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Poisson's Ratio Measurement Using a Pair of PVDF Ultrasonic Transducer

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Abstract This work presents a simple technique to determine the Poisson's ratio of homogeneous solid material using a pair of low cost PVDF ultrasonic transducers. It is based on transducer's property of generating longitudinal and transversal waves depending on the excitation frequency. Mechanical tests were conducted to validate the proposed method, resulting in a good agreement between ultrasonic and mechanical techniques.

Keywords: Poisson's Ratio, Acoustic Application, PVDF Transducer

1. Introduction

The modulus of elasticity and Poisson's ratio of materials are fundamental parameters necessary in structural analysis for the determination of the strain distributions and displacements, especially when the design is based on elasticity considerations(Sideris et al., 2004). Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio. Virtually all common materials become narrower in cross section when they are stretched. The reason is that most materials resist better a change in volume than they resist a change in shape(Fung, 1968).

Several non-destructive techniques for laboratory measurement of Poisson's ratio have been proposed in the literature based on different physical principles, like acoustic resonant frequencies(Chen, 2000), laser Doppler vibrometry (Dubbelday, 1992) or ultrasonic wave propagation (Kumar et al., 2000; Rokhlin and Wang, 2002; Lobkis et al., 2000; Castaings et al., 2000; Hobatho et al., 1998). In particular, ultrasonic techniques are especially well suited for field conditions as they do not impose almost any restrictions to the material to be inspected. The Poisson's ratio determination requires the measurement of longitudinal and transverse waves speed through the material using two different transducers operating at two different vibration modes(Dwyer-Joyce and Hankinson, 2006). This variability among tests occurs mainly due to the transducers swap in the specimens back face for the tests. The measurement procedure becomes easier and its variability is reduced using only one transducer pair.

Although the idea of using one transducer for simultaneous emitting of longitudinal and shear waves is not new(Jen et al., 1998), in this work we propose the use of a relatively low cost, commercially available transducer for this purpose.

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Mechanical waves can be described as a disturbance that travels through a medium, transporting energy from one location to another. The medium can be thought of as a set of interacting particles that oscillates around its point of equilibrium. Many different waves' propagation modes are well known in the literature, including longitudinal waves, shear waves, surfaces or Rayleigh waves and flat waves(Auld, 1990).

The materials properties that affect the propagation speed of longitudinal waves (V_l) and shear waves (V_s) in solid materials are the Young modulus (E), the Poisson's ratio (μ) and the material density (ρ)(Krautkrämer and Krautkrämer, 1990). Eqns. (1) and (2) relates the three above mentioned parameters.

$$V_l = \sqrt{\frac{E}{\rho}\frac{1-\mu}{(1+\mu)(1-2\mu)}} \tag{1}$$

$$V_s = \sqrt{\frac{E}{\rho}\frac{1}{2(1+\mu)}} \tag{2}$$

From eqns. (1) and (2) we can derive eqn. (3) which relates the Poisson's ratio to the longitudinal and shear waves propagation speed.

$$\mu = \frac{2a-1}{2(a-1)} \quad \text{where} \quad a = \left(\frac{V_t}{V_l}\right)^2 \tag{3}$$

According to eqn. (3) the Poisson's ratio can be calculated knowing both propagation speeds. These equations are valid for bulk wave propagation mode.

In this paper, a measurement method based on one pair of low cost transducers, operating in pulsed transmitter-receiver mode is proposed. PVDF transducers' characteristic of vibrating in two different modes depending on the excitation frequency(Wang and Toda, 1999) is used. In particular, Section II describes the proposed method and section III illustrates the experimental results. Finally, Section IV makes some discussion and conclusions.

2. The Proposed Method

2.1 PVDF Ultrasonic Transducers

Although the existence of piezoelectric polymers was already known since 1924, PVDF transducers emerged as a consequence of the Kawai's discovery of the strong piezoelectric effect in polyvinylidene fluoride(PVDF) in 1969 (Kawai, 1969).

PVDF films are thin and flexible, exhibit a quite linear behavior under external loads, considerable bandwidth, high dynamic range, low acoustic impedance, high elasticity and high output voltage. Fig. 1 shows the selected transducer: SDT1-028K PVDF sensor from Measurement Specialties(Measurement Specialties, 1999).

A key characteristic of the PVDF transducer is that it primarily vibrates along Y axis, as Fig. 2a shows, at low frequency range, below 60 kHz,

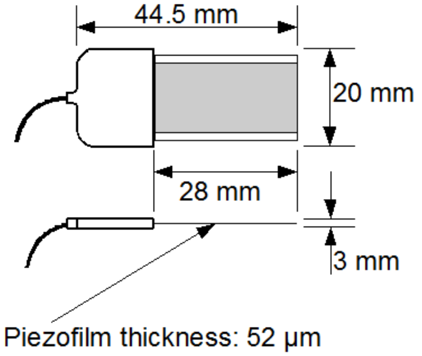

Fig. 1 PVDF transducer from Measurement Specialties(Measurement Specialties, 1999)

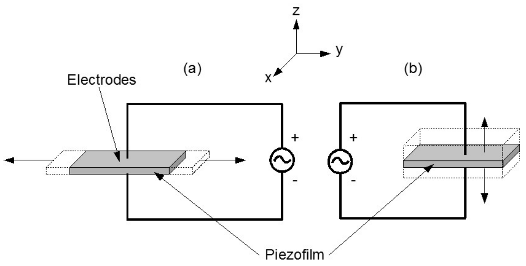

Fig. 2 PVDF transducer oscillation modes (a) transversal, (b) longitudinal

generating mainly shear waves. At higher frequencies, above 100 kHz, the piezofilm vibrates along Z axis, as it is illustrated in Fig. 2b. In this case, the transducer generates mainly longitudinal waves(Measurement Specialties, 1999).

2.2 Test Bench

In order to measure the longitudinal and shear wave's velocity, an experimental test bench was developed. The central component is an IBM PC with software that controls the emission, displays the emitted and received signals and implements the processing algorithms to measure the propagation speed of longitudinal and shear ultrasound waves.

A data acquisition board generates the excitation signal for the emitter and acquires signal from the receiver.

A high voltage linear power amplifier was designed, based on(Duggal, 2004) to connect the board's analog output to the emitter transducer. The amplifier is capable to drive the PVDF capacitive (2.8 nF) load up to 300 $V_{p\text{-}p}$ and 500 kHz.

A low noise amplifier was developed to connect the board's analog input to the receiver transducer. The first stage of the receiver amplifier is a transresistance differential amplifier with an active guard(Franco, 1998). Because the PVDF transducer behaves as a charge generator, it requires a charge amplifier with very low input impedance(Measurement Specialties, 1999). The frequency response is almost flat for a frequency band between 25 kHz to 500 kHz, with a fixed 75 dB gain.

To confirm the transducer capability of emitting of longitudinal and shear waves in the above mentioned frequency range, a test was implemented using a water bath.

2.3 The Proposed Measurement Procedure

Considering the above explained transducer capability, the measurement procedure consists of placing the emitter and the receiver transducer, face to face, in both flat sides of the test specimen.

The longitudinal and shear wave propagation speed are calculated as the ratio of the traveled distance e to the time of flight(TOF), which is the time the waves takes to travel trough the medium, as stated in eqn. (4).

$$V = \frac{e}{TOF} \tag{4}$$

First, the emitter is excited with one burst of a sinusoidal signal at 60 kHz, to generate shear waves into the sample under test. The shear wave velocity is calculated using eqn. (4). Second, the emitter is excited with one burst of a sinusoidal signal at 150 kHz to generate longitudinal waves into the specimen; then the longitudinal propagation speed is calculated. Both signal emitted with a pulse rate frequency of 100 Hz. Finally, the Poisson's ratio can be calculated using eqn. (3).

A good accuracy in the determination of TOF is required to achieve enough precision in the propagation speed calculation; this is not a trivial task, due to the shape of the signal supplied by the transducer corresponding to the received signal. An algorithm based on the one proposed in(Vargas, 1999) has been implemented for TOF calculation. The analytical signal is obtained from the received signal, and then the envelope calculated. A zero phase filter(Mitra, 2008) is used to smooth the envelope and facilitate the maximum search algorithm. To detect the signal a fixed threshold is used. From this initial point, the maximum search algorithm is applied to find the first maximum of the signal.

The points between the 90% and 10% of this maximum are considered to calculate the ascending slope of the signal, using a linear regression algorithm with a least mean square error criterion.

The point where this line intercepts the time axis is considered as the TOF. Fig. 3 illustrates the procedure.

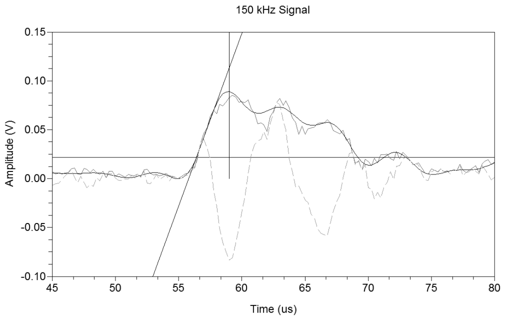

Fig. 3 The graph shows the procedure to determine the TOF. The dashed line is the acquired signal, the solid gray curve is the envelope of the acquired signal and the black solid curve is the envelope filtered with a zero phase filter. The solid horizontal line is the initial fixed threshold, the vertical solid line marks the first maximum and the sloped solid line corresponds to the fitted linear regression of the ascending signal envelope. The interception of this line with the time axis is considered as the TOF

3. Experimental Results

To validate the proposed measurement technique, the Poisson's ratio of five nylon test cylinders was measured using the proposed technique and a mechanical method.

Nylon is a homogeneous material and presents viscoelastic behavior. The nylon test cylinders were manufactured with 7.5 cm base diameter and 15 cm height. All five cylinders were obtained from different nylon blocks.

Fig. 5 shows one test cylinder with the emitter and receiver transducers in the flat faces of the test cylinder. The active transducer area (28 mm. x 20 mm.) is manually placed in the center of the cylinder. Petroleum jelly(vaseline) was used as couplant between the transducer and the cylinder.

Fig. 4 shows the obtained signals from one of the nylon test cylinder at different frequencies, placing the emitter and the receiver transducer, face to face, in both side of the test specimen. For low frequencies(50 kHz and 60 kHz) the emitter vibrates mainly in transversal mode, while for higher frequencies(150 kHz and 200 kHz) vibrates in longitudinal mode.

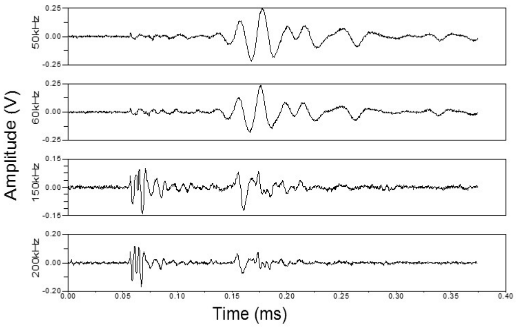

Fig. 4 Signals obtained from one of the nylon test cylinder at different frequencies. The two top graphs correspond to shear mode of the emitter transducer and the two bottom graphs to the longitudinal mode

Poisson' ratio measurement obtained with the proposed method are summarized in Table 1, where the means and standard deviations values of ten measurements are presented.

Considering the test cylinder size and the frequencies used, the waves introduced in the material are bulk waves(Hobatho et al., 1998).

The five nylon test tubes were subjected to compression tests for comparison purposes measuring the resulting transverse and axial deformation. The equipment for these measurements is based on ELE International EI37-5625 product(ELE International, 2008). Table 2 summarize the obtained mean and standard deviation from ten different measurements using the mechanical procedure.

The difference between values in Table 1 and 2 can be explained considering that the ultrasonic method obtains the dynamic Poisson's coefficient and the mechanical method the denominated static Poisson's coefficient. The relation between the obtained values agrees with that obtained by other authors in the literature (Shkolnik, 2006).

Considering what stated above, a good agreement was obtained between the values of the Poisson's ratio obtained using the mechanical method and the ultrasonic method.

Table 1 Nylon test cylinders Poisson's ratio calculated using the proposed method from ten measurements

Test Specimen	Mean values of Poisson's ratio	Standard deviation values
Nylon 1	0.42	0.008
Nylon 2	0.42	0.003
Nylon 3	0.42	0.005
Nylon 4	0.41	0.007
Nylon 5	0.42	0.000

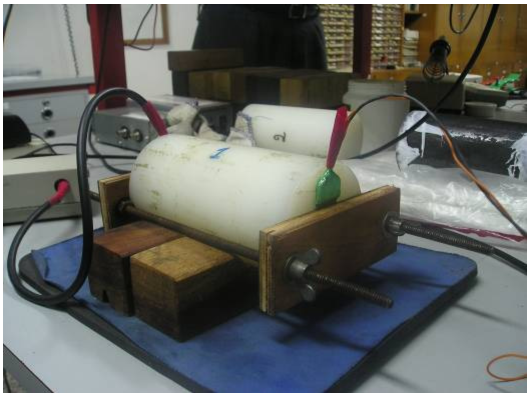

Fig. 5 Nylon test cylinder with the emitter and receiver PVDF transducers in both sides of the cylinder

4. Conclusion

This work presents a simple technique to measure the Poisson's ratio, determining the longitudinal and shear wave propagation speed in a solid isotropic material under test.

Table 2 Nylon test cylinders Poisson's ratio calculated using the mechanical method from ten measurements

Test Specimen	Mean values of Poisson's ratio	Standard deviation values
Nylon 1	0.41	0.021
Nylon 2	0.40	0.027
Nylon 3	0.40	0.012
Nylon 4	0.41	0.028
Nylon 5	0.40	0.022

Mechanical tests were conducted to validate the proposed method, resulting in a good agreement between ultrasonic and mechanical techniques. The proposed method presents a better repetition.

Although the tests were made in cylindrical samples, this method can be applied in the field and can even be used in pulse - echo mode.

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