DEVELOPMENT OF AN ULTRASONIC INTEGRATED SYSTEM TO MEASURE THE MECHANICAL PROPETIES AND ACOUSTICAL CHARACTERISTICS OF MATERIAL

MOHAMAD AZRUL BIN AMAT

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FAKULTY OF ART, COMPUTING AND CREATIVE INDUSTRY
UNIVERSITI PENDIDIKAN SULTAN IDRIS

ABSTRACT

This study is carried out to develop a computerized ultrasonic-based measurement system for mechanical properties and acoustical characterization of non-porous solids materials. The system employed the pulse-echo method using both longitudinal and shears waves. This system consists of a pulser/receiver generator, transducers, picoscope and personal computer. The developed system offers user-friendly procedure, yet producing accurate and reliable measurement results. The software for the system is developed using Microsoft Visual Basic Version 6.0. The front panel display is divided into the connection and control panel, the display panel and the calculation panel. The programming code for software algorithm is divided into the connection programming code, the control programming code, the display programming code and the calculation programming code. There are eight parameters of the mechanical and acoustical properties of solids materials are discussed in this study; longitudinal velocity, shear velocity, acoustical impedance, Poisson's ratio, Young modulus, Bulk modulus, Shear modulus, and compressibility. The performance of the system is tested on 4 different types of solid materials; acrylic, aluminum, mild steel and copper. The results proved that the developed system is suitable for nonporous solid materials and the measurement error compare to the references is acceptable. However, to assess the ability of this developed system, more measurement in variety of test material should be carried out.

PEMBANGUNAN SISTEM BERSEPADU ULTRASONIK UNTUK MENGUKUR UNSUR DAN CIRI-CIRI MEKANIKAL DAN AKUSTIK BAHAN PEPEJAL

ABSTRAK

Kajian ini dijalankan untuk membina sistem pengukuran ultrabunyi berkomputer untuk pencirian mekanikal dan akustik bagi bahan pepejal. Sistem dibina dengan kaedah gema-denyut menggunakan gelombang membujur dan ricih. Sistem yang dibina terdiri daripada penjana pendenyut-penerima, transduser, pikoskop dan komputer. Perisian untuk sistem tersebut dibina dengan menggunakan Microsoft Visual Basic Versi 6.0. Sistem yang dibina menggunakan prosedur yang mesra pengguna, menghasilkan keputusan yang mempunyai kebolehpercayaan dan ketepatan yang tinggi. Paparan antaramuka perisian tersebut terdiri daripada panel sambungan dan kawalan, panel paparan dan panel pengiraan. Kod program untuk algoritma perisian pula terdiri daripada kod sambungan, kod kawalan, kod paparan dan kod pengiraan. Terdapat lapan ciri mekanikal dan akustik yang dibincangkan dalam kajian ini iaitu halaju membujur, halaju ricih, galangan akustik, nisbah Poisson, modulus Young, modulus pukal, modulus ricih, dan kebolehmampatan. Sistem yang dibina diuji ke atas 4 jenis bahan pepejal yang berbeza iaitu perspex, aluminium, besi dan tembaga. Keputusan daripada sistem yang dibina membuktikan bahawa sistem tersebut sesuai untuk bahan pepejal yang tidak berliang dan bacaa ralat pengukuran dibandingkan dengan nilai rujukan adalah boleh diterima. Walaubagaimanapun, untuk menguji kemampuaan sistem yang dibina, lebih banyak pengukuran perlu dilakukan pada pelbagai jenis bahan pepejal.

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SYMBOL	
ρ	Density
d	Thickness
m	Mass
V	volume
v_L	Longitudinal velocity
v_S	Shear velocity
ν	Poisson's ratio
E	Young Modulus
G	Shear modulus
K	Bulk modulus
B	compressibility

CHAPTER 1

INTRODUCTION

1.1 Introduction

This research involves a study on the development of a computer-based measurement system to measure the mechanical properties and acoustical characterization of solid materials. The apparatus to measure the mechanical properties and acoustical characterization of solid material is by determine the velocities of ultrasound travel in the test material and the velocities value will be applied in the defined equations to calculate the mechanical properties and acoustical characteristic. This calculation is done automatically by computer system. The ultrasonic pulse-echo technique will be used to determine the velocities travel in material. Ultrasonic testing is the sub method of the Nondestructive Testing (NDT) or as known as Nondestructive Evaluation

(NDE). The system developed use the Ultrasonic NDT instrument integrated with a computer device. The output signal from the Ultrasonic NDT instrument will be converted to digital data by the computer device and the data is sent to the computer. Computer system manipulates the data and display the result.

This chapter consists of six sections; those are background of study, problem statement, research objectives, research questions, significance of the study, scope and limitation of the study and scope of the report which is the technology used extensively in this study.

1.2 Background of Study

The evolvement of today's technology without exception is essentially corporates with the material science and engineering field. As the world keeps moving, manufactories are constantly develops and produces new products. Meanwhile, to make our live much better, the discovery of new technology makes this world have possibility to improve the existing products such as vehicles, buildings, machineries and other necessaries that human needs. Consequently, this modern trend caused the material science and engineering plays important role in the contributions to the evolvement of today's technology. As we can see all things developed and produced involves of materials.

Generally, material science and technology is an interdisciplinary field which is concern in a study on structure, properties and behavior of materials and involves

the discovery and designing new materials. Material science and engineering significantly supports the industries, buildings constructions and manufacturing sectors. Hence, the study to the properties of materials provides important information for the quality control and material properties determination. The information assist in selecting a material to use in desired application whether it meet the required specifications. Technically, with appropriate material are used in any application will effectively give a good service life time, performances and economically less cost. In addition, the purpose to measure material properties is for engineering design.

Materials properties are categorized in several types of properties and one of the categories are mechanical properties. Mechanical properties are the characteristics of material behavior and reaction when the material is subjected to mechanical loading or stresses. Most of materials used in buildings construction, vehicles and industries involves of solid materials such as metals, ceramics, glass, composite material and etc. Mechanical properties are comprise with properties of elastic modules (elastic modulus, shear modulus, Poisson's ratio and bulk's modulus), yield strength, ultimate stress, elongation and ductility. Overall, mechanical properties such as elastic modules are significant properties that have to be considered and concerned when to choose a solid material. The elastic properties of solids are key properties for the design of mechanically-loaded components (Ashby 1996).

As the name applied, in the early era of material engineering, the conventional method to determine the mechanical properties is done by mechanical tests. These tests are destructive testing. The mechanical properties are obtained with several type of forces applied to the specimens of a material. Each type of forces is used to deform

or break the specimens in which to get the useful information to determine some mechanical properties that is relate to the applied force. These tests required well-prepared or bulky specimens and involves a period of time. Figure 1.1 shows the type of forces applied to the test specimen during the mechanical tests.

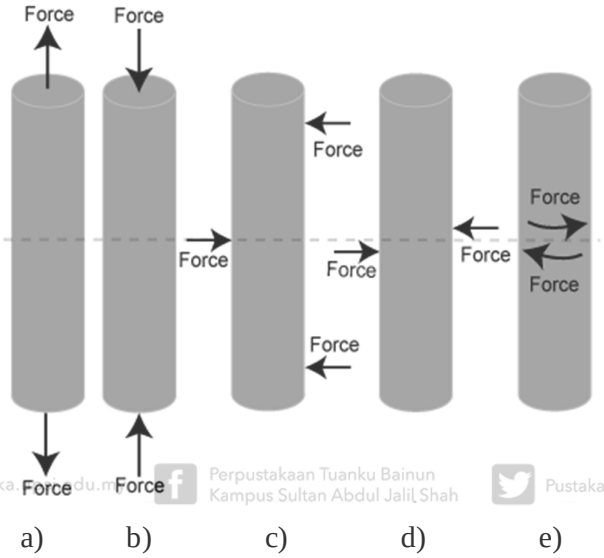

Figure 1.1. Type of forces applied to the test specimen. a) Tension, b) Compression, c) Bending, d) Shear and e) Torsion

In contrast to the destructive test, there are several of NDE (nondestructive evaluation) techniques can be used to characterize mechanical properties, e.g. electromagnetic, radiometric, and ultrasonic (McMaster, 1959; Green, 1973; Vary, 1973; Krautkramer and Krautkramer, 1977; Hayward, 1978). The speed of wave propagation and wave energy loss underlie ultrasonic mechanical property determinations. Accordingly, ultrasonic depends on measuring physical and acoustical properties via the interaction of elastic stress waves with microstructural and morphological factors (Mason, 1958; Kolsky 1963; Fu, 1982).

There is an established theoretical foundation and empirical basis for ultrasonic measurement of elastic moduli (Truell et al., 1969; Schreiber & et al., 1973). Conversely, ultrasonic assessment of mechanical properties like strength and toughness are currently based primarily on empirical correlations (Vary, 1978).

Ultrasonic materials characterization may be divided into two major categories. The first category pertains to measurements that are related to mechanical properties, e.g. elastic moduli, tensile strength, yield strength, fractures toughness. The second category pertains to material conditions that govern mechanical properties and dynamic response, e.g. microstructure, morphology (grain size, shape, and distribution).

Common applications of ultrasound to NDT are concerned with the detection and characterization of material flaws or measurement of material thickness. Ultrasonic measurements can also be used for the characterizations of material properties such as elastic moduli, material microstructure, hardness, can be estimated from the ultrasonic measurements (Papadakis 1976; Briks & Jr Green 1991).

1.3 Problem Statement

The standard method to determine mechanical properties are mechanical testing and destructive testing. The samples or specimen of the test material will be destroyed or will be broken. This requires amount of samples or bulky size of sample to do several

types of testing. This test involves some cost and the testing will be conducted in a period of time. Moreover, for a new designed material, it may require high cost to test the material since the material in the phase of research and development in which the resources are limited. So, the material cannot be provided with large or bulky size of sample. In contrast, if the designer or researcher is only concern to the basic of mechanical properties material which are the elastic constants the nondestructive testing (NDT) is an alternative.

The characterization of mechanical properties by nondestructive evaluation (NDE) or nondestructive testing (NDT) has been studied for a long time and the ultrasonic technique has been used for decades. The ultrasonic nondestructive testing has revolutionized and become more advance for recent years. The growing of advanced technology in computing and digital processing, make it possible to develop integrated system of ultrasonic testing integrates with personal computer (PC) and small portable nondestructive testing instrument have emerged. Ultrasonic testing is very useful to characterize flaws in a material and to determine some of material properties such as elastic modules. But, ultrasonic testing equipment are not widely use and available in Malaysia market. The advanced ultrasonic testing equipment is totally costly to purchase from abroad.

Therefore, a study should be carried out to focus on the development of the mechanical and acoustical properties measurement system of the solid materials. The basic mechanical and acoustical properties are referred to the longitudinal velocity, shear velocity, acoustical impedance, elastic constant, Poisson's ratio, Young modulus, Bulk modulus, Shear modulus and compressibility, which are determined by

travelled measurements of ultrasound waves through solid materials under controlled conditions.

1.4 Introduction of Computer-based Ultrasonic for Mechanical Properties and Acoustical Characterization of Solid Materials System

The computer-based ultrasonic for mechanical and acoustical characterization of solid materials (UMACS) system is developed to study the relationship between the mechanical and acoustical characterization of solid materials and the velocity of ultrasonic waves travel in the materials. The longitudinal velocity and shear velocity travel in the solid material will be measured and the velocities will be used to determine six parameters of mechanical and acoustical characterizations of solid materials; acoustical impedance, Poisson's ratio, Young modulus, Bulk modulus, Shear modulus and compressibility.

In the computer-based UMACS system, the ultrasonic waves are produced using the ultrasonic transducer where the electrical energy exited by a pulser/receiver generator. The time-domain signal of ultrasonic wave result from the test then will be converted to digital at the sampling rate of 200 MHz by picoscope and transferred to the personal computer via Universal Serial Bus (USB) port. The personal computer system manipulates the data for further processing. The developed computer-based UMACS system processes the data and measures the velocity of ultrasonic wave which is used to calculate the mechanical and acoustical characterization of the tested materials. The system is able to process and calculate the parameters within 5 minutes compared to the conventional method which require hours to be completed.

Besides, the system also does not destroy the tested materials since the ultrasonic testing technique is a nondestructive testing method. The conventional method also requires large size and quantity of the test materials for different tests to determine the mechanical and acoustical characterization of materials because the conventional method is one type of destructive testing. In contrast, the developed system only needs small size of the test materials and do not require complicated samples preparation.

1.5 Research Objective

The objectives of this study are:

1.5.1 To develop a computerized version of non-destructive measurement system to measure mechanical properties and acoustical characterization for solid materials. The system will be implemented base-on ultrasonic measurement techniques.

1.5.2 The ultrasonic-based measurement (Pulse-echo) technique will be used as the apparatus of this system.

1.5.3 To test the performance of the measurement system on four different types of solid materials.

1.6 Research Questions

1.6.1 How to determine the mechanical properties and the acoustical impedance?

1.6.2 How integrate ultrasonic NDT instrument with personal computer and manipulated the output from it to get the useful data?

1.6.3 Would be this system will give equal or similar result as the standard measurement?

1.7 Significant Of Study

At the end of this study, a complete user-friendly measurement system is expected. The system is accessible to researchers or students who are involved in material design and intend to determine the mechanical properties of a solid material.

1.8 Scope and Limitation of Study

The main aim of this study is to develop the mechanical properties and acoustical characterization measurement system. The apparatus used in this system are pulser/receiver (Olympus Panametric NDT model 5072PR), transducer (Olympus Panametric NDT 2.25MHz) and USB digital memory oscilloscope (Picoscope 3204).

The measurement system also involves the development of computer-based system to analyse the acoustic signals generated by Olympus Panametric NDT model

5072PR pulser/receiver and determine the mechanical and acoustical properties of the solid materials. Hence, the digital oscilloscope is connected with the personal computer via USB port.

The mechanical properties and acoustical characterized measured are longitudinal velocity, shear velocity, acoustical impedance, Poisson's ratio, Young modulus, Bulk modulus, Shear modulus, compressibility and elastic constant. This study are carried out to test the performance of the system on four different types of solid materials; glass, aluminum, mild steel and acrylic.

1.9 Scope of Report

This report is divided into six chapters. The first chapter, CHAPTER 1 covers the background of study, problem statement, research objectives, research questions, significance of the study and scope and limitation of the study. CHAPTER 2 describes about ultrasound, ultrasonic testing pulse-echo and the studies of measurement apparatus system for the mechanical and acoustical characterization of solid materials.

CHAPTER 3 describes about the development of mechanical and acoustical characterization system, the development of computer-based UMACS, the physical properties of samples and the measurement of mechanical and acoustical properties of sample. CHAPTER 4 describes about the performance of the computer-based mechanical and acoustical characterization system on the solid materials. Finally, CHAPTER 5 covers the conclusion, uniqueness and limitation of the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the literature review of the research. This chapter consists of three sections; the ultrasonic, ultrasonic testing pulse-echo technique and mechanical properties and acoustical characteristics of solid materials

2.2 Ultrasonic

The term of sonic is referred to the sound wave. The sound wave audibility to the human ear called an audio. Normally, the range of frequency audible for human

are between 20 Hz to 20 kHz and the children capable to hear the frequency up to 25 kHz. Ultrasonic is the sound wave beyond the frequency that human can hear. Ultrasonic is a sound wave with higher frequency than the upper limit of human audible range (Hendee & Ritenour, 2002).

Ultrasonic sound wave are usually used to penetrate a medium and the reflection wave or supply focused energy of the ultrasonic sound wave travelled on targeted medium are useful for many application of instrumentation that is applied in medical, industrial and material engineering. Ultrasonic not only can be applied in solid materials, it also can be used to measure the ultrasonic velocity, attenuation coefficient and characteristic impedance of liquid materials (McClements & Fairley, 1991).

In medical applications, the ultrasonic wave is used to detect and locate any abnormal growths in human bodies. The ultrasound pulse is transmitted through the patient's bodies and the reflected pulse is analysed to determine the location the abnormal tissue or organ in human bodies. In addition, the ultrasound are also usually used for relieving rheumatic pain (Njeh, Kearton, Hans, & Boivin, 1998), dental cutting (Denisova et al., 2009), destroying unicellular organisms, removing kidney stones and brain tumor without shedding blood (Sumi, Wakabayashi, Tanabe, & Kubota, 2004) and the movement of velocity of blood flow in human body.

Meanwhile, In industrial application, the ultrasonic wave is used for soldering and drilling purposes (Shoh, 1975), cutting and welding purposes (Shoh, 1975), emulsifying immiscible liquids like mercury and water (Shoh, 1975), cleaning of tiny

objects like watches (Leighton, 2007; Shoh, 1975) and the sterilization of water and milk in industrial applications (Shoh, 1975).

2.2.1 Type of Ultrasonic Sound Wave

There are two types of ultrasonic sound waves are commonly used in ultrasonic testing. The waves are longitudinal and shear. In longitudinal wave, the particles motion in the medium vibrates parallel to the direction of the wave travels. Since the longitudinal wave involving the compressional and extensional forces to the medium, this wave also called as pressure or compressional wave. In Shear wave, the particles motion in the medium are vibrates perpendicular (transverse) to the direction of the wave travels. The shear wave also called as transverse wave because of the particles motion vibrates transversely.

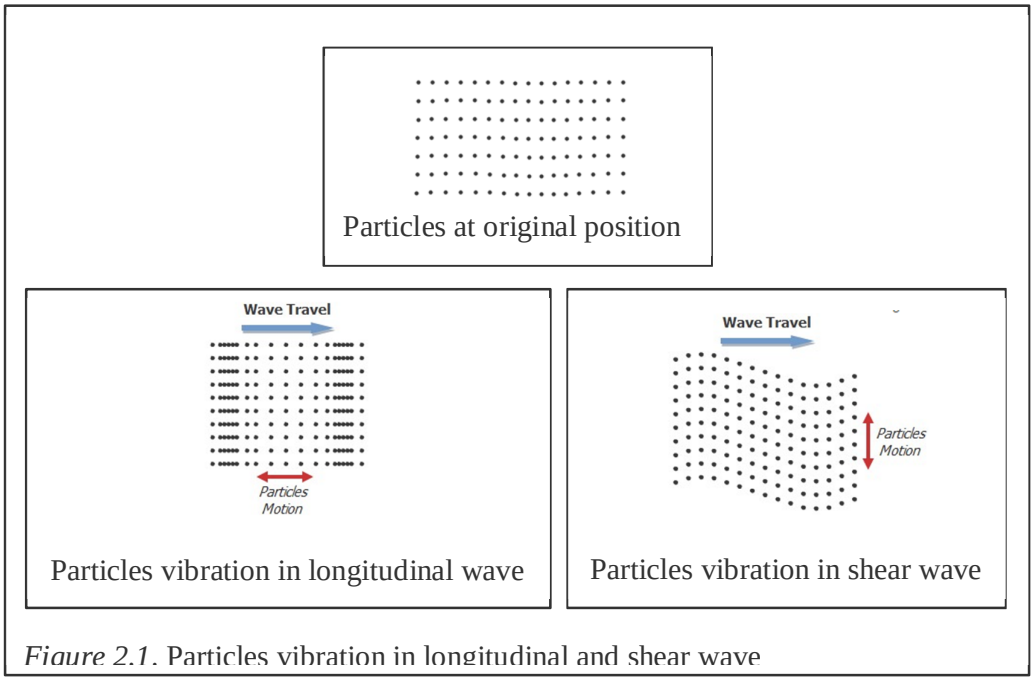

Figure 2.1. Particles vibration in longitudinal and shear wave

2.3 Ultrasonic Testing Pulse-echo Technique

Ultrasonic testing is the one method of a nondestructive testing. There have several techniques of ultrasonic testing used in material testing. The most common used and the simplest setup is pulse-echo. In this study, only pulse-echo will be focused since it the simplest setup.

Figure 2.2 shows the common setup of ultrasonic testing pulse-echo system. The setup consists of pulser/receiver, transducer and oscilloscope.

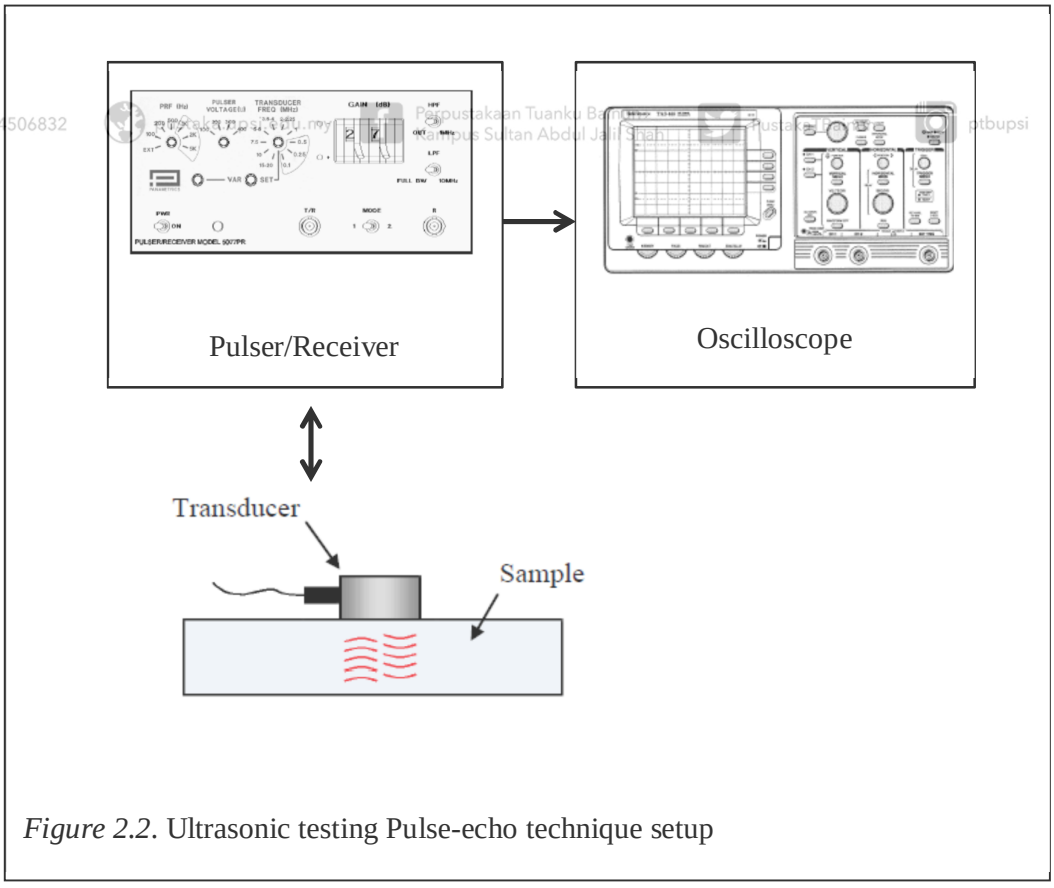

Figure 2.2. Ultrasonic testing Pulse-echo technique setup