An Experimental Study of the Influence of Carburizing Treatment Holding Time on the Structure and Hardness of 16NC6 Steel

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ABSTRACT

Low carbon steel with carbon content ranging from 0.15% to 0.3% cannot be hardened through quenching and tempering processes and there is little to no martensitic transformation occurring upon quenching. To improve the surface hardness, carburizing is commonly employed. Through this treatment, the surface composition of the low-carbon steel is altered by the diffusion of carbon, resulting in a hard outer casing with good wear resistance. This work investigates the effect of the carburizing treatment temperature and holding time on the crystallographic structure, hardness, and hardened surface layer dimension of commercial low-carbon steel 16NC6. The steel was carburized at 900°C for different holding times of 1, 2, and 3 hours. After the carburizing and quenching processes, the hardness values and the morphology of the crystallographic structure were measured and characterized.

Keywords-carburizing; quenching; low carbon steel; structure; hardness

I. INTRODUCTION

Heat treatment processes can be used to modify the surface and structural properties of low carbon steel in order to have a hard outer surface and a ductile and tough inner core, which is beneficial for engineering applications such as cams, gears, and shafts. These properties assist the resistance in wear and shock, thus extending the life of the component [1-3]. Carburizing is an ancient thermo-chemical heat treatment used to harden the surface of low carbon steel by diffusing carbon into it. The steel typically must be subjected to quenching in order to achieve the desired hardness [4, 5]. Carburizing is used to introduce carbon into the surface layer of steel. The process involves heating the steel in a carbon-rich environment, typically a carbon-rich gas or a bath of molten carbon-rich compounds, at a temperature above the steel's critical temperature. This allows carbon to diffuse into the surface layer of the steel, creating a hard, wear-resistant surface layer known as the case. The influence of carburizing treatment holding time on the structure and mechanical properties of low carbon steel can be significant. Holding time is the time period that the steel is exposed to the carbon-rich environment during the process. A longer holding time will result in a deeper case and a higher carbon concentration in the surface layer, improving hardness, wear resistance, and other mechanical properties. However, it is important to note that holding time should not be too long, as excessive carburizing can lead to the formation of carbides and other undesirable structures. These structures can reduce the toughness and ductility of the steel and make it more brittle. As a result, it is important to carefully control holding time during the carburizing process in order to achieve optimal results. In summary, carburizing treatment can greatly improve the structure and mechanical properties of low carbon steel, but it is important to control holding time in order to achieve optimal results. The influence of holding time on the structure and hardness of low carbon steel is an important topic of research, and a deeper understanding of this relationship can lead to the development of better carburizing processes and more advanced materials [6-11].

This study aims to investigate the effects of carburizing treatment on low carbon steel and to produce cemented steel through this process. Carburizing treatment involves exposing the low carbon steel 16NC6 to a carbon-rich environment for different periods, using holding time as a parameter. The study aims to examine how variations in carburizing treatment temperature and holding time affect the crystallographic structure, hardness, and dimensions of the hardened surface layer. In addition, the study seeks to provide insight into the chemical composition of the steel before and after carburizing treatment. The study aims to provide valuable information for industrial applications, such as the manufacturing of gears and other mechanical components. During the carburizing process, carbon diffuses into steel and reacts with iron to form iron carbide compounds. The study aims to examine the impact of carburizing time and temperature on the transformation rate of low carbon steel into cemented steel layers. Optical microscopy was used to analyze micrographs of the samples and the thickness of the carburized areas, and micro Vickers was used to measure the microhardness of cross-sectional samples of the cemented steel [11-16].

II. MATERIALS AND EXPERIMENTAL METHOD

The low carbon steel used in this study was procured from the local market (AFNOR 16NC6) and underwent chemical analysis according to ASTM E 415-99a using spectroscopic methods. The results showed that the chemical composition of the steel, in weight percent, was: 0.17% C, 0.26% Si, 0.67% Mn, 0.92% Cr, 1.2% Ni, 0.027% Mo, and 0.228% Cu. The samples were machined into cylindrical shapes with 18mm diameter and 5mm length. To prepare the samples for carburizing, all specimens were mechanically polished to reduce roughness to a level of Ra = 0.25μm, using sandpaper. The steel substrates then underwent pack carburizing treatment at various parameters. The samples underwent carburizing at a temperature of 900°C for time periods of 1, 2, and 3 hours. After carburizing, the specimens were immediately quenched in oil and tempered at a low temperature to further improve their behavior. After the carburizing treatment, the cross-sectional samples were prepared and polished. These samples were etched in a solution consisting of 100ml water, 2ml of 40% HF, and 5ml of 30% H_2O_2. This type of etching is widely used to highlight the different zones of cemented steel [9-18]. A Zwick Roell microscope was used to examine the metallographic preparation and observe the morphological details and thickness of the cemented layers. The hardness profile of the samples was measured across the cross-sections using a Zwick Roellmicroindenter with a load of 500gf.

III. RESULTS AND DISCUSSION

A. Structure

Figure 1 displays the optical micrographs of the microstructure of the steel before undergoing the carburizing treatment. Figures 2-4 display the optical micrographs of the microstructure after undergoing carburizing at 900°C and quenching for each holding time treatment.

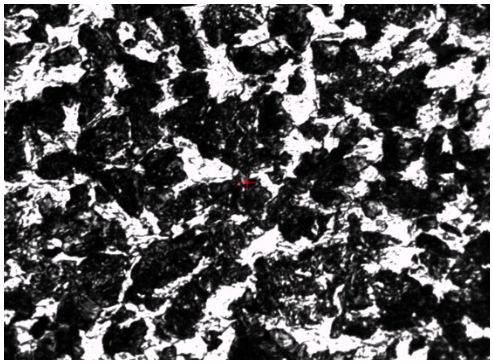

Fig. 1. Microstructure of the steel before the carburizing treatment.

(a)

(b)

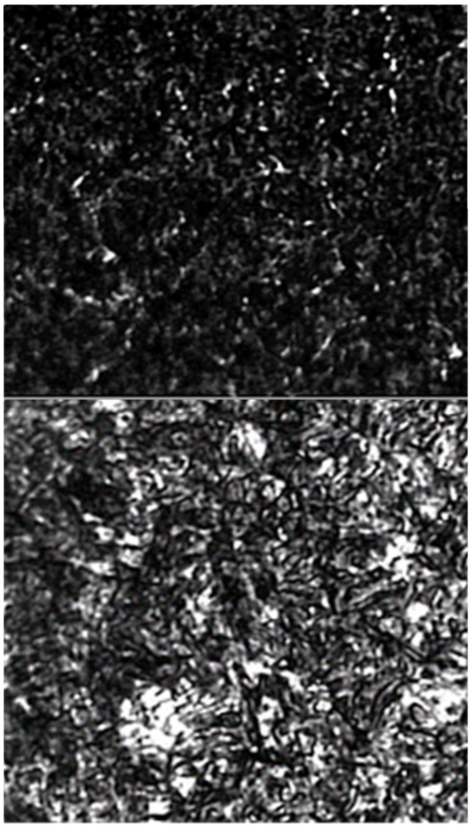

Fig. 2. Micrograph after carburizing at 900C° and quenching for 1h. (a) Surface zone,(b) inner area.

Figure 2 displays the micrographs of the surface zone and inner area of steel that was carburized for 1 hour at 900°C. In this case, the thickness of the cemented steel region was estimated to be 1mm and was divided into an outer zone of approximately 0.5mm and an inner diffusion layer of 0.5mm.

Figure 3 displays the micrographs of the steel that was carburized for 2h at 900°C. The thickness of the cemented steel region was estimated to be 1.4mm and was divided into an outer zone of approximately 0.7mm and an inner diffusion layer of 0.7mm.

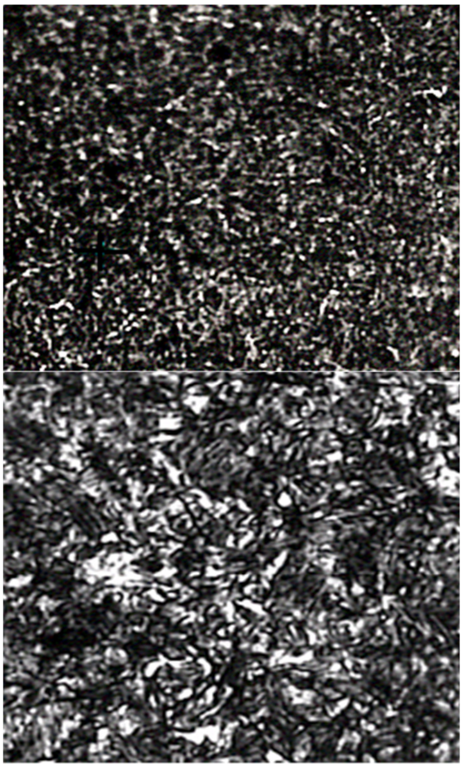

Fig. 3. Micrograph after carburizing at 900C° and quenching for 2h. (a) Surface zone,(b) inner area.

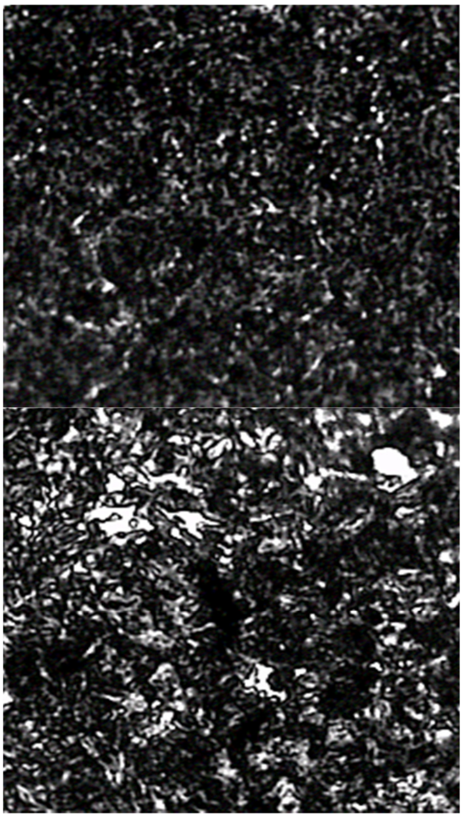

Fig. 4. Micrograph after carburizing at 900C° and quenching for 3h. (a) Surface zone, (b) inner area.

Figure 4 shows the micrographs of the steel that was carburized for 3h at 900°C. In this case, the thickness of the cemented steel region was estimated to be 1.9mm and was divided into an outer zone of approximately 0.9mm and an inner diffusion layer of 1mm.

As observed, the diffusion of carbon atoms to the surface of low steel leads to the formation of new phases with carbon atoms in the surface area. A martensitic microstructure is evident in the surface zone of the samples, and the temperature has the most significant effect on the structures and the development of the carburized layer. The thickness of the carburized zone of steel increases when the treatment holding time increases.

B. Chemical Composition

For each treatment holding time, the sample underwent chemical analysis according to ASTM E 415-99a using spectroscopic methods. The results, shown in Table I, indicate the chemical composition of the steel in weight percent.

TABLE I. CHEMICAL COMPOSITION AFTER CARBURIZING

	C %	Si %	Mn %	Cr %	Ni %	Mo %	Cu %
1h	0.63	0.25	0.65	0.91	1.188	0.031	0.222
2h	0.81	0.26	0.64	0.90	1.17	0.028	0.232
3h	1.03	0.27	0.63	0.90	1.22	0.029	0.225

C. Hardness

Figures 5-7 show the hardness versus depth for steel carburized at 900°C for 1, 2, and 3 hours and Figure 8 summarizes the results. In Figure 8, it is observed that the hardness profile curve has three regions. The first region, corresponding to the outer layer, has a very high hardness due to the formation of hard martensitic compounds and new iron carbides during the carburizing treatment. The second zone, corresponding to the diffusion zone, exhibits a decrease in hardness values, which can be attributed to the reduced rate of carbon diffusion into the steel substrate. The third zone has a fixed hardness value, corresponding to the hardness of the steel substrate.

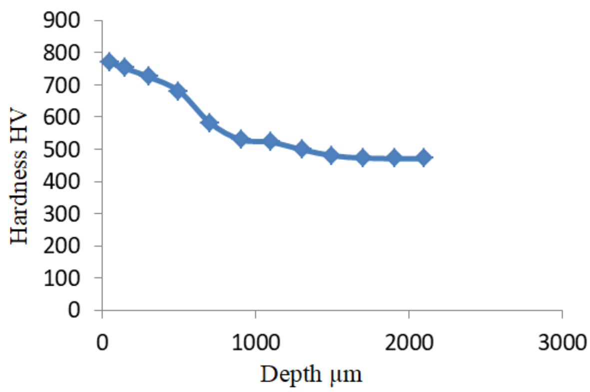

Fig. 5. Hardness of steel carburized at 900°C for 1h.

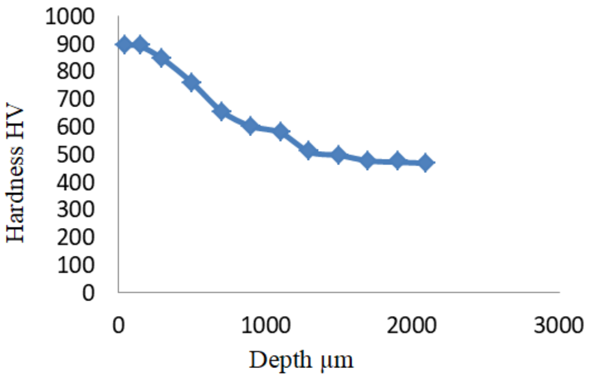

Fig. 6. Hardness of steel carburized at 900°C for 2h.

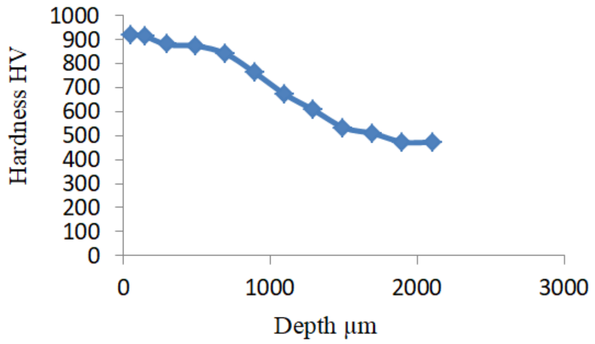

Fig. 7. Hardness of steel carburized at 900°C for 3h.

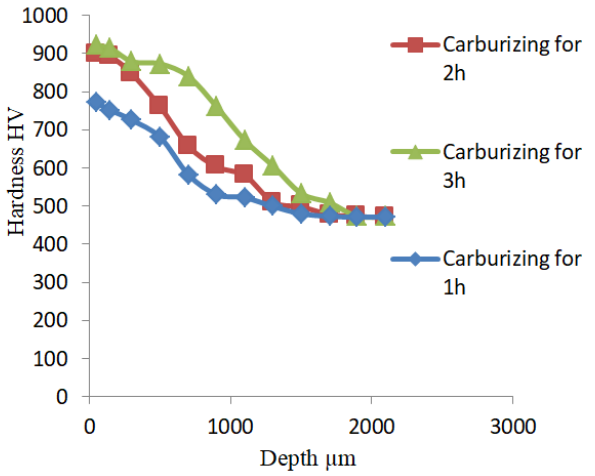

Fig. 8. Hardness of steel carburized at 900°C for 1, 2, and 3 hours.

IV. CONCLUSION

Based on the results and the analysis presented in this study, the following conclusions can be drawn:

- The carburizing treatment of low carbon steel can effectively increase the surface hardness and produce a hardened layer, which is composed of a combination of martensite and expanded austenite.
- The hardness of the carburized layer increases with increasing treatment holding time, with the thickness of the layer also increasing with time.
- The crystallographic structure of the carburized layer is greatly affected by the temperature and holding time of the carburizing treatment, with a transition from ferrite and pearlite to martensite and new iron carbides observed in the outer layer.
- The chemical composition of the steel is also affected by the carburizing treatment, with increase in the percentage of carbon observed after treatment.
- The carburizing treatment provides a useful method for improving the wear resistance and durability of low carbon steel components, particularly in applications where high hardness and resistance to wear are critical.

Overall, this study provides valuable insight into the effects of carburizing treatment on low carbon steel, with important implications for industrial applications such as the production of gears and other mechanical components.

It is recommended that further research should be conducted to explore the optimization of the carburizing treatment temperature and holding time in order to improve the hardness and crystallographic structure of the carburized steel. In addition, it would be interesting to investigate the impact of different quenching methods on the hardness and structure of the carburized steel. Furthermore, it would be valuable to evaluate the performance of carburized steel in various applications, such as wear resistance and corrosion resistance, to fully understand the benefits of this treatment for practical use.

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