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HEAT TREATMENT OF LOW ALLOYED STEELS 17CrNiMo6 AND 20CrMo5 – CARBURIZATION

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SUMMARY
This paper is concerned with carburization heat treatment. Standard carburization generally entails several steps: carburization of the surface layer by carbon diffusion at high temperatures, subsequent hardening and stress relief. This combination of hard surface and resistance to breakage upon impact is useful in parts such as a cam or ring gear, bearings or shafts, turbine applications, and automotive components that must have a very hard surface to resist wear, along with a tough interior to resist the impact that occurs during operation. This paper present carburization in solid done on two low alloyed steels: 17CrNiMo6 and 20CrMo5 and their properties obtained after carburization.

1. INTRODUCTION
Hardening is a process that includes a wide variety of techniques is used to improve the wear resistance of parts without affecting the softer, tough interior of the part. This combination of hard surface and resistance to breakage upon impact is useful in the parts such as the cams or ring gears, bearings or shafts, turbine applications, and automotive components that must have a very hard surface to resist wear, along with a tough interior to resist the impact that occurs during operation. Most surface treatments result in compressive residual stresses at the surface that reduce the probability of crack initiation and help arrest crack propagation at the case-core interface. Further, the surface hardening of steel can have an advantage over through hardening because less expensive low-carbon and medium carbon steels can be surface hardened with minimal problems of distortion and cracking associated with the through hardening of thick sections.

2. THERMOCHEMICAL TREATMENT

Thermochemical treatment of the steel is a treatment which is performed as combination thermal and chemical activities with the aim of partial change of the chemical composition, microstructure and properties of the surface layer.

This heat treatment results in microstructural changes based on the changes in the chemical composition surface layer by absorption and diffusion of the elements like C, N, B, Cr, Al, W, Si, etc.

Thermochemical processing is performed by heating parts in solid, liquid or gaseous medium, enriching the surface layer with elements such as C, N, B, Cr, Al, W, Si and others by diffusion of their atoms from the outside environment. The process of thermo-chemical treatment consists from: formation of active atoms of the elements near the surface or directly to the metal surface; contacting the atoms of the diffusing elements with the surface and dissolving them in the grid of a metal (absorption); diffusion of absorbed atomic elements into the depth of a metal.

Depending on the elements that diffuse in the surface layer, there are next processes thermochemical treatment, namely:

- carburizing - carbon enrichment;
- nitriding – enrichment by nitrogen;
- carbonitriding (cyanization) - carbon and nitrogen enrichment;
- diffusion metallization – enrichment steel surface with elements, mostly metallic:
- chromizing - enrichment with chromium;
- siliconizing – enrichment with silicon;
- aluminizing - enrichment with aluminum [1].

Difference between treatment enrichment with non-metallic and metallic elements is: non-metallic elements form interstitial solid solution with iron, and metallic elements form supstitutial solid solution.

Thermochemical treatment is always run at elevated temperature, because the process of diffusion is accordingly faster.

Thermochemical treatment has to achieve some advantages:

a) increase in hardness in the surface layer,
b) increase wear resistance,
c) increase dynamical strength,
d) increase resistance to oxidation at elevated temperature,
e) increase resistance to corrosion.

3. CARBURIZING OF STEELS

Carburizing is a thermochemical process in which surface layers of steel are enriched by carbon. The final properties of the carburizing parts are obtained only after quenching and tempering. The aim of carburizing is to obtain high surface hardness, high wear resistance and toughness of core. High surface hardness and high wear resistance are achieved by enriching the surface layer with carbon up to the eutectoid or hypereutectoid concentration and quenching. High toughness of core is achieved using steel with low content of carbon (0,10 to 0,25%). That means that because of low stability of austenite, they have low hardenability, and after quenching kept good core toughness [1].

There are three ways of carburizing:

Carburizing →
- in solid (charcoal+ Na_2CO_3 ($BaCO_3$))
- in liquid (Na_2CO_3 + NaCl)
- in gases (natural gas; methane-butane mixture)

Carburizing is carried out at temperatures above the point A_{C3} or 850-950 °C when austenite can to disperse the highest percentage of carbon (up to 2% C), Fig. 1.

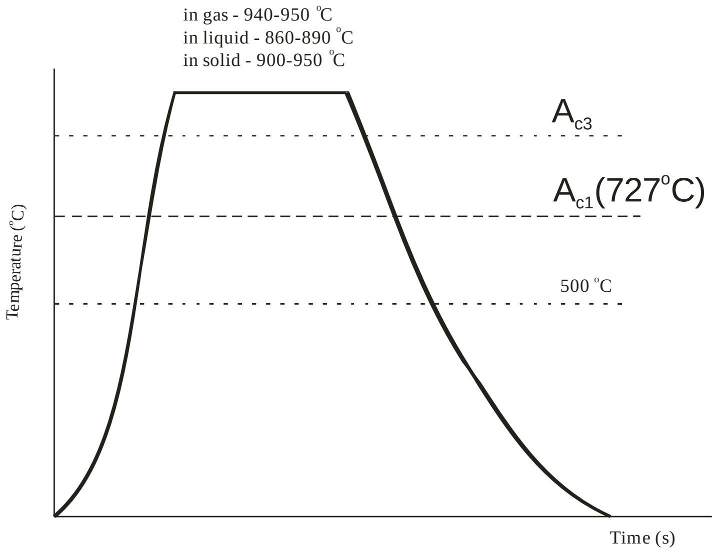


Figure 1. Diagram of thermochemical treatment in various environments [1]

3.1. Carburizing in solid

Steel parts have to be placed in the metallic box with coal rich of carbon, the top end of box was well-closed using mixture of clay, water glass and NaCl. Boxes are made of low-carbon steel, gray iron or heat resistance steel. In the reciprocal effect of the oxygen from the air that is left between the coal granules, with carbon from charcoal, CO is formed (eq. 1). Since the oxygen is the lack in the atmosphere, does not produce CO_2.

$$2C_{coal} + O_2 = 2CO$$

$$2CO = CO_2 + C \qquad \ldots (1)$$

The carbon got on this way is free and penetrate into the steel surface and increases concentration of carbon in surface layer of certain thickness. CO_2 generated during treatment reacts continuously with carbon from coal and generate new amounts of CO necessary for formation of carbon which is able to be absorbed in steel surface.

Steel parts in boxes are placed in furnace at the temperature 600-700 °C and heated to carburization temperature (900-950 °C). Holding time at this temperature depends on the required depth of carburization layer. In accordance to literature [1], for achieving a layer thickness of 0.1 mm, it is necessary to hold it for 1 hour.

Relation of time and temperature to carbon penetration (diffusion) is shown at Figure 2.

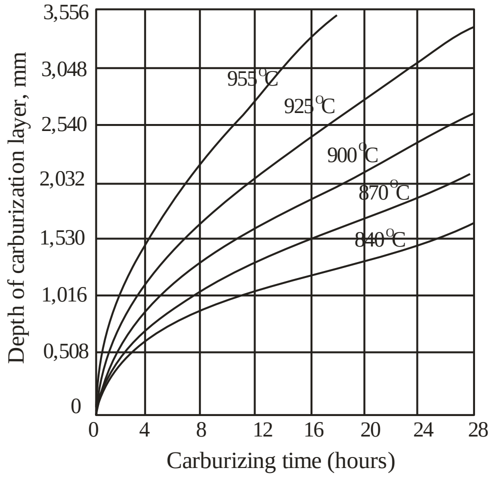


Figure 2. Relation of time and temperature to carbon penetration [2]

Depth of carburized layer is higher if temperature is higher and process time is longer. Influence of the alloying elements on depth of carburizing layer is presented at Figure 3. The alloying elements tend to be formed as carbides (Cr, W, Mo and Mn), and show little influence on the increase in the depth of layer while Ni and Si reduce the depth of cementation.

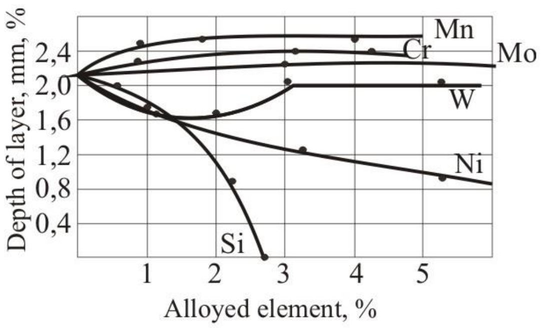


Figure 3. Influence of alloying elements on depth of carburizing layer [1]

4. EXPERIMENTAL PART

Procedures of carburization were done at Metallographic laboratory of Institute "Kemal Kapetanović" - Zenica and BNT - Novi Travnik [3].

4. 1. Data of materials

Chemical composition of steel 17CrNiMo6 in accordance to literature [4] and steel 20CrMo5 which is not standardized [5] is presented in Table 1.

Table 1. Chemical composition

Material	Content of element, (%)							
	C	Si	Mn	P	S	Cr	Ni	Mo
17CrNiMo6 WN. 1.6587	0.15-0.21	≤ 0.40	0.50-0.90	≤ 0.035	≤ 0.035	1.50-1.80	1.40-1.70	0.25-0.35
20CrMo5 WN. 1.7264	0.18-0.23	0.15-0.35	0.90-1.20	≤ 0.035	≤ 0.035	1.10-1.40	---	0.20-0.30

Steel grade 17CrNiMo6 was registered as a grade in 1991 and is therefore one of the most contemporary grades in the alloy bar market. It is characterized by high case hardness and depth combined with excellent core strength. Recently the grade has been developed further by slightly increasing Carbon and Manganese content and this led to the new designation

18CrNiMo7-6, which is the current official designation for this steel under Euronorm EN 10084, which supersedes DIN17210 [3, 4].

Heat treatment of steel 17CrNiMo6 in accordance to standard BAS EN 10084:2009 [6] and steel and 20CrMo5 which is not standardized [3, 5] is given in Table 2.

Table 2. Heat treatment

Treatment	Material	Temperature range (°C)
Carburizing	17CrNiMo6	880-980
	20CrMo5	840-880
Tempering	17CrNiMo6	150-200
	20CrMo5	150-180

Typical mechanical properties of steel 17CrNiMo6 in accordance to literature [3, 4] and steel 20CrMo5 in accordance to literature [5] achievable in the core section of various diameters after carburizing, hardening and tempering, are given in Table 3.

Table 3. Mechanical properties

Diameter (mm)	Yield strength (N/mm^2)		Tensile strength (N/mm^2)	
	17CrNiMo6	20CrMo5	17CrNiMo6	20CrMo5
11	Min 835	735	1180-1420	1080-1380
30	Min 785	685	1080-1320	980-1270
63	Min 685	540	980-1270	780-1080

These two steel have got applications:
- steel 17CrNiMo6 - for heavy and highly stressed gear parts in mechanical engineering with high toughness requirements, such as gear wheels, plate wheels, drive pinions and worm shafts,
- steel 20CrMo5 - for components in mechanical engineering and vehicle construction with high core strength, such as gear wheels and drive bevel gears with high tooth root strength.

4.2. Carburization of samples

The samples were put in the box and coated with coal rich of carbon; the top end of box was closed, Figure 4.

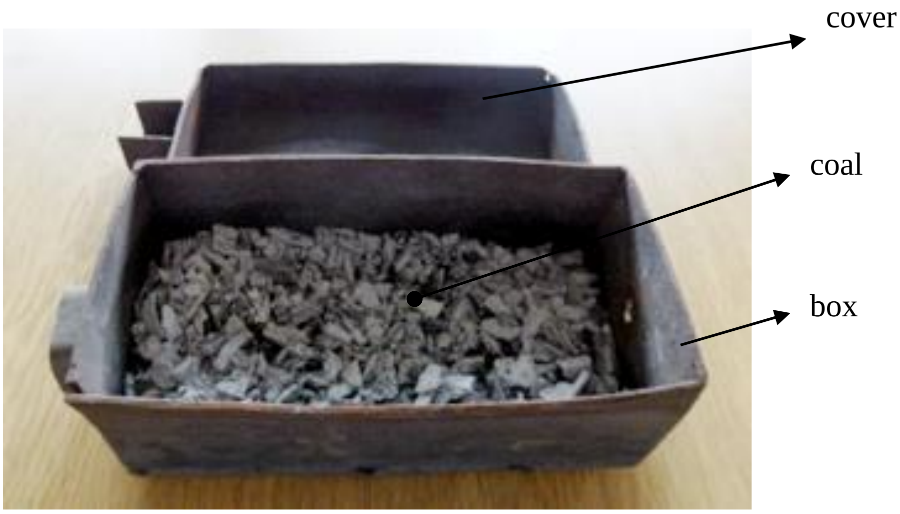


Figure 4. Box with coal rich of carbon

For the sample of steel 17CrNiMo6 furnace was heated to temperature of 350 °C and the box with sample was put in the furnace and after the temperature was reached the 900 °C the time of heating counted about eight hours, and then got it out. After the sample was cooled on air, it was put again in the furnace for tempering, Figure 5.

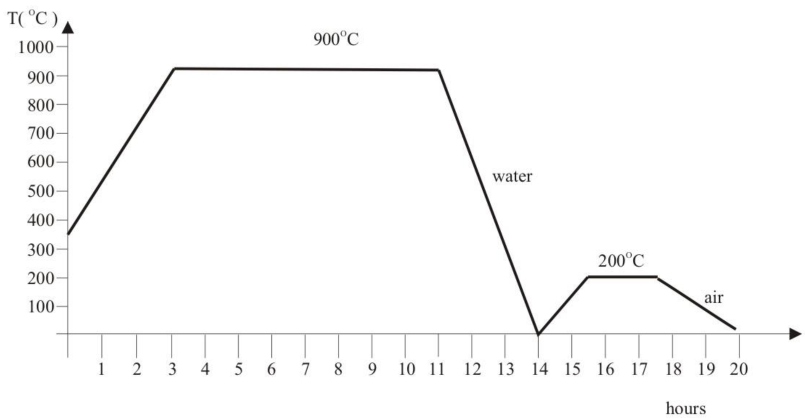


Figure 5. Diagram of performed heat treatment, 17CrNiMo6 [3]

For the sample of steel 20CrMo5 furnace was heated to temperature of 900 °C and box with sample (top end of box covered with clay to prevent oxygen introduce) was put in the furnace of heating time of sixteen hours. After time was reached the sample was cooled on air, and then put in the other furnace at 850 ° C, holding 15 minutes and quenching in oil, Figure 6.

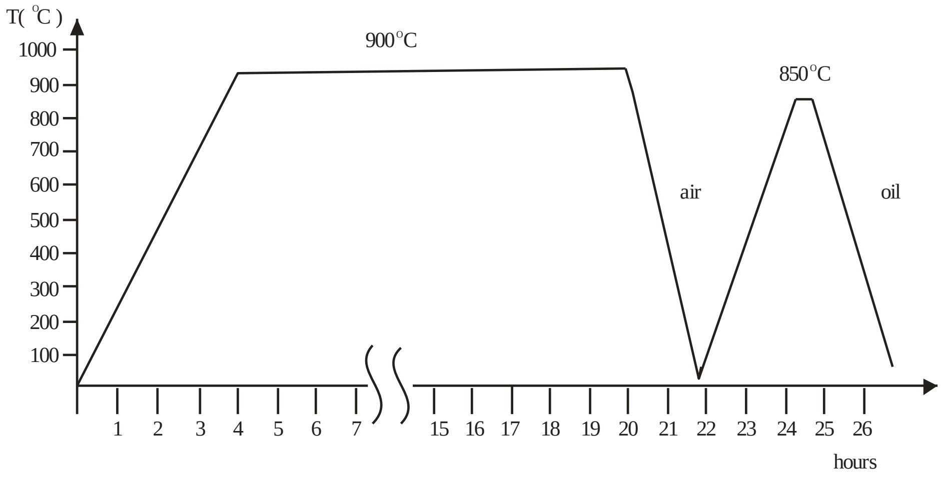


Figure 6. Diagram of performed heat treatment, 20CrMo5 [3]

4.3. Metallographic testing

Following metallographic specimen preparation steps were done before metallographic tests:

Cutting: the sample was cut into metallographic specimen from the large sample that was be carburized by cutting machine.

Mounting: sample after cutting mounted with plastic material by automatic pressing, and heating device.

Grinding: the mechanical preparation after mounting was finished to remove the rough layers from the surface of the sample by manual preparation.

Polishing: Polishing is the final mechanical preparation stage in obtaining a flat, scratch-free surface for metallographic examination, which was done by the diamante suspensions, 9 μ and 3μ.

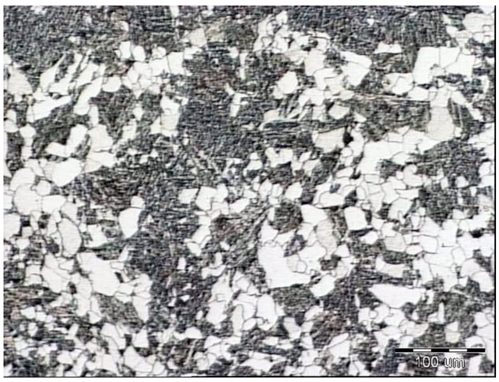
Etching: for etching the 2% HNO_3 (NITAL) was used, that is a suitable for low alloyed steels.

Microstructural examination was performed using light (optical) microscope OLYMPUS PMG3, bright field, magnification 100x and 500x.

Microstructures of steel 17CrNiMo6 at carburized surface region is given at Figure 7a) and microstructure at core of sample is given at Figure 7b).

x 100

a) carburized surface
martensite and retained austenite

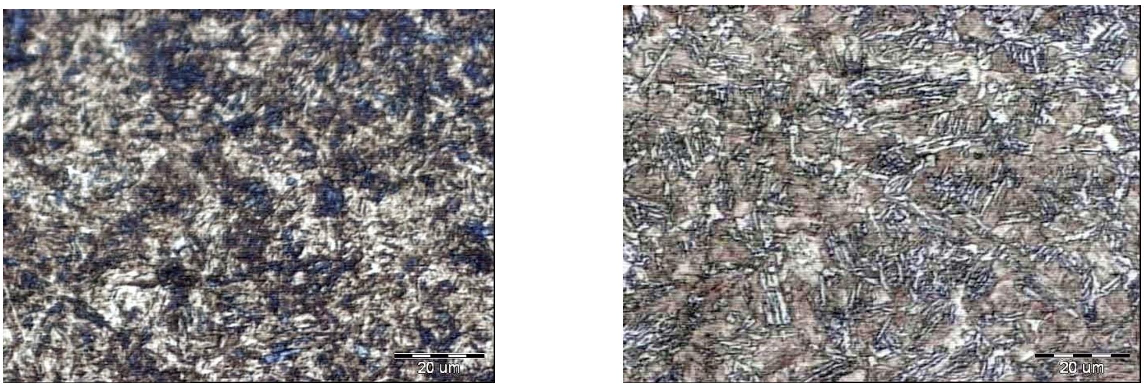


x100

b) core of sample
proeutectoid ferrite, pearlite, low carbon martensite

Figure 7. Microstructure of the carburized sample of steel 17CrNiMo6

Microstructures of steel 20CrMo5 at carburized surface region is given at Figure 8a) and microstructure at core of sample is given at Figure 8b).



x 500 x500

a) carburized surface
martensite and retained austenite

b) core of sample
proeutectoid ferrite, pearlite and bainite

Figure 8. Microstructure of the carburized sample of steel 20CrMo5

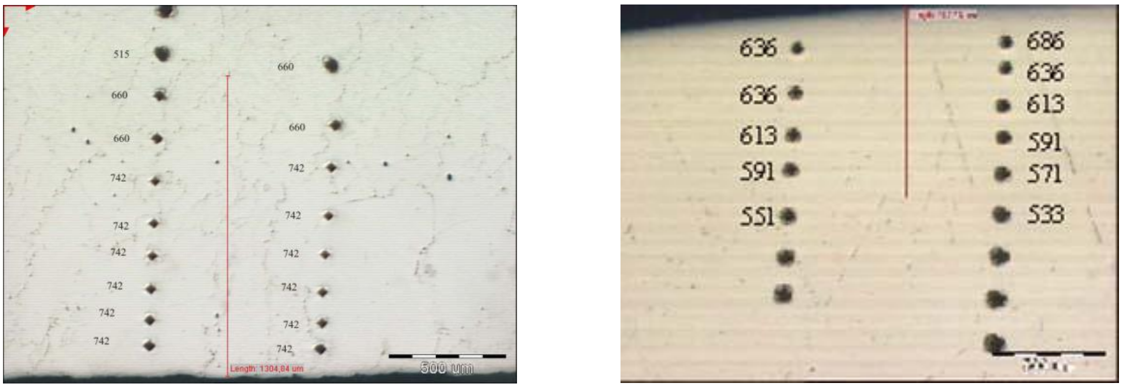
4.4. Measuring of depth of carburized layer

Applied heat treatment should be tested using the standard BAS EN ISO 2639:2004 [7] to determine the depth of the carburized layer.

The case-hardening depth (CD) signifies the distance from the surface of a case hardened work piece to the point, where the Vickers hardness is generally 550 HV1 [7].

4.4.1. Hardness Tests

For hardness measurement was used the device for hardness and microhardness testing ZWICK and light microscope for measuring carburization depth. In accordance to BAS EN ISO 2639:2004 was performed hardness measurement in two parallel lines. Hardness value and depth of carburization layer of treated steels are given at Figure 9.



a) 17CrNiMo6 *b) 20CrMo5*

Figure 9. Hardness and depth of carburization layer of steel

5. ANALYSIS OF TEST RESULTS

Steel sample 17CrNiMo6 was treated in laboratory furnace at Institute „Kemal Kapetanović“ - Zenica, while the sample of 20CrMo5 steel was treated in industrial conditions at „BNT Holding“ - Novi Travnik. The microstructure of the carburized layer in both samples is martensite and retained austenite. In the core of steel sample 17CrNiMo6 revealed microstructure of proeutectoid ferrite and low carbon martensite. In the core of steel sample

20CrMo5 proeutectoid ferrite, pearlite and bainite. Steel sample 17CrNiMo6 was cooled in water after carburization and 20CrMo5 in air, and after qunching, steel sample 17CrNiMo6 was heated at 200 °C for 2 hours and steel sample 20CrMo5 at 850 °C for 15 minutes. Cooling to room temperature was done at the air for both samples. The achieved values of the carburized layer depth are 1.3 mm for 17CrNiMo6 steel and 0.8 mm for steel 20CrMo5.

6. CONCLUSION

The required depth of the carburized layer is determined by the work conditions of the machine element being carburized. According to the literature data [1, 8], carburized layer depth in the solid material is about 0.5 to 2 mm. Effective carburized depth is achieved at hardness of 550HV1. For the sample of 17CrNiMo6 was measured at a depth of 1.3 mm and the sample 20CrMo5 at a depth of 0.8 mm. The difference in the depth of carburized tested samples is in the different chemical composition and applied different carburized treatment.

7. REFERENCES

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