Journal of the Korean Society
for Nondestructive Testing
Vol. 28, No. 6 (2008. 12)

Poisson's Ratio Scanning Using Immersion Ultrasonic Testing

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Abstract Poisson's ratio is one of elastic constants of elastic solids. However, it has not attracted attention due to its narrow range and difficult measurement. Transverse wave velocity as well as longitudinal wave velocity should be measured for nondestructive measurement of Poisson's ratio. Hard couplant for transverse wave prevents transducer from scanning over specimen. In the present work, a novel measurement of Poisson's ratio distribution was proposed. Immersion method was employed for the scanning over the specimen. Echo signals of normal beam longitudinal wave were collected. Transverse wave modes generated by mode conversion were identified. From transit time of longitudinal and transverse waves, Poisson's ratio can be determined without information of specimen thickness. This technique was demonstrated for aluminum and steel specimens.

Keywords: Poisson's Ratio, Immersion Ultrasonic Testing, Mode Conversion

1. Introduction

Poisson's ratio, defined as the ratio of lateral contraction to longitudinal elongation, is one of the elastic constants, which are material parameters that relate stress and strain (Pollard, 1977). Many elastic constants have been used to determine the materials property, but Poisson's ratio hasn't been given much attention due to its narrow range (Kumar, Jayakumar, Raj and Ray, 2003; Shin, Yoon and Kim, 2008). However recently it has been reported that Poisson's ratio is closely related with the bonding forces and sound wave speeds in a certain material (Kumar, Jayakumar, Raj and Ray, 2003). Thus besides the classical method of measuring Poisson's ratio with mechanical loading, determination from longitudinal and transverse wave speeds can be also used as a nondestructive method. The sound wave speeds have been measured seperately, each longitudinal or transverse wave at one time, because transverse wave is hardly transferred in liquid medium. This method had many difficulties, which were another downsides of Poisson's ratio among the elastic constants, such as pasting or removing solid couplant and damage to the specimen during measurement (Shin, Yoon and Kim, 2008).

Mode conversion from longitudinal wave to transverse wave was reported with contact type longitudinal transducer, not only at oblique incident but also at normal angle, using liquid couplant (Kim, Lee and Kim, 2003). Mode conversion for normal incidence is known to be impossible, but it is true only for infinite plane wave. The finite size of wave source is considered as the reason of mode conversion for normal incidence. Localized stress that longitudinal wave exerts to a surface causes transverse strain as well as normal strain, resulting in the

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mode conversion to transverse wave.

Longitudinal and transverse wave speeds can be simultaneously measured using immersion method and Poisson's ratio can be determined from measured wave speeds (Shin, Yoon and Kim, 2008). Unlike contact method, immersion method allows fast scanning over the specimen. Also, this method allows simultaneous measurement of longitudinal and transverse wave speeds according to mode conversion, therefore reducing the time required.

In the present work, "μ-scan (Poisson's ratio scan)" system which can determine distribution of Poisson's ratio in a specimen using immersion method has been proposed. An immersed transducer scanned over a surface of the specimen. Wave modes were identified from the pulse-echo signals. The Poisson's ratio was determined from the transit times of longitudinal and transverse wave modes.

2. Theoretical Background

Poisson's ratio is defined as the ratio of lateral contraction to longitudinal extension and therefore can be expressed with Lamé constants as below (Pollard, 1977).

$$\mu = -\frac{\varepsilon_{22}}{\varepsilon_{11}} = \frac{\lambda}{2(\lambda + G)} \tag{1}$$

where μ is Poisson's ratio, ε_{22} is transverse strain, ε_{11} is axial strain, and λ and G are Lamé constants.

Since longitudinal and transverse wave speeds are given as (Pollard, 1977)

$$c_\lambda = \left(\frac{\lambda + 2G}{\rho}\right)^{1/2} c_t = \left(\frac{G}{\rho}\right)^{1/2}, \tag{2}$$

where c_l is the speed of longitudinal wave, c_t is the speed of transverse wave, and ρ is density of the medium. Combining eqns (1) and (2), we can get

$$\left(\frac{c_\lambda}{c_t}\right)^2 = \frac{\lambda}{G} + 2 = \frac{2-2\mu}{1-2\mu} \ . \tag{3}$$

The transit times of longitudinal and transverse wave modes are as follows:

$$\tau_\lambda = \frac{2d}{c_\lambda}, .\tau_t = \frac{2d}{c_t}, \tag{4}$$

where d is thickness of specimen, τ_l is the transit time of longitudinal wave, and τ_t is the transit time of transverse wave. The relationship between ratio of transit times of wave modes and Poisson's ratio is given by

$$\left(\frac{c_\lambda}{c_t}\right)^2 = \left(\frac{\tau_t}{\tau_\lambda}\right)^2 = \frac{2-2\mu}{1-2\mu} \tag{5}$$

Finally Poisson's ratio can be obtained by

$$\mu = \frac{1}{2}\frac{2-R_t^2}{1-R_t^2} , \tag{6}$$

where $R_t = \tau_t/\tau_l$ is the ratio of transit times of longitudinal and transverse waves. Eqn (6) does not have the term of specimen thickness, d. Therefore, Poisson's ratio can be determined from the ratio of transit time of longitudinal and transverse wave modes without prior information of specimen thickness.

3. Immersion Scanning

Specimens of aluminum and steel were employed in order to verify proposed method. Each of them has parts of two different thicknesses as shown in Fig. 1.

An ultrasonic pulser-receiver (Panametrics 5800) and a broadband longitudinal transducer (5 MHz center frequency and 12.7 mm diameter) were used to obtain pulse-echo signal. The distance from transducer to the top surface of specimen was about 52.5 mm. RF signals were digitized with 12 bit resolution and 200 Ms/s.

Typical pulse-echo signals obtained from steel specimen are shown in Fig. 3. The echo from the surface is referred to as "Front," and the longitudinal echoes from the bottom are referred to as 2P, 4P, ... , and mode converted echoes 1P1S, 2S, 3P1S, ... The numbers in the front of P and S, as shown in Fig. 2, represent

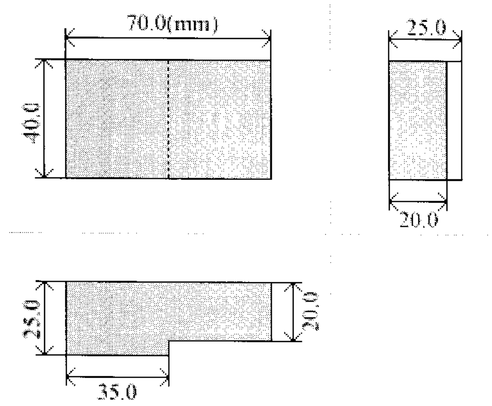


Fig. 1 Dimensions of the specimen used in the present work

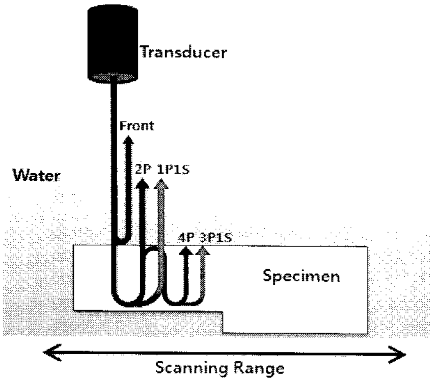
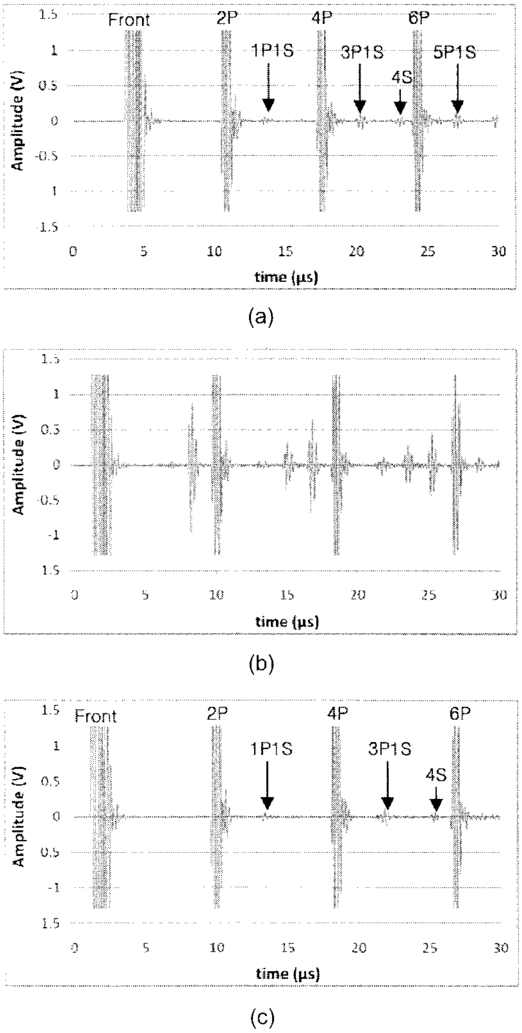


Fig. 2 Experimental setting and wave diagram. Transducer is immerged in the water and scanning range is a little larger than specimen size in order to assure that the whole specimen is scanned.

the number of wave modes involved in the echoes. Fig. 3(a) and (c) show the different time intervals between echoes due to different thickness at each position. When the transducer passes the stepped area, signals from both bottoms with different depths are detected at the same time (Fig. 3(b)), so the measurement of the transit times was impossible.

The time intervals between echoes are also different according to different materials properties, as shown in Fig. 4(a), the pulse-echo signals from aluminum specimen. Besides, it is evident that the ratio of transit time of mode-converted echo and longitudinal echo is different in different materials. However, as shown in Fig. 4(b) and (c), the materials with relatively greater Poisson's ratios such as copper and brass were hard to obtain the mode-converted echoes at this moment. It is experientially assumed that greater Poisson's ratio influences the speed of transverse wave to become slower, making damping bigger, and efficiency to be lower (Shin, Yoon and Kim, 2008).



(a)

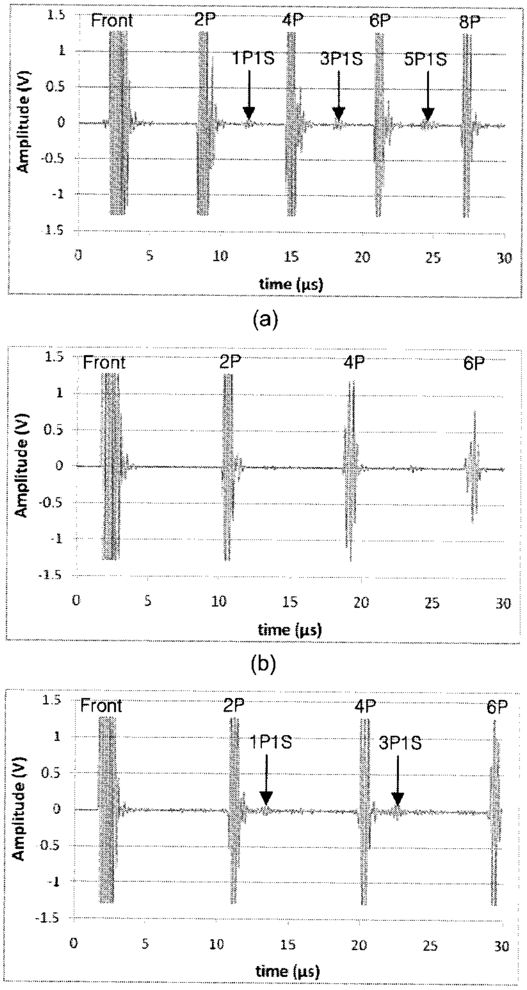
(b)

(c)

Fig. 3 Typical pulse-echo signals from the steel specimen (a) at 20 mm thick, (b) at the stepped area between two thicknesses and (c) at 25 mm thick

4. Calculation and Image Mapping

First, the echo signals were analyzed with an algorithm that automatically finds locations of the



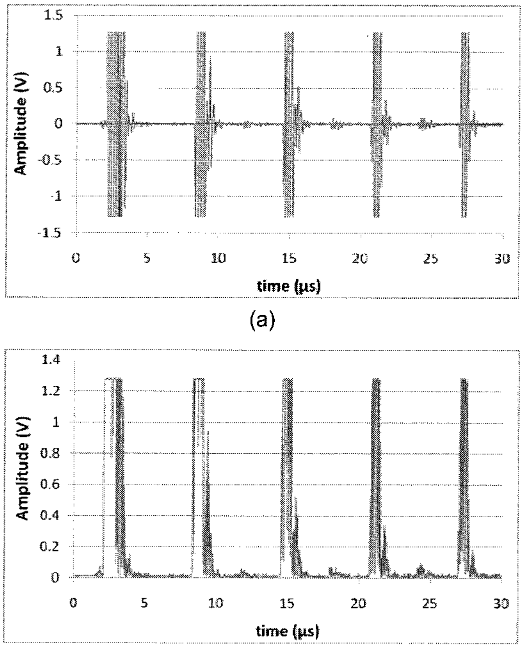
(a)

(b)

(c)

Fig. 4 Typical pulse-echo signals from the specimen of (a) aluminum, (b) copper and (c) brass

peaks. The original data was divided into unit intervals, which is set by detector frequency over transducer frequency, and converted into the absolute values, as shown in Fig. 5. After obtaining the local maximum in each unit interval, a threshold for peak determination was set using the principle of histogram. Some peaks that are actually included in one peak can be appeared to be different peaks because of the transducer frequency, thus these peaks are needed to be merged in to one peak. The front peak was found with the fact that time interval between front and 2P is the same with time interval from 2P to 4P. Then 1S1P peak was found, and if



(a)

(b)

Fig. 5 Signal processing of the algorithm. (a) the original data, (b) processed data

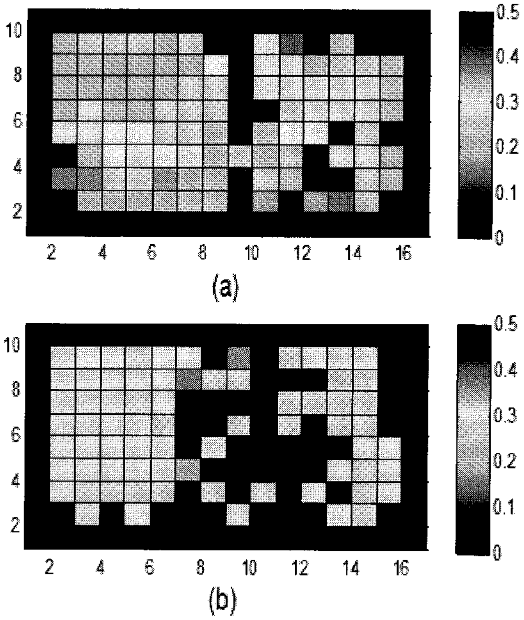


Fig. 6 μ-scan results of (a) aluminum and (b) steel specimens. Each pixel corresponds to 5mm of the specimen both horizontally and vertically. The color bar on the right side represents Poisson's ratio in range of 0 to 0.5

1S1P is not apparent enough, the algorithm automatically detected 3S1P instead of it.

With the peaks detected, time intervals and Poisson's ratio were calculated using eqon (5). If the calculation is invalid, for example dividing by zero due to no detected transverse wave echo, the program automatically sets the Poisson's ratio to 0, for convenience of mapping. Although the time intervals change with difference in thickness, Poisson's ratio can be obtained independently of specimen thickness. It is demonstrated more obviously in Fig. 6, which shows the distribution of Poisson's ratio in aluminum and steel specimens. The similar color tone represents similar value of Poisson's ratio, from which can be assumed that Poisson's ratio is the same in one material, regardless of thickness. In the stepped area, the echoes from both bottoms were detected, thus Poisson's ratio was hard to be determined. Also, when the specimen thickness was too thin, mode conversion seemed to be hard to be occurred, resulting in no Poisson's ratio data in most of the 2 cm region. Therefore, in the two regions, stepped area and thin area, some inaccuracy of Poisson's ratio occurred. However, except these experimental limitations, the distribution of Poisson's ratio was fairly even.

5. Conclusions

In the present work, a novel measurement of μ-scan (distribution of Poisson's ratio in the specimen) was proposed. Poisson's ratio can be obtained from the immersion method using only transit time. Mode conversion enables to measure transverse wave velocities using immersion test of normal incident of longitudinal waves. This method can be applied to identify variation in material properties of specimen such as sintered ceramics and weldments.

Immersion method was employed for the scanning over the specimen. Echo signals of normal beam longitudinal wave were collected. Transverse wave modes generated by mode convertsion were identified. From transit time of longitudinal and transverse waves, Poisson's ratio can be determined without information of specimen thickness. This technique was demonstrated for aluminum and steel specimens.

Acknowledgment

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (No. 2007-00467).

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