Defect Detection of Fiberglass Composite Laminates (FGCL) with Ultrasonic A-Scan Signal Measurement

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Abstract. Fiberglass composite laminates are widely used in many industries, due to its advantages of high specific strength and high specific modulus. Invisible defect such as delamination and inclusion may cause composite structural failure. Therefore, several research on ultrasonic testing for composite material defect detection have been done for the past few years. However, improper parameter setup may lead to significant error to determine the behavior of defects. In this paper, the intensive study on defect detection with ultrasonic single crystal immersion transducer has been conducted. In general, the defects detection thru acquired signal is determine the behavior of defects through the certain ultrasonic parameter setup such as sound velocity, pulse width, gain, sampling rate and transducer distance with specimen surface. Furthermore, an A-scan signal interpretation for FGCL defect detection is demonstrated and illustrated. This research is focusing on for FGCL with maximum thickness up to 10 mm in ambient temperature. The result shows an appropriate ultrasonic parameter will result better signal interpretation analysis.

1. Introduction
Fiberglass composite laminates provide an alternative to conventional structural materials because it combines high strength and low weight properties. In addition, it resists to corrosion and have thermal and electrical insulation properties. Therefore, the wide applicability of fiber-reinforced composites have created the need for correspondingly advanced non-destructive testing (NDT) techniques for inspection and failure detection during manufacturing and maintenance activity. Various types of NDT have been applied for composite laminates inspection including ultrasonic testing, radiography, sheography, thermography and visual inspection [1]. However, ultrasonic testing is the most widely technique being used because it offers a wide application of testing conditions such as portability, easy to maintain, minimum operational trained and able to give accurate results during inspection [2].
Several parameters of ultrasonic testing need properly setup by experienced inspection operator in order to acquire a good signal for fiberglass composite laminates. This procedure creates dependency with experienced inspector and even worst compromise with quality issue when there are insufficient numbers of inspector [3]. In addition, lack of study on certain technical criteria may mislead signal interpretation for the inexperienced ultrasonic testing inspector. Therefore, several researchers have focused on ultrasonic parameter setup beside some researcher tends to optimize the parameter estimation using developed algorithm which is called Modified Artificial Bee Colony (MABC) [4]. Lately, some researcher developed an automatic defect detection based on estimation of histogram parameters in ultrasonic IR thermography [5]. Thus, in our work was studied on defect detection with ultrasonic single crystal immersion transducer to determine an appropriate ultrasonic parameter setup and educate the standard of procedure (SOP) for inexperienced ultrasonic inspector. In this study, A 2.25 MHz frequency of immersion single crystal transducer was used because of the specimen material and thickness as suggested by D. Ensminger and L. Bond [6].

2. Method approach

2.1. Overall research flow chart

In this study, there are several process flows that have been achieved starting from the sample preparation to fabricate artificial defects, experimental setup for the ultrasonic measurement process, parameter evaluation to determine an appropriate setup of each sample, signal acquisition from pulse-receiver unit for personal computers, signal verification to determine correct interpretation signal base on several types of defects and finally result compilation as shown in figure 1 below.
2.2. Ultrasonic testing setup

The specimen used in this research is fiberglass composite laminates with 7.4 mm in thickness (24 plies). Three categories of defect have been fabricated before inspected using various types of ultrasonic parameter setup. A 2.25 MHz frequency of immersion single crystal transducer was used and connected to the pulse-receiver unit before converting the acquired signal into A-scan power spectrum display. The scanning path and acquired signal are based on one-fixed-point starting from point (a) and followed by point (b), (c), (d) and (e) as shown in figure 2 below.

Thus, during ultrasonic testing measurement, the inspection point have to be fixed while determining the parameter setup. Based on normal procedure, the distance between specimen surface and transducer was set to be 10 mm while material velocity was set 2740 µs according to sound velocity equation 1 below as provided by ASTM E494 standard for FGCL specimen.

$$v_1 = \frac{A_n t_1 v_k}{A_n t_k}$$ (1)

Where:
- $A_n$ = distance from list to $N$th back echo on the known material, m (in.), measured along the baseline of the A-scan display,
- $n_1$ = number of round trips, unknown material,
- $t_1$ = thickness of unknown material, m (in.),
- $v_k$ = velocity of unknown material, m/s (in.),
- $A_k$ = distance from the first to the $N$th back echo on the known material, m (in.), measured along the baseline of the A-scan display,
- $n_k$ = number of round trips, known material, and
- $t_k$ = thickness, known material, m (in.).

All these equipment were immersed in the water for pulse echo travelling purpose. Specimen holder is used in order to differentiate the signal between specimen and water tank container material. Once experimental setup has been completed, the calibration procedure is required. In this stage, fiberglass composite laminates specimen with no defect is used to measure the thickness and to confirm the signal appearance as no defect condition. Basically, this procedure will take a few minutes if performed by an experienced inspector.
2.3. Signal displays
Basically, there are three main regions in A-scan power spectrum signal display as shown in figure 3 below. That is initial pulse, front wall and back wall interface. The amount of received ultrasonic energy was displayed in A-scan signal as a function of time. Initial pulse is the travelling pulse from piezoelectric sensor to the top surface of the specimen which near to time zero while the front wall interface is the reflection of pulse known as echo from top surface of the specimen. Back wall will appear later in time, showing that the sound has travelled further to reach this surface. If a flaw occurs, the flaw reflection signal will appear earlier than back wall signal.

![Signal displays diagram](image)

**Figure 3.** A-scan power spectrum signal of composite laminated material

2.4. Ultrasonic parameter determination
In this step, several parameter setups have been studied to determine which parameter give significant result where finally being used as a guideline for an inexperienced ultrasonic inspector. Type of defect was fixed into 2 mm along this experiment. This experiment starts by determining an appropriate distance between the transducer and specimen, then followed by material sound velocity for the correct time of flight diffraction (TOFD) interpretation, signal type for display purpose, pulse width for signal resolution, gain for pulse amplitude strength and sampling rate for correct signal acquisition as shown in table 1 below.

| Items               | Unit |
|---------------------|------|
| Distance            | mm   |
| Material sound velocity | μs   |
| Signal type         | -    |
| Pulse width         | ns   |
| Gain                | dB   |
| Sampling rate       | MHz  |

**Table 1.** Ultrasonic parameter setup.

3. Result and discussion
In this section, two experiments were performed which is signal comparison between defect and non-defect of fiberglass composite laminates and signal comparison of defect specimens between several types of ultrasonic parameter setup. Detail result will be discussed in following section below.
3.1. Signal of defect and non-defect specimen

Based on signal comparison between defect and non-defect FGCL as shown in figure 4 below, the single crystal immersion transducer are capable to detect and measure the defect. According to time-of-flight along x-axis, second back wall signal occurs in 2 mm and 4 mm defect region while there are no second back wall signal exist in non-defect specimen.

![Signal comparison between defect and non-defect FGCL](image)

**Figure 4.** Signal comparison between defect and non-defect FGCL.

3.2. Signal of various parameter setup

In this experiment, the parameter setup is found to be classify into significant and insignificant as the result obtained. Sound velocity, sampling rate and transducer distance is classified into significant to the result while gain, pulse width and signal type are classified into insignificant parameter to the result. However, those insignificant parameter setups are required to be fixed during inspection in order to achieve good result. Table 2 below show the suggested parameter setup for fiberglass composite laminates.

| Items                  | Value | Class       |
|------------------------|-------|-------------|
| Sound velocity (µs)    | 2740  | Significant |
| Sampling rate (MHz)    | 25    | Significant |
| Distance (mm)          | 10    | Significant |
| Gain (dB)              | 15    | Insignificant |
| Pulse width (ns)       | 50    | Insignificant |
| Signal type            | Full  | Insignificant |

The appropriate value for FGCL sound velocity is in the range of 2500 µs to 2800 µs. The higher the sound velocity, the wider the front wall or back wall. Therefore, improper sound velocity setup will cause incorrect signal interpretation during ultrasonic inspection. In this study, the transducer frequency used was 2.25 MHz, while this sampling rate control option gives four options which are 6.25 MHz, 12.5 MHz, 25 MHz and 50 MHz. The sampling rate was set 25 MHz since the sampling rate should be five to eight times greater than the transducer frequency. The distance between the
transducer and specimen surface is set not more than 10 mm since it will further the front wall and the back wall peak signal from initial peak.

One of the insignificant parameter setups in this inspection was gain. The gain is used to control the amplitude of the signal and keep the signal fit in the display window. The gain was set not more than 20 dB because the amplitude will increase over 100 percent that exceed the display window. The following insignificant parameter setup was pulse width. Pulse width is used to control the time-of-flight data from 50 ns to 500 ns in increments of 20 ns. The pulse width was set as low as 50 ns since the time-of-flight data will exceed the display window. Finally, the last insignificant parameter setup was signal type where it does not affect the measurement result. The author used full rectification form since it has a full rectification effect and easy to determine the peak signal. Another type of signal is a radio frequency (RF) type as shown in figure 5 below.

![Figure 5. Ultrasonic radio frequency (RF) signal type.](image)

4. Conclusion

Several trials of pulse-echo ultrasonic testing for defect and non-defect fiberglass composite laminates were performed in order to identify an appropriate parameter setup. From the results obtained, the single crystal immersion transducer is able to detect and measure the fiberglass composite laminate panel up to 8 mm in thickness. As an appropriate ultrasonic parameter setup, some parameter such as sound velocity, sampling rate and distance gives significant results prior small changing while others parameter such as gain, pulse width and signal type give less significant and more on signal display purpose only. For further research work, the author plan to use various types of material in order to propose an appropriate parameter setup especially between homogenous and non-homogenous material for inexperience inspector guideline.

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