QUALITY CONTROL OF PRECIPITATION HARDENED ALUMINIUM ALLOY PARTS VIA EDDY-CURRENT NONDESTRUCTIVE EVALUATION

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Abstract: *Precipitation hardening is the most common method in the strengthening of aluminium alloys. This method relies on the decrease of solid solubility with temperature reduction to produce fine precipitations which impede the movement of dislocations. The quality control of aluminium alloy specimens is an important concern of engineers. Among different methods, non-destructive techniques are the fastest, cheapest and able to be used for all of parts in a production line. To assess the ability of eddy current as a non-destructive method in the evaluation of precipitation hardening of aluminium alloys, 7075 aluminium alloy specimens were solution treated at 480°C for 1 hr. and followed by water quenching. Afterwards, the specimens were aged at different temperatures of 200, 170, 140, 110 and 80°C for 8 hr. Eddy current measurements was conducted on the aged specimens. Hardness measurement and tensile test were employed to investigate the mechanical properties. It was demonstrated that eddy current is effectively able to separate the specimens with different aging degree due to the change of electrical conductivity during aging process.*

Keywords: *7075 aluminium alloy, precipitation hardening, Eddy current, Non-Destructive evaluation.*

1. INTRODUCTION

Eddy current non destructive evaluation is based on the induction of current in the conductive material placed in an alternative magnetic field (faraday's law). The induced current (eddy current) generates a magnetic field (Ampere's Law) opposing with the primary magnetic field to reduce it (Lenz's law). In eddy current testing, primary magnetic field is provided by the coil which is being fed by an alternating current. A secondary coil is also used to pick up the changes of magnetic field caused by presence of conductive material in the primary magnetic field.

Eddy current depends on the frequency and material electromagnetic properties. Usually in eddy current testing, the magnetic field parameters are constant and only the electromagnetic properties affects the eddy current outputs. Magnetic permeability and electrical conductivity are the two main properties affecting eddy current response. It is also known that harmonic analysis, as an eddy current output used for ferromagnetic materials, depends on the shape of magnetic hysteresis loop[1].

The variation of chemical composition, microstructure, stress and strain in conductive materials affects electromagnetic properties. Many investigations prove the applicability of this method in the determination of microstructure and mechanical properties of metals. Yin et al. used eddycurrent technique in the measurement of electromagnetic properties of power station steels [2]. Permeability and ferrite/austenite fraction were measured by multifrequency eddy current technique [3]. It was demonstrated that in low frequency range, eddy current output depends mostly on the magnetic permeability, and as the frequency increases, dependence of the eddy current on the electrical conductivity increases due to the increase of induced current in the samples[2-6].

In Kashefi's researches, the carburizing and decarburizing depth of steel were determined by eddy current [7, 8]. Tempered martensite embrittlement and hardness profile of the induction hardened steel parts were also ascertained by this method [9, 10]. Effect of the elastic stress in the different aluminium alloys on pulsed eddy current output was studied by Morozov et al. [11].

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During aging, by heating the super saturated aluminium alloy, the excess solute elements leave their highly stressed places to produce stable fine particles of an impurity phases. These particles harden the material by obstructing the motion of dislocations. In addition, this process affects the electrical conductivity by two competitive mechanisms. First the purification of matrix from the alloying elements, and decreasing of the vacancies retained in the alloy after quenching from solution treating process. These two phenomena increase the electrical conductivity. The second mechanism is the scattering of the conduction electrons with precipitations which reduces the electrical conductivity. Therefore, because of the importance of heat treatment controlling of this alloy and the ability of eddy current method in the monitoring of electrical conductivity variations, the capability of this non-destructive technique was investigated in the control of aging process of 7075 al-alloy.

2. EXPERIMENTAL PROCEDURE

7075 aluminium alloy with chemical composition summarized in Table 1 was used in this study. Before heat treatment, 3 tensile samples according to ASTM–B557 and also a cylindrical sample with 16mm in diameter and 20cm in length were prepared for each degree of aging. These samples were solution treated at 480 °C for an hour then followed by water quenching. Different degrees of aging were carried out on samples by heating at the temperatures of 200, 170, 140, 110 and 80 °C for 8 hr. discs with 2 cm length were cut from end of cylindrical samples for hardness measurement. Tensile test was applied on the specimens at room temperature and strain rate of 0.002 s^{-1}. Eddy current test was conducted on the samples at the optimum frequency of 6 KHz at which the eddy current response has the maximum resolution in the separation of samples with different aging temperatures. Schematic of eddycurrent measurement is illustrated in Figure 1. This system consists of a function generator to apply sinusoidal current to a coil (with 1900 turns, 150 mm length and 16mm in diameter) and an A/D card to convert the probe voltages to digital data and to interface with personal computer. Impedance output was calculated by dividing the coil voltage to current (equation 1), and impedance phase angel was measured from equation 2, then according to equation 3, the real and imaginary impedance were calculated.

Table 1. Chemical composition of 7075 Al-alloy.

Element	Al	Cu	Mn	Mg	Zn
Wt%	Bal.	1.25	0.25	2.305	5.2
Element	Ti	Cr	Si	Fe	Pb
Wt%	0.18	0.25	0.38	0.45	0.45

$$|Z| = \left|\frac{V}{I}\right| = \sqrt[2]{X^2 + R^2} \quad (1)$$

$$\Phi = 360\left(\frac{\Delta t}{T}\right) \quad (2)$$

$$|X| = |Z| \sin\varphi, \; |R| = |Z| \cos\varphi \quad (3)$$

In these equations, Z, V, I, X, R, φ, and T are

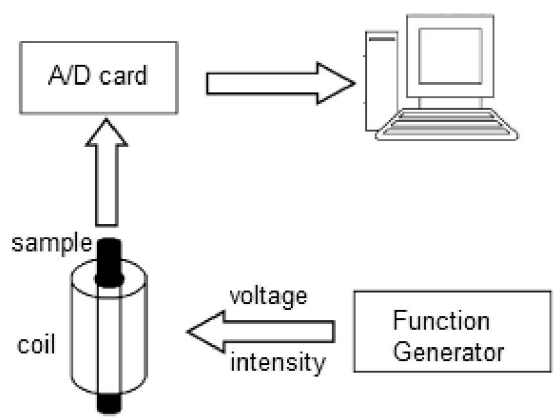

Fig. 1. Schematic of eddy current evaluation.

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respectively Impedance value, Voltage, electrical current, induction resistance, real resistance, phase angle, the time difference between two adjacent peaks of voltage and current waves and T is wave length.

3. RESULTS AND DISCUSSIONS

3. 1. Mechanical Properties

The variations of mechanical properties with aging are tabulated in Table 2. Different aging degrees were produced by 8 hr. heating at different temperatures of 80, 110, 140, 170 and 200 °C. Hardness, ultimate tensile and yield strength are increased with increasing temperature up to 140 °C, while their total elongation decreases, then, their variation are reversed in the further temperatures. The sequence of precipitation can be explained by the following:

Solid solution→GP Zones→GPΠ Zones→η' →η

An increase in the temperature of super saturated solid solution leads to the formation of small dispersed GP Zones with coherent interface. Until the precipitates are small and coherent they can be cut by dislocations. In further temperatures or aging times, precipitates growth and GPΠ Zones forms. Further aging results in formation of η'. GPΠs are bigger than initial GP zones, and increase the strength of samples by Orowan mechanism. η' also strengthens the alloy due to the non-coherent strain of its interface. Over aging increases the distance between the precipitates and also produces η particles with non-coherent interface, thus, reduces the hardness of alloy[12, 13]. In fact, the maximum harness will be obtained when the precipitates are mostly GPΠ and with significant amount of η' particles[14]. Therefore, it can be said that in 140 °C, the presence of these two precipitates caused the maximum strength in the samples.

3. 2. Eddy Current Study

Figure 2 shows the position of impedance points for different aging temperatures. Impedance plane can be described by two parameters of impedance value and phase angle. Variations of these two parameters with aging temperatures are displayed in Figure 3. As aging temperature increases, these two outputs decrease. As it was mentioned before, during aging, purification of alloy matrix increases the electrical conductivity resulting in the generation of more eddy current in the samples. In contrast, formation of the small particles which scatter the conduction electrons, reduce the conductivity. Hence, it can be said that the decrease of eddy current outputs are refers to the domination of effect of purification in the increase of electrical conductivity. It should be reminded that increase of induced current in the samples, due to the increase of conductivity, generates more magnetic field opposing with primary field, and hence reduces the magnetic flux density. Therefore, an increase in the conductivity results

Table 2. mechanical properties variations with aging temperature.

Aging Temperature(ºC)	80	110	140	170	200
Hardness(Vickers)	132	155	190	160	124
0.2% offset yield strength(MPa)	336	365	580	370	298
Ultimate Strength(MPa)	403	481	591	461	357
Elongation%	11.45	10.49	6.57	8.4	12.9

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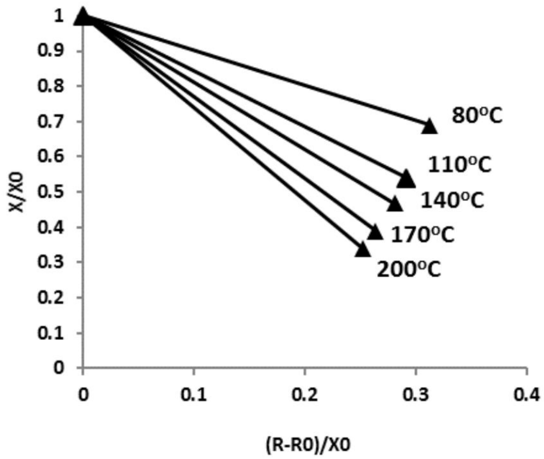

Fig. 2. Impedance plane and effect of aging temperature on location of impedance point.

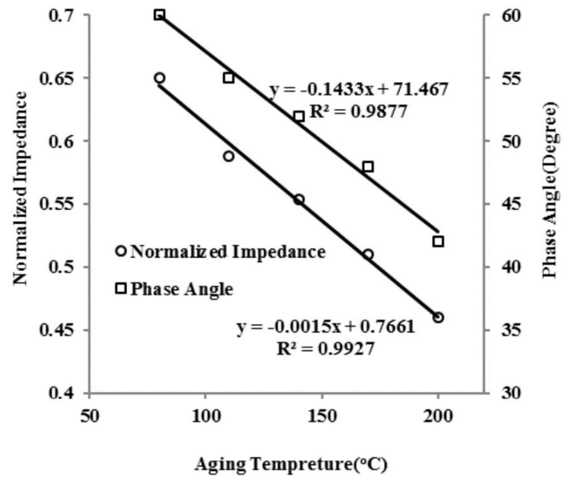

Fig. 3. Variation of Normalized Impedance and Phase angle with Aging temperature.

in the reduction of induction resistance (XL) and real resistance(R). According to equation 1, increasing conductivity in the samples due to the aging process, reduces the impedance value.

Controlling the aging process in order to achieve the maximum strength is an important issue in the heat treatment of industrial parts.

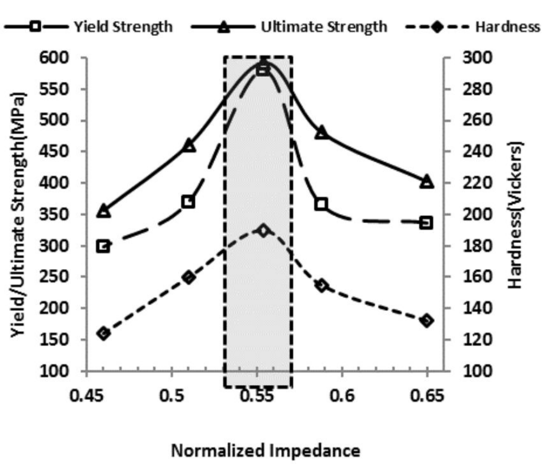

Fig. 4. Relationship between the mechanical properties and normalized impedance.

Figure 4 illustrates the relationship of mechanical properties with eddy current response. This figure also depicts the quality control range defined for the variation of impedance values from which acceptable strength or hardness can be obtained. In the variation range of 0.53 to 0.57 of normalized voltage, the changes of hardness, yield and ultimate strength are in the range of 175 to 190 Vickers, 480 to 580 and 530 to 591MPa, respectively. Thus, in this impedance range, eddy current technique can automatically separate parts with the maximum mechanical properties from the unaccepted ones.

4. CONCLUSION

In this study, the applicability of eddy current non-destructive method was investigated in the evaluation of aging process of 7075 Al-alloy. This technique was capable in assessment of different degrees of aging due to their difference in electrical conductivity. Good resolution in the determination of mechanical properties provides to define a controlling range of impedance in order to obtain the parts with maximum hardness, yield and ultimate strength.

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