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Surface Characterization of Carburized Steel by Eddy Current

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Abstract In the carburizing process, it is necessary to control the surface carbon content in order to obtain desirable materials properties. Although quantometry is the most common method for determination of surface carbon content, being destructive, costly and time consuming are some disadvantages of this method. Eddy current testing has long been used as a technique for investigation of defects. However, determination of surface carbon content in carburized steels is a new application for this method which has been studied in this research. Sixteen AISI 4118 steel samples have been carburized in an enriched carbon gas carburizing furnace. Carbon potentials in the furnace were different for each sample; therefore, samples with various surface carbon contents were produced. Subsequently, the carbon content of all samples was measured using quantometry. Finally, determining the optimal frequency, eddy current testing was applied for all samples and the relationship between surface carbon content and various parameters such as normalized impedance and phase angle has been established. The study shows a good relationship between the carbon percent and phase angle can be established (R^2=0.91) using phase angle. Besides, the effect of temperature on the relationship was also investigated using three levels in 0, 30 and 80 °C. The formulas presented, shows improvement in corresponding corrections in experimental data.

Keywords Carburizing • Eddy current • Normalized impedance • Phase angle • Surface carbon

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Introduction

Nowadays, application of non destructive methods is not limited to detect defects and cracks. Considering the advantages of non destructive methods in industrial quality control, in the recent years, several researches have been focused on non-destructive determining the mechanical and physical properties of materials as a substitution for destructive method which results in saving time and energy as well as providing 100% quality control in mass production lines.

Among different methods, non destructive eddy current technique has distinctive advantages. Suitable sensitivity to chemical composition, microstructure, mechanical properties and residual stress makes it a reliable alternative to conventional destructive methods [1,2].

Recently Konoplyuk [3] discovered an appropriate relation between the hardness of ductile cast iron and the output voltage of eddy current device. Uchimoto and Check [4,5] found the same relation for gray cast iron. Decarburizing depth was also studied using harmonic analysis [6] and on the base of difference in magnetic properties (magnetic relative permeability), between ferrite and pearlite phases [7]. Zergoug [8] found relation between mechanical micro-hardness and impedance variations. Rumiche et al [9] investigated the effect of microstructure on magnetic behavior of carbon steels by electromagnetic sensors and the effect of grain size on magnetic properties were investigated and proved by other researchers [10,11]. With the growing demands for nondestructive measuring of physical and mechanical properties of materials in mass production lines, there is a strong potential for research on the new applications for the nondestructive eddy current technique.

Carburizing has long been used in industry to improve surface hardness and fatigue resistance of steel parts while maintaining the toughness of the core. Proper control of surface carbon content is a major factor in performing a successful carburizing process and providing essential mechanical properties for the part. Traditionally, this has been done using costly chemical analyzing methods such as quantometry. The aim of the present research is to establish a relation between surface carbon content and the responses of the carburized part to electro–magnetic induction.

Experimental Process

The present research was conducted on AISI4118 steel. The composition of the steel is presented in Table 1.

All the samples were prepared as rod specimens with 2.5 cm in diameter and 15 cm high and were carburized at 900 °C for 7 hours in a gas carburizing furnace. The carbon potentials of the furnace were different for each sample but kept between 0.4 and 0.9. After carburizing, all samples were cooled in air and normalized using induction heating process. Short austenetizing time and, therefore, elimination of surface decarburizing was the main reason for choosing the induction heating process. Finally, surface carbon content of all samples were determined using quantometry and are displayed in Table 2.

Table 1 Chemical composition in weight percentage

C	Si	Mn	P	S	Cr	Mo	Ni	Al	Fe
0.196	0.25	0.75	0.02	0.008	0.8	0.18	0.06	0.01	Rest

Table 2 Surface carbon content of samples used in the research

Sample No.	1	2	3	4	5	6	7	8
Surface carbon (%)	0.83	0.45	0.53	0.71	0.81	0.88	0.68	0.65
Sample No.	9	10	11	12	13	14	15	16
Surface carbon (%)	0.91	0.72	0.88	0.74	0.78	0.44	0.55	0.88

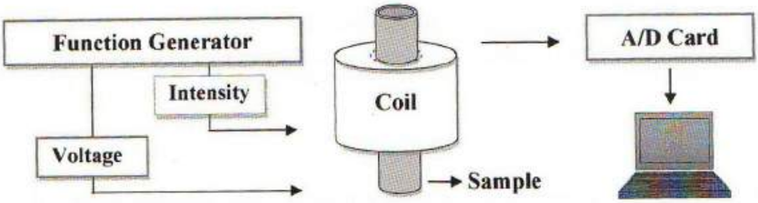

Fig. 1 General synopsis of the experimental apparatus

A sinusoidal current with a frequency ranging from 650 Hz to 4 kHz was applied to the coil for all tests. A schematic representation of the device is shown in Figure 1.

Voltage and current of the coil were measured and the impedance and phase angle of the coil were calculated for each sample.

In order to calculate the impedance (Z) and phase angle (ϕ) of the coil for all samples, voltage (V) and intensity (I) of the coil were used using Eq.(1) and (2), respectively [1].

$$Z = V / I \tag{1}$$

$$\phi = 360\left(\Delta t / \lambda\right) \tag{2}$$

Where Δt is the time difference between two adjacent peaks and λ is the wave length. The calculated impedance (Z) for each sample was divided by the impedance of the empty coil (Z0) to make a new parameter. This parameter (Z/Z0) is called normalized impedance [1, 2, 13].

Apart from carbon content at the surface, the effect of temperature was studied using three levels; 0°*C*, 30°*C* and 80°*C*.

Results and Discussion

In each frequency ranging from 650 to 4000 Hz, regression analysis was applied between percentage of surface carbon content and two parameters (normalized impedance and phase angle). Eventually the correlation coefficient (R^2) was

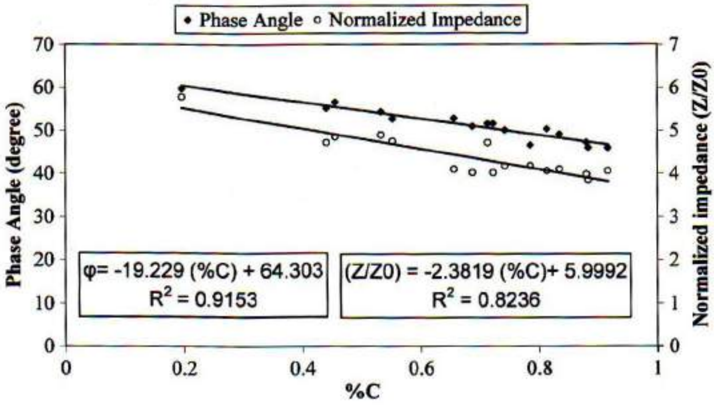

Fig. 2 Relationship between Phase angle and normalized impedance with percentage of carbon of surface at 650Hz

calculated for two above-mentioned parameters. The maximum R^2 (0.91) was observed in 650Hz frequency which indicates maximum relationship between surface carbon content and two parameters. Thus, 650Hz frequency was selected, as an optimum frequency, for all experiments in this research. The relationship between surface carbon content and normalized impedance is shown in Fig. 2 which indicates a fairly good relationship ($R^2 = 0.82$). Figure 2 also shows the best relationship, which is, between surface carbon content and phase angle (ϕ). The correlation coefficient is 0.91 at 650Hz frequency. As can be seen, in Fig. 2, Z and ϕ decrease with increase in surface carbon content. This could be due to the increase in pearlite percentage with increasing carbon content. The increase in pearlite percentage, in turn, causes an increase in the resistance (R) and a decrease in the permeability (μ) [2,12]. Keeping the relationship between μ and X in mind, the reduction of X with μ can be established [1,2].

In ferromagnetic alloys such as steel, the effect of permeability or reactance is stronger than the effect of resistance [12,2]. As a result, the impedance decreases with increasing the percentage of carbon. Because of the relationship between the phase angle and X/R ($\tan(\phi) = X/R$), the phase angle (ϕ) also decreases.

As magnetic and electrical properties of materials are strongly depend on temperature, the effect of temperature has also been studied. Figure 3 displays the influence of temperature on the output of the Eddy current evaluation used for determining the surface carbon content of the samples. The figure shows variation of evaluated carbon content at the surface for temperatures in the range of 0-80°C using Eddy current method. An increase in the temperature results in an increase in the specimen's resistance [1,13] but a small increase in the temperature does not have a noticeable effect on μ and X [1,12]. Consequently, an increase in temperature results in an increase in R without noticeable effect on X, resulting in increasing Z and decreasing ϕ.

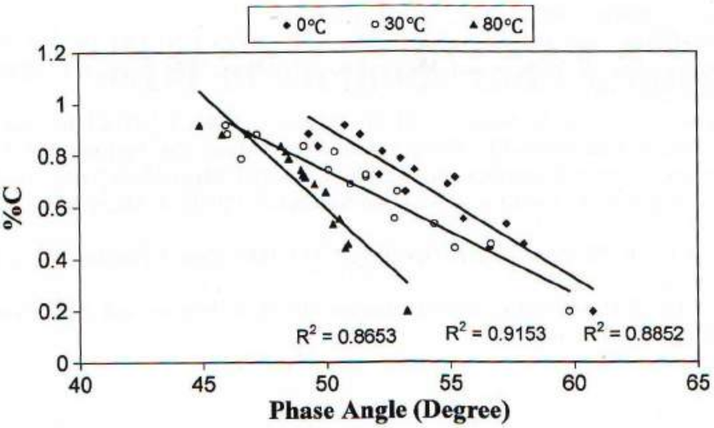

Fig. 3 Effect of temperature on the relationship between carbon surface percentage and phase angle

Equation (3) shows the corresponding temperature corrections for evaluation of the surface carbon content.

$$\%C = \left(-1E-05T^2 + 0.0008T - 0.0584\right)\varphi + \left(0.0008T^2 - 0.047T + 3.8282\right) \quad (3)$$

As a result, one has to keep in mind the temperature effect of the test and apply the corresponding corrections to the results.

Conclusion

In the present study, normalized impedance and phase angle show a strong relationship (R^2=0.91) with carbon content at the surface of carburized steel samples. The effect of temperature on the relationship was also investigated and the temperature related corrections for evaluation of the surface carbon content were calculated.

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