EFFECT OF THE INDUCTION HARDENING ON MICROSTRUCTURES OF THE SELECTED STEELS

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Abstract

The induction hardening is a well-developed technology in many industrial applications, e.g. automotive, tool manufacturing, casting technology, sheet metal forming etc. The induction hardening is generally employed for a surface hardening because the current induced during this process is concentrated directly under the surface of the workpiece due to the “skin effect”. Recently, more and more companies are opting for induction-based hardening solutions because it is ideal for integrating into production lines. This technology is extremely energy-efficient, particularly when compared to wasteful methods such as furnace carburizing. Additionally, transportation times and costs are reduced in this method. The most popular application of induction heat treatment is hardening of steels and cast irons. Hardening of components made from steels may be done for the purpose of obtaining certain properties including - but not limited to - strength, fatigue and wear resistance. The microstructure of steel prior to heat treatment (also referred to as the initial structure or structure of the parent material) also has a significant effect on results of the heat treatment and required process parameters. This paper presents a methodology of revealing of a microstructure after the induction hardening and results of a microstructure observation of two selected steels treated with the induction hardening using microscopy techniques. These microstructures examinations provide information about a prediction of required properties.

Keywords: Induction hardening, microstructure, steel, C45, St52-3

1. INTRODUCTION

An intelligent manufacturing technology is an essential asset in times of growing competition among the manufacturers of various components. Induction hardening is used to strengthen a specific area of a part: single piece, surface hardening of selective areas. Induction hardening is a process often used for the surface hardening of steel and other alloy components. The parts to be heat treated are placed inside a copper coil and then heated above their transformation temperature by applying an alternating current to the coil. The alternating current in the coil induces an alternating magnetic field within the work piece which causes the outer surface of the part to heat to a temperature above the transformation range. Induction hardening is a process used for the surface hardening of steel and other alloy components [1]. In the context of induction hardening, the expression short-cycle austenitization is also used, since by comparison with furnace processes the austenitizing temperature is reached within just a few seconds. The hardening temperatures are generally approx. 50 to 150 °C higher than with conventional furnace hardening. The process sequence during hardening consists essentially of heating, holding, quenching and possibly a subsequent tempering process, and is thus significantly shorter than the process sequence for conventional case hardening. The process is monitored by an appropriate control system so that the hardening results are reliably reproduced. The microstructure properties can be set to the required depth in carbon-based materials by varying the frequency employed, the energy input, the quenching method and the constant coupling distance between workpiece and inductor [2].

2. MATERIAL FOR THE RESEARCH

Material for the research were a pipe and a bar made from two kinds of steels after induction hardening trials carried out according to test parameters. The grades of those steels are presented according to the standard DIN. First of them is the non-alloy quality structural steel C45 (1.0503 is the numeric designation). The nominal composition (wt.%) of C45 is [3]: 0.43 - 0.50 % C, 0.5 - 0.8 % Mn, max 0.4 % Si, max 0.045 % P, max 0.045 % S, max 0.4 % Cr, max 0.1 % Mo, max 0.4 % Ni, and Cr + Ni + Mo = max 0.63 %. It has a low hardenability in water or oil; fit for surface hardening that gives this steel grade a high hardness of the hardened shell. The second investigated material is the non-alloy quality structural steel St52-3 (1.0570 is the numeric designation). The nominal composition (wt.%) of St52-3 is [3]: max 0.22 % C, max 1.6 % Mn, max 0.55 % Si, max 0.035 % P, max 0.035 % S, max 0.3 % Cr, max 0.08 % Mo, max 0.3 % Ni, min 0.02 % Al, and Cr + Ni + Mo < 0.48 %.

Classical non-alloy structural steels are a cost-effective solution for many simple applications. Main application of C45 medium carbon steel grade is for mechanical engineering and automotive components. Typical applications include tools, shafts, nuts, bolts, connecting rods, screws, rollers. According to some producers C45 offers a reasonable tensile strength [4] and according to some others opinion - excellent tensile properties and good machinability [5]. This grade can be flame or induction hardened to produce a good surface hardness with moderate wear resistance. C45 is widely used for components that require better properties than mild steel but does not justify the costs of an alloy steel [4].

ST52-3 steels is a low alloy, high strength structural steel which can be readily welded to other weldable steel. With its low carbon equivalent, ST52-3 steel possesses good cold-forming properties. ST52-3 steel plate is supplied in normalized or control-rolled condition. ST52-3 steel has many applications. Generally ST52-3 steels is used for machinery parts, mobile equipment, crane, boom, chassis, buildings, bridges and most structural activities [6]. As stated by [7] this grade is only used for unhardened components.

3. METHODOLOGY OF RESEARCH

The cross-sections were cut off from the investigated pipe (formed from steel St52-3) and the bar (made from steel C45), and then included using compression mounting. The mounting process should not cause any damage to the microstructure of the specimen. Pressure and heat are the most likely sources of damage during the mounting process. The included cross-sections were prepared according to a scheme of sample preparation established for steels using concept of planar grinding and polishing, in which several specimens are placed in a holder with the side to be prepared facing down [8]. Time of rotation with application of abrasive materials with various grit sizes in subsequent steps was a result of the gained earlier experience [9]. Final polishing is intended to produce a scratch-free surface for metallographic analysis. Proven etchant was selected from authoritative sources such as [10,11] to reveal the microstructures of the investigated materials after induction hardening and to be able to characterize the microstructures by light microscopy (LM) and scanning electron microscopy (SEM). The surfaces of the studied specimens were etched with nital solution to enhance the contrast between the phases occurring in the steels microstructures. Nital is a mixture of nitric acid (HNO_3) and alcohol (C_2H_5OH) commonly used for etching steels. It is especially suitable for revealing the microstructure of carbon steels. Nitric acid is a strong oxidizer, and alcohol is a fuel. Mixing them together can be potentially dangerous if you don't have the proper knowledge or equipment to do so. Conditions and parameters of etching process are essential to obtain a good quality true microstructure of a steel. A well known tip for Nital application in the case of alloy steels is 'etch for a few seconds to minutes'. The performed experiments with etching of the investigated materials showed that too long etching led to over etching effect - see **Figure 1a** showing the studied over etched by nital steel ST52-3 close to specimen surface. 5 % Nital is a common metallographic etchant for etching mild steels, low alloy carbon steels, cast irons and some tool steels. 2 % and 3 % Nital solutions for metallographic applications are also possible. The authors opinion about possible results of applications is the following: in the situation when the over etched (darker) area will appear after 10 seconds application with 5 % Nital then one can prepare the specimen once again and use 5 % Nital for 5 seconds or change the solution to 3 % Nital and try to etch a bit longer. When the preparation is complete and maximum detail revealed, a microscope may be used to make visual observations and photomicrographs. Microscope selection and configuration is an important step in the analysis of prepared samples. The type of information that is of interest and the size of the specimen being viewed will dictate the type of microscope that will be most suitable for the application. The specimens' surfaces were analyzed visually. Microstructural observations of the examined steels were performed by means of Olympus GX71 light microscope and FE SEM Hitachi 4200 scanning electron microscope equipped with Noran X-ray spectrometer.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Metallographic observation of polished and etched metallographic specimens by means of the light microscope enabled to select an appropriate way and parameters of etching (**Figure 1**).

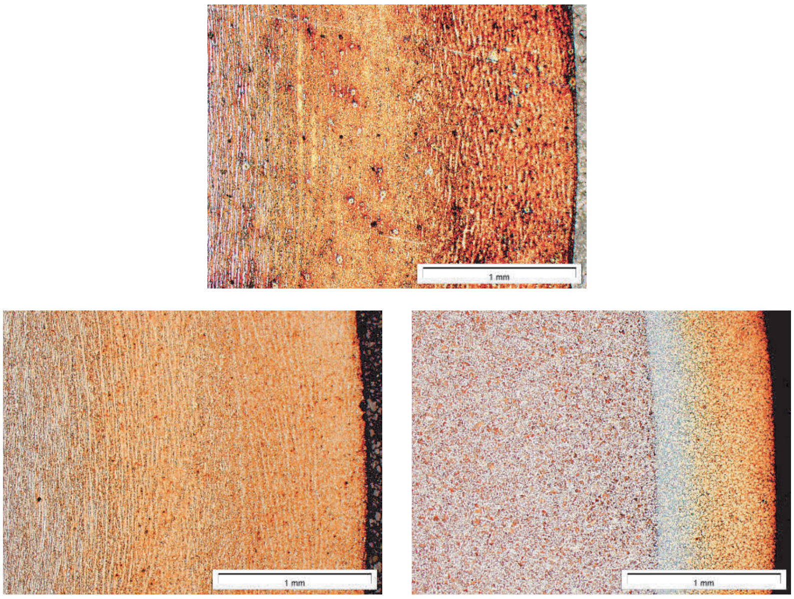

Figure 1 Steel St52-3 initial microstructure in the core area and influenced by induction hardening close to specimen surface, over etched with nital (too long time of etching) - upper image and revealed after correctly applied time and percent concentration of Nital solution - bottom left image; steel C45 microstructure correctly revealed - bottom right image. LM images

Two kinds of steels are the materials for the research and also two kinds of components - the pipe and the bar. The application of scanning electron microscope facilitated observations of the investigated steels using greater magnification. Initial microstructures of C45 and St52-3 steels occurring closer to core area without direct induction hardening influence is presented in **Figure 2** with a lower magnification (LM image - upper left and upper right image) and a greater magnification (SEM image - bottom left and bottom right image).

In the case of the bar from C45 steel well known ferrite-pearlite microstructure is visible (**Figure 2** upper left and bottom left images). Ferrite (white) and pearlite (dark) are noticeable in LM image (upper left) of C45 steel. Regarding the pipe from St52-3 (**Figure 2** upper right and bottom right images) a characteristic layered arrangement of phases is conspicuous what could be related to story of production of those component. Additionally, in the case of the pipe the shell thickness is a key factor which is approximately 3 mm unlike the studied bar with 25 mm thickness.

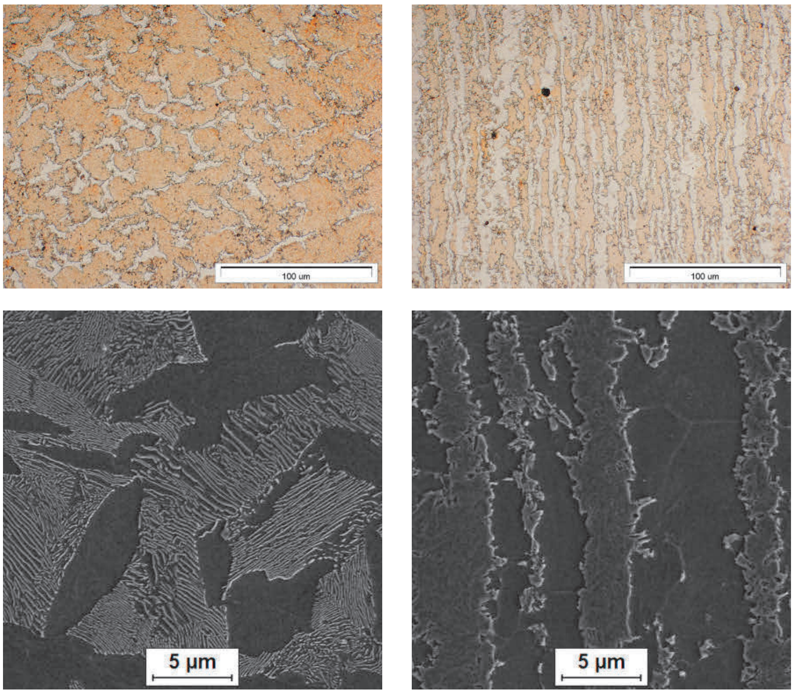

Figure 2 Microstructures of C45 (upper left and bottom left image) and St52-3 steels (upper right and bottom right image) without direct induction hardening influence

For comparison, **Figure 3** is dedicated to the microstructures of the C45 and St52-3 steels being a result of induction hardening influence. A martensite is a required microstructure in the surface layer of the both materials. A martensite is a very hard and strong phase with needle-like structure of iron and carbon. It is only formed by very rapid cooling from the austenitic structure.

Looking at the photomicrographs (**Figure 3**) in the case of both steels can be seen in the surface layer areas with needle-like microstructure of martensite, but you can also find a mixture of tempered bainite and martensite. Additionally, the depth of hardening has an effect on the properties and potential possibilities for application of the studied components. The applied conditions and parameters of the induction hardening have resulted in different depth of hardening in the components from C45 and St52-3 steels. In the case of first of them the depth of hardening was approximately 0.5 - 0.6 mm. In the second case - pipe was not hardened from the outer edge to the inner edge. Here the depth of hardening was approximately 2.0 mm (**Figure 1**).

5. CONCLUSION

The aims of the work were to examine the influence of selection of etching conditions on the microstructures of the studied steels and to investigate the influence of induction hardening on the microstructures of the investigated components made from those steels. The aim was achieved. The studies have shown that even application of a well-known Nital etchant requires appropriate conditions and parameters of etching to reveal a real microstructure of the observed steels.

The performed researches enabled to confirm a presence of induction hardening influence on the microstructures of C45 and St52-3 steels. The applied conditions and parameters of induction hardening affect the depth of hardening and contribute to appearance of a required martensite structure. It was found that the applied parameters of induction hardening should be improved to obtain only martensitic structure in the surface layer.

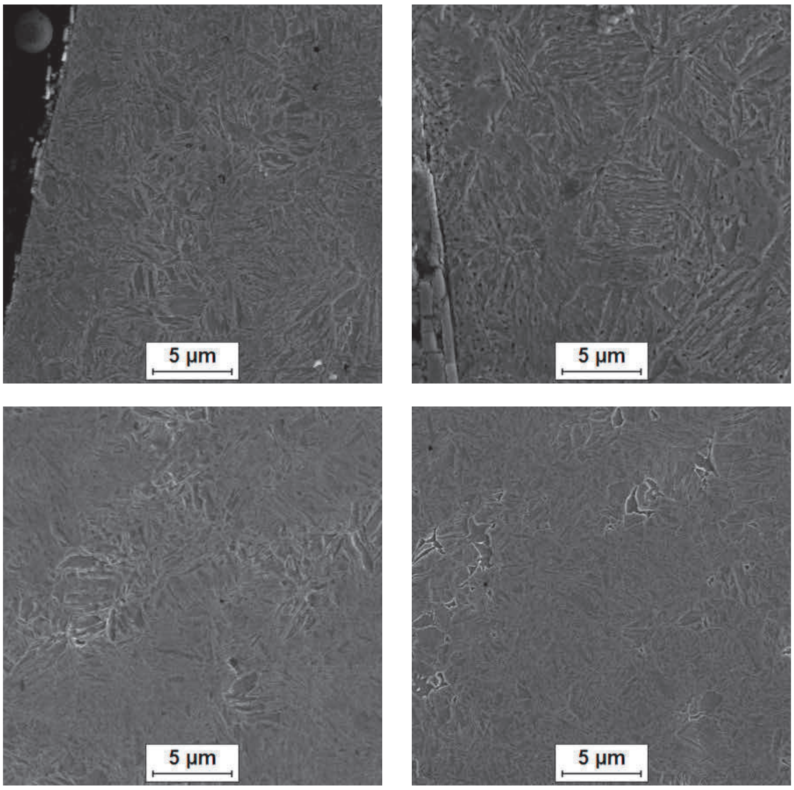

Figure 3 Photomicrographs of microstructures of C45 (upper left and bottom left image) and St52-3 steels (upper right and bottom right image) influenced by induction hardening in the surface layer

Similar approaches were used in previous investigations [12-18]. The multivariate and non-parametric analytical techniques, worth to use, were presented in action in the following papers [19-24], so the specific image analysis methods [25-30] with high reliability and objectivity.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the *statutory research No. 11/990/BK_18/0057 carried out at the Silesian University of Technology.*

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