The Effect of the Ultrasound Transmission Across Solid-Nanocomposite Materials

Najibah A Latif, Salmiah K, M A Ahmad, Mimi Azlina Abu Bakar

Abstract*: *Ultrasound has been developed as a technique to determine the object and distance detected. It is quite challenging to identify and localise the defects, especially in mechanical parts. Nanomaterials namely multi-walled carbon nanotube (MWCNT), nanoclay and graphene mix with epoxy to be nanocomposites for example which have not been explored using ultrasound method to determine better coupling performance with transducer. Ultrasonic equipment was set up to run the experiment with four main components, namely transducer, personal computer, oscilloscope and indicator whereas to determine the reflection coefficient. Based on the result, nanocomposite of graphene filler gave a lower value of reflection coefficient, which is 0.08299 compared to MWCNT and nanoclay filler of nanocomposites. It is shown that graphene filler of nanocomposite has better coupling performance. The differentiation of the values may be affected by roughness of the nanocomposites.

Keywords*: *polymer, nanocomposite, reflection coefficient, transducer, ultrasound.

I. INTRODUCTION

Ultrasound technology has been broadly used in numerous fields of engineering such as medicine, structures and material analysis as well as contacting surfaces. In the industry application, monitoring and inspection have attained by the measurement of operating temperature, signals from vibration or acoustic release [1]. Using ultrasound method especially in industry, it can detect hidden cracks, discontinuities in ceramics, plastics as well as metals and also for water level inspection.

Ultrasonic is a non-destructive test that requires a solid, liquid or gas or any medium to travel through. It is inaudible sound above 20 kHz in frequency [2]. Normally, ultrasound moves faster in solids than in liquids as well as gases. The behavior of the acoustic wave is affected by the acoustic properties of the medium it passes through. A sound wave is partially reflected whenever it is incident on a boundary between two different densities of materials. The velocity remains constant inhomogeneous medium [3].

The ultrasound is produced in transducer where a piezoelectric crystal can vibrate very quickly when electrified with high frequency alternate current (AC) voltage. The intensity of energy reflected and transmitted at a boundary is dependent on the acoustic impedance of the medium involved [4].

Several scientists have used reflection coefficient measurement from ultrasonic pulse to characterize the properties of the material for certain applications such as for journal bearing, an electronic device and biomedical implant [1], [5], [6]. Some studies have attempted to explain reflection coefficients from solid-solid interfaces as well as the similar case of reflection from a layer of embedded pores. Long time ago, Tattersall [7] had analyzed the ultrasonic involved in reflection coefficient on two layers system. The fraction reflected and transmitted can be determined using (1) and (2), respectively if the acoustic impedance, Z of the materials of the boundary are known [2]. In this experiment, the acoustic impedances of each material are known since the density of the materials were earlier measured. Equation (3) is referred to an acoustic impedance is directly proportional to density, ρ and sound of speed, C. The meaning of the symbols in the (1) and (2) are R is referring to reflection coefficient and T is known as transmittance.

$$R_{12} = \frac{Z_1 - Z_2}{Z_1 + Z_2} \tag{1}$$

$$T = \frac{2Z_2}{Z_1 + Z_2} \tag{2}$$

$$Z = \rho C \tag{3}$$

Several early publications described the principle of reflection from contacting surfaces (solid-solid interfaces) for instance, in machine elements [8],[9]. In ultrasound system, it can receive the waveforms in two ways which are by reflection and attenuation through transducer device. According to Matthew [10], wear debris and oil analysis were successfully examined using the ultrasonic technique. The author found out that this technique has potential to monitor changes and acid content of lubricating oil. Meanwhile, work by Krolikowski [11], that reported about an investigation of hard steel based on transmission coefficient measurement using a dry-coupled of ultrasonic method. In conjunction with that, the experimental results appeared to exceed the theoretical ones both for a fraction of the real contact area and for contact stiffness [11].

Revised Manuscript Received on October 30, 2019.

Najibah A. Latif, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia. Email: najibah.latif99@gmail.com

Salmiah Kasolang, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia. Email: salmiahk@salam.uitm.edu.my

Mohamad Ali Bin Ahmad, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia. Email: mohama9383@salam.uitm.edu.my

Mimi Azlina Abu Bakar, Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia. Email: mimi_azlina@salam.uitm.edu.my

Besides, some of the advantages of this technique over electrical methods are due to its non-destructive nature and no requirements for electrical isolations of the tested material is involved.

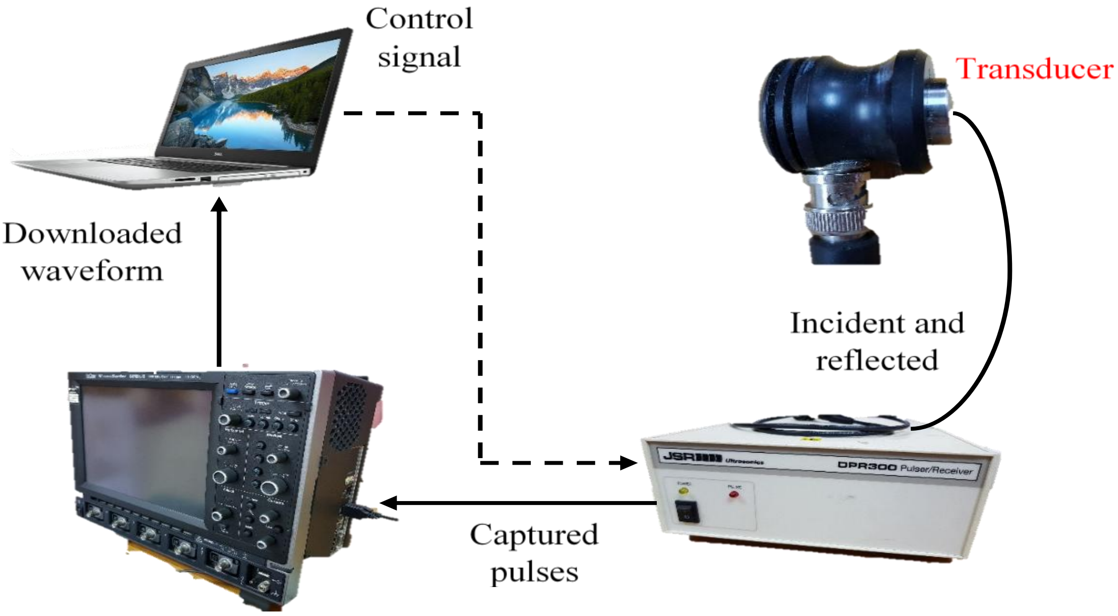

Fig. 1. Schematic diagram of ultrasonic measurement

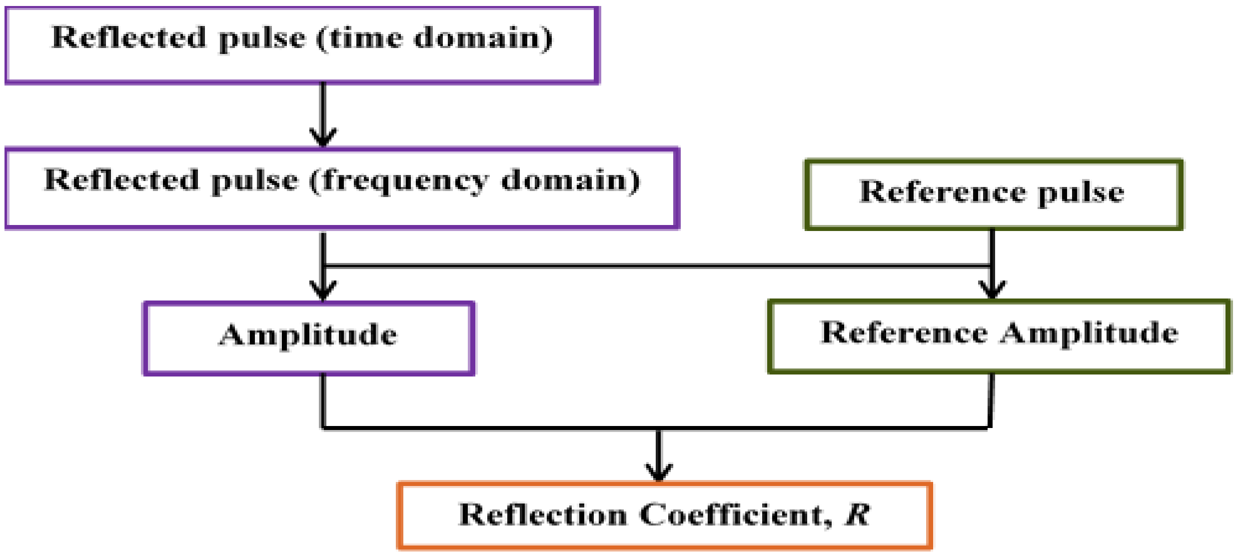

Fig. 2. Flowchart of the Data Processing

In this paper, due to the principle and reason this technique has been deployed to investigates the coupling performance based on reflection coefficient of the material substrates of the pistia leaves [12], [13] for engineering applications. The coupling performance based on the reflection coefficient values have been discussed.

II. METHODOLOGY

Three different nanomaterials were namely as multi- walled carbon nanotube (MWCNT) nanoclay and graphene which are mixed with epoxy polymer to make nanocomposite materials were deployed to test the transmission between the Perspex. The densities, poison ratio, and tensile modulus were measured before the reflection coefficients calculated (refer to Table I).

Fig. 1 shows the ultrasound system schematic diagram used in this work. There are four main components that play an important role which are personal computer (PC), an ultrasonic pulser receiver (UPR), a digitizer (oscilloscope) and transducer were set up in this experiment. Fig. 2 shows the data processing flowchart. Results (time-domain waveform) from the oscilloscope were converted into frequency-domain waveform using Microsoft Excel. Fig. 3 shows the schematic diagram in reflection coefficient on two layers' system. Before doing the experiments on nanocomposites materials, the reference ultrasonic pulse was taken as an incident signal from a Perspex interface.

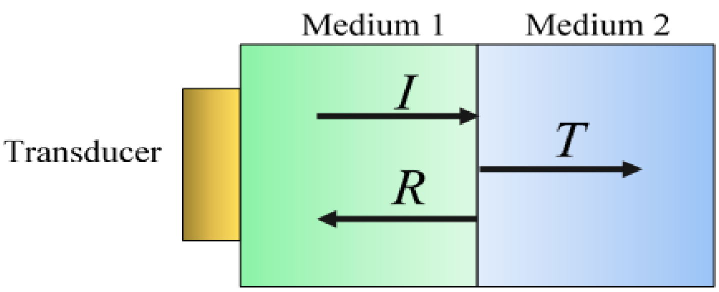

Fig. 3. Schematic diagram of an ultrasonic wave travelling through a solid-solid system

Table-I: Tensile modulus, E and density, ρ of the nanocomposite materials

Nanocomposite Material	Graphene	MWCNT	Nanoclay
Tensile modulus, (GPa)	5.90	2.54	1.63
Density, ρ (kg/m^3)	1148	1139.3	1173
Poison ratio [14]	0.19	0.41	0.28
Acoustic impedance, z (kg/(m^{2}s) x 10^6	2.7265	2.5937	1.563

III. RESULTS AND DISCUSSIONS

The results of the analysis are presented in Fig. 4. It shows the pattern of the amplitude for nanocomposite materials against frequency after converted using fast fourier transform (FFT) from time-domain signals. The results indicate a steep positive slope until 3.9 MHz and then fall again respectively. It can be seen from the data in Fig. 4 that the amplitudes slightly similar since all the pattern overlap each other. The use of a reference signal also reduced any inherent errors effect in the measurement [3], [12]. Nanoclay-filled of nanocomposite material gives the highest peak value of amplitude at 47.983 mV. Graphene-filled of nanocomposites material has the lowest peak amplitude at 43.201 mV than MWCNT-filled of nanocomposite, which has 46.77 mV. This variation of amplitude value may influence by the acoustic value, geometrical properties, structure configuration, surface condition and mechanical properties of the materials. The reflection coefficient data are shown in Table II. It can be seen that the reflected pulse of the nanoclay-filled is the highest than the other nanocomposite materials. The results indicate that nanoclay-filled has better reflection pulse due to the lowest acoustic impedance value than others. As the concentration of all nanomaterials is similar, the reflection coefficient values vary each other. Graphene-filled of nanocomposite gives the lowest reflection coefficient value about 0.08299 followed by 0.1077 of MWCNT-filled and 0.3464 of nanoclay-filled. Nanocomposite material of graphene-filled gives better absorption of the acoustic energy and prevents the wave of amplitude to reflect. The variation of the values also due to the effect of the mechanical properties like densities and acoustic impedance value of the materials. The surface configuration may act an important influence due to different fillers used since they have different shape and size of the nanomaterials in nanocomposite materials. In addition, Drinkwater et al. [8] found that, the different values also may affected by the particulate contaminants at a solid coupled interfaces. The greater the difference of acoustic impedance (product of wave speed and density) between the two materials, the greater the proportion of the wave reflected [13]. However, in this study, it can be concluded that nanomaterial of graphene-filled was much impressed of reflection coefficient value which gave the lowest as well as shows better coupling performance in perspex-nanocomposites interfaces.

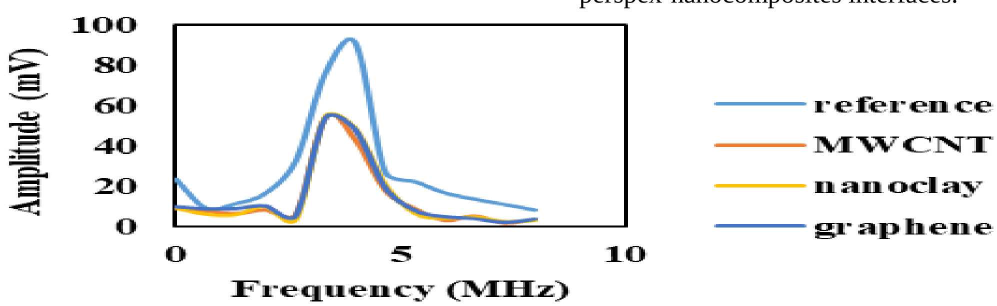

Fig. 4. Amplitude spectra of reflected signals for nanocomposite materials

Table-II: Reflection coefficient results

Pistia substrates material	Reflection coefficient
MWCNT	0.1077
Nanoclay	0.3464
Graphene	0.08299

III. CONCLUSION

The reflection coefficient of nanocomposite (mixed with epoxy polymer) materials of MWCNT, nanoclay and graphene fillers using ultrasound method has been conducted to investigate the effect of nanocomposite on ultrasonic wave propagates through a medium .

The results indicate that the reflection coefficient of nanocomposite with graphene filler gave the lowest value compared to the others nanocomposite materials. It is because of the acoustic impedance effect where influenced by the densities of the materials as well as surface configurations and surface conditions of the materials during the experiment run. This preliminary study shows that nanocomposite with graphene filler gave better coupling performance according to the lowest value obtained after calculated.

ACKNOWLEDGMENT

The authors would like to thank MOE and MESTECC for awarding grants to support this research. The authors are in debt to University Teknologi Mara (UiTM) Shah Alam, Selangor Malaysia and the Malaysian government for the opportunity given through Scholarship Bumiputera Academic Training Scheme.

REFERENCES

1. S. Kasolang, N. S. Mohamad, M. A. A. Bakar, A. Jumahat, and N. R. N. Roselina, "The effect of titanium dioxide nanoparticles on bio-lubricant film thickness using ultrasonic reflection," in *Proceedings of Malaysian International Tribology Conference 2015*, pp. 324–326.
2. M. G. L. Roes, S. Member, J. L. Duarte, M. A. M. Hendrix, E. A. Lomonova, and S. Member, "Acoustic Energy Transfer : A Review," *IEEE Trans. Ind. Electron.*, vol. 60, no. 1, pp. 242–248, 2013.
3. S. Kasolang, "An ultrasonic investigation of various aspects of hydrodynamic lubrication in a journal bearing," University of Sheffield, 2008.
4. R. Ghaffarivardavagh, J. Nikolajczyk, S. Anderson, and X. Zhang, "Ultra-open acoustic metamaterial silencer based on Fano-like interference," *Phys. Rev. B*, vol. 99, pp. 1–10, 2019.
5. X. Shi, S. Zhang, Z. Wang, and G. Xu, "Ultrasound Transducer and Amplifier Design in Transcranial Ultrasound Stimulation System," in *7th Asia Pacific International Symposium on Electromagnetic Compatibility I Ultrasound*, 2016, pp. 828–830.
6. A. Ibrahim, S. Member, M. Meng, S. Member, and M. Kiani, "A Comprehensive Comparative Study on Inductive and Ultrasonic Wireless Power Transmission to Biomedical Implants," *IEEE Sens. J.*, vol. 18, no. 9, pp. 3813–3826, 2018.
7. H. G. Tattersall, "The ultrasonic pulse-echo technique as applied to adhesion testing," *J. Phys. D. Appl. Phys.*, vol. 6, no. 7, pp. 819–832, 1973.
8. B. Drinkwater, R. Dwyer-joyce, and P. Cawley, "A study of the transmission of ultrasound across solid-rubber interfaces A study of the transmission of ultrasound across solid – rubber interfaces," *J. Acoust. Soc. Am.*, vol. 101, pp. 970–981, 1997.
9. B. Drinkwater, R. Dwyer-joyce, and P. Cawley, "A study of the transmission of ultrasound across solid – rubber interfaces," *J. Acoust. Soc. Am.*, vol. 101, no. 2, pp. 970–981, 2014.
10. M. P. Appleby, "Wear Debris Detection and Oil Analysis using Ultrasonic and Capacitance Measurements," University of Akron, 2010.
11. J. Krdlikowski and J. Szczepek, "Prediction method of contact parameters using ultrasonic," *Wear*, vol. 148, pp. 181–195, 1991.
12. Najibah.A.Latif, S.kasolang, M.A.Ahmad, and M.A.A.Bakar, "Influence of Lubricant factors on Static Coefficient of Friction for Pistia Leaves Surfaces and Micro Fiber Fabrics," *J. Tribol.*, vol. 16, pp. 30–41, 2018.
13. Najibah Ab Latif and Salmiah Kasolang, "Wetting property of pistia stratiotes," *Ind. Lubr. Tribol.*, vol. 69, no. 3, pp. 399–403, 2017.
14. H. V. Duarte and A. F. Á. Lázaro Valentim Donadon, "Mechanical properties of nanocomposite laminated structure and its sensibility to modal analysis procedure," *Lat. Am. J. Solids Struct.*, vol. 11, pp. 245–259, 2014.

AUTHORS PROFILE

Najibah A. Latif is the final year Mechanical Engineering PhD's student at the Universiti Teknologi MARA (UiTM) Shah Alam. She received a bachelor's degree in Mechanical Engineering with Honour from Universiti Tun Hussein Onn Malaysia (UTHM) and master's degree also in Mechanical Engineering by research at Universiti Tun Hussein Onn Malaysia (UTHM). During master research, she focused on mehanical sound and vibration on bio-polymer materials. She has been awarded a vice-chancellor award during a bachelor's degree. She is one of the Board of Engineer Malaysia (BEM) and Institution of Engineer Malaysia (IEM). Her current research focuses on biomimetic and tribology studies. Her publications can be accessed using this link https://scholar.google.com/citations?user=I3ECfmcAAAAJ&hl=en.

Salmiah Kasolang is a Profesor in Mechanical Engineering Faculty at Universiti Teknologi MARA (UiTM) Shah Alam. She is a Founder of Center for Tribology (CenTRIB), Research Interest Group and as a Chairman of iMETA, Institute of Mechanical Engineering and Technology Advancements. She received a PhD (Mechanical and Manufacturing Engineering) at University of Sheffield, United Kingdom, M.Sc. In Manufacturing System Engineering at Universiti Putra Malaysia (UPM), Malaysia and B. Sc. In Agricultural Engineering at University of Wisconsin-Madison, United States of America. The Field of Specialisation and Research Interests are in Hydrodynamic lubrication in journal bearing, Wear testing and analysis, Oil analysis technique, Numerical simulation of lubrication, Tribology in human biological system, Ultrasonic reflection measurement technique, Total quality management, lean manufacturing and environmental management system, Fluid dynamics, fluid atomization and Biomimetics investigation. The link of her publication can be accessed using this https://scholar.google.com.my/citations?user=9XJsZG4AAAAJ&hl=en.

Mohamad Ali Bin Ahmad is currently a senior lecturer at Universiti Teknologi MARA (UiTM) Shah Alam Selangor. He received a bachelor's degree at University of Malaya (UM) in Mechanical Engineering with Honour. Both master's and PhD's degree are from Universiti Teknologi MARA (UiTM) Shah Alam. He is one of the board of engineer Malaysia (BEM) member, The Institute of Engineers, Malaysia (IEM) member, Institution of Mechanical Engineers (IMechE) member, Malaysian Society for Engineering and Technology (MySET) member, Malaysian Tribology Society (MyTribos) member and Society of Tribologists & Lubrication Engineers (STLE) member. His present research focuses on tribology, especially in journal bearing issues. His publication can be accessed using this link https://scholar.google.com.my/citations?user=0PLVbrQAAAAJ&hl=en.

Mimi Azlina Abu Bakar is an associate professor in the Mechanical Engineering Faculty at Universiti Teknologi MARA (UiTM) Shah Alam Selangor presently. She was born on 1974 at Kota Bharu, Kelantan. She received a B. Eng (Hons) Materials Engineering at Universiti Sains Malaysia, MSc (Materials Engineering) at Universiti Sains Malaysia (1999 – 2003) and PhD (Applied Physics) at Universiti Kebangsaan Malaysia. The teaching area are in strength of materials, materials science and mechanical engineering design II. The research interest in natural fiber reinforced polymer composites and biomaterials for bone implant, including fabrication and processing methods, materials characterization and mechanical testing and characteristic. The scholar citation can be checked using this link https://scholar.google.com.my/citations?user=poFGe-0AAAAJ&hl=en