ULTRASONIC TECHNIQUES TO PRODUCE DAMAGE PROFILES THROUGH THE THICKNESS OF A SAMPLE

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INTRODUCTION

There are two basic approaches to quantitative nondestructive evaluation (NDE); the first is concerned with images and the second is concerned with material properties. The objective of the first approach is to produce an exact image of a defect or anomaly in a given sample. The defect may arise in the manufacturing process or it may occur later in the service life of the sample (i.e. damage produced by impact or mishandling). Ideally, the NDE method should produce a clear image and be capable of locating the defect in lateral extent as well as depth which would allow an observer to determine the damaged volume. In the second approach, the objective is not principally to produce an image, but rather to relate some acoustic parameter with a material property parameter. As a bonus, some of the NDE techniques in this second category also produce an image of the damaged or defect area.

Information from both approaches is required to properly disposition defective or damaged composite parts or structures. If damage or a defect is found in a part during manufacture, what should be done with the part? How critical is the damage/defect? Should the part be scrapped or can it be finished and will it meet the service specifications? If damage occurs subsequent to manufacture, can the part or structure be kept in service or should it be retired for cause? All these questions can only be answered with the aid of quantitative NDE data.

This paper addresses the problem of producing a clear image of the lateral extent of damage as well as the damage profile through the sample thickness in graphite/epoxy composites. Two techniques, (gated ultrasonic backscatter and gated pulse-echo) are described. C-scan images of impact damage in both laminates and filament wound material are presented and the results compared with damage data obtained from photomicroscopy and thermal deplying using gold chloride penetrant.

DESCRIPTION OF THE EXPERIMENTAL TECHNIQUE

Two different ultrasonic techniques have been used to obtain damage profiles through the thickness: Ultrasonic backscatter and pulse echo. The ultrasonic backscatter technique has been described elsewhere (References 1, 2), and the pulse-echo technique is well known so the experimental details will not be given here.

As far as can be determined, most backscatter and pulse-echo C-scans have been done as averages of the entire thickness of the sample. The new development presented here permits a damage profile as a function of the sample thickness to be obtained.

Figure 1 shows the schematic arrangement of the ultrasonic transducers and the sample. Two transducers were used (although three are shown for descriptive purposes), one whose beam was normal to the sample surface and one inclined at an angle γ to the surface normal. As a sender, the normal transducer emits a pulse which impinges upon the sample and is scattered in all directions as well as being transmitted through the sample and reflected from the back wall. The angle transducer receives that portion of the total signal which is backscattered at the angle γ. The sending transducer also receives that portion of the incident pulse reflected from the front and rear sample surfaces as well as from the entire sample thickness. By proper signal processing, a backscatter signal and a pulse-echo signal may be obtained.

The time interval between the front and back surface reflections is twice the ultrasonic wave transit time through the sample. This time interval was divided into several equal increments. The received signals from the front and rear surface of the sample were peak detected. The output of the received signal from the front surface was used to establish a zero time. In the usual backscatter or pulse-echo C-scan, the transducers receive energy from the entire sample thickness. In these experiments, the peak detector gate for each transducer was set to cover only a specified time window (i.e. twice the sample transit time divided into a predetermined number of equal intervals each of width Δt). A delay was introduced between the reception of the front surface reflection by the normal transducer, the start of the angle transducer detector gate, and the normal transducer gate. The delay was set at 0 for the first scan, at Δt for the second scan, at 2 Δt for the third scan, at 3 Δt for the fourth scan, etc., until the time window had progressed entirely

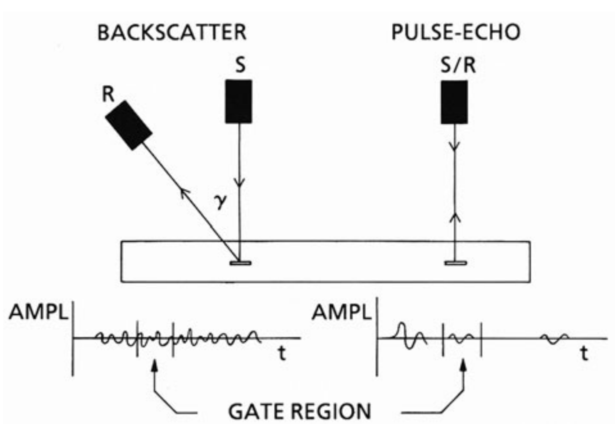

Fig. 1. Schematic diagram showing the elements of time-gated ultrasonic measurements (S and R signify sending and receiving transducers respectively).

through the sample. The backscattered and pulse-echo signals for each scan came from that portion of the total backscattered and pulse-echo signal appropriate to a particular layer of the sample. By using the reflected signal from the front surface as zero time, the system had, in effect, a front surface follower. Any misalignment between the scan plane of the transducers and the surface of the sample is negated. With this transducer arrangement, a backscatter and a pulse-echo C-scan can be obtained at the same time.

The peak detectors are analog devices, thus the transducers can move continuously, and a scan can be performed in a few minutes. The analog signal from the peak detectors was digitized by an A/D converter in the computer. A much longer time is needed for a scan if the backscatter and pulse-echo signals are first digitized at each transducer position.

EXPERIMENTAL RESULTS AND DISCUSSION

Gated backscatter and gated pulse-echo measurements were performed on the same graphite-epoxy plate (Hercules IM7XG/2502) 4 inches X 6 inches and 32 plies (0.180 inches) thick, subsequent to impact. The fiber layup was $(+45/90/-45/0)_{4S}$. This plate was impacted by a 5/8 inch diameter ball at an energy of 22.5 ft-lbs. The rear surface of the plate was unsupported while the two long sides were lightly clamped.

The gated backscatter results are shown in Figure 2. Seven scans

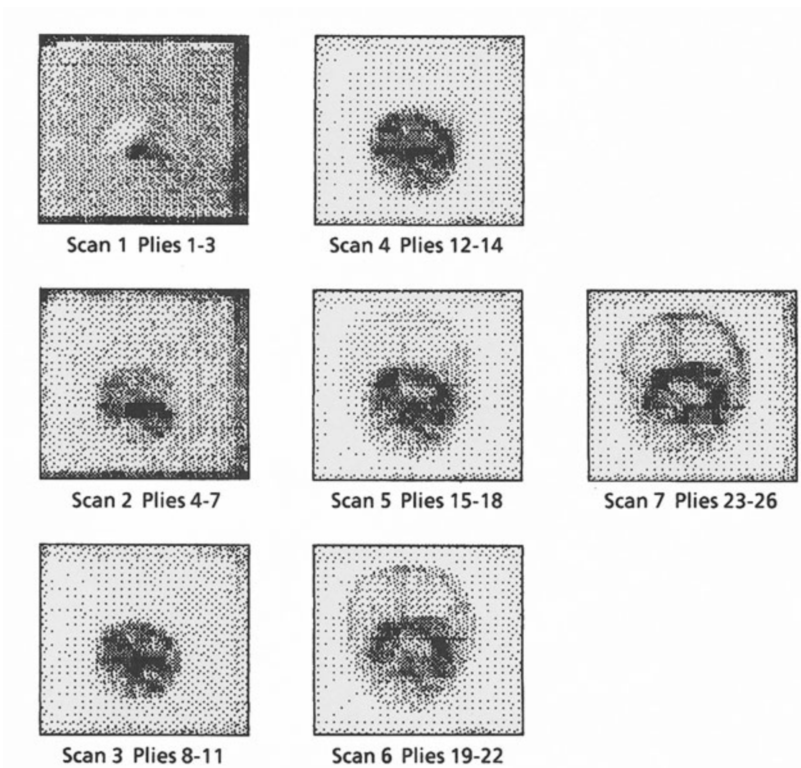

Fig. 2 Time-gated backscatter C-scans showing impact damage profile through the sample thickness in a laminate plate.

are shown, each scan covering three to four plies of the sample. Although the time interval gates for the backscatter and pulse-echo scans were identical, the number of plies covered by the two types of scans was different because of the difference in path length of the signal in the sample (see Figure 1). In the sample, the backscatter signal travels at an angle to the sample surface normal while the pulse-echo signal travels normally.

The first backscatter scan shows damage very near the surface. In Figure 2, Scans 2 and 3 show a central region of damage about 1 inch in diameter. The same central damage region is evident in Scans 4 through 7. In addition, a larger oval region becomes evident in Scan 4 and becomes more apparent in Scans 5, 6, and 7. Note the vertical feature just above the central area in Scans 6 and 7.

The results of the gated pulse-echo experiments are shown in Figure 3. Six time intervals were chosen for this test, each scan covering about five plies of the sample. In the first three scans, the impact damage is confined to an area of about 1 inch in diameter. In Scans 4 and 5, a larger area outside the 1 inch diameter area is evident.

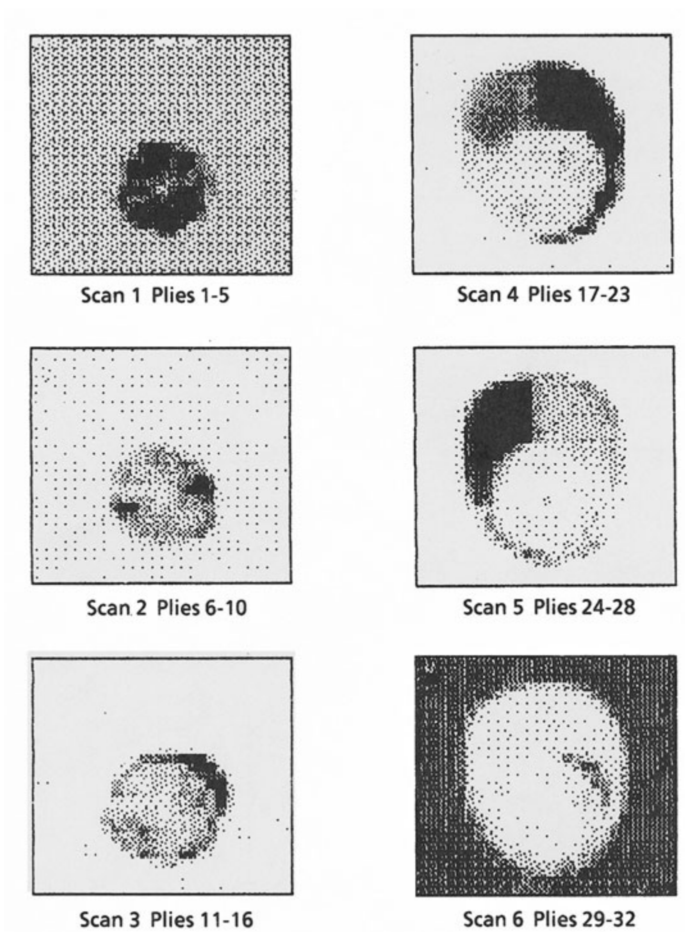

Fig. 3 Time-gated pulse-echo C-scans showing impact damage profile through the sample thickness in a laminate plate.

Note that the darker portion (the darker the image, the higher the amplitude of the reflected signal) of this outside area shifts sides in Scan 4 vs. Scan 5. Also, there is a sharp vertical boundary separating the darker and lighter parts (compare with the vertical feature in Scans 6 and 7 of Figure 2). Only a few details are visible inside the light oval area of Scan 6.

Figure 4 presents damage area maps for each ply obtained from photomicroscopy. The graphite/epoxy plate discussed above was sectioned through the center of the impact and one half was potted in epoxy. Additional slices were cut from the potted section at 0.075" intervals. One face of each slice was polished and examined with a microscope for the type and extent of damage in each ply. The extent of damage from each slice was combined to produce the isometric damage map shown in Figure 4.

The damage (as shown in Figure 4) is slight in the first four plies (as shown by Scan 1 of Figures 2 and 3) then increases in area in Ply 5 and is roughly constant down to Ply 22. Large delaminations are apparent in Plies 22, 23, and 24. From Ply 25 to Ply 32, the damage area is again about the same size as from Ply 5 to Ply 22. Notice that the delamination in Ply 23 has a very sharp inner edge. Photomicrographs of this region show that the delamination is along the interface between Plies 22 and 23 and then cuts through Ply 23 and runs along the interface between Plies 23 and 24. The cut is very sharp and is shown in Figure 4 as the sharp inner edge on the delamination in Ply 23.

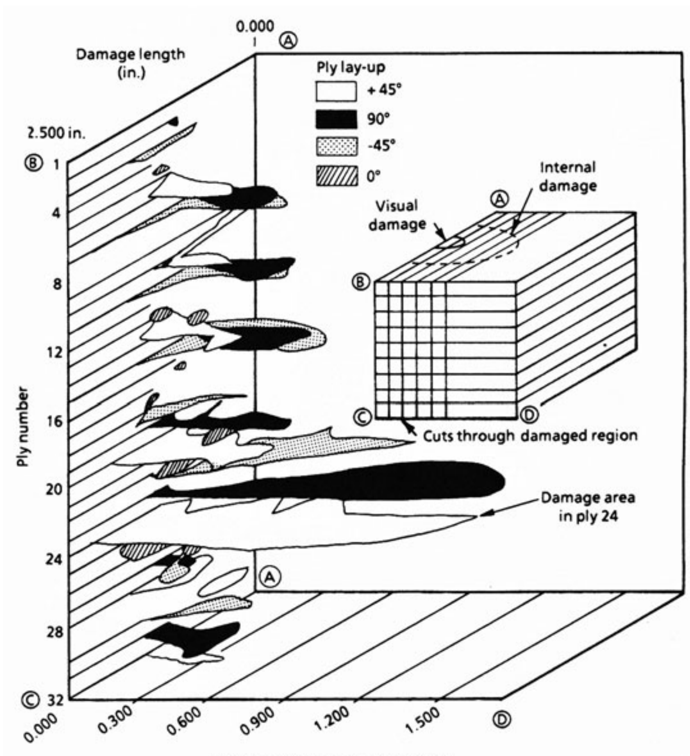

Fig. 4 Microscopy cross section results were used to develop damage area maps for each ply in a graphite/epoxy composite plate. Compare with ultrasonic results from same plate shown in Figures 2 and 3.

The ultrasonic measurements of Figures 2 and 3 and the damage area shown in Figure 4 compare very well. The sharp line outside the central region in Scans 6 and 7 of Figure 2 and the sharp boundary between the light and dark areas in the corresponding place in Scans 4 and 5 of Figure 3 correspond to the sharp delamination boundary shown in the 23rd ply damage of Figure 4.

A graphite-epoxy panel (IM6/3501-6) 4 inches X 6 inches X 0.180 inches thick (32 plies) was impacted by a 5/8 inch diameter ball with an impact energy of 22.5 ft-lbs. The layup was $(0/+45/-45/90)_{4s}$. This panel was supported in the same way as described above. Following impact, the gated pulse-echo technique was used to examine the damage.

Seven C-scans, each representing a thickness of about 4.5 plies, are shown in Figure 5. These C-scans were compared with results of thermal deplying combined with a gold chloride penetrant. The deplying method and application of the gold chloride solution are described in Reference 3. A comparison between the first C-scan of Figure 5 and a photomicrograph of the fourth ply is shown in Figure 6. The agreement between the damage areas shown by both techniques is quite good.

The gated pulse-echo technique was next applied to a filament wound tube. The tube was 12 inches in diameter and 22 inches long. It was filled with RTV silastic to simulate propellant and the exterior surface was covered with a silastic 45E protective layer.

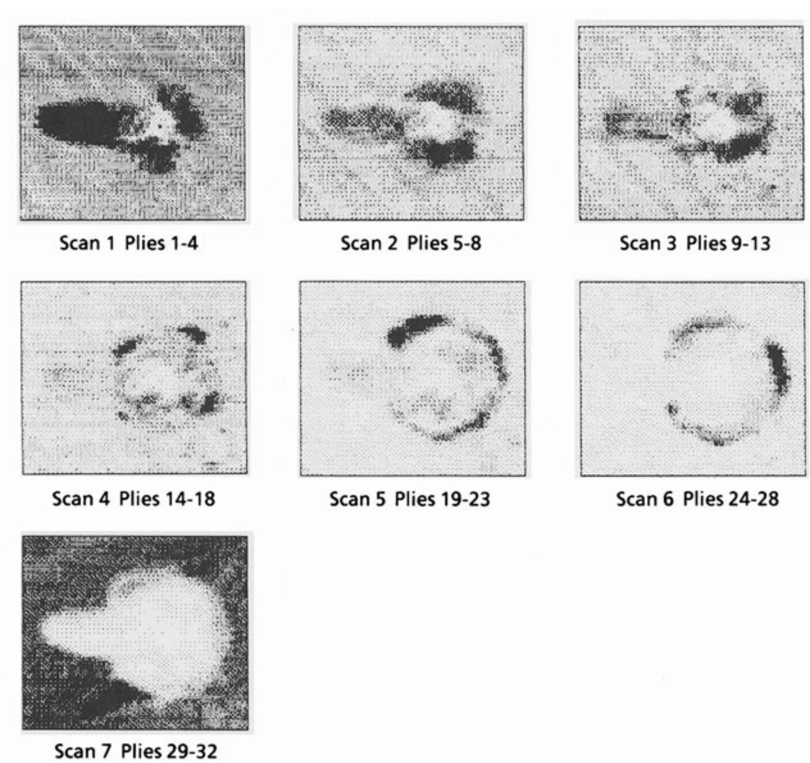

Fig. 5 Time-gated pulse-echo C-scans showing impact damage profiles through the thickness of an IM6/3501-6 graphite/epoxy laminate.

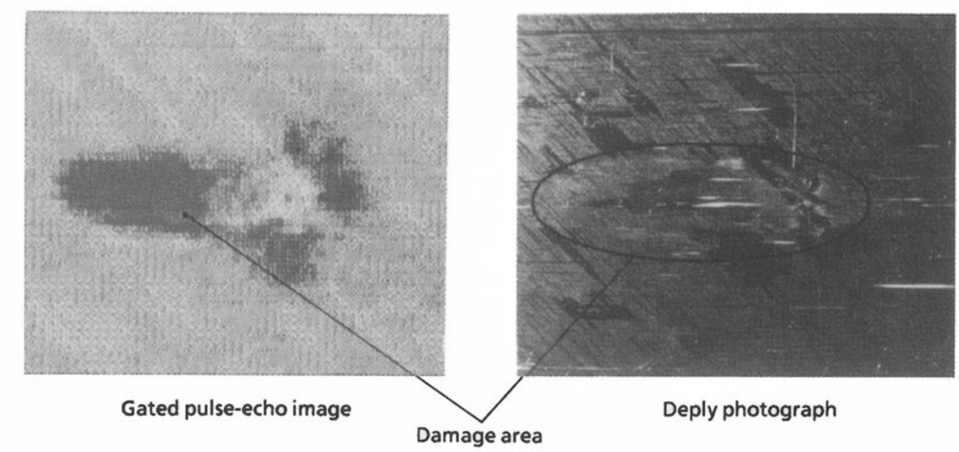

Fig. 6 Comparison of apparent zone of damage imaged by the gated pulse-echo technique with a photograph of damage indication from the deply technique with gold chloride penetrant.

The tube was supported in a wooden cradle and impacted by a 11/4 inch diameter tup with a 2 inch radius at an impact energy of 40 ft-lbs. The layup for this tube was (+21.8/0/90/0/+21.8/0/90/+45). The axial direction was the 0 degree direction. The actual wall thickness of the tube was about 0.2 inches.

The protective layer was removed before the C-scans were performed. The experimental results of the gated pulse-echo measurements are shown in Figure 7. Six scans were obtained, each corresponding to just over 1 ply layer. In Figure 7 black represents maximum reflected energy. Each scan covers an area about 3.5 inches by 4.5 inches. A delamination is evident very near the surface on the right of the impact (first scan). In the second scan, another delamination is apparent also on the right of the impact site. This delamination grows to the left in the next scan. A new delamination appears at the top and bottom of the fourth scan and is still evident in the fifth scan. The back wall signal shows little evidence of any delaminations indicating the the damage is internal.

CONCLUSIONS

Gated backscatter and gated pulse-echo techniques have proven very satisfactory in characterizing the damage profile as a function of depth in a sample. Correlations between the ultrasonic results and those from photomicroscopy and thermal deplying were good. Such correlations indicate that ultrasonic methods can be used with confidence to define the damage volume in composite materials.

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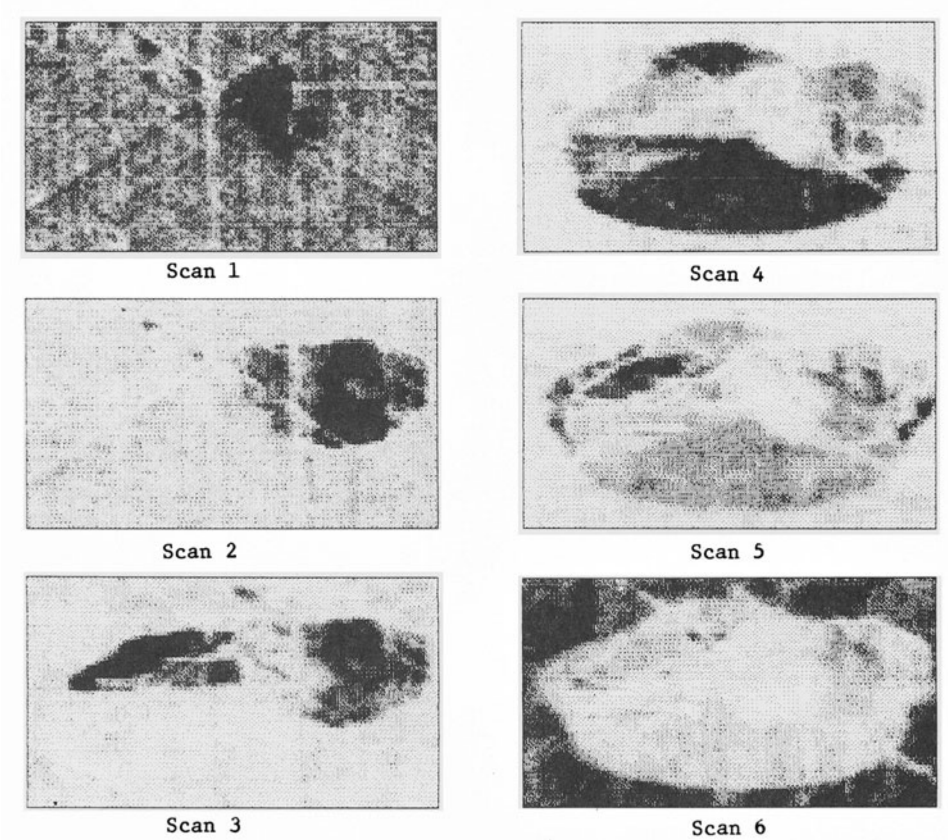

Fig. 7. Time-gated pulse-echo C-scans of a filament wound tube.

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