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Eddy Current method for thickness assessment of carburized layers

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Materials and semi-manufactured products for aviation equipment are usually subjected to increasingly rigorous demands for the quality control. In many cases, like hardened or carburized wheels or rollers assembled in the gear motors, the control procedures enforce necessity of the selective testing of details coming from production lines using destructive techniques. The main aim of diagnostic investigations carrying out on series of final products is to assess qualitatively and quantitatively the layers obtained due to carburizing and induction hardening. Unfortunately, such processes increase the fabrication costs significantly, especially in the case of complex manufacturing technology applied and small-lot production as well. In order to reduce them the attempts for application of non-destructive testing methods are taken for evaluation of either the layers quality or the products subjected to surface treatments. This paper presents the eddy currents method used for the thickness evaluation of the carburized and induction-hardened layers on the basis of the impedance signal variation. The signal was obtained as a result of the so-called 'lift off' effect. A methodology for the quantitative thickness evaluation of the carburized and induction-hardened layers has been elaborated under a range of technological parameters. The measurements ranges were defined in the framework of which an identification of the hardened layer was possible using the commercial defectoscope and reference specimens of the fixed thickness. Tests were carried out on specimens made of the ASM6414 steel and subjected subsequently to carburization and induction hardening. The impedance parameters were measured for selected values of frequency. The results were verified on the basis of metallographic investigations as well as the microhardness measurements captured in the form of profiles taken from specimens' cross-sections of different layer thickness.

Keywords: eddy current, hardening, carburizing, layers, non-destructive technique

1. INTRODUCTION

Eddy Current (EC) method is commonly used in defectoscopy for identification of the surface and subsurface defects [1]. It is also treated as one of the most popular nondestructive techniques used in power engineering and aviation diagnostics for the conductive materials. Nowadays EC method is especially promising in the studies of material properties, measurements of coatings thickness and stress assessments. Moreover, the method is suitable for qualitative and quantitative assessments of diffusive layers obtained due to carburizing and induction hardening [2,3]. This paper presents the results of thickness evaluation of the layers covered on Cr-Ni-Mo steel, using the 'lift off' effect. It arises due to changes in the phase angle of the signal [4]. A methodology for the quantitative thickness evaluation of the carburized and induction-hardened layers made on AMS6461 steel specimens has been elaborated under a range of technological parameters. The results of nondestructive measurements were verified on the basis of metallographic investigations as well as the microhardness measurements captured in the form of profiles taken from specimens' cross-sections with fixed layer thickness.

Thickness control of the hardened layer is carried out on the selected elements coming from manufacturing lines. Up to 25% of such elements may suffer on some damages, what as a consequence, increases the fabrication costs significantly. Development of measurement procedures for the non-destructive inspection of the hardened components layers thickness enables a reduction of these costs on one hand, and an acceleration of the quality control process on the other.

2. EXPERIMENTAL PROCEDURE

Investigations of the hardened layers were carried out on specimens made of the structural toughening AMS6414 steel (40HNMA steel – notation according to Polish Standards). AMS6414 steel is usually used for the production of connecting rods, steering parts, hub propellers and gear motors. Eddy current method is the comparative technique, and therefore, it requires a preparation of a set of reference specimens with fixed layer thickness in order to calibrate signal properly. The shafts made of AMS6414 steel were subjected to surface treatment with different current/time parameters. Specimens with a thickness of the hardened layers in the range from 0,6 mm to 2,5 mm were produced. However, regarding the fact of the limited depth of the magnetic field penetration only specimens of the layer thickness equal to 1,2 mm were selected for further investigations using the EC method (Fig. 1).

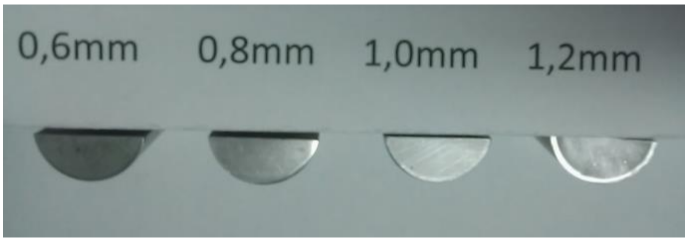

Fig. 1. Selected specimens after the induction hardening with fixed thickness of layer

Rys. 1. Wybrane próbki o różnej grubości warstwy po hartowaniu indukcyjnym

In order to determine the specimens' layers thickness properly, the metallographic observations and microhardness measurements were carried out. Hardness measurements were conducted using the Hysitrons' hardness tester, with the following process parameters: maximum force - 100mN, rate of loading - 10mm/s, holding time at maximum force - 2s (Fig. 2). The distance between the measurement spots was equal to 50 μm.

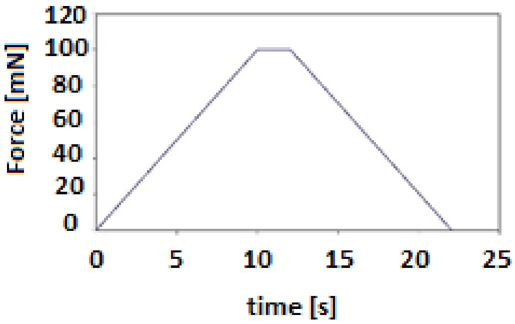

Fig. 2. Scheme of the force variation during hardness measurements
Rys.2. Schemat zmiany siły podczas pomiaru twardości

Metallographic observations and layers thickness measurements were performed using the NIKON optical light microscope at magnifications from 20 to 50 times. It allowed verification of the layers thickness estimated on the basis of selected induction hardening parameters. For thickness inspection also the ZETECs' device MIZ 27 SI, NORTEC 600 defectoscope and the contact probes with the frequency range from 1kHz to 1MHz were applied. For each specimen, a trajectory of signal variation of the eddy current phase angle was evaluated, and as a consequence, the characteristics of the impedance variation were elaborated for different thicknesses of induction hardened layers, Measurements were carried out for the frequency equal to 5 kHz that was adequate for the standard ferromagnetic steel penetration depth applied.

Conductivity and magnetic permeability measurements of the specimens core and layers were also performed. It has to be mentioned, that identification of the thickness variation of layers is possible, if the differences of both these parameters are known, and moreover, if the conductivity difference between the core and layer is no less than 1 MS/m . Measurements of the electrical resistance were carried out by means of the absolute method using voltmeter, amperemeter, and Thermo Haake C10 thermostat. It is well known, that the magnetic permeability (μ) may vary in the case of ferromagnetic materials. Hence, in order to simplify the analysis, the maximum of the relative magnetic permeability determined on the basis of the magnetization curves was applied.

3. RESULTS

The results of the electric conductivity and magnetic permeability measurements of specimen core and layer are presented in Table 1.

Table 1. Electrical conductivity γ [MS/m] of the core and the layer
Tabela 1. Przewodność elektryczna γ [MS/m] materiału warstwy i rdzenia

	Core	Layer
Electrical conductivity γ [MS/m]	2,3	1,1
Relative magnetic permeability μ_r	16,4	11,4

As it is shown, both parameters are sensitive on the type of structure, and therefore, they can be treated as very promising for thickness assessments of the induction hardened layers.

3.1. Microhardness measurements

Metallographic observations and layers thickness measurements enabled identification of the hardened layers thickness estimated on the basis of selected technological parameters of the induction hardening. An example of the microhardness profile for a layer of nominal thickness of 0,6 mm is presented in Figure 3.

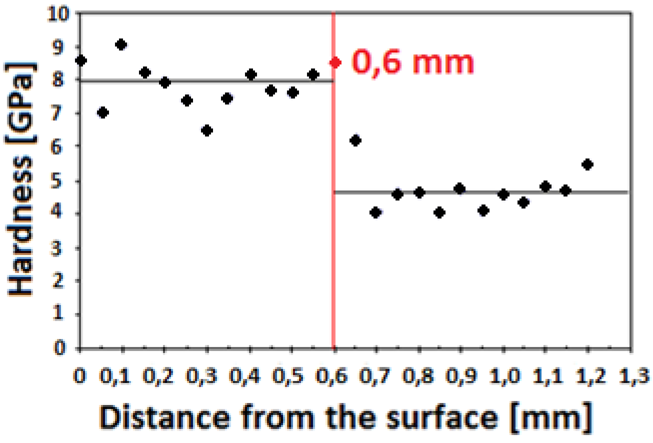

Fig. 3. Microhardness as a function of distance from the specimens surface of nominal thickness equal to 0.6 mm
Rys.3. Wartości mikrotwardości w funkcji odległości od powierzchni próbki o nominalnej grubości warstwy 0,6 mm

On the basis of the hardness drop of more than 3 GPa (equivalent to 300 HV) at 0,6 mm (+/- 0,05) from the external surface of specimen one can conclude, that on such depth the induction hardened zone has its border. Microhardness measurements for the other specimens exhibit a significant hardness decrease outside of the induction hardened layer, and thus, allow the layer thickness to be assessed.

3.2. Metallographic investigations

Microstructural observations of the induction hardened specimens' cross-sections and their quantitative analysis confirmed the results of hardness measurements for all six specimens. The microstructure of the core and layer is presented in Figure 4. It shows layer thickness of 0,62 mm, what gives the deviation of 20 µm in comparison to the thickness estimated (0,6 mm) on the basis of the process parameters. This is within the limits of the measurement accuracy.

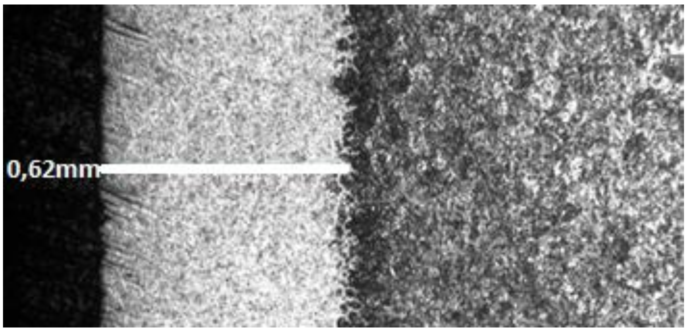

Fig.4. Microstructure of layer and core in the cross-section of induction hardened specimen
Rys. 4. Mikrostruktura warstwy i rdzenia na przekroju próbki hartowanej indukcyjnie

Metallographic observations allowed an identification of the significant differences in the microstructure of core and external layer. In both cases the martensite structure is dominant, however, the core is coarse-grained with some contribution of the retained austenite. The dynamics of the induction hardening process provided in the layer a martensite of high fragmentation and better homogeneity in comparison to the core. This fact explains to some extend a great hardness difference between the layer and core.

3.3. Eddy current measurements

The results of the impedance phase angle measurements carried out on specimens with and without the layer using the Nortec 600 defectoscope are shown in Figure 5. All measurements were conducted at the frequency of 50 Hz by means of a pencil probe. The 'lift off' effect is clearly visible for the specimen without the layer. A diagram in Figure 5 also reveals limitations of the EC method, that is expressed by the results for specimens with layer thickness equal to 1,0 and 1,2 mm (both characteristics coincide themselves).

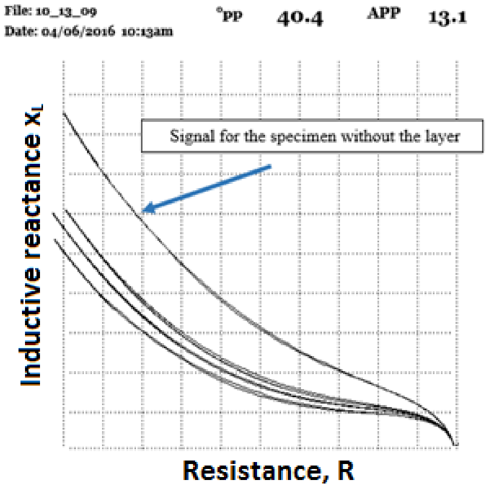

Fig.5. Changes of phase angle of the ET signal as a function of the layer thickness for the frequency of 50 kHz

Rys. 5. Zmiany kąta fazowego sygnału ET w funkcji zmiany grubości warstwy dla częstotliwości 50 kHz

An evaluation of the hardened layer thickness based on the phase angle change is presented in Figure 6. The results demonstrate mutual relationship between the impedance phase angle and layer thickness only in the range from 0,6 to 1,0. As a consequence, a limitation of the ED method for identification of specimens thickness was established in the case considered. This is directly related to the surface nature of the eddy current method.

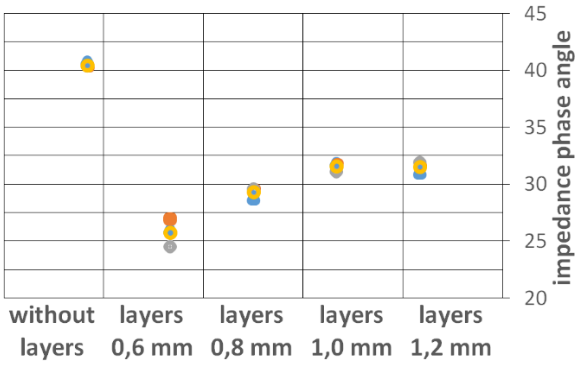

Fig.6. Phase angle measurements for specimens with fixed thickness

Rys. 6. Zestawienie wyników pomiarów kąta fazowego dla próbek o różnej grubości warstwy

Measurements conducted over a wide frequency range (from 5 kHz to 1 MHz) allowed identification of the signal variations for specimens of different layer thickness. Such promising results can be achieved only when the measurement repeatability is maintained, an influence of: (a) the surface quality; (b) residual stresses level of tested specimens; and (c) other factors, on the material permeability and conductivity measurements are taken into account.

4. CONCLUSION

Application of the Eddy Current method for thickness assessment of carburized and hardening layers is better justified in the case of comparative investigations such as indications of thickness differences of the hardened elements or their ordering. Elaboration of a system for the absolute thickness measurement of hardened layers, only on the basis of current indications, requires a very precise preparation of the reference specimens using the same technological procedure as that for the tested components applied. Under these circumstances, a specimen categorization with regard to the thickness range can be carried out. It's an accuracy depends on the number of the reference specimens available.

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