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Ultrasonic and eddy current non-destructive evaluation for property assessment of 6063 aluminum alloy

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ABSTRACT

6063 aluminum alloy is widely used in high-performance structural aerospace and transportation applications for their good mechanical properties. The solution treatment and the aging treatment significantly influence the properties. Therefore, it is necessary to separate unqualified heat-treated parts from qualified treated parts. However, the conventional testing techniques such as optical, scanning electron microscopy, tension testing and micro-hardness testing have been not suitable for inspecting components in service due to the disadvantages of destruction, long time and complex process. This paper uses nondestructive evaluation (NDE) methods including ultrasonic and eddy current techniques to characterize the material properties of 6063 aluminum alloy effectively in the shortest possible time and without destruction. During the heat treatment, the variations in hardness and microstructure determined by traditional methods are correlated with sound velocity and attenuation coefficient, electrical conductivity obtained by NDE techniques, and a close correlation between hardness and ultrasonic sound velocity, attenuation coefficient and electrical conductivity measurement can be obtained. It is suggested from the investigation that a better method is available towards the non-destructive detection to characterize the material properties when conventional testing methods are not applicable.

1. Introduction

The 6063 aluminum alloy (Al-Mg-Si type) is widely used in structural applications, particularly in aerospace and automotive industry, due to the characteristics of good plasticity, good welding performance and corrosion resistance. A lot of researches have been made to improve its mechanical properties by the heat treatment [1–3]. Many fine precipitates are formed during the heat treatment, and the volume fraction, size, shape and distribution of the precipitates influence remarkably the mechanical properties of the alloy. So the mechanical properties especially the hardness of aluminum alloy has the close relationship with the heat treatment in engineering application [4–7].

Conventional testing techniques such as optical or scanning electron microscopy, tension testing and micro-hardness testing, etc., are destructive measurement method. Some samples are taken destructively from several specific locations in one component, and are used for microstructure observation and property tests. However, microstructure and properties tested by the conventional approach just only present part of testing results of the component, and there are differences may exist in other locations [5,6]. Therefore, nondestructive techniques are taken into consideration as alternative techniques on performance testing for the whole component in their production procedure and in service [8,9].

On account of the fact that nondestructive testing doesn't damage the material performance, the change of physical parameters as ultrasonic sound velocity, attenuation coeffcient and electrical conductivity are often used to deduce the variation of microstructure. Among many available nondestructive testing and evaluation (NDE) techniques ultrasonic test and eddy current test are widely studied and applied for characterizing material properties. In the past decades a lot of researches have been made to characterize metallurgical properties [9–11]. As a favorable method ultrasonic test has gained much attention in recent years, in investigating the relationship between the ultrasonic and the mechanical properties such as hardness, strength, impact strength, fracture toughness, etc. [12–15]. Eddy current testing is another important technique used to characterize materials, since eddy currents are influenced by microstructural alterations due to precipitates, cold work hardening, heat treatment, deformation, etc.

Since 6063 Al-alloy is widely used for structural applications, therefore, extensive work has been conducted on characterizing properties by ultrasonic test and eddy current test. However, there is little published data available in literature on the relationship between the 6063 properties and relative ultrasonic test and eddy current test. Therefore, in the

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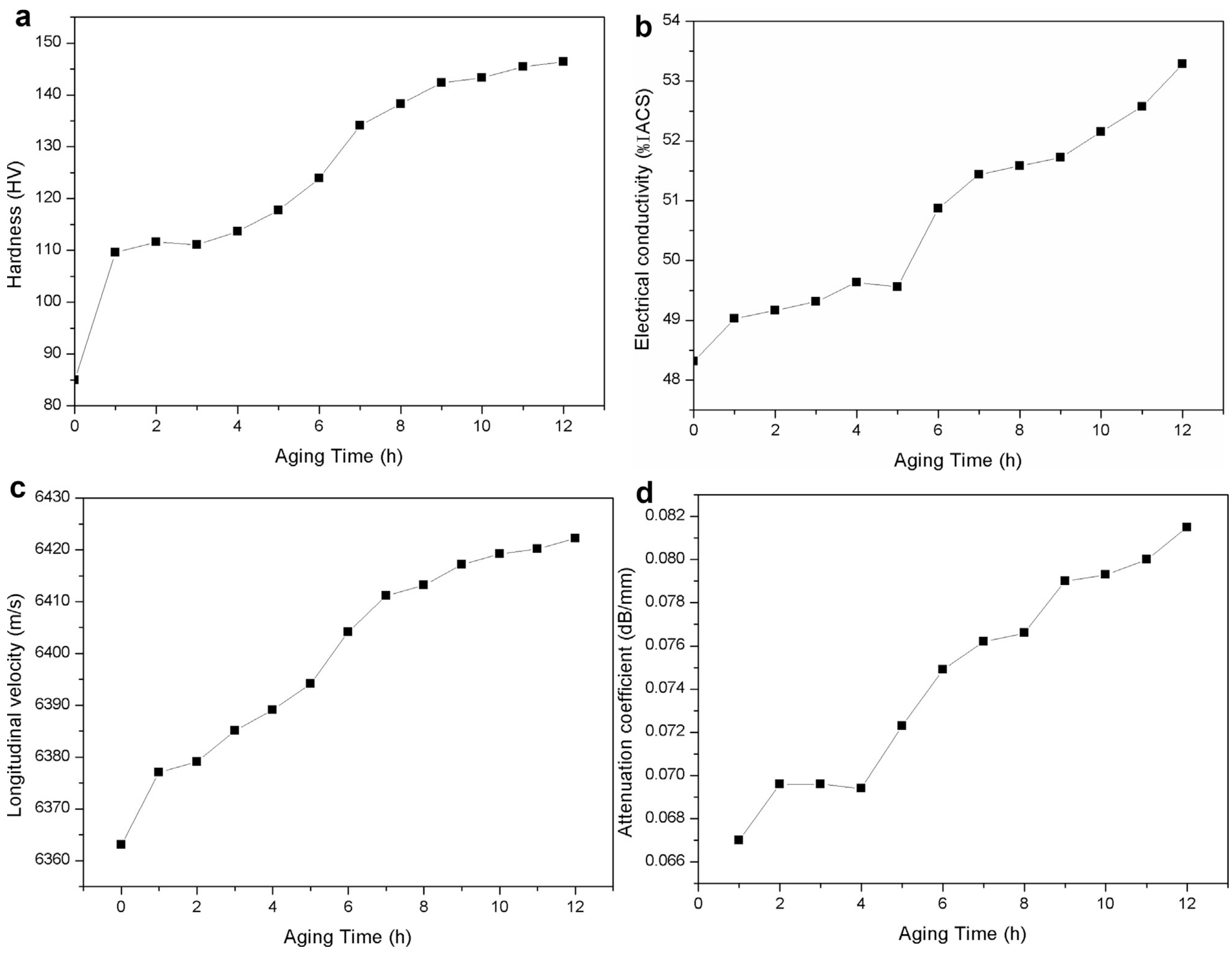

Fig. 1. Graphs of different parameters with respect to aging time at 183 °C for 6063 Al-alloy: (a) hardness, (b) electrical conductivity, (c) longitudinal sound velocity, (d) attenuation coefficient.

present study, a correlation between hardness and microstructure of 6063 Al-alloy with ultrasonic sound velocity, attenuation coeffcient and electrical conductivity are established and discussed.

2. Experimental procedures

2.1. Material and heat treatment

The material used in this research work were aluminum 6063 alloy samples (composition: Mg 0.57 wt%; Si 0.43 wt%; Cu 0.10 wt%; Fe 0.35 wt%; Mn 0.10 wt%; Zn 0.05 wt%; Cr 0.10 wt%; Ti 0.10 wt%). The samples were initially in the form of extruded round bars and were cut perpendicular to the rolling with extrusion in the size of 25 mm in diameter. The samples were put into electric resistance-type heat treatment furnace to be solution heat-treated (SHT) which would dissolve different sorts of precipitates at 535 °C, and then they were quenched in water at ambient temperature to obtain supersaturated solid solution. Artificial aging treatment at 183 °C in heating oven from 1 to 12 h was conducted to speed up the hardening process [16,17].

2.2. Sound velocity measurement

Longitudinal sound velocity through different heat processes of aluminum samples was measured by ultrasonic flaw detector. The calibration standard block was used for calibration of equipment. For high accuracy, the samples were prepared by mechanical grinding and polishing to have a smooth, flat and parallel surface. The plane parallelism between the upper surface and the bottom surface of the sample was checked with a surface plate and a dial gauge [18,19].

2.3. Attenuation coefficient measurement

The acoustic field emitted by ultrasonic transducer is divided into near field zone and far field zone. There is the diffraction attenuation in near field zone in which the ultrasonic beam from a transducer has intensity fluctuation. However, there is the non-diffraction attenuation in far field zone in which the beam is more uniform. The length N of near field zone can be defined as:

$$N = D^2/4\lambda \tag{1}$$

where D is the area of the ultrasonic transducer, λ is the wavelength.

The diameter of the ultrasonic transducer is 10 mm. The frequency of the transducer is 5 MHz and the wavelength for aluminum alloy is 6260 m/s [20]. The height of the samples is 35 mm. According to formula (1), the ultrasonic field of the transducer for samples is beyond near field zone. Meanwhile, the upper surface and the bottom surface of the samples are parallel to each other and the roughness is less than Ra0.002 mm. Consequently, there isn't diffraction attenuation for the samples. According formula (2) the attenuation coefficient can be calculated:

$$\propto = (20\lg B_1/B_2 \ - \delta)/2d \tag{2}$$