NDE OF MECHANICAL PROPERTIES OF AL-7%Si-0.5%Mg ALLOY CASTINGS USING ULTRASONIC WAVE ANALYSIS

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ABSTRACT

In this work, the possibility of using ultrasonic wave analysis for a nondestructive evaluation (NDE) of mechanical properties will be discussed. For this purpose a step plate sand casting of Al-7%Si-0.5%Mg alloy was used. Chilled and refined castings were also produced. The ultrasonic wave parameters; echo height and time interval were measured at the different casting sections, in the as cast and heat treated conditions. GURU II, which is a combination of hardware and software package was used to analyze the ultrasonic waveform. Mechanical properties were also determined at the different casting sections. Results show that, irrespective of casting condition the attenuation coefficient increases linearly with increasing casting modulus while sound velocity decreases. Attenuation and velocity are influenced by heat treatment. Ultimate tensile strength, 0.2% offset yield and elongation percent are correlated linearly with both attenuation and velocity.

Keywords: Ultrasonic, Al-Alloy casting, Mechanical properties.

1.INTRODUCTION

Back-reflected ultrasonic signals have been used for several years to examine castings for internal flaws, such as shrinkage, gas defects and cracks [1]. Several studies have discussed the possibility of evaluating either the physical or mechanical properties of different materials by using ultrasonic. Klin [2] described an ultrasonic technique based on the use of velocity analysis for the NDE of mechanical properties of composite materials. He concluded that the technique is rapid and can be used to scan composite panels for evaluating local differences in material properties and composition. Zummeren et al. [3] reported that an effective way to determine elastic parameters of a sheet of paper, is to find the velocity of ultrasonic wave.

In the areas of metal-matrix composite, Mott [4] correlated the mechanical, fractographic and metallographic results with the observed ultrasonic reflection phenomena. He found that ultrasonics can be used to differentiate between regions of varying mechanical properties.

In the field of nodular cast iron, different researches studied the possibility of correlating the mechanical properties with ultrasonic parameters. Meaningful relationships have been reported between ultrasonic velocity, nodularity and strength [5-6].

The correlation between ultrasonic data and hardness of aged Aluminum alloy (2024) has been investigated [7]. Ultrasonic attenuation was found to decrease consistently with increasing hardness. Adler et al.[8] discussed the characterization of porosity in Al-Si alloy (A357) using the frequency dependence of ultrasonic attenuation, both from the theoretical and experimental view points. It was found that the ultrasonic method agrees well with the determined porosity based on density measurements.

In this work the possibility of correlating the ultrasonic parameters with the mechanical properties of Al-7%Si-0.5%Mg step plate sand casting will be studied. This alloy was chosen for the present study due to its economic importance in large scale castings. Direct contact pulse echo technique and computer-aided waveform analysis will be used for this purpose.

2. EXPERIMENTAL WORK

2.1. *Material*

A step plate sand casting of Al-7%Si-0.5%Mg alloy was chosen to carry out the present program. The plate has casting moduli (casting modulus, M = Volume/surface area) of 7.5, 10, 12.5, and 15 mm (Figure 1). Chilling in drag and grain refining using 40%Ti-4%B master alloy, were carried out for producing castings with a reasonable range of mechanical properties. Each casting was sectioned longitudinally into four plates of 22,33,50 and 75 mm thickness. Then, the plates were sectioned into a number of strips of dimensions 20x20x220 mm. For ultrasonic measurements, the specimens were machined flat and parallel.

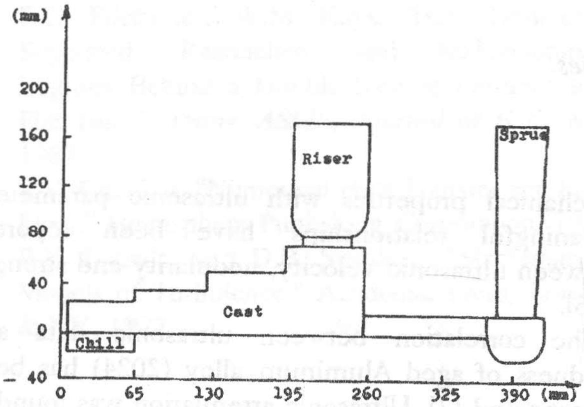

Figure 1. Step plate sand casting.

The specimens were heat treated to the T6 condition (solution treatment at 520 °C for 4 hours and quenched in hot water, then aging at 170 °C for 10 hours and air cooled).

2.2. *Material Testing*

2.2.1. *Ultrasonic Measurements*

Sound attenuation or the decrease in amplitude of the transmitted signal is caused by two factors; the first of these is the real absorption, i.e the conversion of energy into heat. The second factor is the scattering of the waves at the grain boundaries of the material [9-10].

In pulse echo technique, the attenuation coefficient (α) and sound velocity (V) of a longitudinal ultrasonic plane wave can be calculated from the following relations:

$$\alpha = 20/2d \cdot \log (h_1/h_2) \quad \text{(dB/mm)} \quad (1)$$

$$V = 2d/t \quad \text{(m/s)} \quad (2)$$

Where h_1 and h_2 are the amplitude of two successive echoes in the trace of the A-scan display for each inspected point, t is the time elapsed between these echoes and d represents the path of sound wave from the probe to the back wall of the specimen.

The experimental set-up of the ultrasonic wave parameter measurements is shown in Figure (2). It consists of a 2 MHz normal probe, pulser/receiver ultrasonic instrument (NDT 80 1D) interfaced with digital oscilloscope (Texktronix 2230) which is used as a digitizer and a personal computer. GURU II which is a combination of hardware (GPIB) and software (DIGPULSE) package was used to analyze the waveform which is acquired from the digitizer. Thus, the waveform parameters; amplitudes (h1 and h2) and time interval (t) can be measured. Thickness of the strip, was measured by using mechanical comparator of 0.001 mm resolution. The attenuation coefficient as well as the ultrasonic velocity can be calculated from equation 1 and 2 respectively.

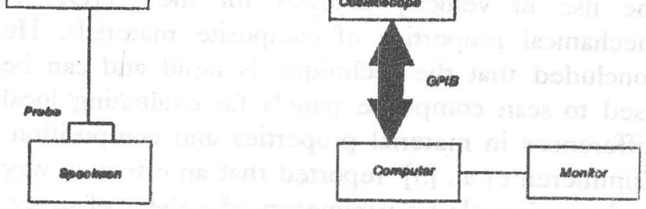

Figure 2. Set-up of ultrasonic measurements system.

2.2.2. *Mechanical Testing*

After ultrasonic measurements, at least two specimens from each plate were turned for preparing tensile specimens of 12 mm gage diameter. 4 ton scale of M.A.N universal testing machine was used for determination of ultimate tensile strength, 0.2% offset yield and elongation percent of the different castings.

3.RESULTS AND DISCUSSION

All results were subjected to statistical analysis. Mean values of attenuation and velocity were taken at the different casting sections. The correlation coefficient (C.C) between each of the ultrasonic parameters and the variables under consideration were also determined. Higher coefficients were chosen for proper mathematical relationships [11]. The fitted curves as well as the experimental data points (mean values) were plotted for each relationship. The effect of casting modulus on attenuation and sound velocity, of the different castings, are presented and discussed. The relationship between ultrasonic parameters and ultimate tensile strength, 0.2% offset yield as well as elongation percent are also discussed.

3.1. *Effect of Casting Modulus*

The variation of attenuation coefficient with casting modulus, for the different castings is shown in Figure (3). For the as cast condition, attenuation increases linearly with increasing casting modulus. Normal casting shows higher values compared with those of the chilled and refined ones.

As reported in literature for Aluminum alloys, porosity has great influence on ultrasonic attenuation [8,12]. For the present castings, the porosity variation have been discussed elsewhere [13]. It has a similar trend to that of attenuation, i.e it increases with increasing casting modulus . This is a direct result to the solidification direction which proceeds towards the riser at the top of the heavy section.This result is in good agreement with those reported in references [8] and [12]. After heat treatment, the attenuation was highly reduced and there is no significant difference between the values of the different castings.

The relationship between ultrasonic velocity and casting modulus, for the different castings is presented in Figure (4). Irrespective of casting condition, the velocity decreases linearly with increasing casting modulus and it ranges between 5689 and 6200 m/s. Normal casting shows higher values followed by chilled and refined one respectively. As could be observed, this trend is inverse to that of attenuation.

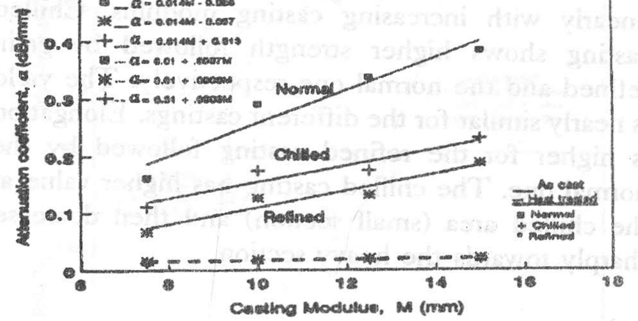

Figure 3. Variation of attenuation coefficient with casting modulus for the different castings.

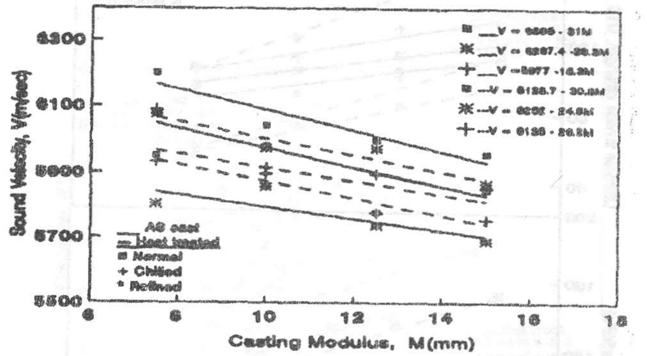

Figure 4. Variation of sound velocity with casting modulus for the different castings.

The sound velocities of the different castings, after heat treatment, are within those of the as cast condition, but in a close range (5740-6100 m/s). This means that the effect of heat treatment on velocity is not sensible as that of attenuation.

From the above results it can be concluded that; the casting modulus has direct influence on both attenuation and velocity. The reduction in ultrasonic attenuation and the increase of velocity are directly related to the decrease in casting porosity. The porosity has a minimum value at the smallest casting section and increases towards the heavy section [13]. Heat treatment has a greater influence on attenuation compared with velocity.

3.2. *Mechanical Properties*

Figure (5) represents the variation of mechanical properties with casting modulus. For the different castings; the tensile strength (UTS), 0.2% offset yield (Ps) and elongation percent (E%) decrease linearly with increasing casting modulus. Chilled casting shows higher strength followed by grain refined and the normal one respectively. The yield is nearly similar for the different castings. Elongation is higher for the refined casting followed by the normal one. The chilled casting has higher value at the chilled area (small section) and then decrease sharply towards the heavy section.

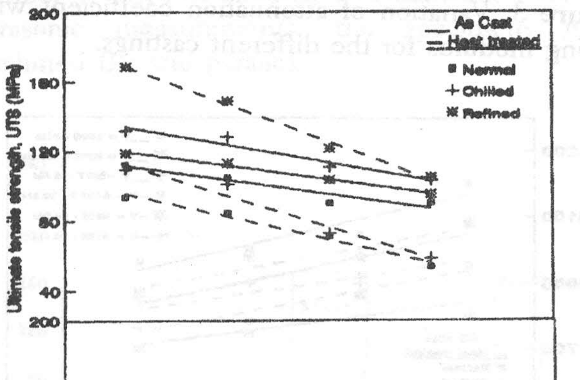

Figure 5. Variation of mechanical properties with casting modulus for the different castings.

In the heat treated condition, the refined casting shows higher strength and yield, while the elongation is the lowest value. This means that an improvement in strength has occurred. For the other two castings, a reduction in strength and an improvement in elongation, specially at the smaller casting modulus have occurred.

The mechanical properties of the different castings are correlated with both ultrasonic attenuation and velocity. Figure (6) represents the relationship between the mechanical properties and ultrasonic attenuation of the different castings. For the as cast condition, the tensile strength, 0.2% offset yield and elongation percent decrease linearly with increasing attenuation. On the other hand, no relationship can be observed for the heat treated condition because attenuation is nearly constant for the different castings (c.f. Figure 3).

Figure (7) shows the relationship between the mechanical properties and ultrasonic velocity of all the castings. For each casting, separately, ultimate strength, yield and elongation increase linearly with increasing ultrasonic velocity.

From the above results it can be noticed that the mechanical properties increase with increasing ultrasonic velocity, and with decreasing attenuation. Thus, general relationships, developed by regression analysis using "Micro Stat." microcomputer statistical software can be expressed as follows:

$$P = C\,V - P_{ov} \quad (3)$$

$$P = P_{o\alpha} - K\,\alpha \quad (4)$$

Where P is the mechanical property (strength, yield or elongation), V is the sound velocity, α is the coefficient of attenuation, C, K, P_{ov} and $P_{o\alpha}$ are material constants, listed in Figures (6) and (7).

These results lead to the possibility of evaluating the mechanical properties of a casting nondestructively by detecting the change of ultrasonic parameters (attenuation or velocity). Velocity is preferred than attenuation because it gives better results for the heat treated condition than that of attenuation and also because the measurement of attenuation is usually more difficult than velocity.

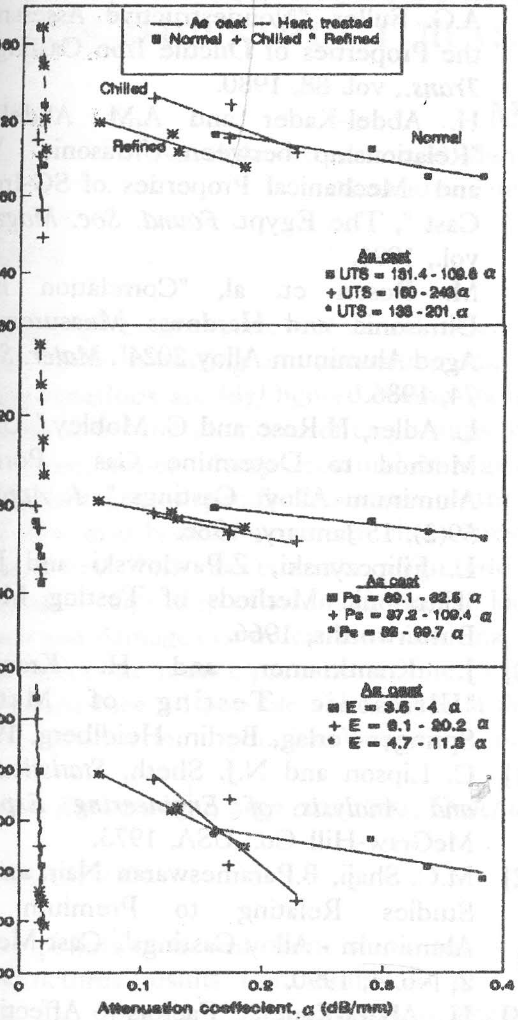

Figure 6. Relationships between mechanical properties and attenuation coefficient for the different castings.

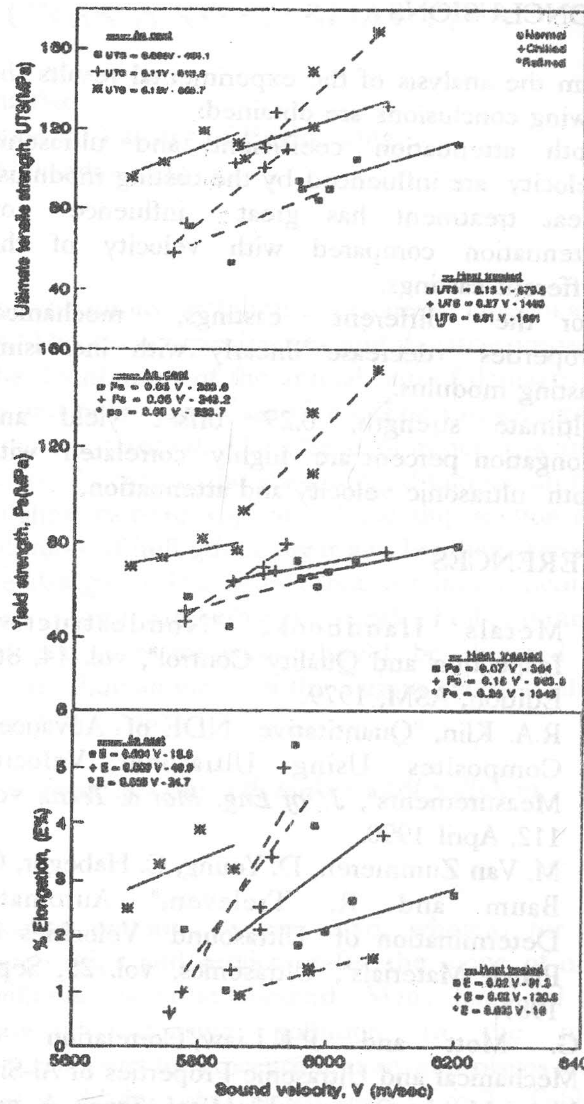

Figure 7. Relationships between mechanical properties and sound velocity for the different castings.

4. CONCLUSIONS

From the analysis of the experimental results the following conclusions are obtained:

1. Both attenuation coefficient and ultrasonic velocity are influenced by the casting modulus.
2. Heat treatment has great influence on attenuation compared with velocity of the different castings.
3. For the different castings, mechanical properties decrease linearly with increasing casting modulus.
4. Ultimate strength, 0.2% offset yield and elongation percent are highly correlated with both ultrasonic velocity and attenuation.

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