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THE INFLUENCE OF CARBONITRIDING PROCESS ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF MICRO-ALLOYED STEEL

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The article deals with the analysis of carbonitrided samples of S460MC microalloyed thermo-mechanically treated steel. The steel surface was saturated with carbon and nitrogen at the temperature of 860 °C. The nitrogen-methanole atmosphere with Amonnia addition was used for surface saturation in the process of carbonitriding. Oil hardening and tempering at 200 °C/1 hour followed after the diffusion saturation of experimental steel sample. The surface layer was composed of martensite, retained austenite and fine carbides of alloying elements. This was demonstrated with light microscopy and confirmed by TEM (transmission electron microscope). The paper also presents the results of chemical composition and hardness measurement.

Key words: micro-alloyed steel, carbonitriding, microstructure, TEM, precipitates

INTRODUCTION

Carbonitriding is one of the surface hardening process of the materials where carbon and nitrogen diffuse into the surface of components in the temperature range 850 ÷ 880 °C. The first step is the saturation of surface in carbon and nitrogen, then the hardening and tempering steps follow [1-3]. This process is favourable compared with carburizing process, because it results in direct hardening from the saturation temperature, shortening the production cycle, reducing production costs and achieving the favourable performance of the surface layers [4]. Thermo-chemical treatment (carbonitriding) is used to increase surface hardness, surface resistance to wear and maintaining tough core of parts.

Microalloyed steel is a class of steels group designed to achieve specific properties by controlled thermo-mechanical processing [5]. Microalloyed steels gain their strength due to the use of reinforcing of the grain boundary and precipitation hardening, which is achieved by the controlled rolling of steels with required chemical composition [6]. The yield strength of strength levels of two steels reflects added strength coming from intragranular carbides present in microalloyed steel [7].

EXPERIMENTAL METHODS AND USED MATERIAL

The rolled strip of the microalloyed steel thickness of about 3 mm was used as a starting material. The S460MC steel is used for tools for cold forming, suitable for production of moldings, car chassis, etc. The aim of analysis was to obtain more detailed information of microalloyed steel after carbonitriding process. Experimental methods used in this investigation were: analysis of the chemical composition, hardness measurement and the microstructure analysis using light microscope and TEM.

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Analysis of chemical composition

The chemical composition of the basic material S460MC in the core of the sample was measured with Spectrotest instrument. The measured chemical composition of the experimental steel satisfies specification in material list for used steel. The measured chemical composition of steel in this study is given in Table 1.

Table 1 **Chemical composition of S460MC steel / wt. %**

Chemical elements	Material S460MC
C	0,043 ± 0,030
Si	0,052 ± 0,050
Mn	1,510 ± 0,050
P	0,015 ± 0,008
S	0,005 ± 0,002
Al	0,072 ± 0,060
Ti	0,005 ± 0,002
Nb	0,009 ± 0,001
V	0,083 ± 0,075
Fe	base

Microstructure analysis

The microstructure of the steel sample S460MC was investigated using the light microscope, type NEOPHOT 30 with attached CCD camera and software programme IMPOR PRO 32.

The microstructure of the starting material of S460MC consisting from ferrite and a small amount of fine carbides is shown in Figure 1 [8, 9].

The microstructure of the surface diffusion layer consists from martensite and retained austenite, which can be seen in Figure 2.

Carbide-ferritic type of the microstructure can be seen in the transitional area diffusion layer of S460MC steel. This type of the microstructure is shown in Figure 3.

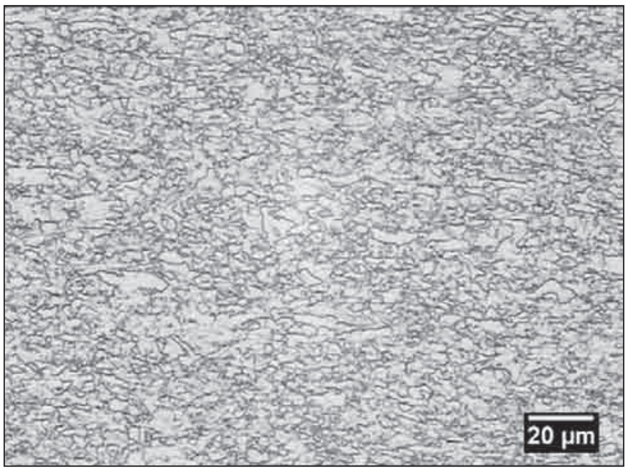

Figure 1 The microstructure of the initial state of microalloyed thermo-mechanically treated steel S460MC

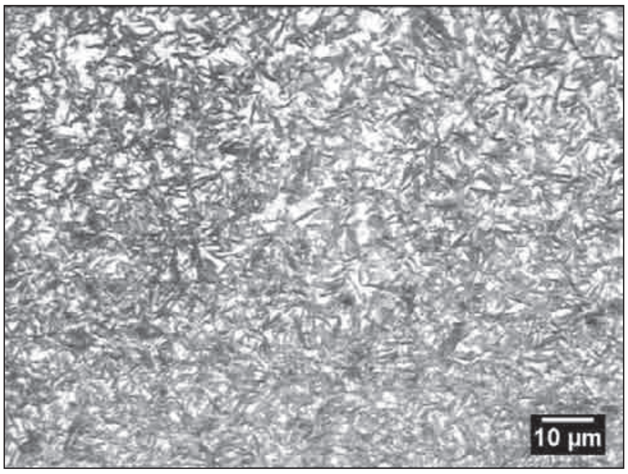

Figure 2 The microstructure of surface diffusion layer

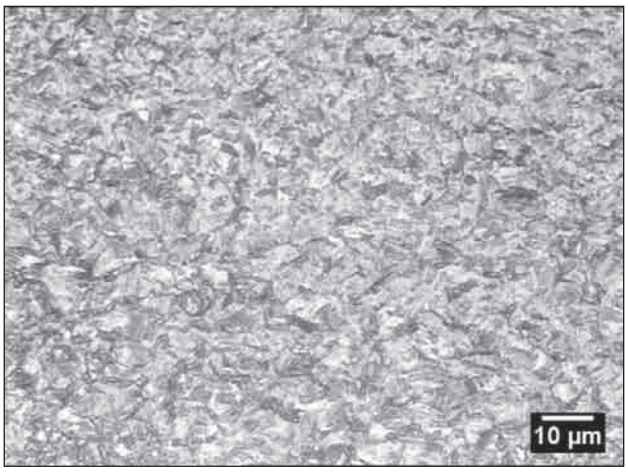

Figure 3 The microstructure of the steel in the transitional area

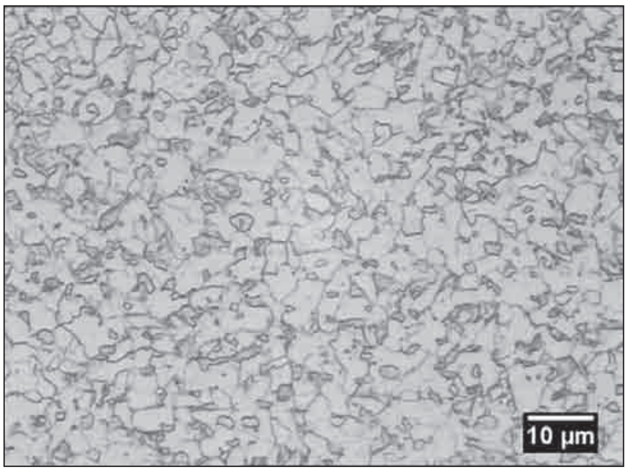

Figure 4 The microstructure of the core of the steel

The core of the steel sample has a ferrite-pearlitic microstructure which is ilustrated in Figure 4.

Today TEMs are probably the most efficient and versatile tools for the characterization of materials over spatial ranges from the atomic scale, through the ever-growing 'nano'regime (from < 1 nm to ~ 100 nm) up to the micrometer level and beyond. The resolution of a TEM is given in terms of the classic Rayleigh criterion for VLM (visible-light microscope), which states that the smallest distance that can be resolved, δ, is given approximately by:

$$\delta = \frac{0{,}61 \cdot \lambda}{\mu \cdot \sin\beta} \quad (1)$$

λ is the wavelength of the radiation, μ the refractive index of the viewing medium, and β the semi-angle of collection of the magnifying lens [10]. In the case of TEM we can simplify this equation to:

$$\delta = \frac{0{,}61 \cdot \lambda}{\beta} \quad (2)$$

For more detailed experimental analysis of thermo-chemical treated S460MC steel (especially in terms of the microstructure of carbide particles) was used the transmission electron microscope JEOL 200CX with greater resolution ability. Carbon replicas were prepared from different areas of the sample (surface layer, transitional area of difussion layer and the materials core).

The precipitates of carbide at the interface of the original martensitic needles can be seen in the microstructure of the surface layer of S460MC steel (Figure 5). It can be also seen the retained austenite and lower bainite. The microstructure of the transitional area diffusion layer is composed of retained austenite and lower bainite, where the precipitates inside bainitic needles are presents (Figure 6). It can see the ferritic matrix at the core of the material in Figure 7. The grains of ferrite are polyedric in shape. The smaller pearlitic colonies, which are present on the grain boundaries and precipitated carbides can be observed in this area.

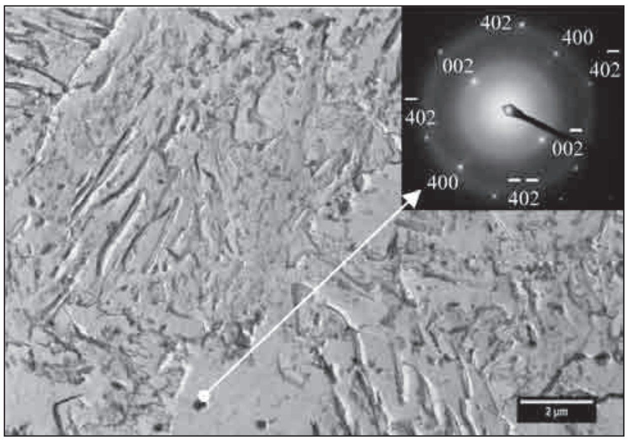

Figure 5 The surface diffusion layer of S460MC steel treated by carbonitriding, diffraction pattern of particles identified M3C – type precipitates TEM of carbon extraction replicas

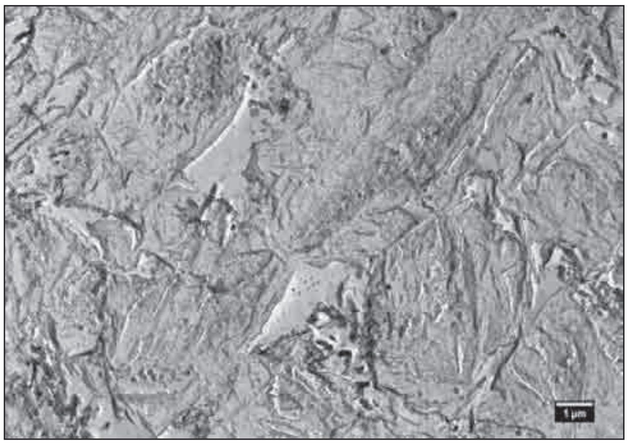

Figure 6 The transitional area diffusion layer of the carbonitrided S460MC steel, TEM of carbon extraction replicas

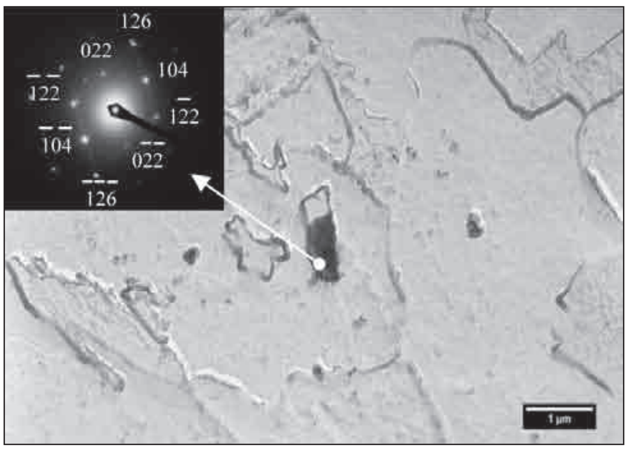

Figure 7 The core of S460MC steel, diffraction pattern of the particles identified MX – type precipitates, TEM of carbon extraction replicas

Hardness measurement

The hardness on the surface of the carbonitrided sample was measured on a flat area by method Vickers with loading 9,81 N. In this experiment were performed 5 measurements and their results are in Table 2.

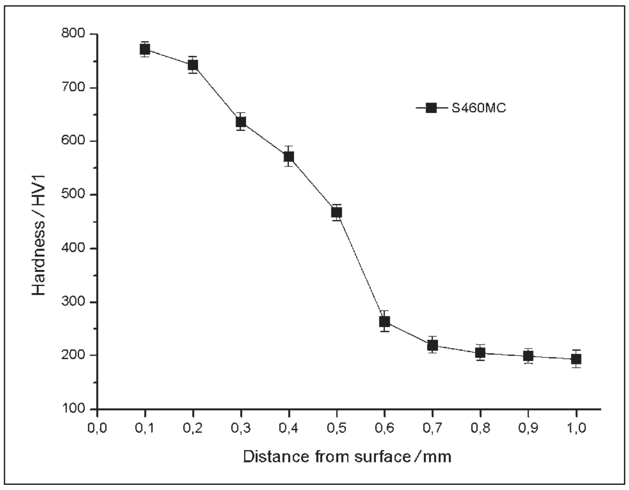

Figure 8 Graph of the hardness in the cross-section of the steel

Table 2 **Measured hardness on surface of S460MC steel**

Number of measurement	Hardness HV1
1	762
2	757
3	751
4	772
5	764

In cross-section of sample, which was thermo-chemical treated, the course of hardness by Vickers method, with a micrometric shift of a table, loading 9,81 N was performed. From measured values of hardness was determined the depth of hardenability (or thickness of layer) in accordance with DIN EN ISO 2639 [11]. The depth corresponds to the value 0,4 mm (Figure 8).

RESULTS

The analysis of thermo-chemical treated sample confirmed that it can be achieved surface layer with high hardness by carbonitriding process. The average value of hardness measured on the surface of carbonitrided sample was 761 ± 8 HV1. Determined hardenability corresponds to the value 0,4 mm. The thickness of diffusion layer (approx. 0,3 mm) can be achieved in a shorter time of carbonitriding (compared with carburizing process). This is possible due to the presence of nitrogen in the furnace atmosphere, the nitrogen increases the rate of diffusion of carbon in the material. The sample of used steel S460MC had fine-grained microstructure. The carbonitriding process (860 °C) does not avoid the unwanted coarsening of the grain. By the process is therefore possible to obtain the diffusion layer on the surface of a material with favorable functional characteristics [12]. The sample structure was investigated using light microscopy and transmission electron microscope (TEM). The martensite, retained austenite and carbide precipitates were seen in the surface diffusion layer of the sample. The core of steel consisted of the ferritic matrix and the grain boundaries excluded pearlite. In this study were identified two types of the precipitates: M_3C and MX. The M_3C and MX precipitates were observed in carbonitriding layer and core of the S460MC steel.

CONCLUSION

The obtained results show that the surface modification of carbonitriding in nitrogen-methanole atmosphere with the Amonnia addition has succeedded to improve the surface hardness of the micro-alloyed steels. The presence of alloying elements (Ti, Nb, V) in steel results in a positive effect of the microstructure (fine grains) and it improves the mechanical properties (hardness, strength).

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Note: The responsible for English language is Bibiana Gondeková the interpreter/translator from Banská Bystrica, Slovak Republic