NDE OF THICK GRAPHITE/EPOXY COMPOSITES: SOME APPROACHES AND PROBLEMS

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INTRODUCTION

Composite materials are being used in many applications because they can be tailored to meet specific design requirements. Fiber and resin type, fiber orientation, layering, and thickness are deliberately used during prepreg layup or filament winding to give a composite structure specific, desirable properties. These quantities are useful design parameters, but produce attenuation of ultrasound and anisotropy in material properties, which cause difficulty in performing NDE. For example, thick, filament wound composites generally have more porosity than prepreg composites, which further increases attenuation of the ultrasonic signal. Geometric and/or viscoelastic effects cause dispersion of the wavespeed and attenuation coefficient i.e. they are frequency dependent. The general anisotropy of the composite causes the wave velocity to be a function of direction. However, some way to inspect structures made from these materials must be found if their usefulness is to be exploited.

In this paper, we mention some of the problems associated with ultrasonic measurements in thick composites. We will present ultrasonic NDE techniques which have been successful and give results of experimental work. Some possible solutions to these problems will be presented.

TWO CAUTIONS

Thick graphite/epoxy materials, especially filament wound materials, preferentially attenuate high frequency ultrasound. In Fig. 1, we compare the Fourier transformed pulses passing through water and a filament wound sample about 1/2 inch thick. The center frequency of the transducer was about 7 MHz. Note that after passing through the filament wound sample, the center frequency is now about 3.5 MHz and the amplitude has decreased dramatically.

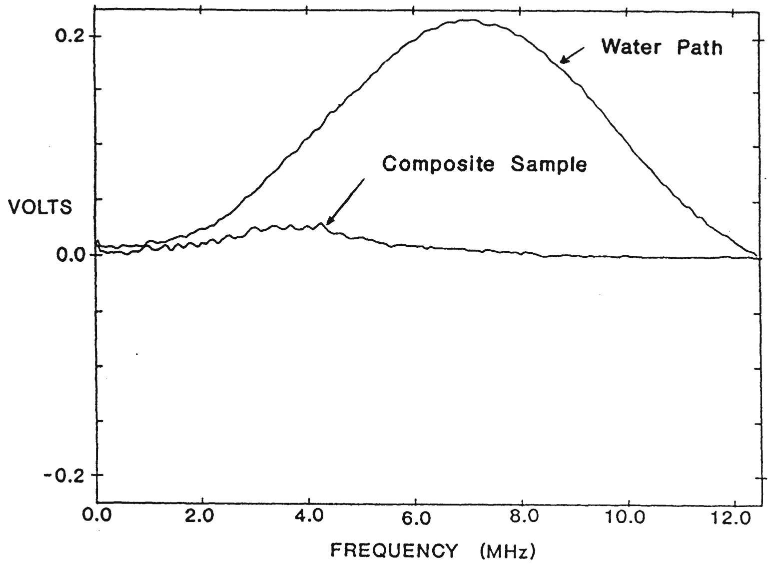


Fig. 1. Comparison Of Pulses Through Water And Filment Wound Material Showing Attenuation Of Amplitude And High Frequencies.

In Fig. 2, the RF envelopes of the pulse passing through a water path and through a filament wound sample are compared. Note that if the feet of the envelopes are aligned, the peaks do not match, and conversely, if the peaks are aligned, the feet do not match. This behavior points out the need to be careful in choosing which part of the wave to use in making time of flight measurements for velocity calculations.

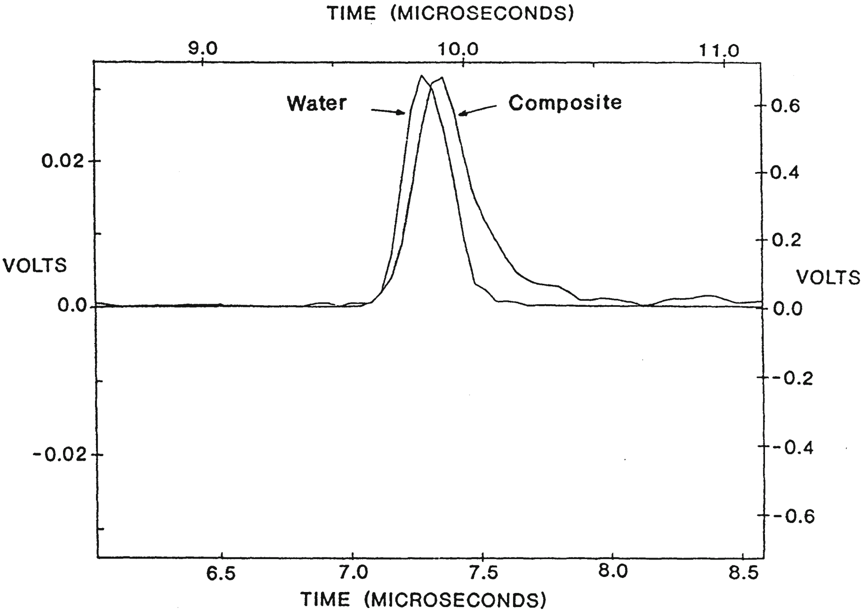


Fig. 2. Comparison Of RF Envelopes For Water and Filament Wound Material Showing Time Shift In Envelope Peak.

EXPERIMENTAL RESULTS

Our approach has been to use an NDE technique that takes advantage of a specific composite property when ever possible. Ultrasonic backscatter [1,2] was used to monitor fiber orientation. the results of backscatter measurements on a cylindrical filament wound specimen are shown in Fig. 3. In Fig. 3a, the peaks at -36° and -215° are from the plus helical windings, the peaks at -330° and -150° are from the minus helical windings, and the peaks at -90° and -270° are from the radial windings. Shown in Fig. 3b is a cylindrical specimen that was hydroproofed before the backscatter data was taken. Note the increased number of peaks that are visible. The peaks apparently result from scattering off cracks produced by the hydroproofing.

Figure 4 shows amplitude and wavespeed C-scans from an impact damaged region of a filament wound specimen. Typically, the background variation in the amplitude data of an undamaged region of filament wound material can vary by several tens of a percent, whereas the typical variation in the wavespeed is only a few percent. Note that the impact damage is difficult to resolve in the amplitude C-scan, but can readily be seen in the wavespeed C-scan.

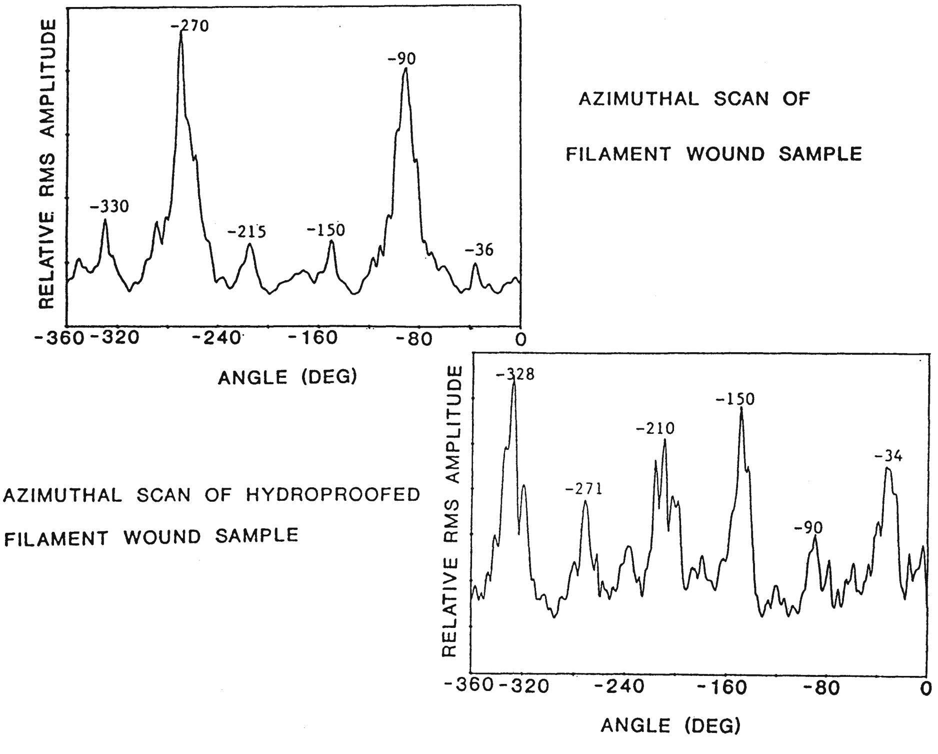
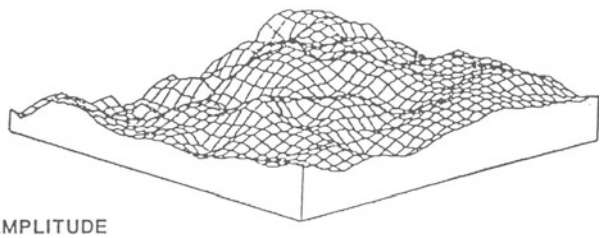
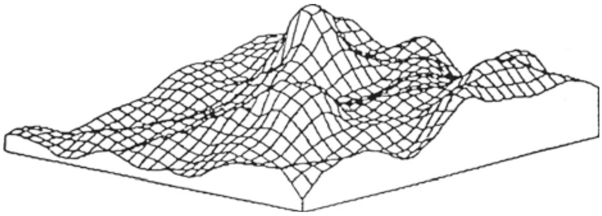


Fig. 3. Ultrasonic Backscatter Results for Filament Wound Material showing Fiber Orientation.



(A) AMPLITUDE



(B) MAXIMUM WAVESPEED MINUS WAVESPEED

Fig. 4. Surface Map Representation Of C-scan Data For An Impact Damaged Sample of Filament Wound Composite.

Another method of examining the data is to plot one property versus another. In Fig. 5, the attenuation coefficient is plotted against the wavespeed. These data were obtained from a filament wound specimen damaged by impact using a multi-parameter C-scan method [3] in which the wavespeed and attenuation coefficient are calculated from amplitude and time-of-flight measurements taken at each pixel. Note that there is an inverse relationship between the change in attenuation coefficient and the change in wavespeed. Such plots show very clearly whether damage has occured in a suspect region whereas an amplitude only C-scan may not.

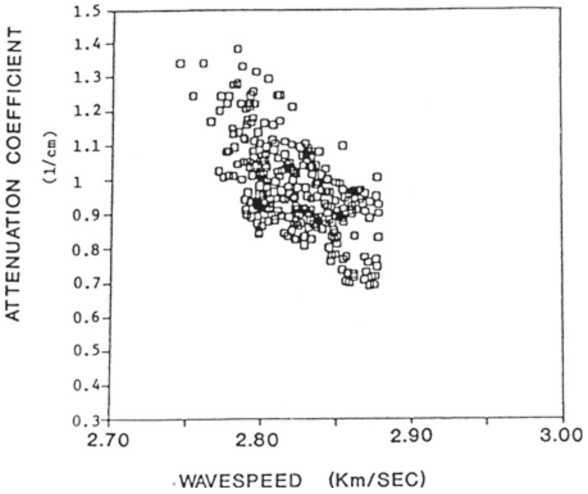


Fig. 5. Wavespeed Plotted Against Attenuation Coefficient For Damaged Filament Wound Material.

Pulse spectroscopy [4] measurements (phase and amplitude) were used to study the frequency dependence of the wave velocity and attenuation coefficient. Figure 6 shows the wave velocity dispersion and Fig. 7 shows the variation in the attenuation coefficient in the axial, radial, and hoop directions in a filament wound specimen. These data were taken with a 1 MHz transducer. Figure 8 shows dispersion measurements in the axial direction of the same specimen using a 2.25 MHz transducer. These figures show the dispersive nature of the filament wound graphite/epoxy material in the in-plane directions.

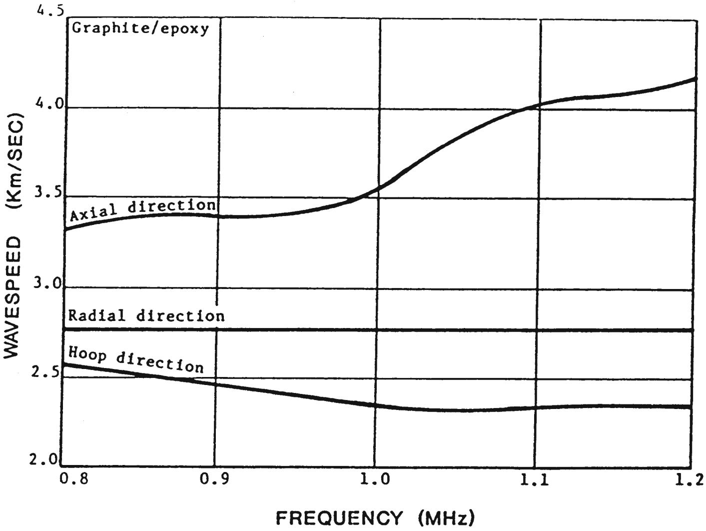


Fig. 6. Wavespeed Versus Frequency For A Filament Wound Sample Using 1 MHz Transducers.

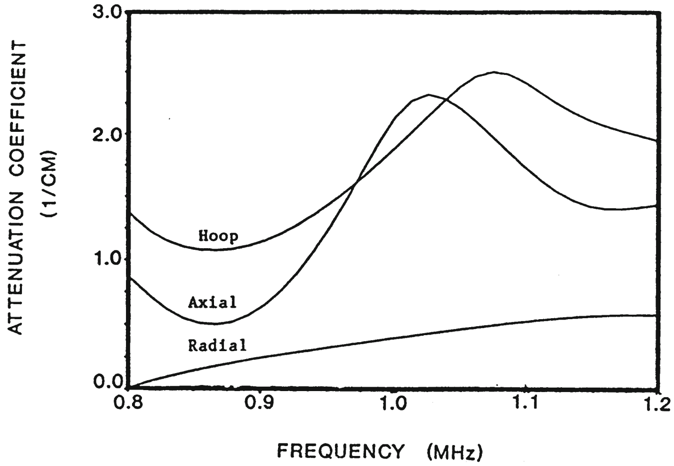


Fig. 7. Attenuation Coefficient Versus Frequency For A Filament Wound Sample Using 1 MHz Transducers.

A recent development has been the capability of digitizing the entire ultrasonic signal at each pixel of a scan and storing the signal in computer memory. From these stored signals, the data can be processed in several ways. For example, C-scans at any depth can be plotted or Fourier transformations done. We have used a digital pulse-echo system to study bond lines between thick composites. Figure 9 shows a digital C and B-scan displaying debonds at the interface between the 2nd and 3rd composite layers. Note that the C-scan is at the depth of the interface between the 2nd and 3rd composites and the B-scan is along the line shown in Fig. 9 (a). Since the B-scan is an ultrasonic "cross-section", other features such as defects in the 1st composite and the interface between the 1st and 2nd composites are also evident.

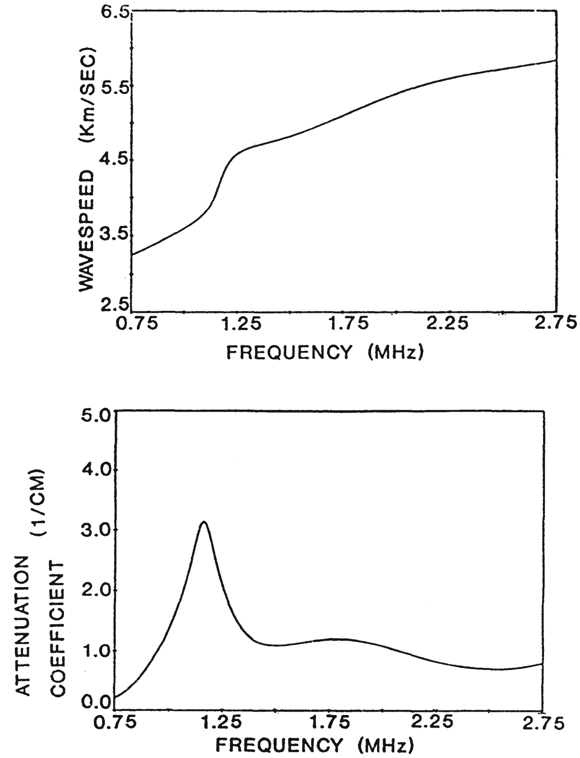
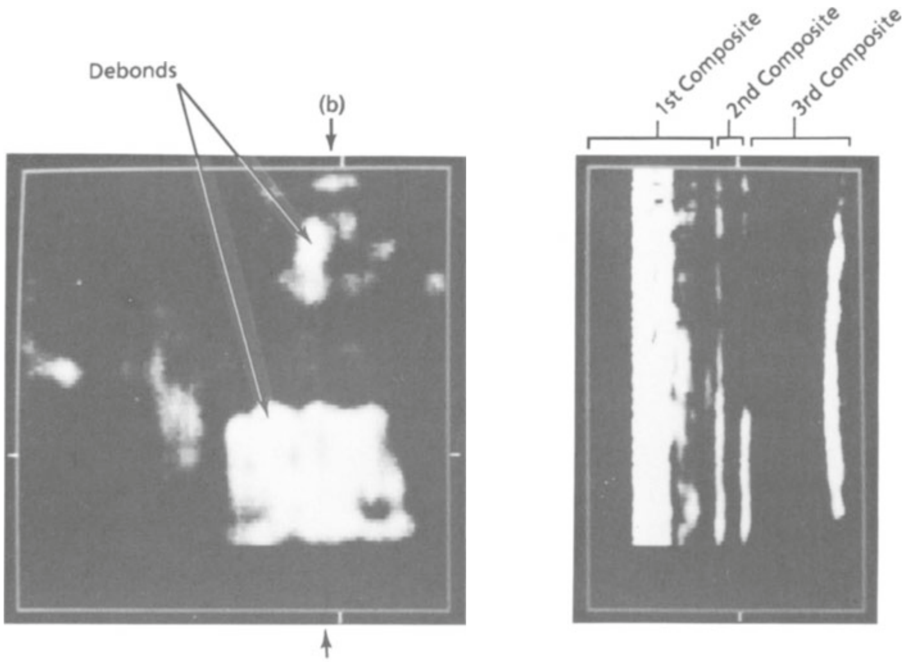


Fig. 8. Wavespeed and Attenuation Coefficient Versus Frequency for the Axial Direction of a Filament Wound Specimen Using 2.25 MHz Transducers.



(a) C-scan at interface between 2nd and 3rd composite

(b) B-scan along line shown in (a).

Fig. 9. Digital Pulse-Echo Scan Disply Showing Debonds in a Thick Multi-Layer Composite Sample.

NEW APPROACHES

One of the major difficulties in inspecting thick or attenuating composites is the lack of penetration depth for an ultrasonic signal because the sample attenuates the signal, particularily the high frequency components. Since the peak voltage that can be applied to the transducer is limited and a signal longer than a pulse results in loss of resolution, some other methods must be tried. One method of increasing penetration is to lower the frequency, typically to around 200 to 500 KHz with a subsequent loss in resolution. We are currently looking at some other methods of achieving greater penetration and still maintaining reasonable resolution. Among the methods under consideration are pulse compression [5], pseudorandom binary noise correlation [6], and time delay spectrometry [7]. One of the major factors we must consider is the amount of computer time needed to process the data, since our goal is to develop a system that can be used in a manufacturing and field environment. Our work is not far enough along yet to choose between these methods.

A second difficulty in inspecting thick composites with ultrasonics is that the image, in general, is formed by waves coming from multiple paths. Hence, the image resolution and signal to noise ratio can be lower than is desirable. In addition, the actual flaw location may be different than shown by the image. One way to improve flaw location and resolution is by using the synthetic aperture focusing technique (SAFT) [8].

In using SAFT, a time shift is introduced in the signal recorded at each transducer position which is the inverse of the time delay resulting from the travel distance of the signal from the tranducer to the flaw and back. This travel distance changes as the transducer scans over the sample, being a minimum when the transducer is immediately above the flaw and increasing as the transducer scans to either side. This time delay correction involves knowing the sound velocity of the wave in the sample material. When the sample is a composite, the problem of determining the appropriate time shift for each transducer position is complicated because the wave velocity is a function of direction in the sample. We are currently working on a (SAFT) algorithm for anisotropic materials which will account for this variation in wave velocity as a function of direction.

ACKNOWLEDGEMENTS

This work was partially supported by Hercules IR&D funds. We wish to thank Janene Rees for assistance with computer software and K.C. Eldredge for typing the manuscript.

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