A STUDY ON NON-CONTACT ULTRASONIC TECHNIQUE FOR ON-LINE INSPECTION OF CFRP

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Abstract

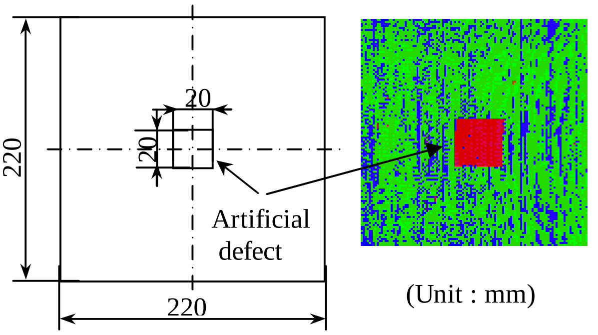
The fabrication process of fiber placement system of carbon fiber reinforced plastic (CFRP) requires real time process control and reliable inspection to ensure quality by preventing defects such as delamination and void. Therefore, novel non-contact inspection technique is required during the non-destructive evaluation in a fiber placement system. For the inspection of delamination in CFRP, various methods to receive laser-generated ultrasound were applied by using piezoelectric transducer, air-coupled transducer, wavelet transform and scanning laser ultrasonic technique. Laser-generated ultrasound was received with a conventional piezoelectric sensor in contacting manner. Then signal characteristics due to defects were analyzed to find a factor for detecting defects. Air-coupled transducer was used for reception of laser-generated guided wave using linear slit array in order to generate high frequency guided wave. And line scan technique was used to confirm the capability of on-line application. The high frequency component of laser-generated guided wave received with piezoelectric sensor disappeared after propagating through delamination region. Nevertheless, it was failed to receive high frequency guided wave in using air-coupled transducer. The first peak of the frequency spectrum under 100kHz in the delamination region is higher than in the sound region. By using this feature, the line scanned frequency data were acquired in fully non-contact generation and reception of ultrasound. This method was proved as useful technique for detecting delamination in CFRP.

1. Introduction

The advantages of carbon fiber reinforced plastic materials (CFRP) are that they are light structure materials and have corrosion resistance, higher specific strength and elasticity. The recently developed 3-dimensional fiber placement system is able to produce a more complex and various shaped structures due to less limitations of a product shape according to the problem in conventional fabrication process. This fiber placement system stacks the narrow prepreg tape on the mold according to the designed sequence and thickness. The non-destructive evaluation was required for these composites greatly to evaluate changes in strength caused by the defects such as delamination and porosity. Additionally, the expectant quality should be satisfied for the high cost fabrication process using the fiber placement system. Therefore, an on-line non-destructive evaluation is required and real–time complement is needed when the defects are occurred [1]. The defect imaging by ultrasonic C-scan technique is a useful technique for the defect detection of CFRP. However, the conventional ultrasonic C-scan technique cannot be applied during the fabrication process because the test piece should be immersed into the water. Therefore, non-contact ultrasonic techniques should be applied during the fabricating process. For the development of non-contact ultrasonic techniques available in non-destructive evaluation of CFRP, a recent laser-generated ultrasonic technique and an air-coupled transducer that transmit and receive ultrasounds in the air are studied [2-3]. In this study, generating and receiving techniques of laser-generated ultrasound and the characteristics of received signals upon the internal defects of CFRP were studied for the non-contacting inspection.

2. Non-contacting ultrasonic measurement technique and experimental set-up

For the development of laser-generated ultrasonic technique in inspecting CFRP, laser-generated ultrasounds were received with a conventional piezoelectric sensor in contacting manner. Then signal characteristics due to defects were analyzed to find a factor for detecting defects. Finally, the factor was investigated in inspection using a non-contacting air-coupled transducer. Line scanning technique was applied to investigate the applicability of on-line inspection for detecting delamination in CFRP. As shown in Fig. 1(a), the unidirectional CFRP specimen has 3mm thickness by stacking 24 plies prepregs with artificial delamination defects of 20mm by 20mm made of teflon film. The delamination inside the CFRP was verified from the ultrasonic C-scan image obtained from the immersion technique as shown in Fig. 1(b). Schematic diagram shown in Fig. 2 represents transmission and reception methods of laser-generated ultrasound applied in this study.



(a) Dimension (b) C-scan image

Figure 1: *Dimension and location of artificial defect.*

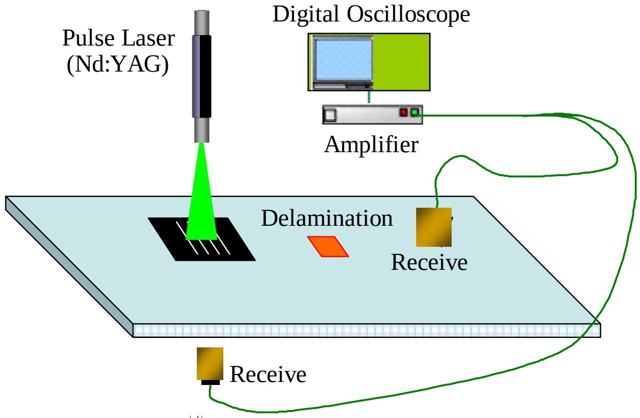


Figure 2: *Schematic diagram of experimental setup.*

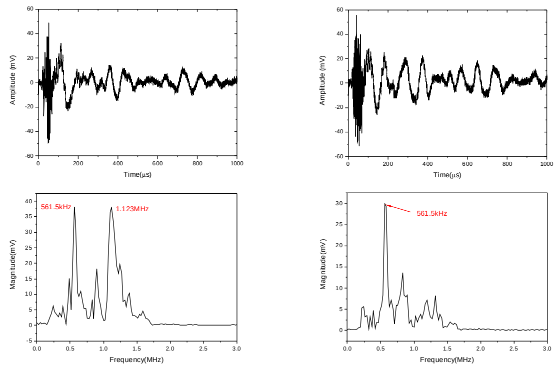
Line scanning measurement was carried out by 5mm step from 30mm in front of defect by using stepping motor. Scanning area was 80mm by 80mm.

In this study, wavelength of fiberized Nd:YAG pulse laser used to generate ultrasonic wave is 532nm and this pulse laser system emits an energy of 32mJ at one pulse through the multi-mode optical fiber to irradiate laser beam to arbitrary position and direction. At terminal of optical fiber, the laser beam outspreads at an angle of 30 degrees. Therefore, laser irradiation can cover whole area of the linear slit array without an additional lens.

3. Experimental results

3.1 Defect signal characteristic of guided wave using piezoelectric receiving transducer

The guided waves generated by the laser irradiation on specimen propagate on normal to fiber direction. The waveforms and frequency domain data shown in Fig. 3(a) and (b) were received by using 1MHz piezoelectric transducer mounted on the same surface as laser irradiation spot without and with delamination respectively. From this time domain waveforms, signal characteristics could not be distinguished clearly between without and with delamination. For the reasonable detection of delamination, the time domain signal was converted into frequency domain through FFT. The high frequency component of 1.123 MHz was suddenly disappeared by delamination.



(a) sound region (b) defect region

Figure 3: *Waveforms and frequency spectrums received with piezoelectric sensor.*

From the result shown in Fig. 3, it is shown that the delamination in CFRP can be evaluated sensitively, when the laser-generated guided wave at nearby 1.1 MHz transmits and receives.

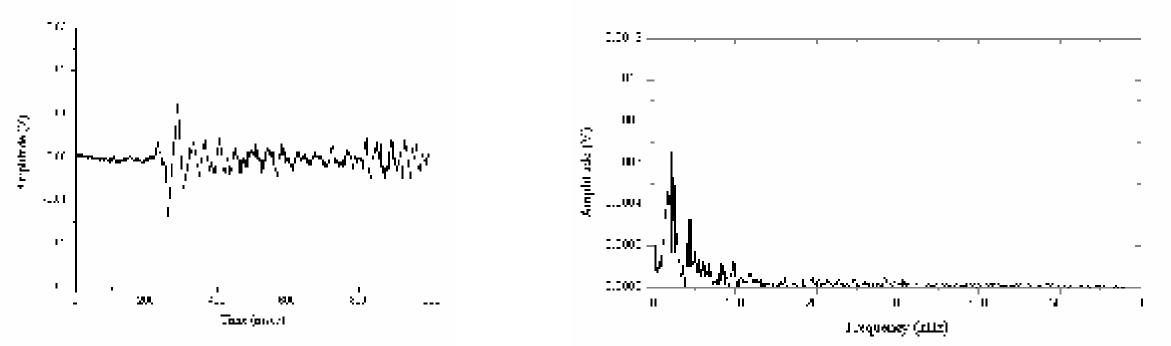
3.2 Reception of laser-generated guided wave using air-coupled transducer

It was tried to generate and receive laser-generated guided wave with a specific frequency components of 1.1 MHz obtained in the previous section by wavelength control technique using linear slit array with an air-coupled receiving transducer [4]. As shown in Eq. (1), if wavelength, l is decided, phase velocity, C_p with frequency, f can be excited.

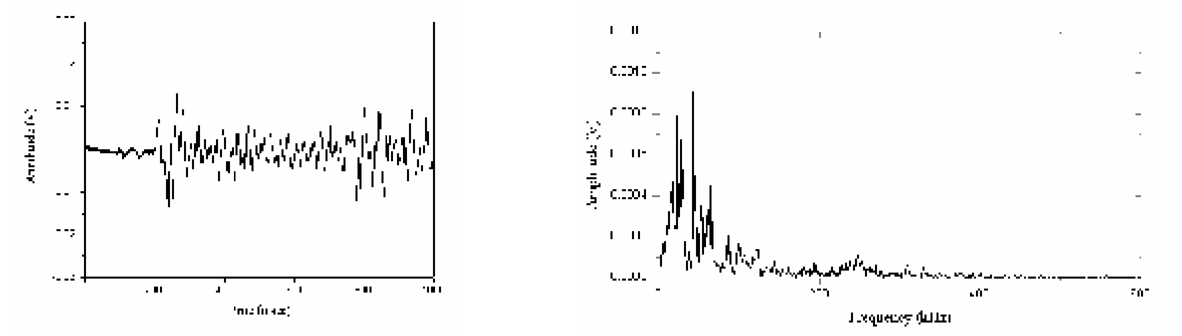
$$C_p = f \times l \qquad (1)$$

Linear slit interval, λ , used in this experiment is decided by dispersion curve and specimen thickness.

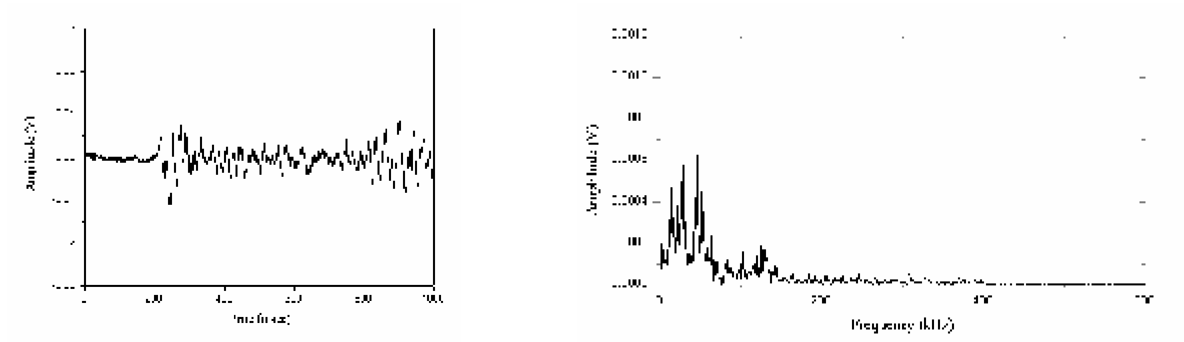
Slit intervals are 0.7mm, 1.4mm and 2.8mm, respectively.



(a) slit interval = 0.7mm



(b) slit interval = 1.4mm



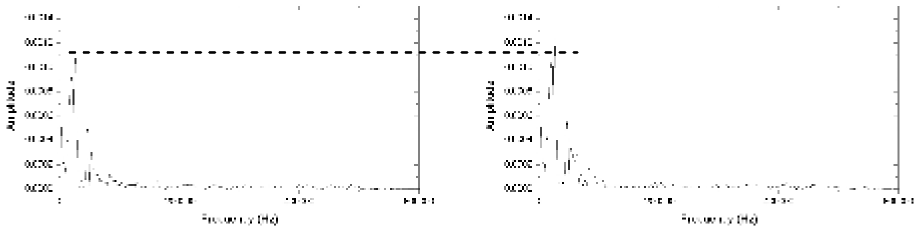
(c) slit interval = 2.8mm

Figure 4: *Time domain waveform and frequency spectrum of guided wave generated by pulsed laser with linear slit array and received with air-coupled transducer.*

Figure 4 shows the waveforms and frequency spectrums of guided wave generated by pulsed laser with linear slit array and received with air-coupled transducer in distance of 80mm from the laser irradiance. According to the previous study, the linear slit array of 0.7mm should be shown high frequency band of 1.1MHz but in this experiment, most of high frequency components were attenuated and very lower frequency components under 100kHz were received. These results represent that when the guided wave generated by laser irradiation propagated through the CFRP and received by air-coupled sensor, most of the high frequency component was attenuated due to the material characteristic of CFRP and low receiving efficiency of air-coupled sensor. In addition, the linear slit array of 1.4mm and 2.8mm was shown the same results. Therefore, the high frequency band of 1.1MHz received by piezoelectric transducer could not be acquired in this specimen.

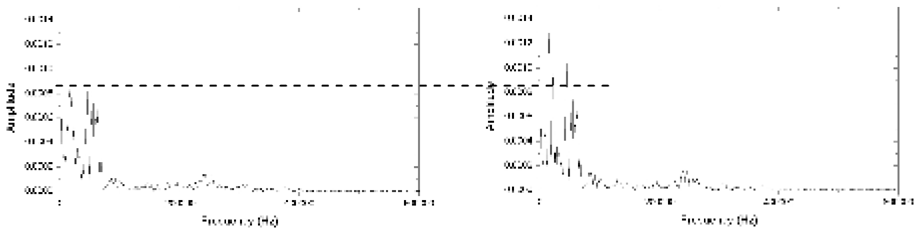
3.3 Defect signal characteristic in frequency domain

Laser-generated guided wave propagated through the sound region and defect region received by air-coupled sensor in manner of line scan. These results are shown in Fig. 5. When laser-generated guided wave propagated through the defect region, first peak of frequency spectrum get higher than in the case of sound region as a mode conversion [5]. It is shown that the first peak of frequency spectrum occurred under the 100kHz is useful signal and the delamination defects of CFRP can be evaluated sensitively. Fig. 6 is shown the amplitude of the first peak of the frequency spectrum data received by every 5mm step using line scanning technique. Like the previous result, it was shown that the first peak of defect region presented the highest amplitude among the received frequency spectrums.



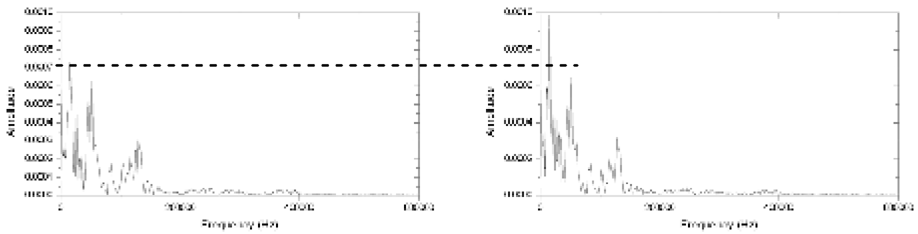
sound region defect region

(a) slit interval = 0.7mm



sound region defect region

(b) slit interval = 1.4mm



sound region defect region

(c) slit interval = 2.8mm

Figure 5*: Frequency spectrums of laser-generated guided wave between sound region and defect region.*

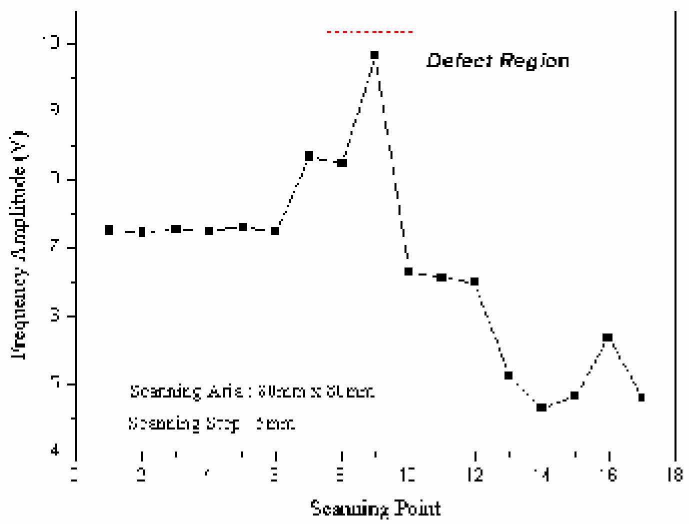


Figure 6*: The diagram of the first peak of the frequency spectrum depending on the scanning step.*

4. Summary

In this study, for the inspection of delamination in CFRP, various methods for the generating and receiving laser-generated ultrasound are applied using piezoelectric transducer, air-coupled transducer, wavelet transform technique and line scanning technique. The high frequency of 1.1 MHz received by piezoelectric sensor in the sound region disappeared after propagated through defect region. However, it could not be received this high frequency guided wave by using air-coupled transducer and linear slit array. In a frequency spectrum of laser-generated guided wave received by air-coupled sensor, first peak of frequency spectrum under 100kHz received in the defect region showed higher than in the sound region. The first peak of frequency spectrum represented approvable parameter to detect delamination in CFRP. By using this feature, line scanning data was acquired in fully non-contacting pitch-catch method and was proved as useful technique for detecting delamination.

5. Acknowledgement

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