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INDUCTION HARDENING OF TOOL STEEL FOR HEAVILY LOADED AIRCRAFT ENGINE COMPONENTS

Induction hardening is an innovative process allowing modification of the materials surface with more effective, cheaper and more reproducible way to compare with conventional hardening methods used in the aerospace industry. Unfortunately, high requirements and strict regulation concerning this branch of the industry force deep research allowing to obtain results that would be used for numerical modelling of the process. Only by this way one is able to start the industrial application of the process. The main scope of presented paper are results concerning investigation of microstructure evolution of tool steel after single-frequency induction hardening process. The specimens that aim in representing final industrial products (as heavily loaded gears), were heat-treated with induction method and subjected to metallographic preparation, after which complex microstructure investigation was performed. The results obtained within the research will be a basis for numerical modelling of the process of induction hardening with potential to be introduced for the aviation industrial components.

Keywords: induction hardening, heavily-loaded gears, heat-treatment, microstructure

1. Introduction

Induction hardening is a new, innovative and energy-saving technology of surface heat-treatment used mainly for axial symmetric steel components or flat elements of machines. This technology is also used for complex geometries as gears, but due to problematic heat transfer model not often applied. Comparing this technology with other, conventionally used for hardening and modification of the surface of the material, one can see a great potential for specific industrial applications. Due to specifics of the process, it allows treatment of material with the same, as not even with higher efficiency, lowering the cost of the heat-treatment process. Additionally application of induction hardening process eliminates a lot of disadvantages linked to conventional methods, and is eco-friendly, as does not produce any toxic gases and wastes in for of used hardening oil or evaporated products of oxidation process.

Although induction hardening is of great potential, it still meats a lot of technological problems to be solved. Statistical high equipment cost and total change in the methodology of the heat-treatment process are the main causes of the problems appearing from applying new technology. Additionally, design of the equipment for induction hardening does not provide possibility of programming crucial parameters for prediction of microstructure and properties of the final product. Thus, there is a need for complex experimental trials that would allow creation of data base for this purpose.

Theoretical and based on the trials reproducibility of results and reliability of the induction hardening process are especially important factors in the field of aerospace industry. As a result, lots of aircraft components manufacturers begun to develop this technology, unfortunately without any successful introduction to every-day production.

To evaluate usability of the method of induction hardening, the researchers from Rzeszow University of Technology try to solve problems concerning trials of induction hardening that would produce lots of results useful for further possibility for numerical modelling of the process. Lack of modelling of this heat-treatment process is a crucial factor that is nowadays of a great potential for understanding the process, allowing application of specific process parameters and development of this technology for heavily-loaded elements of aircraft engine.

The main aim of this article is to present results concerning microstructure evolution of steel after the induction hardening process. The main idea behind that is first of all to investigate the efficiency of the process of induction hardening for representative steel specimen from the aircraft engine components materials base. Secondly the microstructure analysis will allow familiarization with the process and further design of experimental procedure in aim to apply the process for full-size complex geometry elements.

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2. Experimental

Induction hardening trials were performed with use of single-frequency induction hardening HI40 system (Fig. 1) designed and manufactured by ELKON Company in cooperation with The Polish Welding Centre of Excellence specially. The device is a part of Research and Development Laboratory for Aerospace Materials of Rzeszow University of Technology. It is designed for hardening of shafts, pins and gears with tooth-by-tooth method possibilities. It consists of power supply and heating system (induction coil and quenching chamber). Power supply is transistor frequency converter with adapted direct current circuit. It is equipped with adjustable power generator of maximum 40 kW that is able to generate magnetic field of 10-40 kHz frequency. Treated element is positioned in the induction coil area where it is subjected to heating and cooling. The induction coil itself is adjusted to the geometry of treated element and connected to the generator. Both transformer and induction coil are water cooled. The device is equipped with four axis movement possibilities allowing proper positioning of the coil and treated element.

For verification of applied technology, test specimens were produced with application of induction hardening and with conventional oil quenching method. Specimens microstructure was compared in order to see possible impact of the hardening method on the microstructure what would directly impact materials properties. For the experiment two alloy steels were used namely AISI 4340 and AISI 300M. First of them is a low alloy steel dedicated for heat treatment processes. It is chromium, nickel and molybdenum based material of high toughness and strength in heat treated conditions that is conventionally used for production of power transmission gears and shafts, aircraft landing gears and other aircrafts structural elements. As a second material for the research, AISI 300M steel was selected. It is a low alloy vacuum melted steel which is a modified version of the first chosen material that was selected in the study. It has high content of molybdenum and silicon what results in high strength, good toughness, fatigue strength and ductility (Tab. 1).

TABLE 1

Chemical composition of AISI 4340 and AISI 300M steels

Element	Content [%]	
	AISI 4340 steel	AISI 300M steel
Iron, Fe	95,675	93,925
Nickel, Ni	1,65	1,70
Silicon, Si	0,30	1,60
Chromium, Cr	0,90	0,90
Manganese, Mn	0,80	0,90
Carbon, C	0,40	0,45
Phosphorus, P	0,035	0,035
Molybdenum, Mo	0,20	0,40
Vanadium, V	—	0,050
Sulphur, S	0,040	0,040

Investigation of microstructure of the steels was performed in Research and Development Laboratory for Aerospace Materials according to aviation industry standards and requirements. The Laboratory is certified by the National Aerospace and Defense Contractors Accreditation Program what gives certainty about obtained results especially in meaning of aviation industry application and future planned induction hardening introduction and potential application in this sector.

In the first stage of the research heat-treatment process was performed with varying methodology both in conventional way and with induction hardening method. The aim was to obtain

Fig. 1. HI40 induction hardening system in Research and Development Laboratory for Aerospace Materials

specimens after different heat-treatment conditions for microstructure evolution investigation (Tab. 2). In the first stage – State "A" – specimens were submitted to normalization at 927°C for 2 hours and then quenched in oil (in case of conventional hardening) or in helium (in case of induction hardening). State B presents specimens after additional tempering at 302°C for 2 hours. State "C" presents structure evolution after double tempering. In case of AISI 4340 steel specimens were submitted to normalization at 899°C for 2 hours and then hardened from 855°C. They were annealed before hardening for 4 hours (State "D"). In the last stage – State "E" specimens were additionally tempered after hardening in 500°C for 3 hours.

TABLE 2

Investigated states of the materials after different heat treatment stages

State of material	
AISI 300M steel	**AISI 4340 steel**
State "A" Normalization at 927°C/2h → H 871°C/1h	State "D" Normalization at 899°C/2h → AC → H 855°C/4h
State "B" Normalization at 927°C/2h → H 871°C/1h → T 302°C/2h	State "E" Normalization at 899°C/2h → AC → H 855°C/4h → T 500°C/3h
State "C" Normalization at 927°C/2h → FC to 871°C/1h → H 871°C/1h → T 302°C/2h → T 302°C/2h	
where: AC – Air Cooling, H – Hardening (oil or helium quenching), T – Tempering, FC – Furnace Cooling	

For preparation of the specimens, conventional procedures applied in the Research and Development Laboratory for Aerospace Materials were used. Firstly specimens were cut with use of electro-erosion machine, what eliminates any impact of the cutting process on microstructure. Specimens were embedded in the polymeric substance in automated embedding machine. Preparation of the metallographic cuts was performed with the accordance to aviation standards. For the microstructure evolution observation optical microscope by Olympus with digital image recording system was used to ensure reproducible conditions and varying magnification options.

3. Results and discussion

The investigation, that was performed, aimed in comparison of different stages of the effect of heat treatment process on microstructure evolution. Compared were micrographs of specimens submitted to the same heat-treatment procedures with different methods of hardening, namely: induction hardening with use of helium as a quenching gas and conventional hardening with use of quenching oil. Presented micrographs were prepared with the same magnifications for proper comparison effect. Figures 2-4 present different states of AISI 300M steel

a)

b)

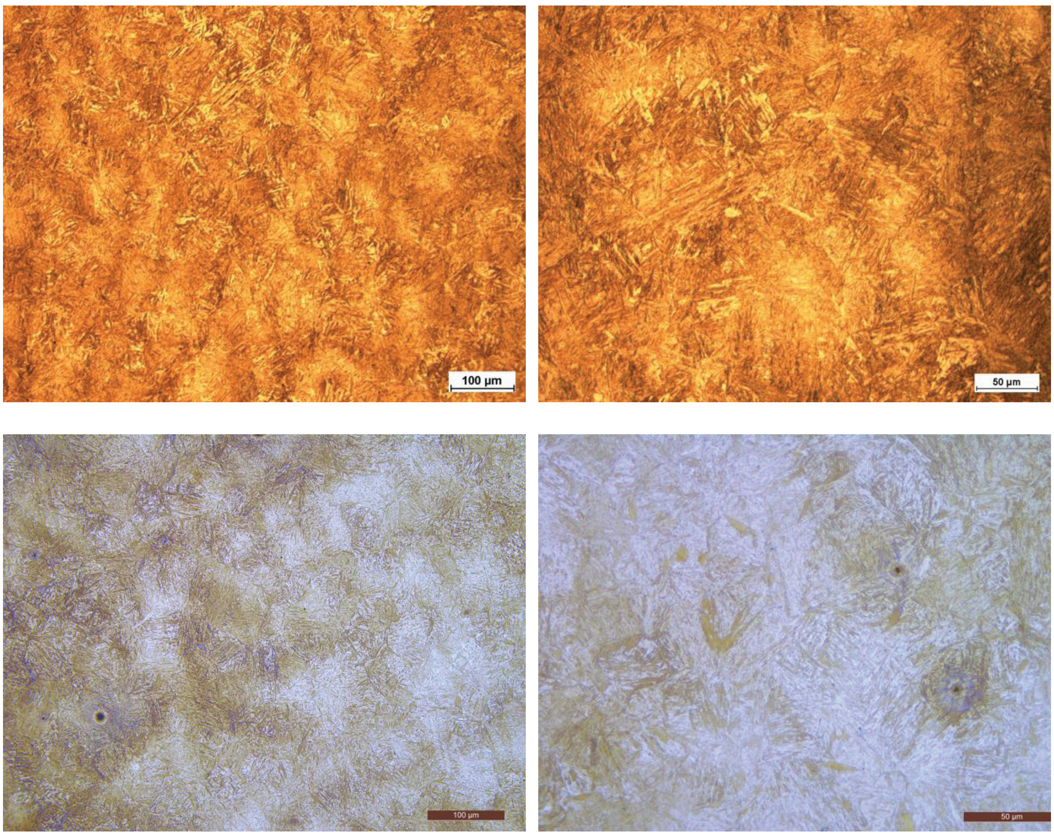

Fig. 2. Micrographs of AISI 300M steel in "A" state after normalization in 927°C for 2 hours, air cooling to 871°C (1 hour annealing) and quenching: a) conventional hardening with oil quenching, b) induction hardening with helium quenching

a) b)

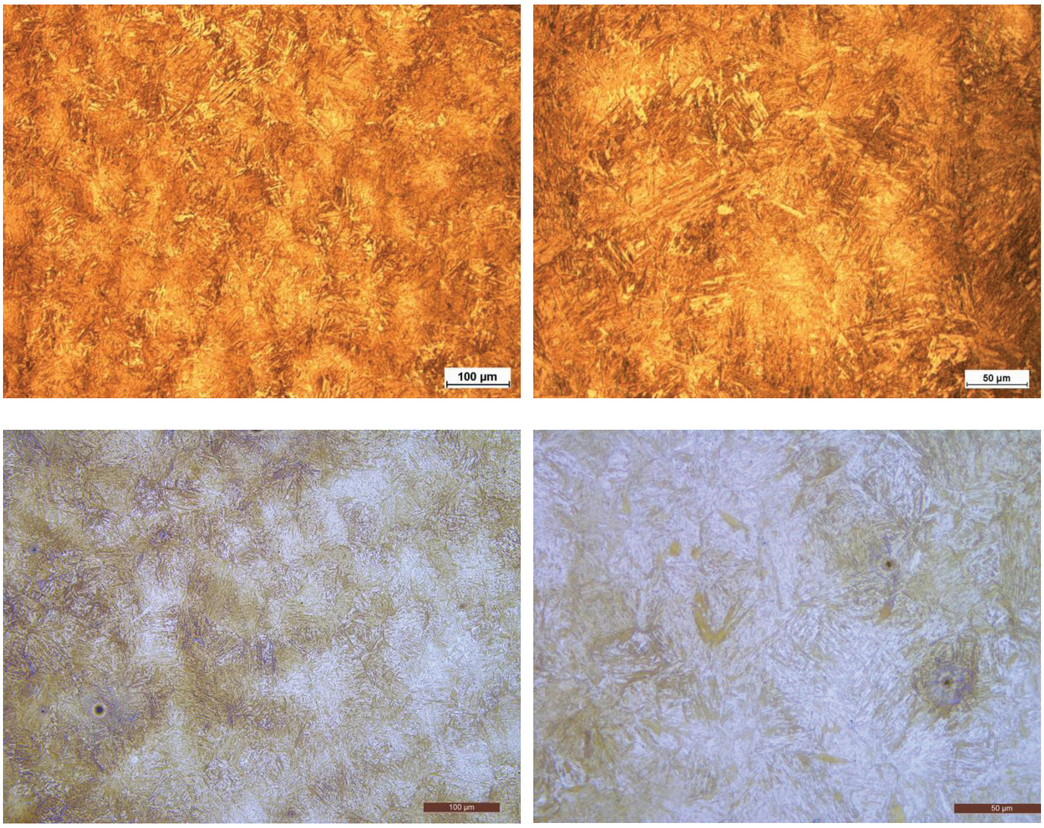

Fig. 3. Micrographs of AISI 300M steel in "B" state after normalization in 927°C for 2 hours, air cooling to 871°C (1 hour annealing) and quenching: a) conventional hardening with oil quenching, b) induction hardening with helium quenching. Specimens after hardening were submitted to additional tempering at 302°C for 2 hours

a) b)

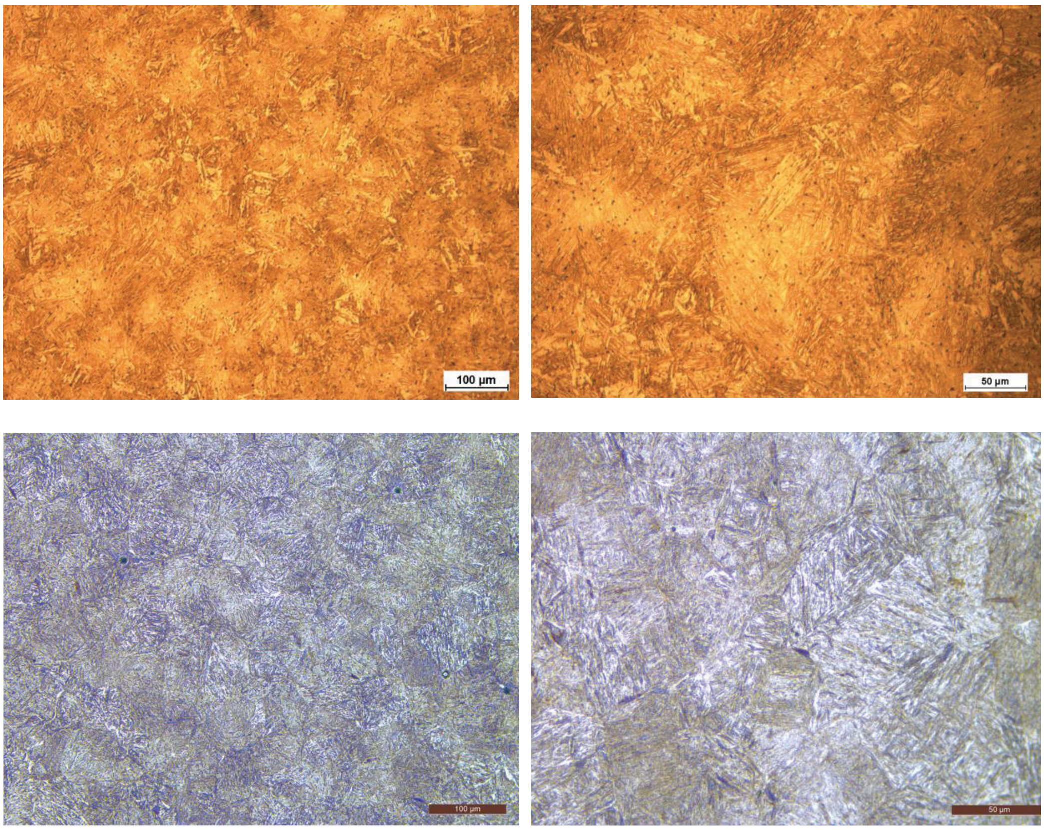

Fig. 4. Micrographs of AISI 300M steel in "C" state after normalization in 927°C for 2 hours, air cooling to 871°C (1 hour annealing) and quenching: a) conventional hardening with oil quenching, b) induction hardening with helium quenching. Specimens after hardening were submitted to double tempering at 302°C for 2 hours

a)

b)

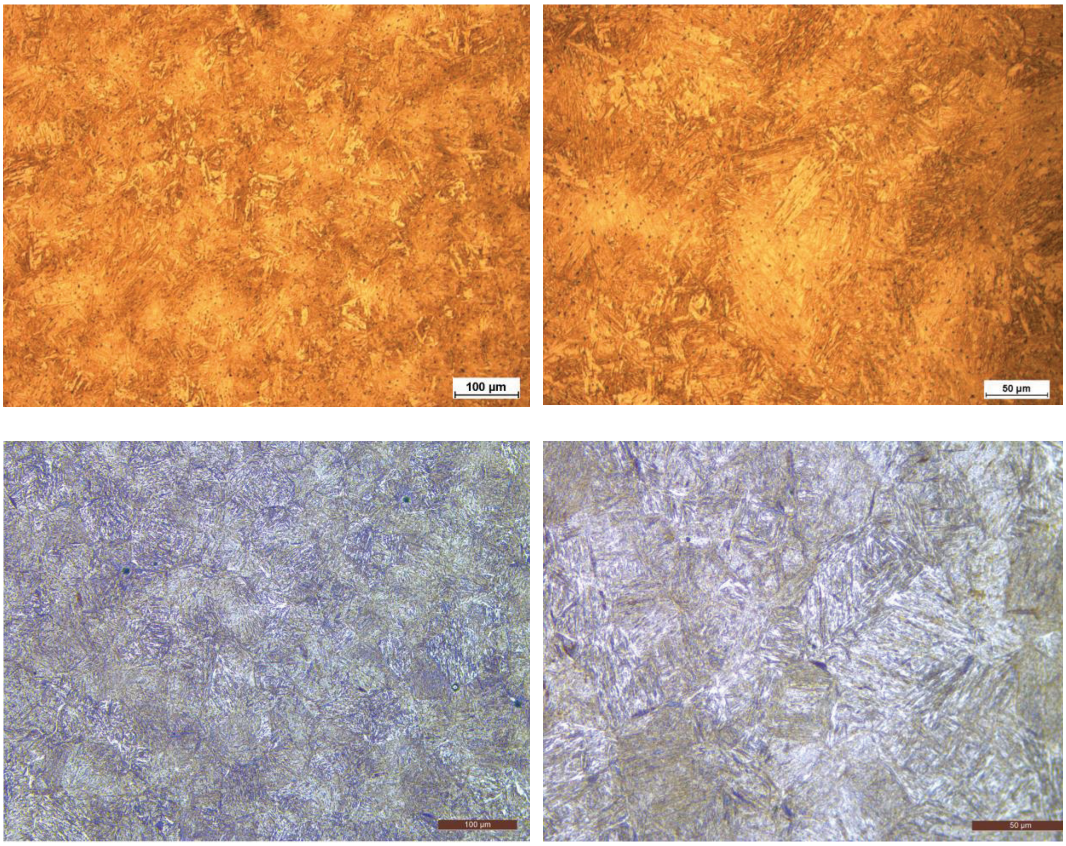

Fig. 5. Micrographs of AISI 4340 steel in “D” state after normalization in 899°C for 2 hours, air cooling to 855°C (4 hour annealing) and quenching: a) conventional hardening with oil quenching, b) induction hardening with helium quenching

a)

b)

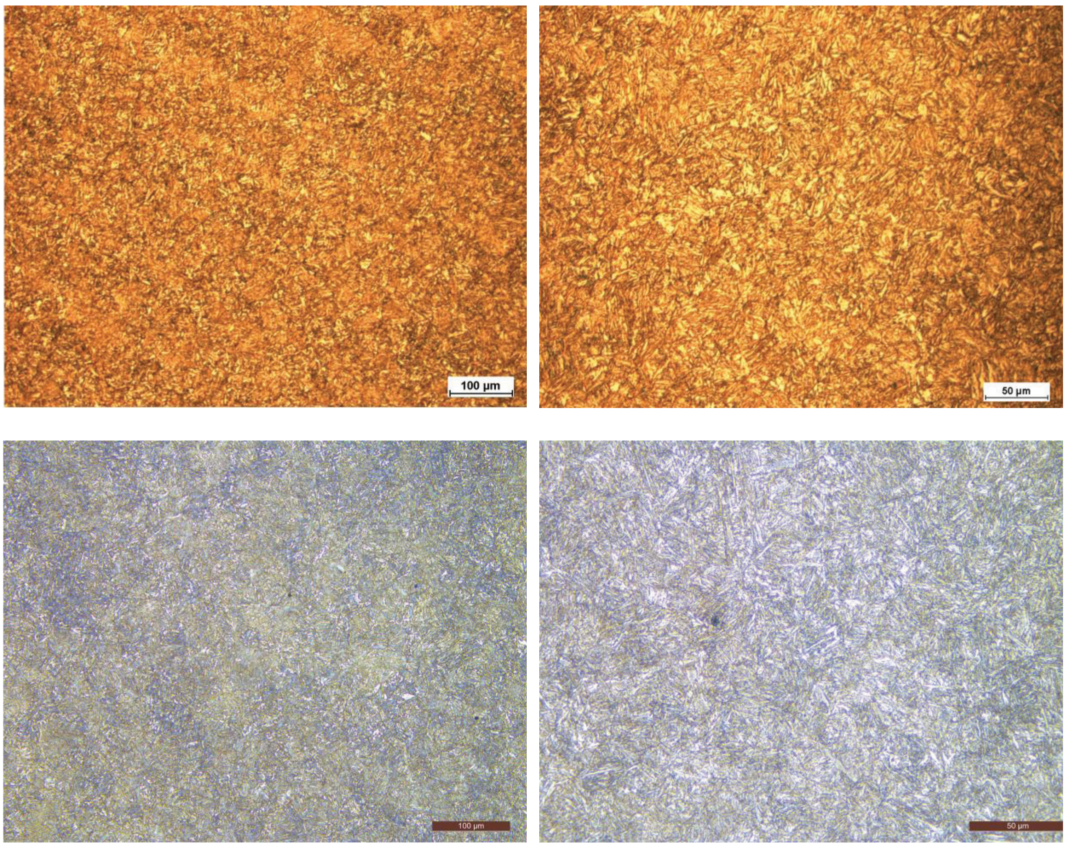

Fig. 6. Micrographs of AISI 4340 steel in “E” state after normalization in 899°C for 2 hours, air cooling to 855°C (4 hour annealing) and quenching: a) conventional hardening with oil quenching, b) induction hardening with helium quenching. Specimens after hardening were submitted to tempering at 500°C for 3 hours

according to performed heat-treatment process methodology (Tab. 2). In the materials "A" state (normalized and quenched) one can observe regular martensitic phase, although in case of helium quenched material after induction hardening process the homogeneity of the grains is higher. Additional tempering of the steel in case of "B" state gives no visible differences in the microstructure, however, second tempering ("C" state) impacts martensitic structure and the needle shaped grains are "softened" in meaning of diffusion processes that occurred through this last stage of the heat-treatment process.

Figures 5 and 6 present changes in the microstructure after heat treatment processes performed according to chosen methodology (Tab. 2) for AISI 4340 steel. The material after induction hardening process shows much finer microstructure to compare with conventional oil quenching. Additionally tempering of the "E" state of material impact stronger refining of the grain microstructure.

4. Conclusions

Induction hardening to compare with conventional oil quenching impacts microstructure of both AISI 4340 and AISI 300M steels. In case of vacuum melted AISI 300M steel induction hardening gives more homogeneity of the microstructure. AISI 4340 steel presents much finer grains to compare with conventional hardening process. The method applied in the research is a promising heat-treatment technology that could benefit much higher control of the process and resulting microstructure and properties of treated steel.

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