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ACOUSTICS 2012

Comparison of different approaches in characterization of impact defects of composite plates

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Composite plate materials are widely used in almost all branches of modern industries and everyday life. Characterization of impact defects of these composite plates is of great interest in the quality control and safety monitoring. A variety of nondestructive methods are available for this purpose; immersion (water-coupled) ultrasonic testing is one of them and is known for its high reliability and efficiency. In this paper, several immersion ultrasonic approaches are compared for their application to characterize impact damage of carbon/epoxy plates. Two sample plates with damage caused by controlled impact are tested. Three testing configurations are discussed and several time-domain and frequency-domain data processing methods are applied. The comparison of the results shows that with an optimized combination of testing configuration, transducer and frequency selection and data processing methods, the defects can be more accurately and easily characterized than conventional ways.

1 Introduction

Characterization of impact defects of composite materials has been of great interest for a long time due to its importance in material health monitoring and control. Because of their complex inner structures and corresponding anisotropy in mechanical properties composite material defects cannot be detected and evaluated through standard procedures like isotropic metallic materials, and so different cases have to be treated differently.

Among different nondestructive testing (NDT) methods, ultrasonic NDT has strong advantages in many aspects and it has been widely used in both industrial application and research [1-3]. Similar sub-techniques have been compared in order to both confirm the results obtained and evaluated the reliability of different methods [1]. Many variants of ultrasonic NDT techniques such as ultrasonic burst phase thermography [2] have still been proposed and tested.

Inspired by some summary work in this area [4] the authors think it interesting and valuable to compare different techniques in characterizing impact defects and this work is a start by comparing different approaches of immersion ultrasonic NDT technique.

2 Experiments

2.1 Sample preparation

Two carbon/epoxy plates with the dimensions of 120mm long, 120 mm wide and 2.35 mm thick are used in this work. The damages of the plates were made by designed impacts: a 50 g impactor with two blades of 0.385 mm wide impacted Sample 1 at a speed of 9.35 m/s and Sample 2 at a speed of 18.27 m/s. It is reasonable that Sample 1 is less severely damaged and its impact defects are correspondingly harder to be detected than Sample 2. This work proves this and most of the discussions are focused on Sample 1.

2.2 Transducer selection

5 MHz transducers are chosen for this work taking advantage of their smaller pulse time duration which will lead to clearly separated waves received after going through the samples. The importance of these clearly separated waves will be discussed later in this paper. In addition, for the purpose of comparison, two different types of immersion transducers, one focused with spherical focus of 4 inches and one unfocused, are chosen for the current work.

2.3 Experimental configurations

In this work three experimental configurations are applied for C-scans on an area of 40 mm x30 mm covering the impacted positions: pitch-catch or transmission-through mode, pulse-echo mode and pseudo pulse-echo mode (Figure 1). As the most widely used modes for ultrasound testing, pitch-catch and pulse-echo modes are chosen due to the convenience of operation and their wide validity in other testing.

A third mode called pseudo pulse-echo mode is also chosen for the purpose of comparison. The schematic of this mode is shown in Figure 1. In the pseudo pulse-echo mode two transducers, the emitter and the receiver, are set at an angular position where the angle between their normal direction and the normal direction of the sample surface is a critical angle. The critical angles of the sample plates are measured in a polar scan shown in Figure 2. In this work, the second critical angle ($\theta_c=30^\circ$) is used instead of the first one ($\theta_c=9^\circ$) because of the convenience of operation.

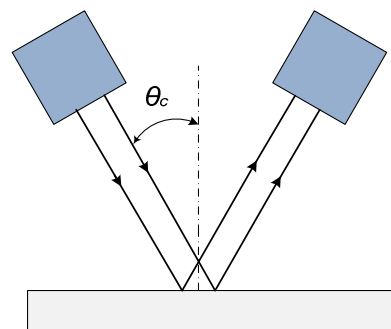


Figure 1: Schematic of pseudo pulse-echo mode at the critical angle θ_c .

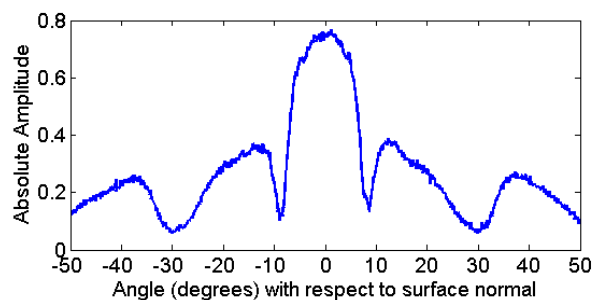


Figure 2: Absolute amplitude of transmitted wave through the sample plates at different incident angles.

3 Data processing

In this section the response signals obtained in the scan using three experimental modes are analyzed first, and followed are the detailed data analysis approaches.

3.1 Response signals

The time-domain response signals obtained at both unimpacted area and impacted area in three modes are shown in Figure 3. It can be observed that at the unimpacted area three response waves are detected for pitch-catch mode and pulse-echo mode and two detected for pseudo pulse-echo mode. This is logical results based on the fact that composite plates have small thicknesses. This characteristic makes it possible to extract more information concerning the inner defects by analyzing the second and even the third response signals because they go through the plates more times than the first one and accordingly contain more information about the inner structures.

It can also be observed that for both pulse-echo and pseudo pulse-echo modes, the interval between the first response wave and the second one experiences more changes than other time ranges. This fact can also be used in data processing for the purpose of obtaining effects of inner destruction caused by impact.

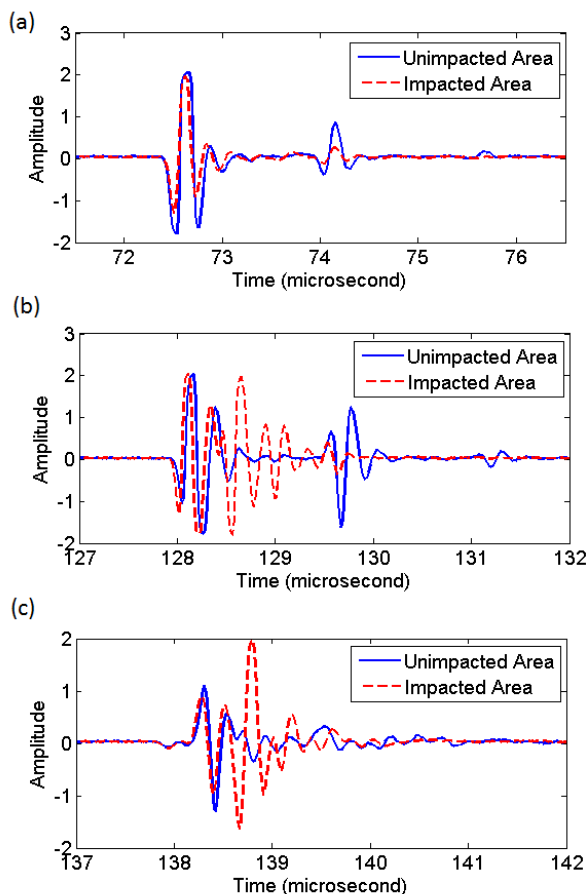


Figure 3: Comparison of response signals at unimpacted area and impacted area for (a) pitch-catch mode, (b) pulse-echo mode and (c) pseudo pulse-echo mode.

3.2 Time-domain data analysis

The properties usually used to characterize material properties in ultrasonic nondestructive testing are time-of-flight (TOF) and amplitude. The damaged structure in the plate can change sound velocity and phase and this can be observed in time-domain through the changes of TOF for specific wave properties like maximum peak, minimum peak and preset threshold. Also, the damaged inner structure can attenuate sound energy leading to decrease in amplitudes. This effect is evaluated in this work by recording the amplitudes of positive peaks and negative peaks and their maximum absolute values.

3.3 Frequency-domain data analysis

As we know different frequency components of a bulk sound beam have different sensitivity to the same structure. Taking advantage of the large frequency range of about 6 MHz, from 1 MHz to 7 MHz, produced by the transducer used, the impact defect can be examined at different frequencies.

Figure 4 shows the comparison of frequency responses between a wave obtained from unimpacted area and one from the impacted area in pitch-catch mode. It can be observed that due to the limited thickness, oscillating components appearing at a period of around 0.66 MHz in the spectrum of a signal obtained from unimpacted area are not obvious in the spectrum of the signal obtained from impacted area. This leads to a relatively large difference in amplitude at those frequencies and they are used in this work to evaluate the effects of damaged inner structure. In addition, the same phenomenon can be observed in pulse-echo mode.

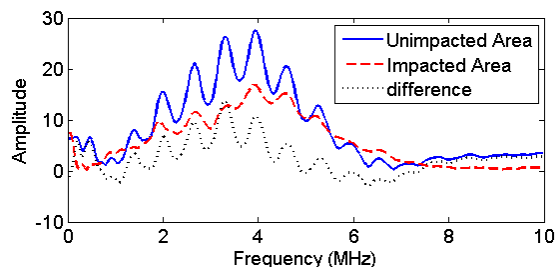


Figure 4: Comparison of the spectrums of response signals at unimpacted area and impacted area for pitch-catch mode.

4 Results and discussion

It is easy to understand that it is more difficult and challenging to detect the impact damages in Sample 1 because it was applied by much less external impact compared to Sample 2. Therefore, for the purpose of comparing the feasibility and sensitivity of the proposed approaches, only the results obtained from Sample 1 are shown in this section.

4.1 TOF and amplitude

In order to compare the feasibility of the most commonly used wave characteristics, TOF and amplitude, in characterizing the impact defect inside the sample plates, both amplitudes and TOFs in a 40mmX30mm C-scan are shown in Figure 5. It can be easily observed that amplitude

is much more sensitive to the inner impact damage of the sample composite plates than TOF. This is probably due to the fact that the thicknesses of the samples are small and so there is no enough length for sound speed change being detected and clearly visualized in the form of C-Scan. The reason that amplitude has strong sensitivity to impact defects is probably that the inner structures of the damaged area are irregular and this causes more energy loss by sound diffraction.

Since amplitude has strong sensitivity in detecting impact defects, the following discussion will focus on amplitude change in both time-domain and frequency-domain.

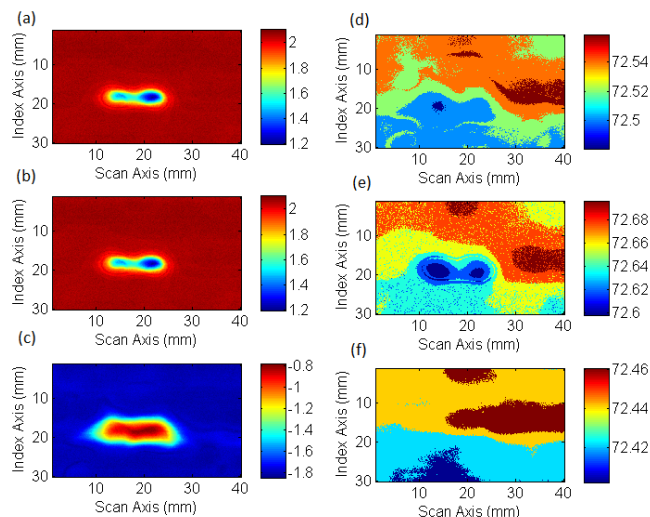


Figure 5: Comparison of the effects of amplitude and TOF in characterizing the impact defect for Sample 1. (a), (b) and (c) are respectively the amplitudes of absolute values, maximum peaks and negative peaks of the first response wave at each position; (d), (e) and (f) are respectively the TOFs to negative peaks, positive peaks and preset threshold.

4.2 Time-domain attenuation

As noticed in Figure 3 in pitch-catch mode there are three waves in time-domain after going through the plates. Their amplitudes are different due to the attenuation they experience in the process of traveling within the plate: the first wave goes through the whole thickness once, the second one three times and the third one five times. It is logical that the more times a wave going through the plates, the more attenuation they get and the more information they carry about the inner structures of the plates. However, the more attenuated the waves are, the smaller the ratio of signal to noise are and this makes the third wave less sensitive to the inner structural defects.

The difference stated above can be observed in Figure 6 through comparison of the amplitudes of the maximum peaks and minimum peaks of the first wave and the second wave obtained in pitch-catch mode. The defect areas obtained from the second wave is much larger than those obtained from the first wave. This does not mean that one of them is less accurate and less reliable in characterizing the inner defects, but they carry the information of the same defects at different levels. Obviously, the results obtained from the second wave tell us more.

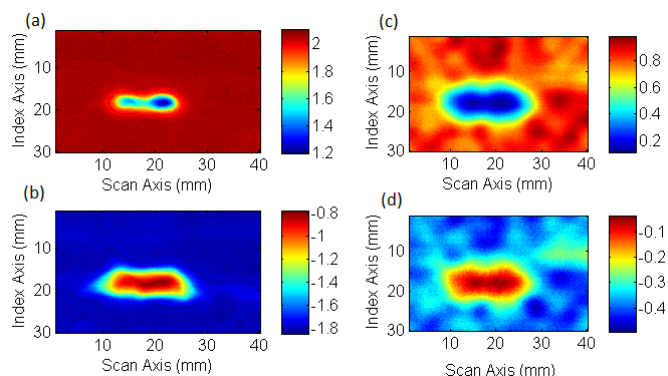


Figure 6: Comparison of the amplitude sensitivity to impact defects of the first wave and the second wave in pitch-catch mode. (a) and (b) are respectively the amplitudes of the maximum peaks and minimum peaks of the first wave; while (c) and (d) are those of the second waves.

For pitch-catch mode the first wave carries enough information to characterize the defects because it goes through the plate once, but for pulse-echo mode and pseudo pulse-echo mode the first wave is mainly specular reflection from the plate surface and therefore not sensitive to the inner defects. For these two cases the signals in the interval between the first and the second waves are more sensitive to the defect because they are mainly the reflection from the inner defects in the plates before the sound reaches the bottom surfaces of the plates. The maximum amplitudes of the signals in the intervals are compared with those obtained from the second wave in pulse-echo mode and the whole waves in the pseudo pulse-echo mode in Figure 7. It can be seen that the interval signals give clear image about the shape of the defects.

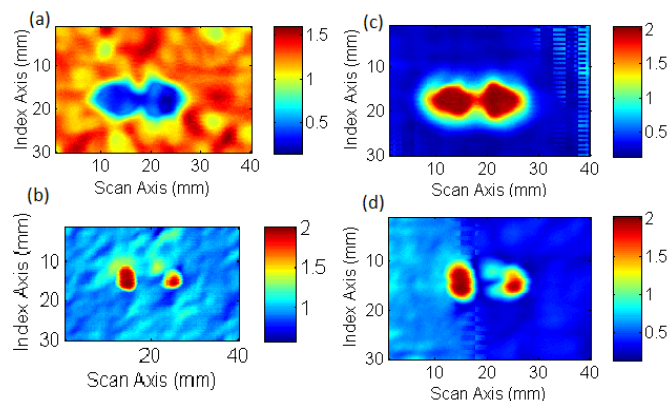


Figure 7: Comparison of the amplitude sensitivity to impact defects of the signal in the interval between the first two waves in (a) pulse-echo mode and (d) pseudo pulse-echo mode and the second wave in (a) pulse-echo mode and the first wave in (b) pseudo pulse-echo mode.

4.3 Frequency-domain attenuation

Based on the fact that sound waves of different frequency have different wavelength, and that sound with different wavelengths have different sensitivity to the defects in the thickness direction, the attenuation of sound energy in frequency-domain may give us information concerning the defect levels at different depth of the plates although it is hard to identify the relationship between the depth and the frequency.

In Figure 8 the attenuation of sound at six different frequencies are shown in the form of spatial C-scan. The

frequencies chosen here are those corresponding to the peaks in Figure 4. The interesting thing is that they all confirm the position of the defects, but the damage level (indicated by color) of the defect relative to the neighborhood areas are different. This is reasonable because at different depth, the damage levels are different.

For all the three modes tried in this study, frequency-domain analysis works well as shown in Figure 8.

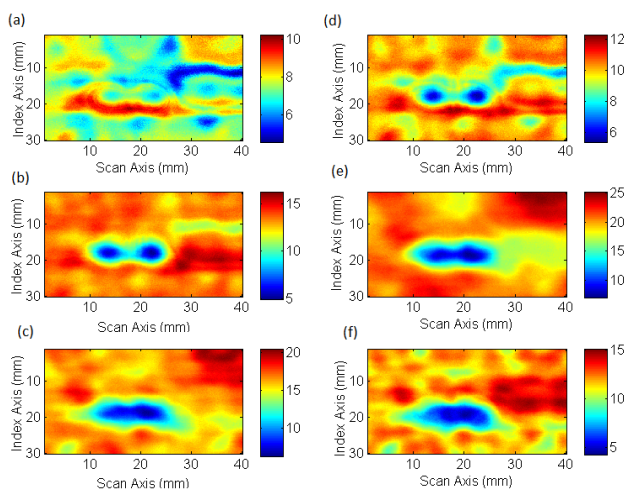


Figure 8: Comparison of the responses of maximum amplitude to the impact defects in pitch-catch mode at different frequency components: (a) 1.98 MHz, (b) 2.67 MHz, (c) 3.30 MHz, (d) 3.93 MHz, (e) 4.58 MHz and (f) 5.25 MHz.

4.4 Effect of transducer types

Through comparison of the results obtained with unfocused transducer and focused transducer, it can be observed that the focused transducer can give better relatively stronger signals and more clear images. Therefore, in this kind of damage detecting focused transducers are recommended.

5 Conclusion

All the three experimental configurations work efficiently in characterization of the impact defects inside the composite plates. Due to the small thickness and the relatively narrow pulse width, more than one wave are obtained and this offers more options in choosing signals from which defect information can be extracted. It is observed that the first two waves carry defect information of different levels in pitch-catch modes and that the signals lying in the interval between the first two waves in pulse-echo mode and pseudo pulse-echo mode work more efficient than other waves.

It is also observed that time-of-flight (TOF) is less sensitive than amplitude in indicating defects. In both time-domain and frequency-domain amplitude can well indicate the defect information. Furthermore, the amplitude changes in frequency due to different sound attenuation at different areas carry information of defects at different depth. It is worth exploring the relationship between the depth and the frequency which promises the possibility of obtaining a three-dimensional representation of defects through a simple C-scan.

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