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A study of PC-based ultrasonic goniometer system of surface properties and characterization of materials

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Abstract. This paper discussed the design and development of a portable PC-based ultrasonic goniometer system that can be used to study material properties using ultrasonic wave. The system utilizes an ultrasonic pulse-receiver card model attached to computer notebook for signal display. A new specific software package (GoNIO) was developed to control the operation of the scanner, displaying the data and analyze characteristics of materials. System testing was carried out using samples with cubic dimension of about 10 mm x 20 mm x 30 mm. This size allows the sample to be fitted into the goniometer specimen holder and immersed in a liquid during measurement. The sample was rotated from incident angle of 0° to 90° during measurement and the amplitude reflected signals were recorded at every one degree of rotation. Immersion transducers were used to generate and receive the ultrasounds that pass through the samples. Longitudinal, shear and Rayleigh wave measurements were performed on the samples to determine the Dynamic Young's Modulus. Results of measurements are explained and discussed.

1. Introduction

An ultrasonic goniometer is based on the principle of reflection and transmission of ultrasound at oblique incidence at plane boundary [1]. It can be used to measure the speeds of compression, transverse and Rayleigh waves irrespective of the shape of the test object provided that the object has at least one plane surface. The method can be used to its best advantage with pulse-echo technique using two transducers, one transmitting and the other receiving and each of which are mounted on rotating arms, the angular positions of which can be accurately determined using vernier on a circular scale. The complete arrangement is immersed in water or liquid tank. The test object is positioned in such a way that the axels of the probes intersect at its surface, which is perpendicular to the plane containing these axes. These arrangements allow the determination of Dynamic Young's modulus through calculation.

In principle, the ultrasonic characterization of materials can be performed in two ways, *i.e.* by measuring sound velocity and sound attenuation. In homogeneous, isotropic and elastic media, the wave velocity, V is given by:

$$V = \sqrt{\frac{E}{\rho} \frac{(1-\upsilon)}{(1+\upsilon)(1-\upsilon)}} \quad (1)$$

where E is the Young modulus, ρ the material density and υ the Poisson ratio.

Ultrasonic waves are attenuated as the waves pass through a material. This attenuation can be caused by beam divergence (distance effect), absorption (heat dissipation) and scattering. Only scattering is affected by the characteristics of the material, mostly because the degree of inhomogeneity in the material and the frequency of the transducer. The attenuation caused by scattering was given as [2],

$$\alpha_s = \begin{cases} 1/D & \text{for diffusion range} \quad \lambda \leq D \\ Df^2 & \text{for stochastic range} \quad \lambda \approx D \\ D^3 f^4 & \text{for Rayleigh range} \quad \lambda >> D \end{cases} \quad (2)$$

where, f is the wave frequency, λ the wavelength and D the average inhomogeneity.

The principle of operation is illustrated in Figure 1 [3].

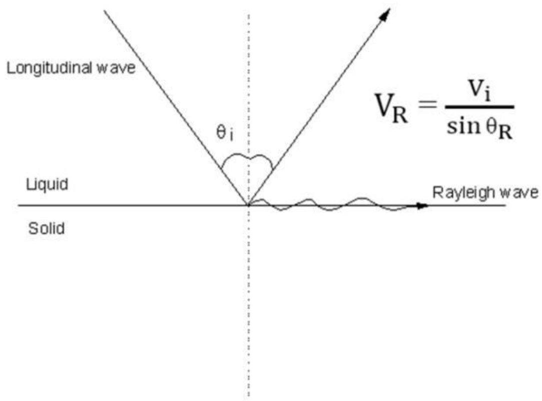


Figure 1. An ultrasonic beam is incident at a critical angle θ_i and Rayleigh wave propagated on the solid surface.

The ultrasonic goniometer was developed for applications that need a variable incidence and detection angle as well as an adjustable distance of incidence and detection point at the region near the transducer also known as Fresnel field [4]. It is very difficult to accurately investigate defects in materials. This is because it can produce multiple indications and the signal amplitude of the reflected signal from the flaw may vary considerably if the flaw located within effective distance from the transducers varies.

Manual ultrasonic measurement of sample using ultrasonic goniometer technique is physically intensive and time consuming. For these reasons, we developed a PC-based ultrasonic goniometer system and used it on a few samples to evaluate its performance. This paper discussed the system developed and its measurement results.

2. Material and Method

The longitudinal wave velocity was measured by conventional ultrasonic flaw detector using longitudinal probe whereas Rayleigh wave velocity was measured using ultrasonic goniometer system developed. Figure 2 shows the system, the samples as well as the control software (GoNIO). The shear wave velocity was then calculated according to the formula [2];

$$q^6 - 8q^4 + 8q^2(3 - 2u^2) - 16(1-u^2) = 0 \quad (3)$$

where $q = V_R/V_S$, $u = V_S/V_L$, V_L = longitudinal wave velocity, V_S = shear wave velocity and V_R = Rayleigh wave velocity.

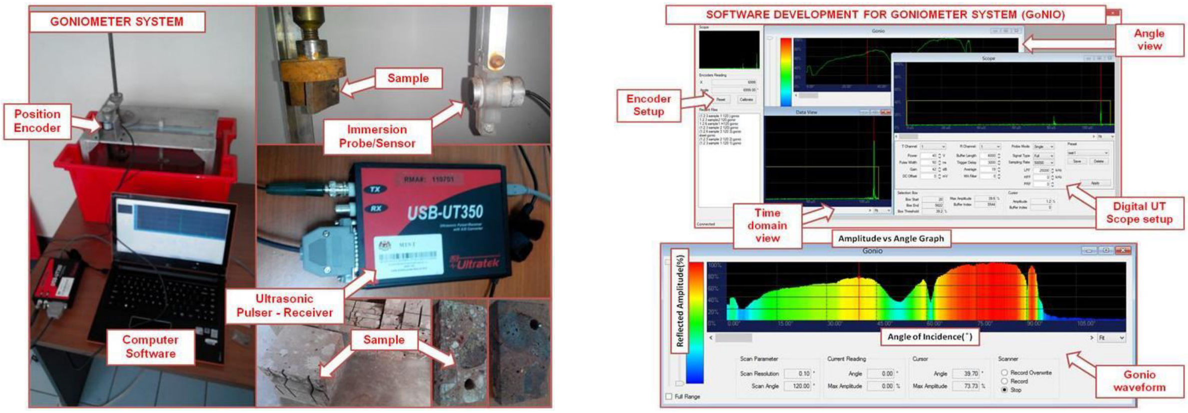


Figure 2. The ultrasonic goniometer system.

The developed ultrasonic goniometer system utilized an ultrasonic pulse-receiver card model attached to computer notebook for signal display showing maximum amplitude against degree of rotation. The immersion transducer frequency of 2.25MHz with 20mm diameter size was used to generate and receive Rayleigh wave ultrasound through the samples. The sample attached to goniometer was rotated from incident angle of 0° to 90° and the amplitudes of reflected signal from the sample were recorded at every one degree of rotation. The distance between transducer and sample is set to 152 mm to obtain maximum amplitude echo. This was based on the near field length calculation according to equation 4:

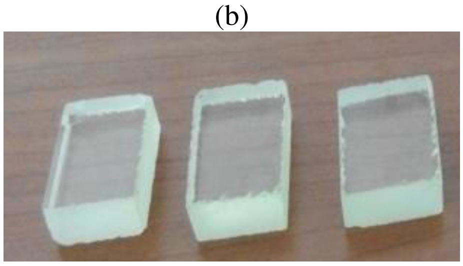
$$\text{Near Field} = \frac{D^2}{4\lambda} = \frac{D^2 f}{4V} \tag{4}$$

where, D = diameter of the probe, f = frequency of the probe and V = velocity of water ($1485 ms^{-1}$)

Figure 3 shows the prepared samples used in the experiments. These are steel, hematite concrete, aluminum and lead glass. The samples were cut to a cubic dimension of about 10 mm x 20 mm x 30 mm so that can be fitted into the goniometer specimen holder. The densities of samples were determined by weighing the samples and measuring the volume water displaced.


(a)


(b)



(c) (d)

Figure 3. The material of (a) steel, (b) hematite concrete, (c) aluminum and (d) lead glass are used in this experiment.

3. Results and Discussion

A typical ultrasonic goniometer result displayed by the system is as shown in Figure 4. It shows the Rayleigh wave critical angle for steel (the vertical green line). Using Snell's law, the Rayleigh wave velocities of the samples were calculated. Figure 5 shows the ultrasonic goniometer data for all four samples. The vertical dashed line indicates the Rayleigh wave critical angle which is caused by the increase of attenuation (Rayleigh scattering) for each sample respectively.

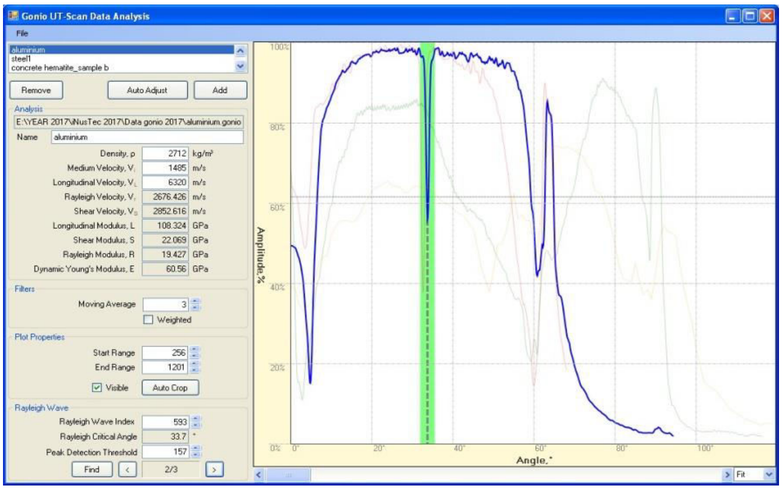


Figure 4. The (GoNIO) software display of goniometer curve characteristic of steel.

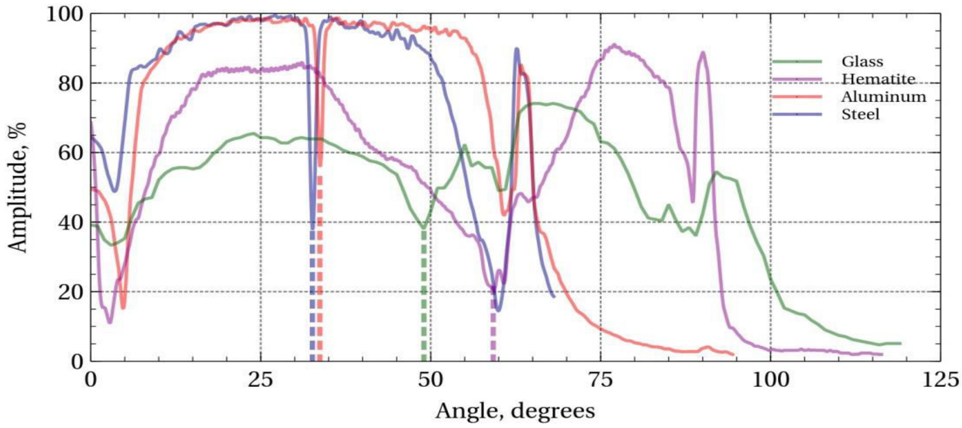


Figure 5 shows the goniometer curve characteristics for all the samples.

The profile of measured data shows the reduction in amplitude at low angle of reflection. This is caused by the geometrical setting and sound divergence causing only partial reflection of ultrasonic wave back to the transducer. Further increase of the reflected angle resulted in better reflection of ultrasonic wave thus increasing the amplitude. The first attenuation of the amplitude is caused by the occurrence of Rayleigh scattering on sample surface that is characteristics of the sample properties.

The ultrasonic goniometer system provides the calculated properties of all the samples based on the amplitude-angle profile data. These values are shown in Table 1 with accompanying referenced values for comparison for Tensile Modulus and Dynamic Young Modulus from goniometer measurement (Thbe Tensile Modulus for these materials were determined using tensile test, a destructive testing method).

Table 1. Comparison Tensile Modulus and Dynamic Young Modulus from goniometer measurement.

Tensile Modulus (Young's Modulus, Modulus of Elasticity) [5]		Dynamic Young Modulus (Goniometer measurement)	
Material	*(10^9 N/m^2, GPa)*	Material	*(10^9 N/m^2, GPa)*
Steel, stainless AISI 302	180	Steel	174.15
Steel, Structural ASTM-A36	200		
Concrete	17	Hematite concrete	20.76
Concrete, High Strength (compression)	30		
Aluminum	69	Aluminum	60.56
Glass	50 - 90	Lead glass	49.73

Table 1 show that the tensile and calculated Young's modulus for steel is very similar, even though the compared steels are of different types. All the other materials show similar traits with the calculated Young's modulus within the range of tensile values. This indicates the ultrasonic measurement can provide reliable values of Young's modulus.

4. Conclusion

A portable PC-based ultrasonic goniometer system was developed to study material properties using ultrasonic wave. The system was tested using samples that can be compared tensile Young's modulus. The ultrasonic goniometer measured the surface Rayleigh wave velocity of the samples and with the combination of conventional ultrasonic pulse echo method gave the complete velocities values that were needed to determined Dynamic Young's modulus. These values were found to be comparably similar, indicating the effectiveness of the ultrasonic method to determine Young's modulus of material.

5. References

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