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DETERMINATION OF HEAT TREATMENT PARAMETERS FOR HEAVILY-LOADED AIRCRAFT ENGINE COMPONENTS

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Abstract

Gears, due to their complex shape, carried load and required accuracy are ones of most complex aircraft engine parts. Single tooth damage usually breaks the power transmission and causes failure of the entire gear system. Adequate sustainability and guarantees of transmission is therefore a condition for secure operation of whole device. Particularly high requirements for reliability are put to transmissions used in the aerospace industry. Due to the loads which are transmitted through the gears, the materials used by the manufacturer must have not only high strength but also show the abrasion resistance of the surface layer and the ductility of the core. Proper parameters matching allows to create an element that can operate at higher stresses and loads. In addition, factor strength and abrasion resistance of the surface layer has a significant impact on the life of the gear. Thermo-chemical treatment of industrial gears is a fundamental process, which gives them adequate mechanical properties regarding loads they carry and the surface conditions of work. Among many methods of thermo-chemical treatment used in the industry, the most distinctive are innovative technologies designed to reduce process costs and being more environmentally friendly. The most promising methods in the discussed field are vacuum carburizing and high-pressure hardening, which by their specification of work significantly reduce the emission of CO_2 and the duration of the process, without reducing the quality of the final product. The main aim of the paper is to present criteria for selection of heat treatment parameters as a part of thermo-chemical treatment process performed using vacuum methods. Proper heat treatment parameters are crucial in programming of some of final material characteristics as grain size and retained austenite morphology.

Keywords: *aircraft engine components, vacuum carburizing, heat treatment, quenching, alloy steel microstructure*

1. Introduction

Nowadays there are many methods of treating steel gears, which aim in increasing strength properties and life-time of treated element [1]. The main objective of conducted researches and technological developments is to modify the surface with additional flexibility while maintaining the core strength of the gear [3]. Method most commonly used in the industry is thermo-chemical treatment, which consists of two basic processes. The first stage, *chemical*, is to modify the surface layer, and is done by applying a coating on the substrate material or by modification of its chemical composition. In case of chemical composition modification a major role suits process called carburization which is based on modification of the surface layer by diffusive addition of carbon [3, 4]. The second stage *thermo* is a treatment process involving 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 [2].

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, proves that it is possible to conduct carburizing in the way in which carbon transported is uniformly distributed over the cross section of the treated element [2, 5, 8].

Another important aspect of analysing of the structure subjected to vacuum carburizing is heat treatment applied in order to transform the austenite to martensite. This process is done by quenching of a steel from the austenitizing temperature to room temperature and then deep-freezing at temperature below -75°C to prevent the re-transformation of martensite to austenite. This paper presents an innovative combination of vacuum carburizing process of gears with the process of high-pressure quenching and different heat-treatment variants in the way. Carburized element is subjected to quenching by passing the gas through the furnace chamber at high pressure with high flow speed of a gas. It is as well modern process as vacuum carburizing itself. Cooling medium must be an inert gas that does not have impact on the process of carburizing. The most commonly used are either nitrogen or argon. With a specially designed heat exchanger and a closed circuit cooling gas transport, the hardening process can be carried out in a furnace used for carburizing, which has a significant impact on reducing of cost of the hardening process and machine operation [6, 7, 9, 10].

An important factor in thermo-chemical process planning is prediction of retained austenite content after the heat treatment (especially after the deep-freezing and tempering). Additionally, it is important to design the process so that material's structure is of appropriate grain size. It has a huge effect on final mechanical properties [4, 5, 8]. To achieve this purpose the authors of the paper studied the impact on the structure of four different heat treatment variants. The first is the quenching of the workpiece directly from the carburizing temperature. Another method involves lowering the temperature of the carburized element to the level of standard procedural austenitizing and then quenching. Further methods include the microstructure refining by cooling the material to a pearlitizing temperature or room temperature before austenitizing.

This paper presents a comparison of four different methodologies for the heat treatment after the vacuum carburizing process. Analysis of the microstructure and properties of the surface layer and core material was used to determine the criteria for heat treatment process which is part of thermo-chemical treatment of heavily-loaded aircraft engine components.

2. Methodology

In the study, alloy steel, common for manufacturing of heavily loaded aircraft engine elements, has been used. The gears have been manufactured by standard industrial way according to specified norms. The areas not desired to be carburized have been coppered using electrochemical methods. Carburizing has been performed in Vacuum Heat Treatment Mono Therm HK.446.VC.10.gr furnace from ALD Vacuum Technologies GmbH. Full process has been performed in the steps described as follows:

1) carburizing,
2) heat treatment,
3) quenching,
4) deep freezing,
5) tempering.

Carburization has been performed by alternate use of acetylene and vacuum pulses to allow diffusion of concentrated carbon into the material. Heat treatment was performed in 4 different variants (Fig. 1). First variant (namely: "VC" variant – vacuum carburizing and quenching) included vacuum carburizing and direct quenching from the carburizing temperature (Fig. 1a). The next one (namely: “A” variant – vacuum carburizing, austenitizing and quenching) included additional austenitizing step at a little lower temperature in which additional impact of austenitization on the carbon diffusive transfer was investigated (Fig. 1b). Third method (namely “RT” variant – vacuum carburizing, room temperature stabilizing, austenitizing and quenching) assumed room temperature structure stabilization, before austenitizing (Fig. 1c). The last process (namely “P” variant – vacuum carburizing, pearlitizing, austenitizing and quenching) was based on additional pearlitization step in which the material fully rebuilt it’s structure before austenitizing (Fig. 1d). All the variants in the heat treatment procedure were performed in the chamber with no oxygen allowance. Quenching was performed with gaseous nitrogen of 10 bar absolute pressure. Quenching was additionally accelerated by industrial turbine with 3000 rpm rotation speed. Slow cooling was performed in the way simulating real “Air Cooling” conditions. Deep freezing and tempering processes were performed in the same way for all the heat-treatment variants according to aircraft industry norms.

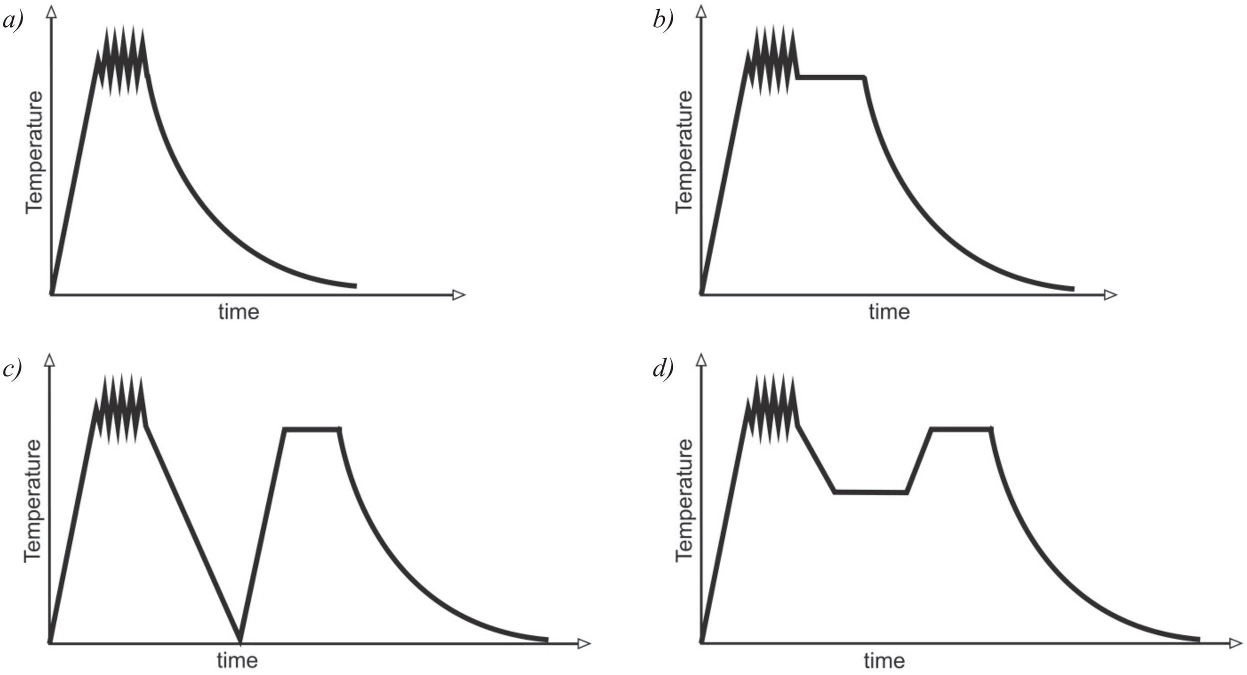

Fig. 1. Four different heat treatment methodologies after vacuum carburizing process: a) “VC” variant: quenching directly after last carburizing pulse, b) “A” variant: austenitizing after the carburizing process followed by quenching, c) “RT” variant: stabilization in room temperature and heating to austenitizing temperature followed by quenching, d) “P” variant: additional pearlitizing normalization step before austenitizing

3. Results and discussion

The paper presents, as a comparison, effect of carburization and heat treatment on the case-depth of treated gear element (Fig. 2). Fig. 3 shows hardness diagram for specified chosen region of the gear (Fig. 2). The results have been shown to prove adequate carburization effect and no influence of the heat treatment process on the effective or total case-depth.

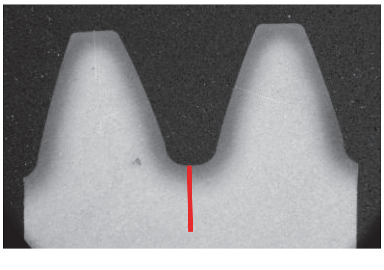

Fig. 2. Hardness profile investigation region for vacuum carburizing process of the gear teeth

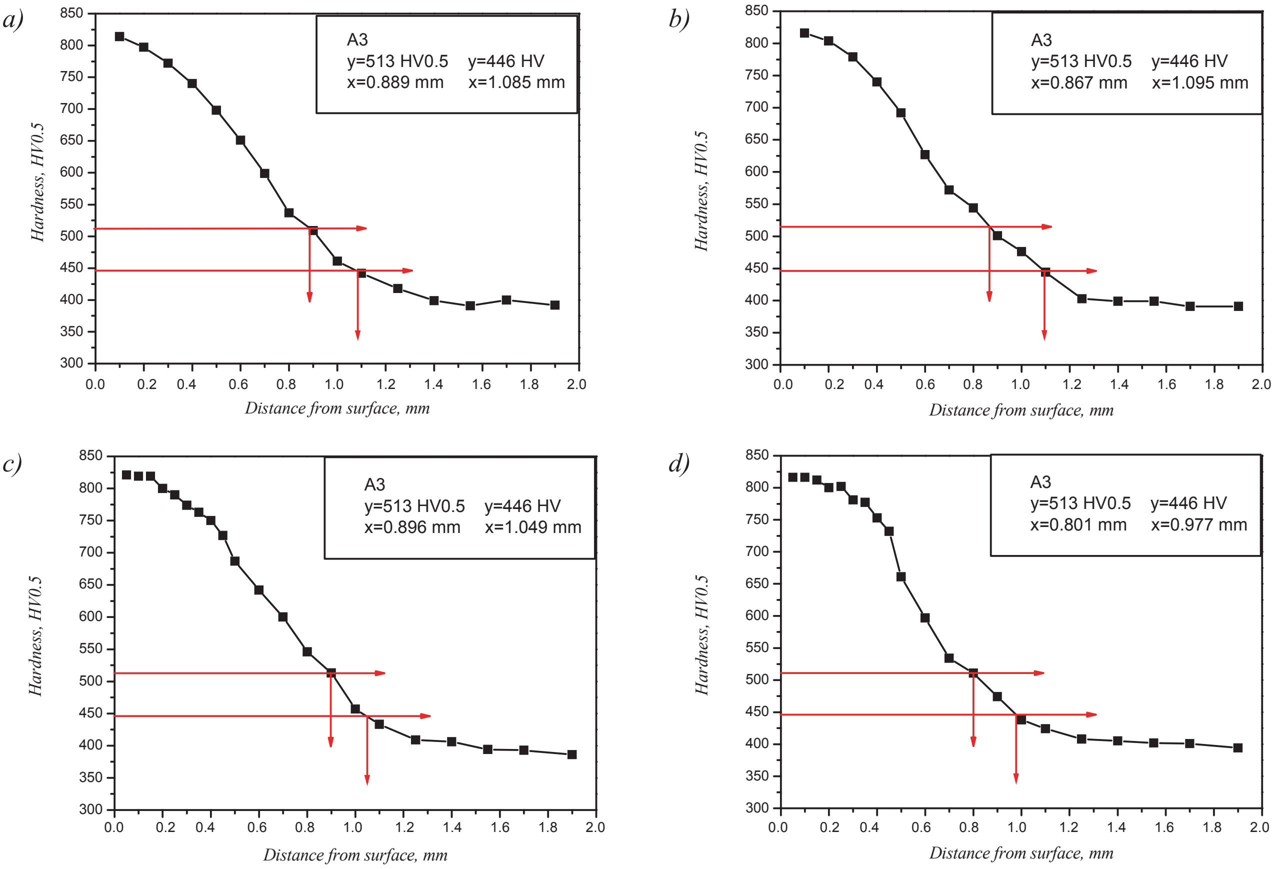

Fig. 3. Hardness profile with effective and total case-depth marked for VC (a), A (b), RT (c) and P (d) heat treatment variant

Main aim of the heat-treatment process as a part of thermo-chemical is a proper programming of the microstructure of the treated elements. Not only is the grain size important. Additional parameter that can be adjusted through proper heat-treatment process is retained austenite percentage in the material. Both pointed factors influence final hardness parameters in the carburized layer and in the core of the gear. Additionally the microstructure type impacts fatigue resistance and creep resistance. While predicting and adjusting proper final parameters of the material it is important to combine the microstructural factors with carburization effect and obtain suitable properties on the surface and in the core of the gear.

In the paper results concerning microstructure of steel after carburizing and following different heat treatment procedures have been presented. Fig. 4-5 presents microstructure photos obtained from scanning electron microscope. In Fig. 4 carburized layer microstructure is presented. Fig. 5 shows core microstructure of specified specimens after different heat-treatment procedures. Fig. 4a presents carburized layer microstructure in the process in which quenching was performed directly after the last carburizing pulse ("VC" variant). Sparse fine carbides can be observed in the microstructure. The same carbides will be observed in the microstructure of the element subjected to a process in which the quenching temperature is being lowered to austenitizing standard procedural temperature ("A" variant) (Fig. 4b), however, much more homogeneous distribution of them can be noted. Additionally retained austenite on the level of 3.8% presents to be lower to compare with "VC" variant, where the level of retained austenite was of 4.2%. When comparing stabilizing in lower temperatures, the specimen stabilized in room temperature ("RT" variant) showed lowest retained austenite amount (3.5%). The specimen, for which the microstructure stabilization was performed in the pearlitizing temperature ("P" variant), after full heat treatment procedure, contained the highest amount of retained austenite on the level of 4.5%. Although, pre-treating as microstructure stabilization is not directly influencing the retained austenite transformation, it is impacting later quenching and deep-freezing process in which it appears

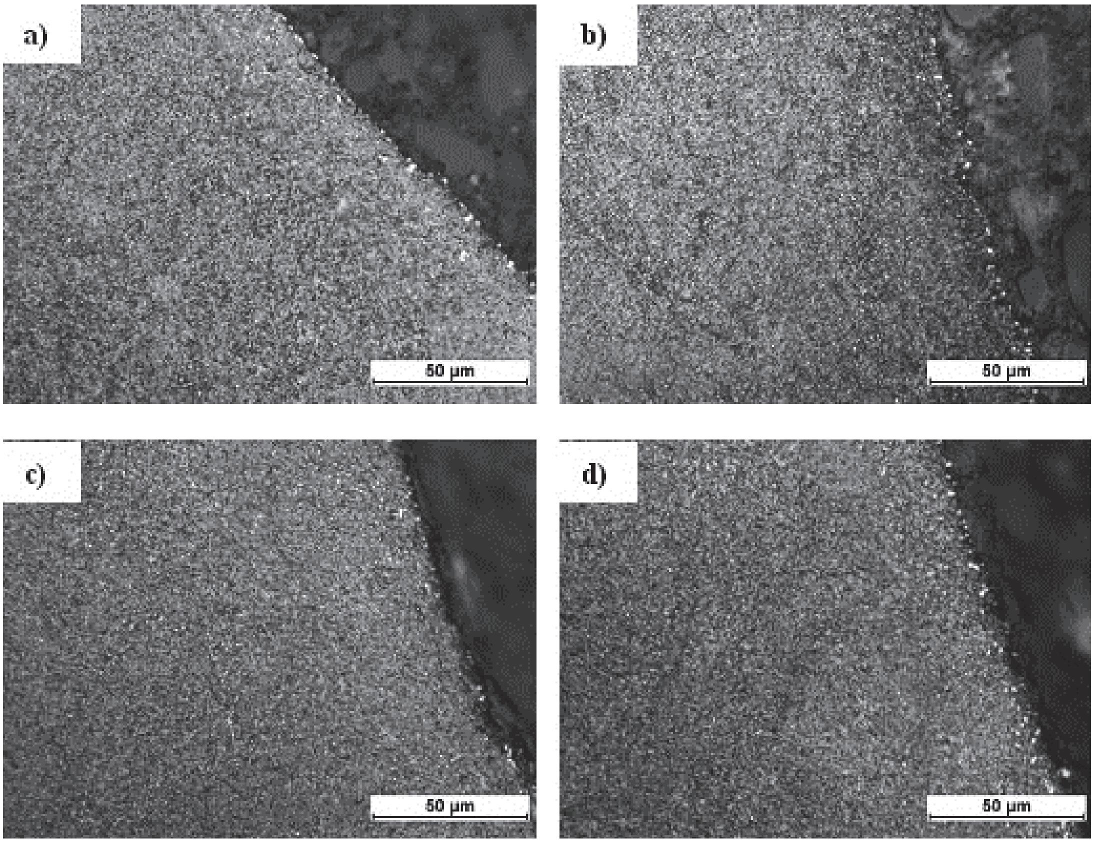

Fig. 4. Carburized layer microhardness in the specified area of the gear teeth for VC (a), A (b), RT (c), and P (d) heat treatment variant

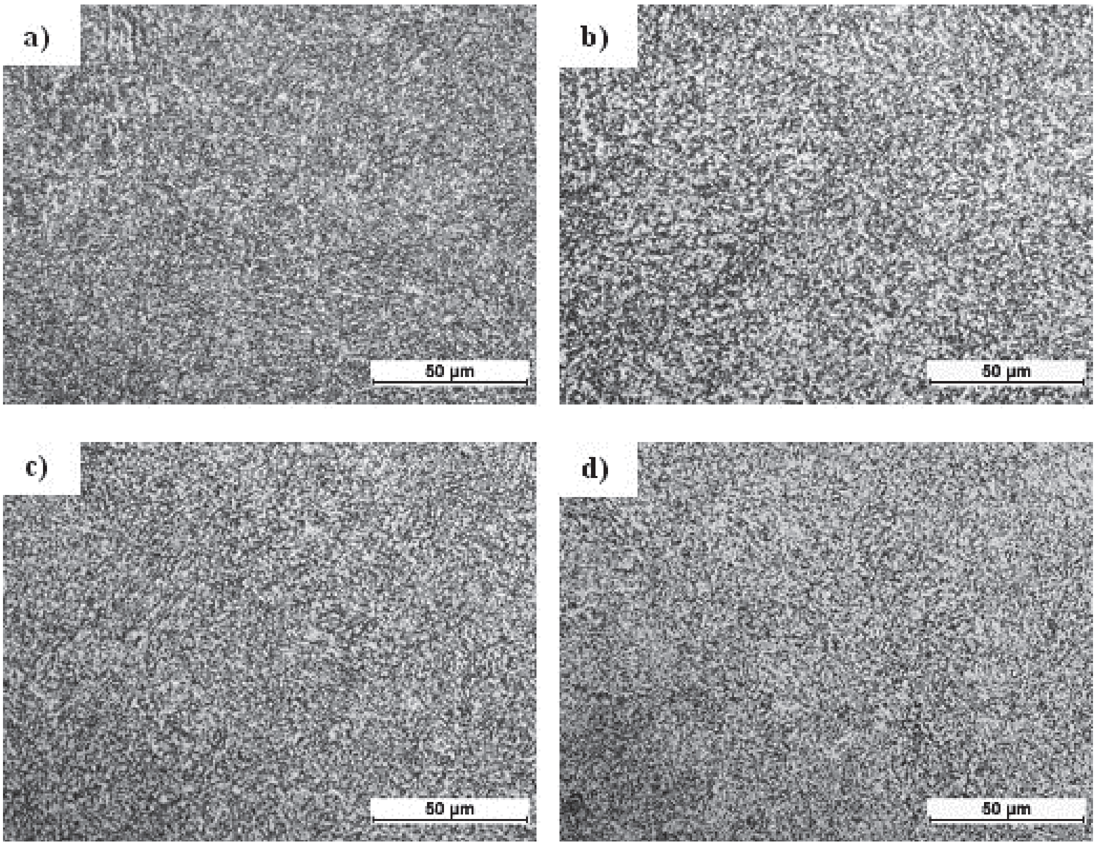

Fig. 5. Core microhardness in the specified area of the gear teeth for VC (a), A (b), RT (c), and P (d) heat treatment variant

4. Conclusions and summary

In the study different heat-treatment procedures in thermo-chemical treatment of heavily-loaded aircraft engine components have been investigated based on alloy steel transmission gears. Their direct and indirect influence on retained austenite amount, grain size and by this on the hardness profile and appearance of secondary carbides in the structure has been studied. The determination of criteria for proper heat treatment are depended on specialized functionality of treated elements. In case of heavily-loaded aircraft engine components as transmission gears it is crucial to program the treatment in aim to fulfil all the requirements put by the constructor. Although, research conducted in the paper showed minor microstructural changes, it is important to get to know deeper their impact on indirect parameters. The researches proved that microstructure stabilization in pearlitizing temperature decreases predisposition of the martensite to retransform to retained austenite in further steps of the process, however stabilization in room temperature increases this predisposition considerably.

Grain size factor investigated in the study was not influenced by heat treatment procedure. All heat-treatment variants consisted of austenitizing and quenching allowing structure refinement and obtaining of martensitic structure.

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