ARPN Journal of Engineering and Applied Sciences

DIMENSIONAL MEASUREMENT OF COMPOSITE LAMINATES PLATE THRU SINGLE CRYSTAL IMMERSION TRANSDUCER AND ULTRASONIC RANGEFINDER TRANSDUCER

M. F. Mahmod[1,2] and Elmi Abu Bakar[3]
[1]School of Mechanical Engineering, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia
[2]Faculty of Mechanical Engineering and Manufacturing, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia
[3]School of Aerospace Engineering, Universiti Sains Malaysia, Nibong Tebal, Pulau Pinang, Malaysia
E-Mail: mfaisal@uthm.edu.my

ABSTRACT

Ultrasonic testing has variety of usage. In composite laminates material, it has been use for defect detection such as flaw, un-bonded, void, micro crack, foreign material occurrences and thickness measurement. In this study, glass fiber composite laminates (GFCL) being used and produced in-housed with dimension 120 mm length x 80 mm width x 2.4 mm thickness. It consist an artificial defect which was drilled 6 mm in diameter. Ultrasonic range finder transducer with frequency 42 kHz and single crystal immersion transducer with frequency 2.25 MHz have been applied in order to study the performance between both transducers. During measurement, gap distance between specimen surface and both transducer had been fixed at 10mm. Moreover, linear motion at x-axis with constant speed being controlled during measurement process. Measurement data from ultrasonic rangefinder and single crystal immersion transducer had been compared to determine the accuracy between both transducer. All the data are required in order to develop ultrasonic scanning unit that applicable for those transducer. However, some experimental data need to be analyze before further development to avoid misleading especially on operational and functionality of ultrasonic scanning unit.

Keywords: composite laminates, single crystal immersion transducer, ultrasonic rangefinder.

INTRODUCTION

In composite laminates manufacturing industries, Ultrasonic testing (UT) widely being use especially during inspection and measurement process where some other nondestructive test (NDT) techniques are not appropriate due to complexity during operation, required only metal base existence and poor detectability. In common application, ultrasonic testing has been applied on defect detection such as flaw, dish bond between interlayer, crack and delamination. Besides, it also being use for material characterization and dimensional measurement. Basically, for composite laminates material, the frequency used is between 100 kHz up to 5 MHz and consider as low frequency (M. F. Mahmod, M. Z. Nohamed Pauzi and Elmi Abu Bakar, 2013). However, this determination of frequency selection is dependent on certain condition such as material characterization, dimension and surface roughness of the subject. A typical ultrasonic inspection system normally required several functional unit included transducer, pulse/receiver, graphic user interface (GUI). Modern computerized ultrasonic inspection system come with motion control system where the GUI are able to control the scanning speed, scanning path and gap distance between transducer and specimen. In this system, pulse/receiver produce high voltage electrical pulse where it was important for transducer to generate high frequency ultrasonic energy which is in the form of wave to penetrate through specimen. However, when there are some flaw or crack occur inside the specimen, the wave was reflected back from flaw surface and it transform into an electrical signal by the transducer before displayed on GUI. Beside detect the occurrences of defect, this electrical signal also give some information included defect characteristic. Currently, there are three different format of ultrasonic data can be gathered which are A-scan, B-scan and C-scan. Each different format provide different view as A-scan for cross sectional view, B-scan for top view and C-scan for 3D view. (Annual Book of ASTM Standards, 1999)

In current practice, there are no specific guideline on transducer selection during ultrasonic inspection process. Transducer are manufactured base on desire application and sometimes, can be special fabricated when necessary. In general, different type of transducer applicable on certain operation base on specimen geometry, material characteristic and surrounding. According to American Society for Testing of Materials (ASTM) standard, thinner specimen required higher frequency while thicker specimen is suggested to use lower frequency or larger diameter (Annual Book of ASTM Standards, 1999). Therefore, several criteria have to be considered on selecting the proper transducer for some application which is desired frequency, bandwidth and focusing to improve inspection capability. In many cases, transducer have been chosen either to enhance the resolution or sensitivity during inspection (Singh, 2013). Hence, there are potential of inaccurate result when improper transducer is used. Single crystal immersion transducer known as single longitudinal wave transducer where it sealed to allow them for submerged under water. Furthermore, water is used as couplant and wave medium

ARPN Journal of Engineering and Applied Sciences

to avoid any interference during inspection and the most attraction feature is the single crystal immersion transducer can be focus spherically or cylindrical during operation (Olympus, 2014).

Several research related on transducer design and performance study to increase the availability of transducer for current application which have been done by previous researcher (Hopkins, Neau and Le Ber, 2011). Besides, Gunarathne and Qureshi applied ultrasonic inspection on non-planar specimen such as in pipeline where it require some approach to construct reference signals based on numerical computation using fundamental properties of acoustic waves and boundary transmission characteristics (Gunarathne and Qureshi, 2002). While some research interested on ultrasonic inspection of specimen surface geometry, Yuu Ono *et al* studied ultrasonic testing on high temperature steel using pulse-echo mode at temperature up to 500 ^{0}C. This immersion ultrasonic probe is protected by sol-gel-sprayed and fully immersed into molten zinc at 450 ^{0}C (Yuu Ono *et al*, 2006). Moreover, Yuu Ono *et al* managed to perform ultrasonic inspection by using 10 MHz single crystal immersion transducer where immersed into 780^{0}C of molten Aluminum as ultrasonic medium (Yuu Ono, Jean-Francois Moisan and Cheng-Kuei Jen, 2003). The purpose of this experimental is to inspect net shape forming of aluminium processing. Another research about transducer have been performed by Komgrit Jaksukam and his friend to determine the ultrasonic output power in the frequency range from 1 MHz to 20 MHz and in the power range 1 mW to 20 W in medical application (Komgrit Jaksukam and Sumet Umchid, 2011).

Since the uses of single crystal immersion transducer quit reliable and supported by many research finding, we selected this transducer and compared to single ultrasonic rangefinder sensor to determine any huge significant instead of data accuracy during ultrasonic inspection. In the earlier stage, manual inspection using ultrasonic rangefinder transducer for glass fiber composite laminates material have been performed by previous researcher. (M. F. Mahmod, M. Z. Nohamed Pauzi and Elmi Abu Bakar, 2013). This development was hardly control instead of scanning motion, scanning path and gap distance between transducer and specimen due to manually operation. Therefore, further reseach have been performed by previous researcher Goh *et al* and Ramzi *et al* to provide better ultrasonic inspection result. They used stepper motor to control the scanning speed and can be program into desired scanning path. The distance between transducer and specimen also can be fixed by using linear shaft as track motion (Goh, Mahmod and Elmi Abu Bakar, 2014) and (Ramzi, Mahmod and Elmi Abu Bakar, 2014). However, the scanning result is limited only for surface defect due to the limitation of transducer used. Therefore, the purpose of this research is to give supportive data on developing portable ultrasonic pulse-echo scanning unit where compatible with both immersion and ultrasonic rangefinder transducer.

METHODS AND APPROACH

Basically there are seven step needs to be carried out in this research as shown in Figure-1 below. Starting from in-house fabricating glass fiber composite laminates (GLCL) panel before drilled hole as an artificial defect, equipment setup for both immersion and ultrasonic rangefinder transducer where certain parameter are fixed, then the inspection process begin by performed size of defect measurement, thickness measurement, then all data gathered will be validate base on averaging approach, result comparison base on both transducer uses and finally result summary.

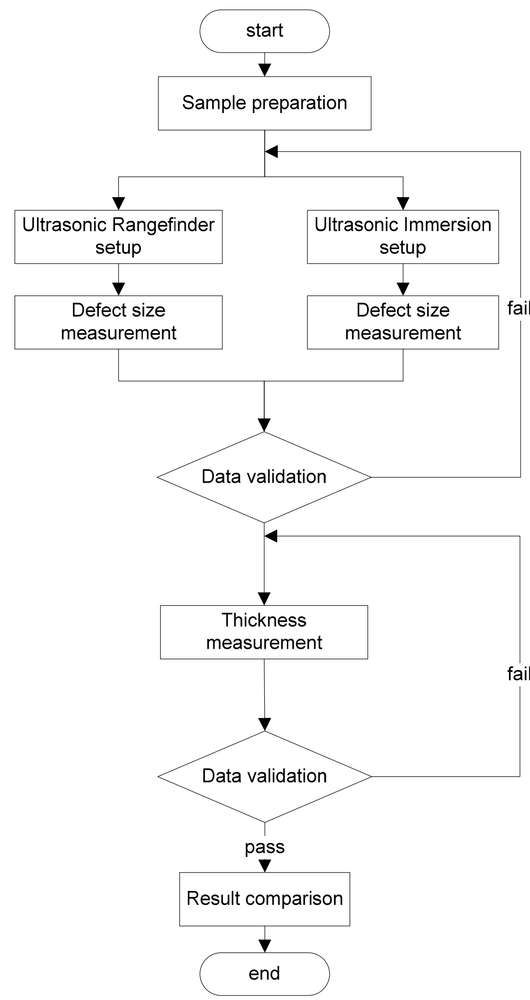

Figure-1. Process flow chart.

Sample preparation

In this study, fiber glass composite laminates (FGCL) panel with artificial defect is used as specimen for ultrasonic inspection. The manufacturing process is done in-house and followed standard procedure. The dimension is 120mm x 80mm x 2.4mm with drilled holes about 6mm in diameter as shown in Figure-2 below. All the drilled holes are considered as artificial defect.

ARPN Journal of Engineering and Applied Sciences

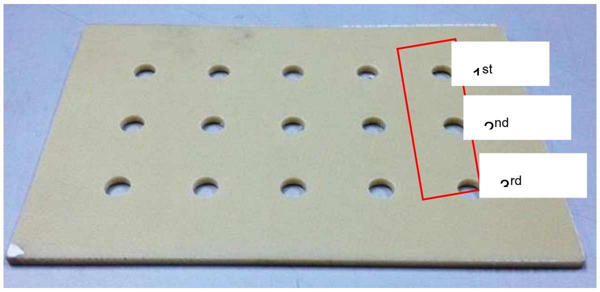

Figure-2. Fiber glass composite laminates (FGCL) panel.

Ultrasonic setup

In this step, Figure-3 show the single crystal immersion transducer setup while Figure-4 show the ultrasonic rangefinder transducer setup. As for comparison, it is noticed that there are large different of maximum reading distance, maximum focus point and operating frequency between single crystal immersion transducer and ultrasonic rangefinder as shown in Table-1 below. A 2.25 MHz frequency of single crystal immersion transducer is used and connected to the 50 MHz pulse/receiver unit before connected to computer for display the result. Then, the data is saved into csv file format before analysis using Matlab software. However, a 42 kHz frequency of ultrasonic rangefinder sensor is used and connected to Arduino Mega 2560 microprocessor before finally connected to computer for display the result. Then, the data in voltage form was analyze by using Matlab software.

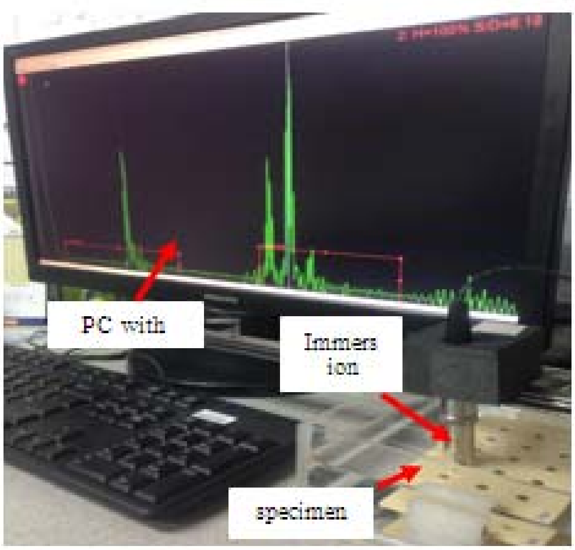

Figure-3. Single crystal immersion transducer setup.

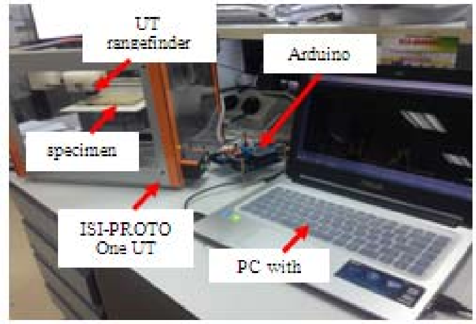

Figure-4. Ultrasonic rangefinder inspection setup.

Table-1. Specification of transducers.

	Single crystal immersion transducer	Ultrasonic rangefinder
Product code	V309-SU-F1.001N-PTF	SN-LV-EZ1
Voltage (V)	5.00	2.50 – 5.50
Frequency (MHz)	2.25	0.042
Reading distance (mm)	0 – 33.76	0 – 6450.00
Weight (g)	48.00	7.00
Diameter (mm)	10.00	16 .00
Focus Point (mm)	12.70	82.55

Defect size measurement

In this inspection process, the artificial defect on which is known 6 mm in diameter on fiber glass composite laminates panel were inspect using both transducer type. Time interval of saved data is used during single crystal immersion transducer inspection. The scanning speed is fixed at 10 mm/sec and data saved time interval is set to 10 ms. Then, the size of defect can be calculate base on time interval and scanning speed. These procedures are applicable to ultrasonic rangefinder transducer. However, calibration works need to apply to ensure accurate scanning speed. Some minor losses such friction, surrounding noise and vibration source from motor need to compromise as this factor is hard to control.

Thickness measurement

All the equipment was calibrated in order to get accurate result. Then, a 2.4 mm thickness glass fiber composite laminates panel is used. For single crystal immersion transducer, the measurement in done by calculating the prominence peak distance between initial front wall of signal with back wall area. Transducer need to ensure fully immersed and the distance to the specimen surface is 10 mm. However, for the ultrasonic rangefinder transducer, this experiment are not applicable because it can't penetrate the wave through specimen block. This is

ARPN Journal of Engineering and Applied Sciences

the reason why single crystal immersion transducer need to apply for this development of pulse-echo scanning unit.

Result comparison

In this step, only size of defect measurement data have been compared among both transducer. The method is the get average of five trial and finally compared to see any huge significant different between transducers reading. For the thickness measurement, the purpose of this experiment is to determine the reliability of single crystal immersion transducer reading as compared to calibration data.

RESULTS AND DISCUSSIONS

Measurement result

The work presented here is focused on measurement analysis in order to determine the significant of ultrasonic measurement data between immersion and ultrasonic rangefinder transducer. It is noticed that, the diameter measurement of drilled hole at glass fiber composite laminates (GFCL) panel surface was previously confirmed by using high resolution microscope. In this study, size of defect is determined by calculate recorded time interval inspection data with scanning speed using Equation. 1 as below:-

$$L_a/X = t_s/t_i \quad (1)$$

where L_a is actual length of specimen (mm), X is size of defect (mm), t_s is time taken for scanning specific path (sec) and t_i is time interval in defect area (sec).

From Table-2 and Table-3 shows the detail measurement data for size of defect using both transducer. Based on the five times measurements using single crystal immersion transducer for each holes, the standard deviation value for first hole was 0.060 while second hole was 0.086 and third hole was 0.0.064. The standard deviation value for first hole using ultrasonic rangefinder was 0.271, while second and third hole was 0.234 and 0.303. Since we know that the lower the value of standard deviation, the more precise the data gathered. Thus, by comparing those standard deviation value from both transducer, it is worth mentioning that the measurement result from single crystal immersion transducer is more reliable than ultrasonic rangefinder transducer. In addition, through the comparison data as shown in Figure-5 below, the percentage of variation for first hole between both transducers was 18.94%, while for second and third hole was 4.81% and 8.21%. In this regard, certain condition must take into consideration to ensure the accuracy of result which is to fix the distance between transducer and surface of specimen, avoid any interference during measurement and finally to calibrate the scanning speed as desired input speed.

Table-2. Experimental size of defects using single crystal immersion transducer.

No. of trials	Experimental Size (mm)		
	Hole 1	Hole 2	Hole 3
1	6.22	6.29	6.53
2	6.35	6.28	6.41
3	6.27	6.36	6.42
4	6.18	6.43	6.56
5	6.26	6.51	6.52

Table-3. Experimental size of defects using ultrasonic rangefinder.

No. of trials	Experimental Size (mm)		
	Hole 1	Hole 2	Hole 3
1	5.02	6.46	5.98
2	5.54	6.97	6.02
3	5.26	6.89	6.25
4	4.96	6.47	5.50
5	5.52	6.69	6.23

VOL. 11, NO. 6, MARCH 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

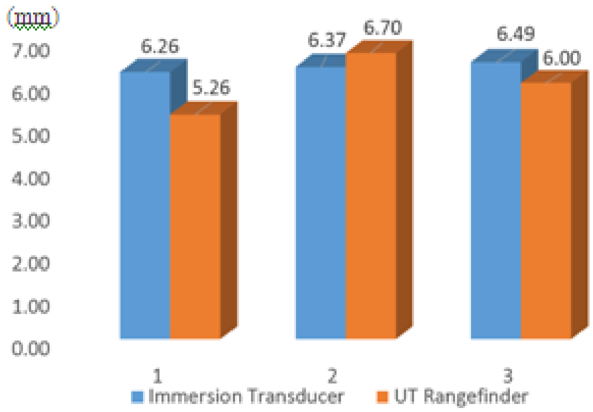

Figure-5. Size of defect comparison data.

Transducer performance

After comparison measurement result between immersion and UT rangefinder transducer, it show that there are some limitation using UT rangefinder transducer which is only applicable on surface defect, unable to perform thickness measurement and detect flaw at interlayer region. Therefore, UT rangefinder transducer are not suitable on defect detection of composite laminates material where the defect occurrences almost at interlayer region. Figure-6 below show the real time single crystal immersion transducer signal where it can detect any discontinuity occur at interlayer region. In this experimental work, foreign material are deliberately add interlayer of composite laminate panel to verify the detectability of single crystal immersion transducer.

Figure-6. Real time single crystal immersion transducer signal.

CONCLUSIONS

Several measurement of defect size using both immersion and ultrasonic rangefinder transducer have been performed to study any significant instead of data accuracy recorded during inspection. Form the result obtained, the finding of this research can be summarized as follows:

1. Ultrasonic rangefinder transducer are not able to detect flaw at interlayer region and to perform thickness measurement due to low frequency of signal wave penetration.

2. The higher the frequency amplitude of discontinuity region, the bigger size of defect. However, some configuration work have been properly setup to get accurate result.

3. Some surrounding disturbance need to control in order to achieve accurate result.

REFERENCES

Annual Book of ASTM Standards (1999). ASTM E1065-99: Standard guide for evaluating characteristics of ultrasonic search units. pp. 1-21.

A. R. Ramzi, M. F. Mahmod and Elmi Abu Bakar. 2014. Development of Multilayer Scanning Array Unit for NDT Application, Conference Competition and Exhibition (CCE) 2014, pp. 404-409.

C. Y. Goh, M. F. Mahmod and Elmi Abu Bakar. 2014. Study on Multilayer Scanning Array Units Performance Using Ultrasonic Transducer, Conference Competition and Exhibition (CCE) 2014, pp. 238-243.

D. Hopkins, G. Neau and L. Le Ber. 2011. Advanced Phased-Array Technologies for Ultrasonic Inspection of Complex Composite Parts, International Conference of Smart Materials, Structures and NDT in Aerospace. pp. 1-10.

G. P. P Gunarathne and Y. Qureshi. 2002. Development of a Synthetic A-scan Technique for Ultrasonic Testing of Pipelines, IEEE Instrumentation and Measurement Technology Conference, pp. 547-552

Komgrit Jaksukam and Sumet Umchid (2011). Development of Ultrasonic Power Measurement Standards in Thailand, 10th International Conference on Electronic Measurement and Instruments. pp. 1-5.

M. F. Mahmod, M. Z. Mohamed Pauzi and Elmi Abu Bakar (2013). Flatbed Scanner Image and Single Ultrasonic Rangefinder Technique for Composite Laminates Defect Detection, International Conference on Smart Instrumentation, Measurement and Application (ICSIMA) 2013, pp. 1-5.

Olympus. 2012. Olympus, URL: http://www. olympus-ims.com/data/File/panametrics/panametrics-UT.en.pdf, access on 22/03/2015.

ARPN Journal of Engineering and Applied Sciences

Singh J. P. Singh. 2014. Review of Ultrasonic Testing Technique. International Journal in IT and Engineering. 2(3), pp. 1-14.

Yuu Ono, Jean-Francois Moisan and Cheng-Kuei Jen (2003). High-Temperature and Broadband Immersion Ultrasonic Probes. IEEE Sensors Journal. 6(3), pp. 580-587.

Yuu Ono, Jean-Francois Moisan and Cheng-Kuei Jen. 2003. Ultrasonic Techniques for Imaging and Measurements in Molten Aluminium. IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control. 50(12), pp. 1711-1721.