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Microstructure and hardness of Pyrowear 53 steel after low-pressure vacuum carburizing at 921°C

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Abstract

The present paper studies and analyzes the low-pressure vacuum carburizing of Pyrowear 53 steel. The carburizing was performed at 921°C. The results after the completion of the treatment process are presented, i.e. microstructure of the surface layer and hardness. The results confirm that carburizing can be effectively used in hardening of the steel.

Keywords

Low-pressure carburizing, diffusion, Pyrowear 53 steel

1. Introduction

Gears are the main components of a transmission's kinematic system. They constitute a critical link in its operation and determine safety of flight. Materials used for their production must have high abrasion resistance, resistance to contact stress on the surface layer, resistance to bending strength at the tooth base, and required properties to withstand cyclic variable loads in the core.

The properties of gears are achieved by thermo-chemical treatment processes, which usually consist of the following steps: (1) carburizing; (2) austenitizing; (3) annealing; (4) quenching; (5) subzero treatment, and (6) low tempering (Figure 1).

Low Low-pressure carburizing (LPC) process is a type of vacuum thermo-chemical treatment process that create technological top layer [1]. Vacuum carburizing process is a self-regulating process, consisting of cyclic saturation and diffusion intervals [2].The mathematical models of the process created with numerical simulations are a basic tool for controlling the carburizing process [3,4]—carbon concentration control. Vacuum carburizing is a non-equilibrium process—intensive carbon saturation as a substrate on the surface of the material occurs [5–7]. In addition, the carburized layer produced by LPC process is free of oxides, which significantly increases the strength properties in static and dynamic conditions [8, 9]. The produced surface layer is a gradient layer: the maximum carbon concentration will be on the top surface and the concentration will decrease as we go below the surface reaching a minimum at a particular depth. Heavy duty gearboxes used in aviation are usually made from high-strength alloy steels like AMS 6308 (the chemical composition of Pyrowear 53 is presented in Table 1) [10].

The LPC process is carried out in the temperature range from 850 to 950°C [7,11–13]. The temperature of LPC process for AMS 6308 was 921°C. Suppose, if a special construction material is used for the furnace, then it is possible to use temperature of 1,100°C during carburizing [14]. The increase in the carburizing temperature reduces carburizing time. However, there will be a risk of grain growth in the austenite range, which adversely affects the properties such as strength and microstructure of the layer.

This paper analyzes the results of carburizing process at 921°C on the microstructure for AMS 6308 steel. The carburization time was selected to ensure the effective case hardening depth

Table 1. The chemical composition of the Pyrowear 53 (AMS 6308) steel

Element	Min	Max
Carbon	0.07	0.13
Manganese	0.25	0.50
Silicon	0,60	1.20
Phosphorus	–	0.015
Sulfur	–	0.010
Chromium	0.75	1.25
Nickel	160	2.40
Molybdenum	3.00	3.50
Copper	1.80	2.30
Vanadium	0.05	0.15

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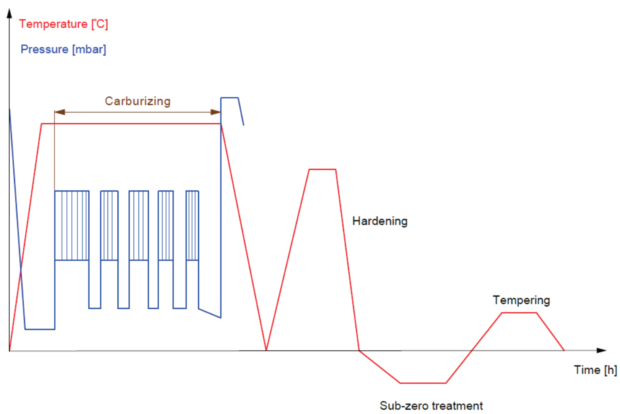

Figure 1. The schematic view of the heat treatment of LPC process.

in the range from 0.9 to 1.2 mm. The steel was carburized for different carbon and diffusion cycles. The influence of total carburization time on carbides formation and the hardness profiles are presented in this paper.

2. Methodology

This study used the samples cut from the gears made from Pyrowear 53 steel, which was delivered by P&W Rzeszow were analyzed (dimensions 10 mm × 10 mm × 5 mm). Prior to the LPC process, the samples were washed in ultrasonic cleaner. Then, the LPC process was performed in MonoTherm® HK.446.VC.10.gr furnace made by ALD Vacuum Technologies GmbH.

The vacuum carburizing process was performed at 921°C for different number of diffusion and carburization cycles—25 cycle of acetylene for a total time 26 min, and total time carburizing process—480 min. The samples were hardened with standard oil procedure after the carburizing process and then, the optical microscopy, spectroscopy, and hardness tests were performed:

- The effective case depth was measured via micro hardness tester (0.9–1.2mm).
- Microstructure of the case and core was analyzed.
- The cross-sections were analyzed in term of microstructure and chemical composition using Scanning Electron Microscope.

3. Results

The hardness profiles were measured on cross-section of gear tooth in the pitch and root direction, Figure 2. The effective case depth was defined at 513 HV. The achieved values of effective case depth for temperature 921°C were in the expected range 0.9–1.2 mm.

The microstructure of the carburized layer, transition layer, and core microstructure is presented in Figure 3.

The microstructure shows the phase transformation from austenite to martensite. No significant numbers of carbides were found. However, the trapped carbides can be seen at the surface, which can affect the residual stress [15]. The retained austenite has an effect on residual stress after final heat treatment.

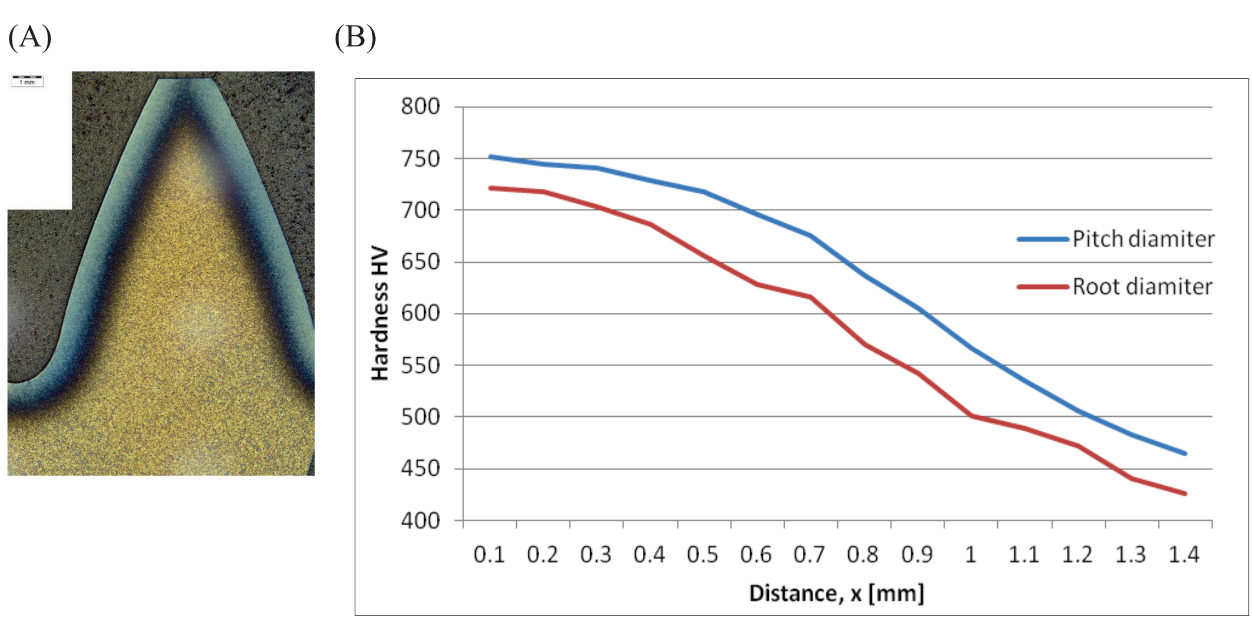

Figure 2. (A) Cross-section and carburizing layer of gear tooth, (B) Hardness profile for carburizing temperature 921°C measured in the pitch and root line direction on the teeth gear.

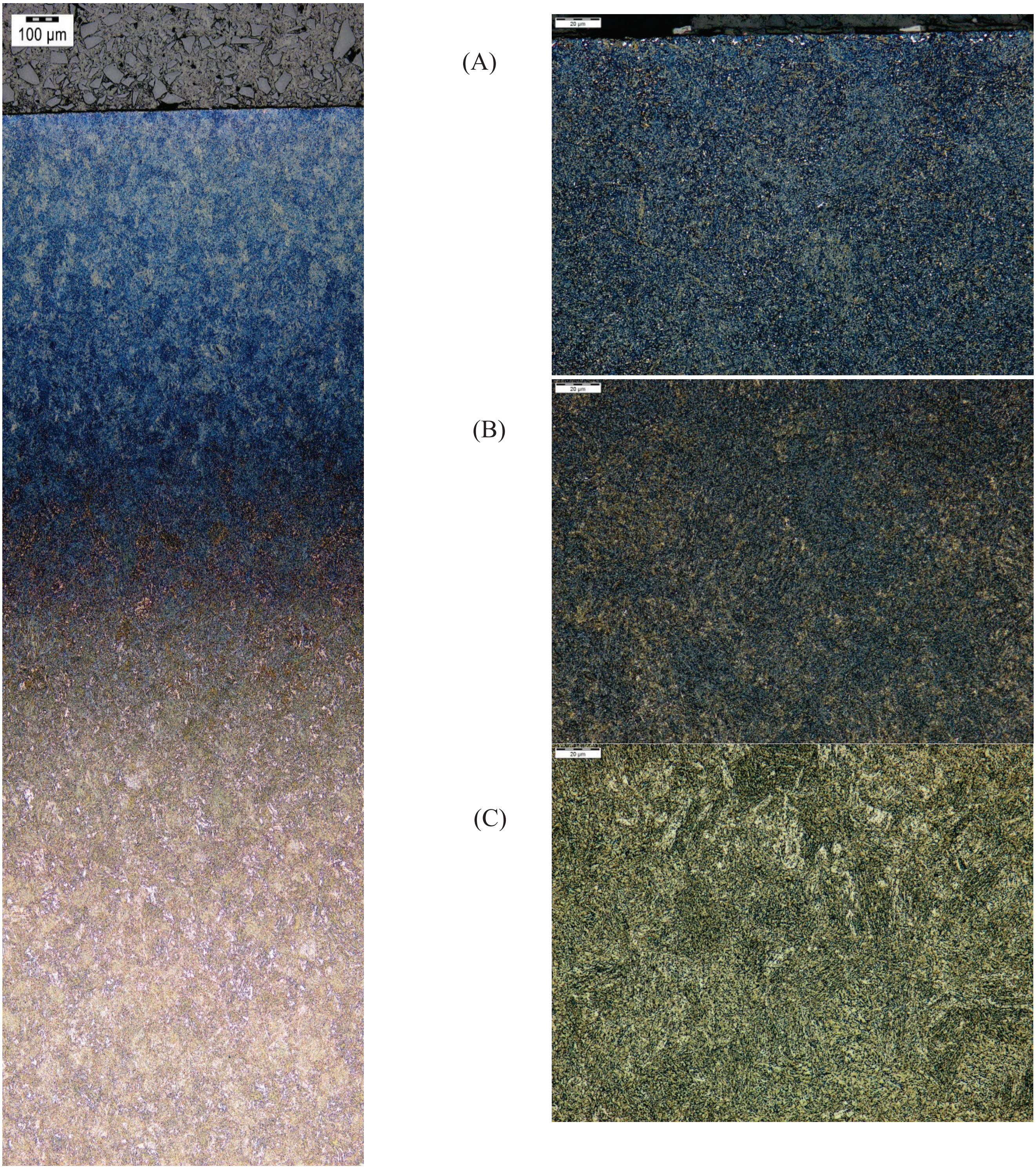

Figure 3. Microstructure of carburizing layer. (A) microstructure layer, (B) microstructure transition layer, (C) microstructure of core.

4. Conclusions

The diffusion plays a controlling role in carburization process. The properties of carbon and its structural changes during carburization plays crucial role in the process of phase transformation. The microstructure after the phase transformations is presented, Figure 3. We assume that the hardness of the martensite is proportional to the carbon content, and based on that the hardness profiles were determined, Figure 2. Finally, the values of effective case depth, 513 HV, for temperature 921°C were achieved in the expected range 0.9–1.2 mm.
The evaluated carburized case is a carbon concentration gradient case. A carburized case with required case depth is obtained using cycles of acetylene dosing and diffusion, and then a microstructure obtained after performing full heat treatment is shown in Figure 3. The carbon concentration in carburized case is sufficient because it does not cause carbides precipitation, which will have a negative impact on the strength of carburized case of gears operating under varying load conditions. There is a difference in the concentration or case depth between the pitch diameter and root diameter, which has been caused by the geometry of teeth and size of active surface area for carbon absorption during carburizing process. The advantage of LPC process is that the process fully controllable and repeatable for diffusive enrichment of surface layer. This process is characterized by the formation of an oxidation-free case and constantly.

Acknowledgments

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