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ACETYLENE FLOW RATE AS A CRUCIAL PARAMETER OF VACUUM CARBURIZING PROCESS OF MODERN TOOL STEELS

Abstract: Carburizing is one of the most popular and wide used thermo-chemical treatment methods of surface modification of tool steels. It is a process based on carbon diffusive enrichment of the surface material and is applied for elements that are supposed to present higher hardness and wear resistance sustaining core ductility. Typical elements submitted to carburizing process are gears, shafts, pins and bearing elements. In the last years, more and more popular, especially in highly advanced treatment procedures used in the aerospace industry is vacuum carburizing. It is a process based on chemical treatment of the surface in lower pressure, providing much higher uniformity of carburized layer, lower process cost and much lesser negative impact on environment to compare with conventional carburizing methods, as for example gas carburizing in Endo atmosphere. Unfortunately, aerospace industry requires much more detailed description of the phenomena linked to this process method and the literature background shows lack of tests that could confirm fulfilment of all needed requirements and to understand the process itself in much deeper meaning. In the presented paper, authors focused their research on acetylene flow impact on carburized layer characteristic. This is one of the most crucial parameters concerning homogeneity and uniformity of carburized layer properties. That is why, specific process methodology have been planned based on different acetylene flow values, and the surface layer of the steel gears have been investigated in meaning to impact on any possible change in potential properties of the final product.

Keywords: vacuum carburizing, heavily-loaded gears, thermo-chemical treatment, microstructure

1. Introduction

Modern industrial production treatment processes of materials are accelerated by the needs coming from the society, that are linked to increasing importance in safety and environmental requirements coming from European union regulations. Most of them concern lowering toxic gases emission in the industrial processes, other lowering fuel consumption and noise by the engines [1]. Heat treatment and thermo-chemical treatment is one of the crucial technological processes of steels that are of great importance not only in the meaning of final element properties but also of social, environmental and economic importance [2,3,4]. Manufacturers of aircraft engine components all over the world fight with trends in the production to develop and apply newer and more advanced in the technological and innovative meaning treatment processes [4]. One of them concerns carburizing and heat treatment of steel components. Nowadays, aviation industry, due to strict regulations and requirements, is mainly focused on gas carburizing process. As vacuum carburizing have been already successfully introduced in the automotive field, aviation sector is still on the level of implementation, bothering with problematic homogeneity of the carburized layer and reproducibility of obtained by conventional methods results. That is why, research laboratories develop this method of thermochemical treatment for steel materials to meet all the requirements, especially taking into account ones in the aviation industrial sector [5].

Vacuum carburizing process is of a great significance, concerning much higher temperature of the process, greater homogeneity of carburized layer, and possibility to apply high-pressure gas quenching, which is directly linked to the carburizing aiming in much higher reproducibility of results [6,7]. It has become an attracted scientific and technological case hardening process in aerospace industry due to significant advantages in comparison with gas carburizing. The main assets of vacuum carburizing are: shortening time of the process, absence of external oxidation, high efficiency and reproducibility, power saving and ecological safety. Another attractive benefit of the carburization process is the compressive residual stresses develop at the surface [9].

Vacuum carburizing occurs in the self-regulation mode consisted of cyclic intervals of saturation and diffusion. In the stage of dosing hydrocarbons to the working chamber, the interaction between acetylene molecules and steel surface appears. Carbon atoms adsorb directly on the saturated surface and simultaneously almost continuous carbide layer is formed. In the next step absorbed carbon is transferred into the material by diffusion. The proper regulation of the rate of mass exchange between gaseous and solid state and diffusion in the solid state is required to control the process. Additionally, of a great importance is stability of the atmosphere in the working chamber. That is why controlling the acetylene flow through the process of saturation is so important [10].

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In practical attitude carburization is the method of thermo-chemical treatment which involves two stages. In the first step the surface layer is modified by addition of carbon to the material with its diffusion causing the gradient of carbon content from the surface to the inner. The gradient of concentration induce the gradient of hardness. Carburizing is followed by hardening and tempering of element in order to give it a martensitic structure, which additionally increases strength properties of treated element in the entire volume [6,7]. One of the fundamental aspects of the vacuum carburizing is homogenous distribution of carbon in the surface layer what is usually not achievable in the other - classical types of carburizing processes. The mathematical description of the process of gas distribution in a vacuum, confirms possibility to conduct carburizing in the way in which transported carbon is uniformly distributed over the cross section of the treated element. In the study authors focused their effort to investigate impact of acetylene flow in the working chamber on the uniformity of this distribution affecting final homogeneity of carburized layer [11,12].

2. Results and discussion

To investigate acetylene flow rate impact on the homogeneity of the carburized layer, three different values have been chosen: 50, 250 and 750 l/h. In the conventional procedures acetylene flow rate should be increased in case of increasing carburized surface area of treated element. That is why for the study, small, gear-shaped specimens of the same geometry and surface area were chosen (Fig. 1a). They were fabricated from AISI 9310 steel, which is conventionally used in the aerospace industry for heavily loaded elements of aircraft engine transmission systems. This kind of steel from the AISI group is reach in chromium, nickel and molybdenum, presenting high mechanical properties, hardenability, impact strength and fatigue resistance. It is a good example for applied study, as it has been one of the main materials used in the vacuum carburizing process development for aerospace elements in recent years.

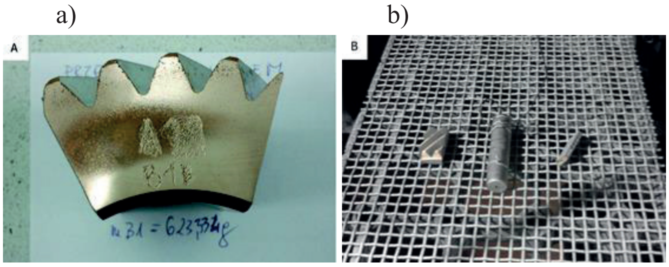
a) b)

Fig. 1. AISI 9310 steel specimen, a) free view, b) mounted in the chamber of the furnace

Three different acetylene flow rates have been applies for the same carbon saturation phase model and whole thermo-chemical process conditions. Specimens were preheated to 925 °C with isothermal pause at 600 °C. Scheme of the carburizing process is presented in figure 2. Additionally in the treatment procedure, sub-zero treatment and one step tempering were applied.

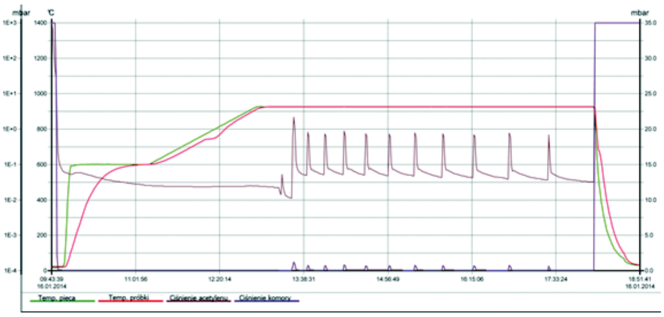

Fig. 2. Thermo-chemical treatment procedure protocol of AISI 9310 steel gear element used in the study

Specimens after the process with three different acetylene flow rates were named: B1 – 750 l/h acetylene flow, B2 – 250 l/h acetylene flow and B3 – 50 l/h acetylene flow. Gear elements were cut into the cross-sections and submitted to metallographic investigation. Metallographic cuts were prepared according to aviation standards with use of certified procedures. Figures 3-5 present microstructure of specimens after carburizing process with different acetylene flow rate values. The micrographs were prepared for tip and pitch diameter of the tooth and additionally for the core area. Based on the investigation one can conclude impact of acetylene flow rate on the morphology of microstructure elements in the carburized layer. Specimen B1 carburized with 750 l/h acetylene flow shows microstructure consisting of retained austenite in high-carbon martensite. It is additionally characterized by appearance of high amount of small-size carbides of high dispersion level near the surface. Decreasing acetylene flow rate to 250 l/h for B2 specimen decreases the volume of retained austenite visible in the microstructure. Much lower content of the carbides can be additionally observed. They appear mainly near the surface of the pitch diameter area of the tooth. Specimen B3 carburized with 50 l/h acetylene flow rate is characterised by very high amount of retained austenite. Compared to specimen carburized with 250 l/h is shows similar lack of carbides in the surface area.

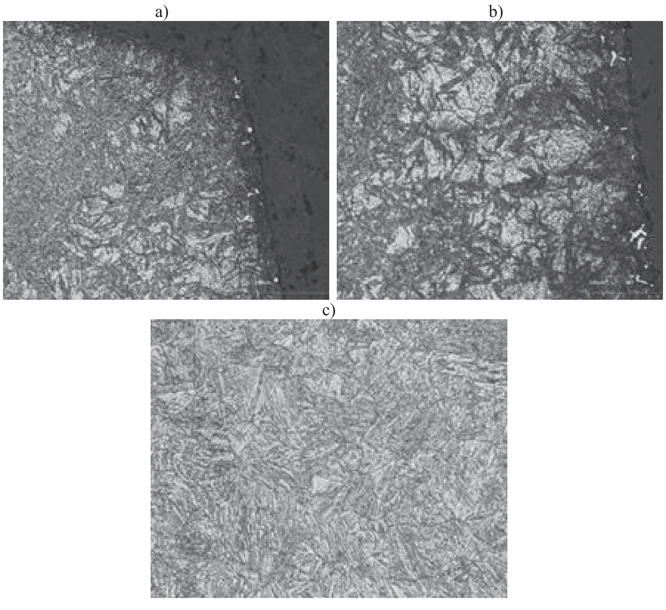
a) b) c)

Fig. 3. Microstructure of specimen B1 carburized with 750 l/h acetylene flow rate: a) tip of the tooth, b) pitch diameter of the tooth, c) core

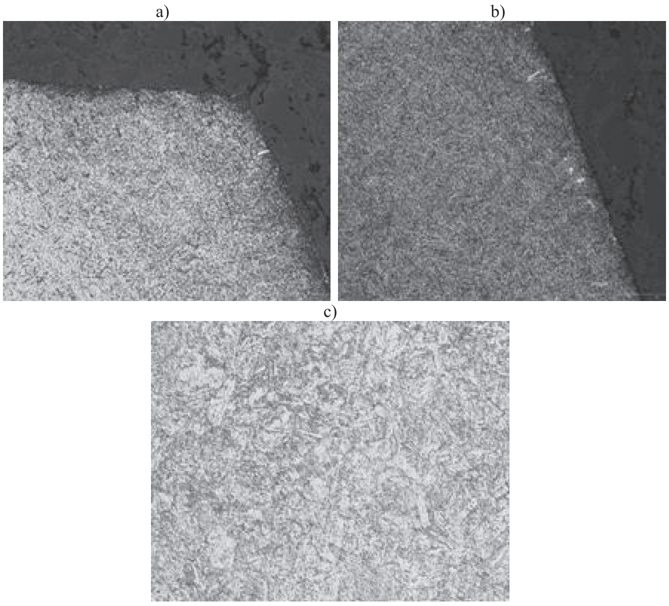

Fig. 4. Microstructure of specimen B2 carburized with 250 l/h acetylene flow rate: a) tip of the tooth, b) pitch diameter of the tooth, c) core

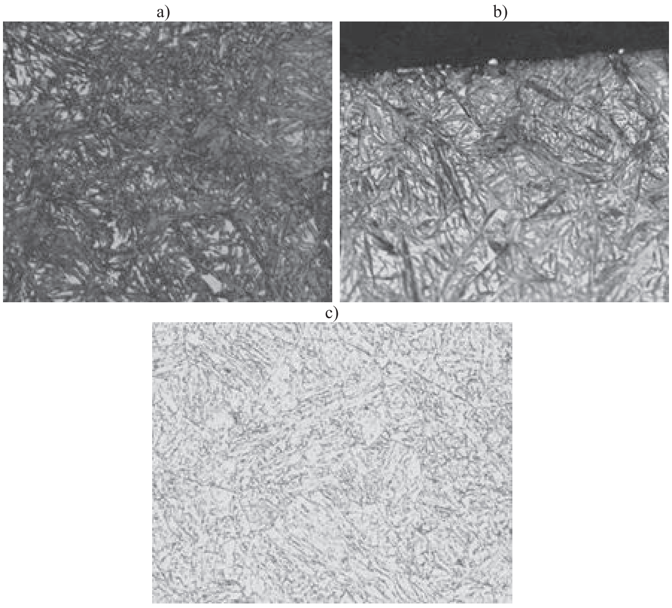

Fig. 5. Microstructure of specimen B3 carburized with 50 l/h acetylene flow rate: a) tip of the tooth, b) pitch diameter of the tooth, c) core

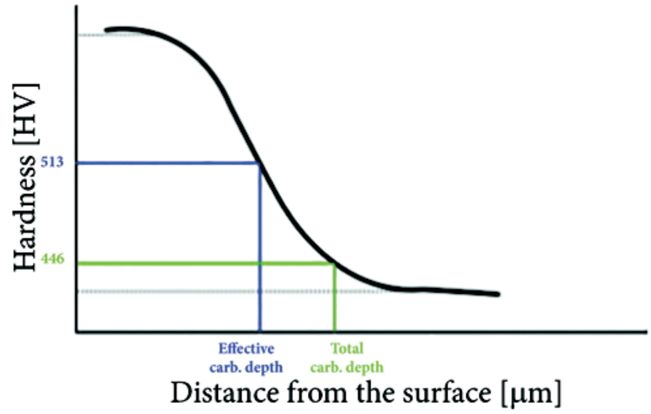

Fig. 6. Scheme for derivation of total and effective carburizing depth according to AMS standards

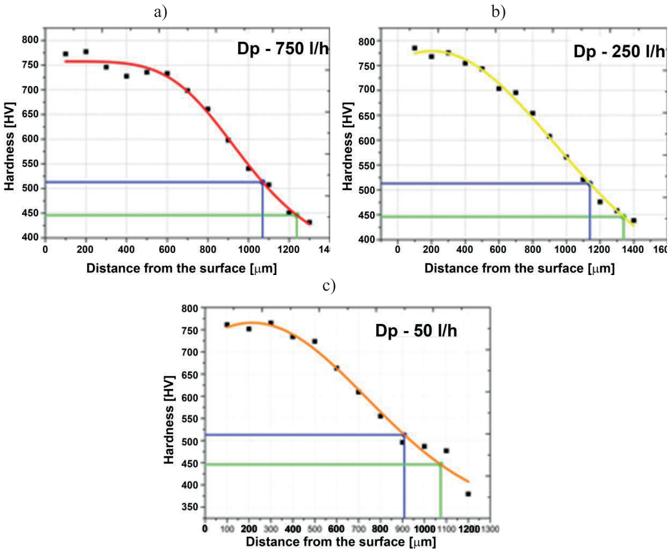

Fig. 7. Hardness profile for pitch diameter of the teeth for: a) B1 specimen with 750 l/h acetylene flow, b) B2 specimen with 250 l/h acetylene flow and c) B3 specimen with 50 l/h

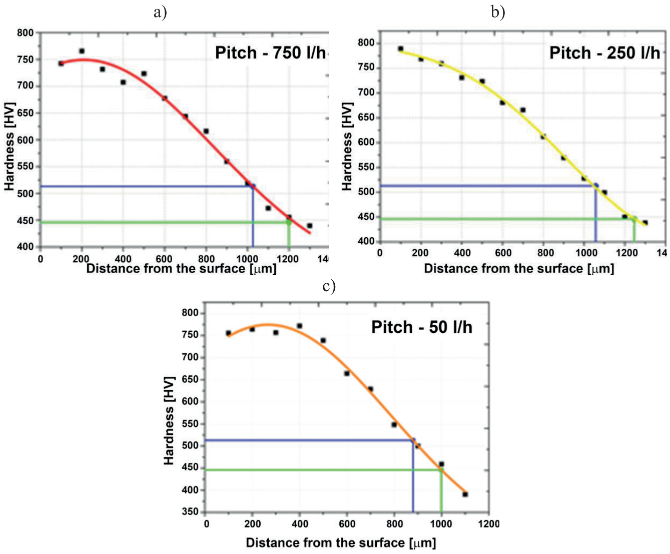

Fig. 8. Hardness profile for pitch generator radius of the teeth for: a) B1 specimen with 750 l/h acetylene flow, b) B2 specimen with 250 l/h acetylene flow and c) B3 specimen with 50 l/h

In the next step, hardness profiles for layers carburized with three different acetylene flow rates values were measured. Effective and total carburizing depth were derived according to AMS standards based on the critical values for accordingly 513HV for effective and 446HV for total carburizing depth (Fig. 6). For comparison, results have been presented separately for pitch diameter (Fig. 7), pitch generator radius (Fig. 8) and the notch area (Fig. 9) of the teeth. All curves obtained in the measurement are characterised with smooth changes concerning Plato regions near the surface and going to the core of the tooth.

Based on performed analysis of the curves presenting hardness profile of carburized layer it was concluded that acetylene flow rate strongly impacts effective and total carburizing depth. Table 1 presents values for effective and total carburizing depth for tip, pitch diameter and the notch area of the teeth in investigated representative elements of gears.

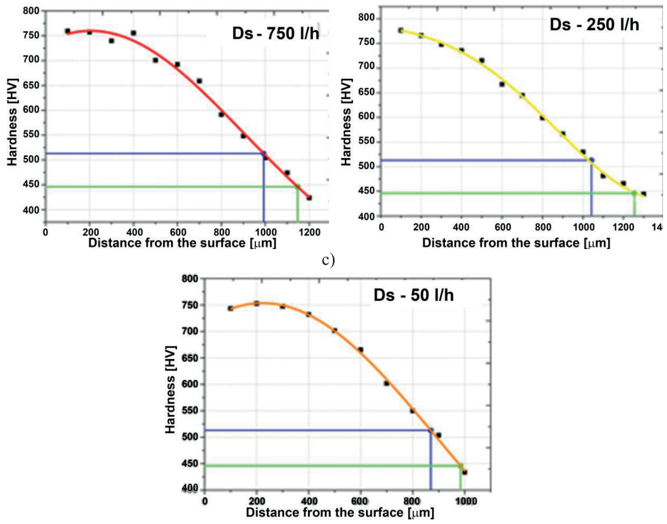

Fig. 9. Hardness profile for notch of the teeth for: a) B1 specimen with 750 l/h acetylene flow, b) B2 specimen with 250 l/h acetylene flow and c) B3 specimen with 50 l/h

TABLE 1

Effective and total carburizing depth values derived based on hardness profile curves

Acetylene flow rate [l/h]	Effective carburizing depth [μm]			Total carburizing depth [μm]		
	Investigated area					
	Dp	Ds	Pitch	Dp	Ds	Pitch
750	1069,48	992,6	1025,39	1237,67	1147,39	1199,43
250	1139,7	1041,95	1057,35	1273,39	1339,35	1246,53
50	957,39	869,82	879,82	1038,09	998,95	1077,32

Maximum value for both effective and total carburizing depth was observed for 250 l/h acetylene flow rate value. Additionally most smooth changes of the Plato regions were observed in case of analysed curves for this acetylene flow values. Lowers carburizing depth was observed for specimen B3. In this case acetylene flow rate on the level of 50 l/h was not enough for uniform distribution of the carbon in the surface area through the carburizing process. Lower values observed for 750 l/h acetylene flow rate are caused by oversaturation of carbon on the surface of the material, blocking further diffusion into the material. Performed investigation proves that 250 l/h is most convenient acetylene flow rate to be used in case of characteristic of vacuum carburized layer.

3. Conclusions

Analysis of acetylene flow rate impact on carburized layer of representative gear elements made of AISI 9310 steel proved dependence of the microstructure and hardness profile from this variable. Analyzed specimen, submitted to carburizing with varying acetylene flow rate from 750 to 50 l/h proved that there is a dependence and possible critical value that is responsible for oversaturation of the carbon on the surface through the treatment process. To high amount of carbon in the carburizing atmosphere of the furnace limits diffusion process of this element into the material and forces formation of carbides in the surface area. Thus, most convenient value for acetylene flow rate for investigated process is 250 l/h. Results obtained within the research will be used for more detailed investigation of the acetylene flow rate on the microstructure and diffusion mechanisms of carbon in the AISI 9310 steel. They will be used later on for preparation of database and coefficients allowing prediction of acetylene flow rate need for specific surface area of carburized element.

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