USING NONDESTRUCTIVE EDDY CURRENT TECHNIQUE AS A TOOL FOR QUALITY CONTROL OF CARBURIZED STEELS

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Abstract

The eddy current method has been recently used to determine physical and metallurgical properties of steel parts. Determination of surface carbon content in carburized steels is a new application for non-destructive eddy current method, which has been studied, in present research. The relation between the surface carbon content and two parameters; impedance and phase angle has been established. The study shows a good relationship between the carbon percent and phase angle can be established (R2=0.91) using phase angle. Besides, the effect of temperature on the relationship was also investigated. The formulas presented, shows improvement in corresponding corrections in experimental data.

Key Words: Eddy current method, Surface carbon content, Phase angle

Introduction

In an extensive research, Kogon et al. [1] have inspected the effect of the carbon content on the magnetic and electrical properties of thermally treated carbon steels. Recently, Konoplyk et al. [2] have demonstrated a good relationship between hardness of ductile cast iron and the induced voltage using Eddy current method. Cech [3] and Uchimoto [4] et al. in two separate researches have examined this relation in gray cast iron as well as lift off effect on the responses. Establishing a relation between harmonic analysis of induced current with the depth of decarburization, Mercier et al.[5] concluded the EC method can be used to detect decarburization depth during heat treatment of steels.

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 surfaced 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.

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

All the samples were prepared as rod specimens with 2.5 cm in diameter and 15 cm high and were carburized at 900 ^{o}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.

Table2: Surface carbon content of samples used in the research

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

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.

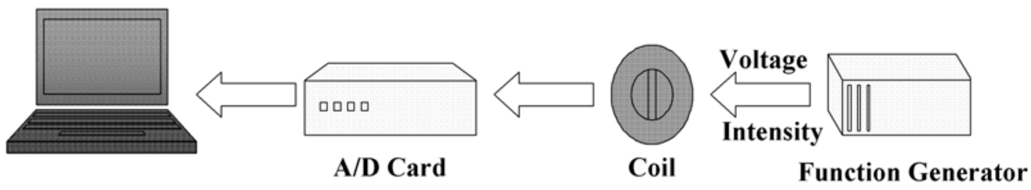

Figure 1: General synopsis of the experimental apparatus

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

Apart from carbon content at the surface, the effect of temperature was studied using three levels; 0, 30 and 80^{0}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 (R2) was calculated for two above-mentioned parameters. The maximum R2 (0.91) was observed in 650Hz frequency which indicates maximum relationship between surface carbon content and two parameters. Thus, 650Hz frequency was selected, as optimum frequency, for all experiments in this research. The relationship between surface carbon content and normalized impedance is shown in Figure 2 which indicates a fairly good relationship (R2 = 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 Figure 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) [1,6]. Keeping the relationship between μ and X in mind, the reduction of X with μ can be established [6,7].

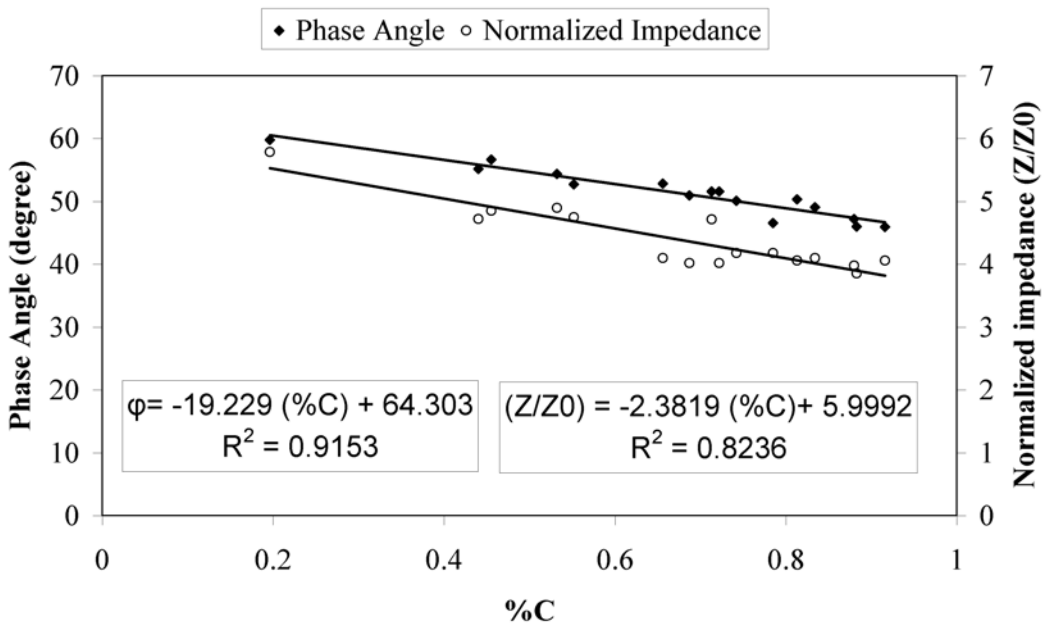

Fig 2: Relationship between Phase angle and normalized impedance with percentage of carbon of surface at 650Hz

In ferromagnetic alloys such as steel, the effect of permeability or reactance is stronger than the effect of resistance [1,6]. As a result, the impedance decreases with increasing the percentage of carbon. Because of the relationship between the phase angle and X/R ($\tan(\varphi) = X/R$), the phase angle (φ) also decreases.

As magnetic and electrical properties of materials are strongly depend on temperature, the effect of temperature on has also been studied. Figure 3 displays the influence of temperature on the outcome of the Eddy current evaluation used for determining the surface carbon content of the samples. The figure 3 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 [7,8] but a small increase in the temperature does not have a noticeable effect on μ and X [1,7]. Consequently, an increase in temperature results in an increase in R without noticeable effect on X, resulting in increasing Z and decreasing φ.

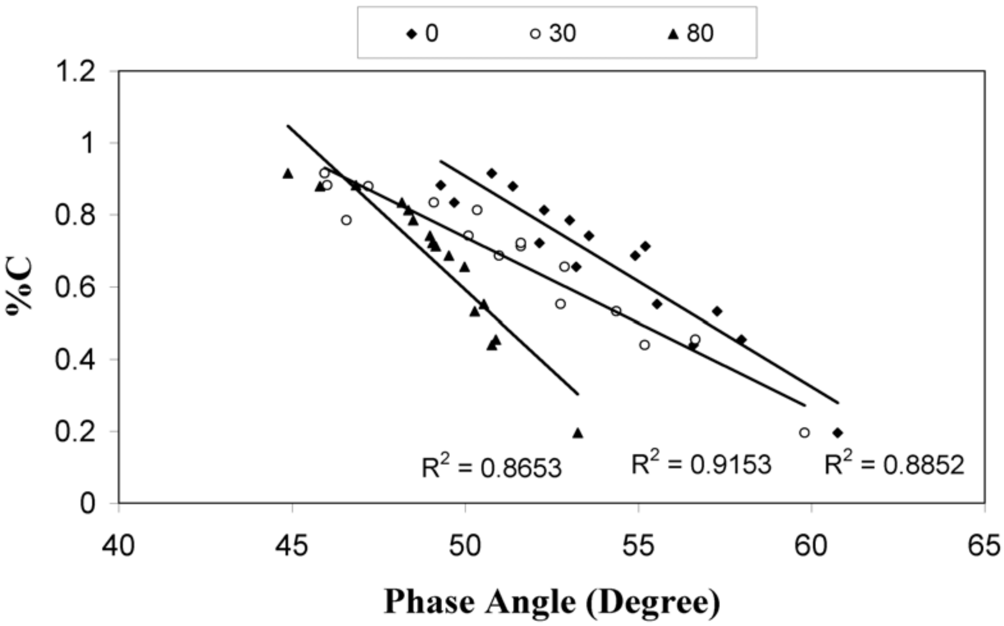

Fig 3: Effect of temperature on the relationship between carbon surface percentage and phase angle

Following equation shows the corresponding temperature corrections for evaluation of the surface carbon content.

%C = (-1E-05T2 + 0.0008T - 0.0584) φ + (0.0008T2 - 0.047T + 3.8282)

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 this study, normalized impedance and phase angle show a strong relationship (R2=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 corresponding corrections for evaluation of the surface carbon content was calculated.

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