table 1.

Table 1. Chemical composition of steel 20X (standard GOST 4543-71) [7]

Steel	**Chemical composition, wt.%**					
	C	**Si**	**Mn**	**P**	**S**	**Cr**
20X	0.17-0.23	0.17-0.37	0.5-0.8	max.0.035	max.0.035	0.7-1.00

Microstructure of initial state of the steel 20X is the ferrite-pearlite microstructure, Figure 1.

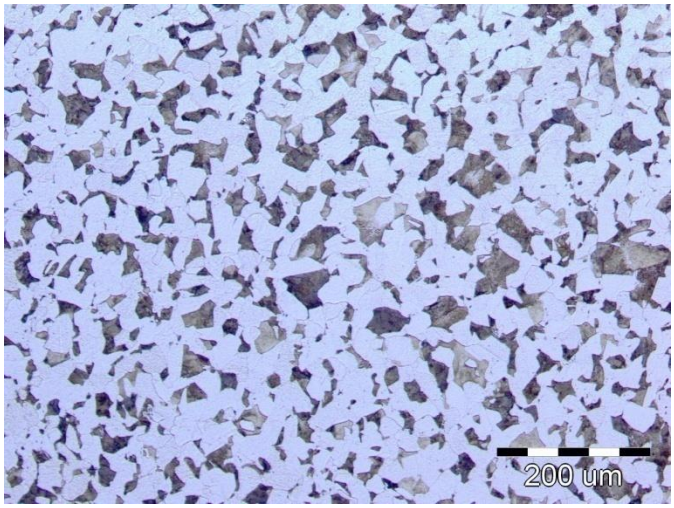


Figure 1. The ferrite-pearlite microstructure of initial state (Nital, x100)

Carburizing process was performed in the atmosphere of endogas (Table 2) at 925 °C for 13.5 hours. C-potential at this temperature was 1.2. Before quenching the temperature in the furnace was decreased to 880 °C and C-potential was 0.8. Holding time at 880 °C was 1 hour. From the temperature 880°C steel 20X was quenched in oil. Low temperature tempering was not performed during the heat treatment process. Diagram of the heat treatment is presented in Figure 2. The furnace for cementation is shown on Figure 3.

Table 2. Chemical composition and other parameters of the gas atmosphere (endogas)

CO_2 [%]	**CH_4 [%]**	**CO [%]**	**H_2 [%]**	**Dew point [^{0}C]**	**Temperature of Endothermic Generator [^{0}C]**
0.250	0.0	21.5	38.6	4.1	1000

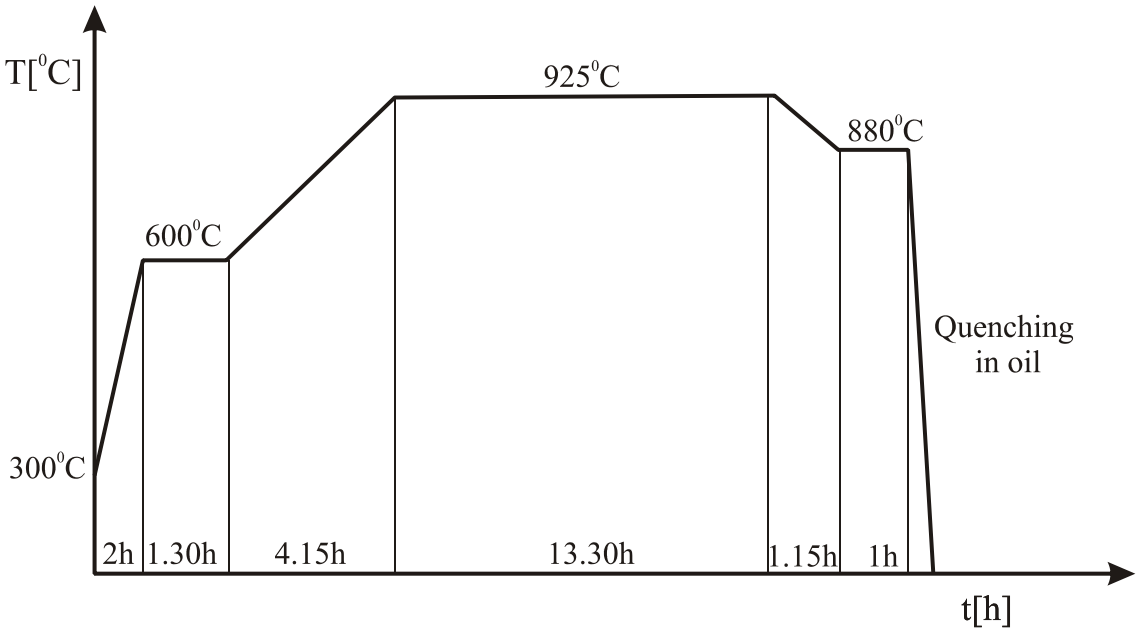
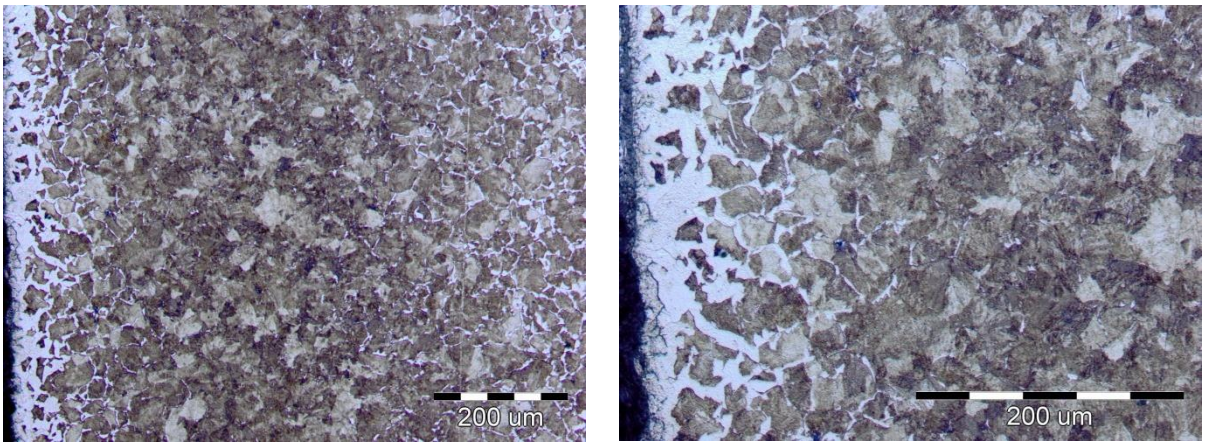


Figure 2. Diagram of the heat treatment

Figure 3. Pit furnace for cementation made by company Bosio

3. RESULTS AND DISCUSSION

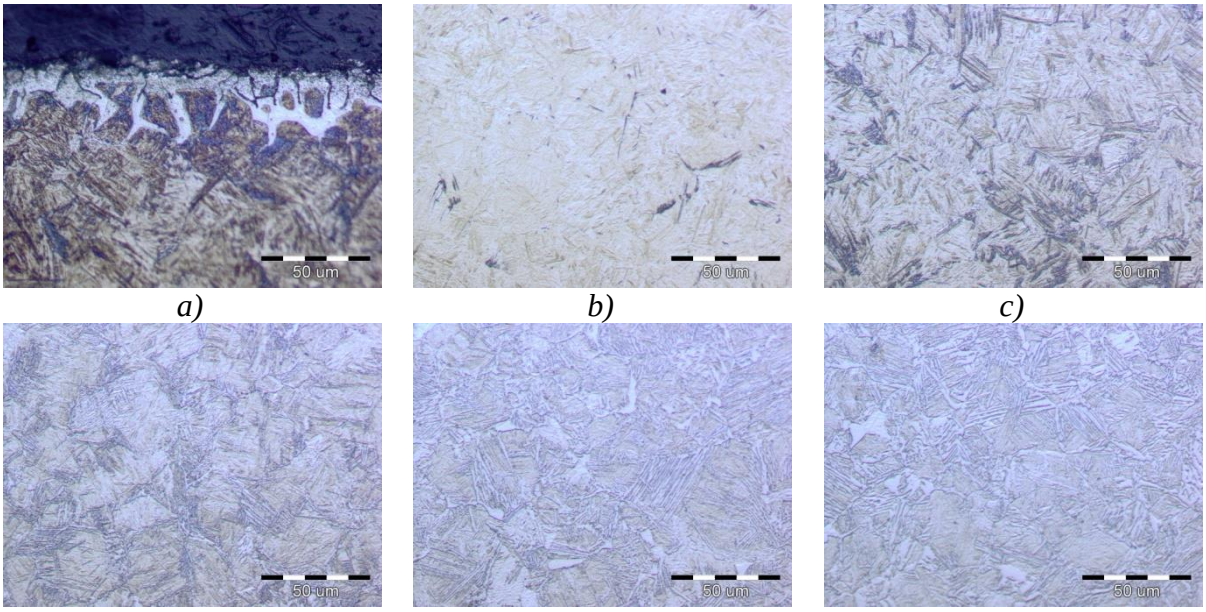
The microstructure analysis was performed for samples after carburizing without quenching (cooling on the air) and in the quenched state. For analysis of microstructure an optical microscope with maximum magnification of 1000x was used. Analysis of microstructure of the sample after cooling in the air indicates presence of the decarburised layer on the surface, Figure 4a and 4b. Under decarburised layer, cemented layer with pearlite microstrucure is present. Center of the sample was the ferrite-pearlite microstructure.



a) *b)*

Figure 4. Microstructure of surface of sample after cooling on the air: a) magnification x100 and b) magnification x200, Nital

After carburasing and quenching in oil martensite microstructure of steel 20X is noticed, Figure 5. On the surface plate martensite is present and in the center presence of lath martensite is noticed. On the surface of the sample, the decarburised layer is present too. Decarburised layer is less pronounced than in sample which was cooled in the air.



a) *b)* *c)*

d) *e)* *f)*

Figure 5. Microstructure of steel 20X after carburasing and quenching at six points from surface a) to the center f), x500, Nital

The depth of carburized and hardened layer was determined according to the standard BAS EN ISO 2639:2004 using Zwick equipment (device for testing hardness and microhardness) and optical microscope Olympus PMG3. The hardness was measured in two lines with HV1 test. The case hardened depth is the perpendicular distance between the surface and the layer having a hardness of 550 HV1 according to ISO 6507-1 [5,6]. Results of determination of the depth of carburized and hardened layer are given in Figure 6. The depth of carburized and hardened layer was 0.828 mm.

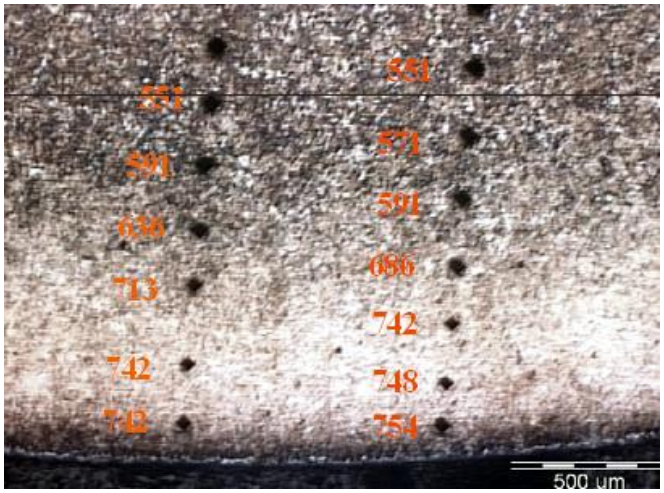
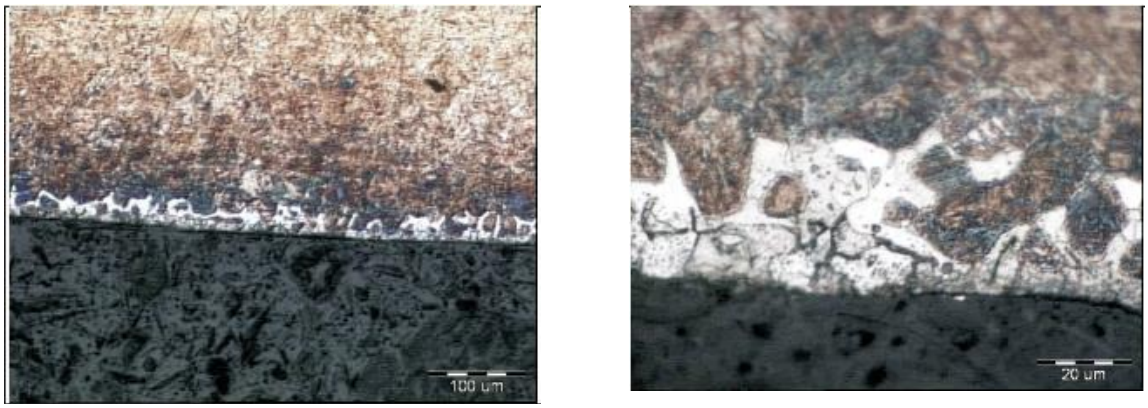


Figure 6. Determination of the depth of carburized and hardened layer

The depth of decarburization estimated according to standard ASTM E 1077-01 (R2005) [8] showed that a complete decarburization was 10.1 μm, a partial decarburization was 20.4 μm i.e. the total depth of decarburization was 30.5 μm, Table 3 and Figure 7. Determination of the depth of carburized and hardened layer and the depth of decarburization was done on Institute “Kemal Kapetanović” in Zenica.

Table 3. Results of measuring of the depth of decarburization

Sample		**The depth of decarburization**					
		1	2	3	4	5	**Average**
20X	a complete decarburization	13.4	14.6	6.7	8.2	7.4	**10.1**
	a partial decarburization	17.9	22.0	21.3	17.5	23.2	**20.4**
	a total depth of decarburization	31.3	36.6	28.0	25.7	30.6	**30.5**



2%HNO₃ *x150* *2%HNO₃* *x750*

Figure 7. Example of decarburization

4. CONCLUSIONS

In this paper the results of analyzing of microstructure of steel 20X after carburizing process were presented. Microstructure was martensite and the depth of carburized and hardened layer was 0.828 mm. However, the decarburized layer was noticed on the surface of carburized samples on both samples (cooling in the air and quenching in the oil). The total depth of decarburization was 30.5 μm. The reason for decarburizing is a presence of a nonequilibrium state during one period of time when the carbon concentration in steel was higher than in the gas atmosphere. Possible reasons for that could be:

- Variation of the C potential during the process,
- Process was done in the new furnaces (there is possibility that a new retort accept a carbon on itself),
- Blowing an oxygen probe with air,
- Possibility of moisture presence in the floor concrete of the retort.

5. LITERATURE

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