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AN INITIAL STUDY ON A NON-INVASIVE ULTRASONIC TOMOGRAPHY FOR GLASS FIBRE REINFORCED EPOXY (GFRE) COMPOSITES PIPE

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Graphical abstract

Abstract

The purpose of this paper is to introduce an application of ultrasonic tomography on the E-glass fibre reinforced epoxy composite pipe. The paper presents a transmission mode ultrasonic tomography. Mathematical estimation of ultrasonic wave propagation between the E-glass composite pipe and other media boundaries are of interest in this paper. In the case of direct transmission, the reflection and transmission coefficient of transmitted ultrasonic wave was calculated.

Keywords: Acoustic impedance; composites pipe; glass fibre reinforced epoxy composites; ultrasonic tomography; ultrasound propagation

1.0 INTRODUCTION

Significant growth in the development and application employing fibre reinforced thermoplastic polymer composites is observed in recent years [1]. Glass fibre reinforced thermoplastic polymer composites had applied in a wide range of applications as oil and gas industry, automotive industry, aerospace industry, and printed circuit board (PCB) materials due to their excellent mechanical properties, dielectric properties, and thermal resistance [1-5].

The most common glass fibre composite types that used in fibre glass is the E-glass composites pipe, it is alumina-borosilicate glass with an additive that is less than 1%. Experimental GFRE composites pipe contains nearly 60% of glass fibre and 40% of epoxy resin. It is a 3 layers GFRE composites pipe as the experimental pipe show on the right hand side of Figure 1. A Perspex pipe at the left hand side of Figure 1 is an experimental pipe that used in previous

experiments. From Figure 1, it illustrates the important role plays by tomographic in visualizing the conditions of a process transportation pipeline that are essentially opaque compare to a lab-scale research work which normally using perspex pipe.

Tomography denotes the process images visualization techniques, which capable to produce cross-section distributing information in a process column by obtaining a cross-section image of substances such as gas, liquid or oil while flowing in the process column simultaneously. Process Tomography is efficient to be used to visualize the cross-section images of mixtures of substances flowing in an opaque process column.
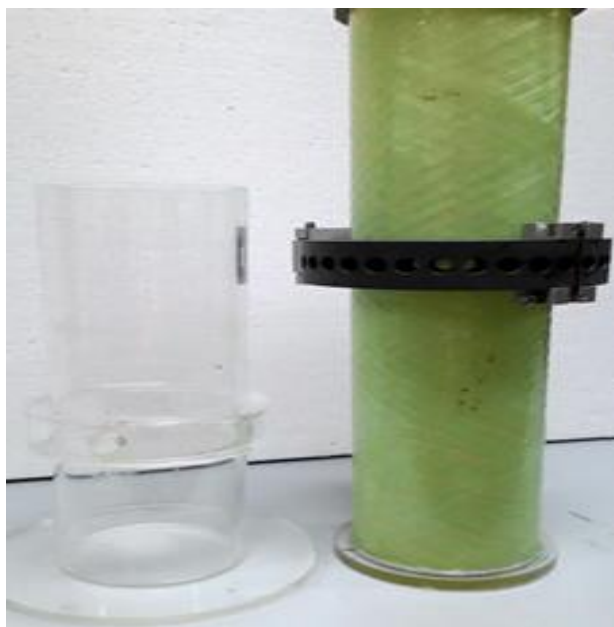

Figure 1 Experimental GFRE composites pipe (Right) and a Perspex pipe (Left)

Among the sensing methods of process tomography, electrical process tomography including electrical capacitance tomography (ECT) based on permittivity value measurement and electrical impedance tomography (EIT) is more popular in recent years. This is because of electrical process tomography is convenient, low cost and safe compared with other methods based on nuclear magnetic resonance (NMR), X-ray or y-ray and ultrasound *etc.* [6]. But, electrical process tomography had faced on the disadvantages of sensitivity problem, inverse problem [7] and fast forward problem [8].

Process tomography or Industrial process tomography indicates the non-invasive method of obtaining the phases distribution of the industry process column. By using tomography techniques, several measurements like velocity or phase fraction boundaries can be determined and analysed. Thus, various tomography sensors are used for the purpose of obtaining information such as phases flow patterns, phases flow velocity and phases boundaries investigation.

Then, sensors output data are then used to generate desire dimensional images to monitoring or analysis the process system involved. Therefore, tomography techniques can help to provide problems solution and improve process performance of system [9]. Furthermore, for industrial applications, non-invasive tomographic techniques are more reliable and intended to be applied which meets the particular industrial requirements.

Ultrasonic tomography is a tomographic that detects the acoustic impedance properties changes between investigated objects and numbers of ultrasonic transducer are placed around the process column. Ultrasonic tomography system is essentially applying the reflection mode [10] and the transmission mode [11], [12]. After measurements taken by proper excitation strategy have been completed, the local properties of the investigated flow can be visualized or calculated by a particular reconstruction algorithm and both of the modes can successfully be employed for investigating multiphase flow with the assist of the suitable image reconstruction algorithm.

Ultrasonic tomography technique is one of the tomographic that has the advantage in two-component flows imaging for invisible process pipeline on-line monitoring and control [13], [14].

In this paper, the interest of this research study is to predict the amount of the ultrasonic wave penetrates between the interactive media that is a variation in acoustic impedance.

2.0 ULTRASONIC WAVE AT BOUNDARIES

Acoustic impedance, Z, of a material depends only on the material's physical properties and independent of the wave characteristics and frequency. Acoustic impedance is important for the acoustic transmission and reflection determination of the material's boundary that is, the variability of acoustic impedance value, ultrasonic transducer design, and the material's sound absorption assessment [15].

Acoustic impedance as in Equation 1, is the complex ratio of sound pressure to particle velocity and can be used to describe the interaction of ultrasound with a material, where the acoustic impedance in analogous to electrical impedance [16].

$$Z = \rho c \qquad (1)$$

Where Z is the acoustic impedance (kg/m^{2}s); ρ is the density of the medium (kg/m^3); c is the sound velocity in the medium (m/s). The difference of acoustic impedance at the interface of two materials will control the amount of energy reflected. This means that if the impedances are similar, most of the acoustic energy will be transmitted.

Assuming the ultrasonic energy losses between the transducer/couplant/composites pipe wall are zero, the investigations of ultrasonic wave propagation described as a ratio in Equation 2 and 3 for some conditions Figure 2 are described as follows:

$$\text{Reflection coefficient}, \text{R} \ = \ \frac{P_r}{p_e} \ = \ \left[\frac{Z_2 - Z_1}{Z_2 + Z_1} \right] \tag{2}$$

$$\text{Transmission coefficient}, \text{D} \ = \ \frac{P_d}{P_e} \ = \ \left[\frac{2Z_2}{Z_2 + Z_1} \right] \tag{3}$$

Where p_e the incident wave is sound pressure, p_r is the reflected wave sound pressure and p_d is the transmitted wave sound pressure.
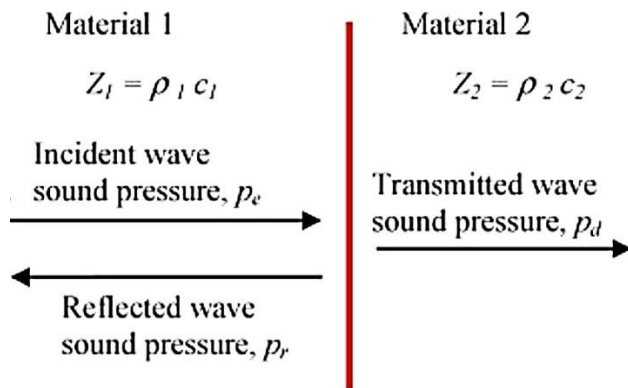

Figure 2 Ultrasonic wave propagation at media interface

2.1 Ultrasonic Wave Propagation from Composite Pipe into Liquid (water) Media

At room temperature, the acoustic impedance of E-glass fibre reinforced epoxy composites is $Z_1 = 5.43 \times 10^6$ kg/m^{2}s and for water (represents liquid media), $Z_2 = 1.5 \times 10^6$ kg/m^{2}s, and the calculation for R and D on the E-glass fibre reinforced epoxy composites/water interface is as below:

$$\text{R}_{(composites/water)} = \frac{1.5 \times 10^6 - 5.43 \times 10^6}{1.5 \times 10^6 + 5.43 \times 10^6} = -0.5671 \\ => -56.71\% \tag{4}$$

$$\text{D}_{(composites/water)} = \frac{2 \times 1.5 \times 10^6}{1.5 \times 10^6 + 5.43 \times 10^6} = 0.4329 \\ => 43.29\% \tag{5}$$

2.2 Ultrasonic Wave Propagation from Liquid (water) to Gas Media

At room temperature, both the acoustic impedance of liquid (water) and gas (air) are 1.5×10^6 kg/m^{2}s and 430 kg/m^{2}s respectively, and by using the same calculation method as stated before, the calculation for R and D on the liquid (water)/gas (air) interface is presented as follows:

$$\text{R}_{(liquid/gas)} = \frac{430 - 1.5 \times 10^6}{430 + 1.5 \times 10^6} = -0.9994 => -99.94\% \tag{6}$$

$$\text{D}_{(liquid/gas)} = \frac{2 \times 430}{430 + 1.5 \times 10^6} = 0.0006 => 0.06\% \tag{7}$$

The negative sign in both cases indicate the reversal of the phase relative to the incident wave. As in study case 1, it is found that a percentage of 43.29% of ultrasonic wave energy can be transmitted into the liquid media while a normal incident wave is propagated through the composite boundary. This transmitted wave energy will be detected by the ultrasonic receivers on the other side of the composite pipe, and it will go through a signal amplifying stage before a measurement is taken. However, in the study case 2, 99.94% of ultrasonic wave energy will be reflected at the liquid/gas boundary due to the large differences of acoustic impedance between the liquid and gas media, which means a near total of ultrasonic wave will be reflected at the liquid/gas interface and that is only 0.06% of the transmitted ultrasonic wave energy can be penetrated through the liquid/gas boundary into gas medium.

3.0 CONCLUSION

The mathematical modelling approach shows that an ultrasonic wave can be propagated through the composite pipe wall into the liquid media. As a result, it creates research opportunities to gain an insight into the opaque composite pipe in the industrial liquid transportation process by using ultrasound tomographic. 43.29% of transmitting ultrasonic wave energy is able to be detected by the ultrasonic receiver on the opposite side, if the wave transmission pathway is free from gases. Basically, signal amplifying is involved on the signal acquisition and processing stage. And, the transmitted ultrasonic incident wave will be totally reflected and not to be detectable in the condition of gas as the obstacles present in the transmission path.

Acknowledgement

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