INTRODUCTION

This paper will report on the results of a study of the application of advanced digital data acquisition technology to the problem of impact damage in composites. This area was chosen for the study because of the importance of developing better damage characterization methods and the limited scope of the damage itself. Low energy impacts on composite specimens typically produce very small indentations at the impact site and internal delaminations at the interfaces between lamina. Thus, one can very accurately set the ultrasonic time gates for imaging the delaminations on a layer-by-layer basis.

Conventional ultrasonic methods are typically capable of producing C-scan images which show the total area damaged by an impact in a composite. More advanced instrumentation than is currently available in the field can provide detail as a function of depth by using multiple gates on the detected and filtered signal. The advent of high speed transient recorders with the capability to digitize, store and transfer large amounts data has provided the capability to perform many analog functions in software. This should provide either more information or better resolution than current capabilities.

SPECIMENS

Quasi-isotropic, 32-ply graphite composite specimens with epoxy or PEEK (polyetheretherketone) matrices were prepared. 16 x 4-inch flat panels were fabricated. Each panel was impacted at four equally spaced points with different loads. During impact, the panels were supported by a 4-inch diameter cylinder placed under the panel. The impact energy was transmitted through a 1/2-inch diameter spherical impactor. Impact energies ranged from 5 ft-lb to 30 ft-lb. The lower impact energies were of greatest interest for ultrasonic inspection due to the fact that less apparent damage was visibly evident. The higher impact energies produced very evident physical damage on both the impacted side and on the back side.
EXPERIMENTAL PROCEDURE

The impacted specimens were ultrasonically scanned using a laboratory scanning system which included a LeCroy 200 MHz transient recorder. Complete details on the system are given elsewhere [1]. An area of 2 x 2 inches centered on the impact site was scanned using a 0.01-inch step size. Data was collected in various modes to be able to compare the performance of several data collection and analysis methods. Conventional methods were simulated by using only the detected and filtered back surface reflection for the image data. In order to simulate more advanced systems, time gates were set at the round trip transit times for several of the lamina. Finally, time gates were simultaneously set at various multiples of the round trip transit time for a single lamina, and the minimum or maximum value of the rf waveform in that gate was digitized. This final configuration was selected to test our ability to generate multiple C-scans simultaneously and also determine the extent to which individual delaminations separated by one or more plies could be distinguished.

RESULTS

The specimens were first radiographed after the impacted area was soaked in a radio-opaque penetrant, CH$_2$I$_2$ (diodomethane), in order to provide standards for comparison with the ultrasonic data. Figure 1 shows radiographs of a 10 ft-lb impact site in a graphite/epoxy specimen.

![Radiographs](image_url)
and a 20 ft-lb impact site in a graphite/PEEK specimen. The graphite/epoxy specimen shows the regular pattern of damage due to low energy impact with little visual surface indication. In contrast, the graphite/PEEK specimen shows the cracked fibers pushed out of the back surface which is characteristic of the higher energy impacts.

Figure 2 shows the "conventional" results for all of the impact sites. A 10 MHz focused transducer was used. As was expected, the back surface reflection provides good information on the overall extent of the damage but little detailed information. The edge enhanced images [2] of this same data, which are shown on the right, add little real information but do show the dimple due to the impactor in the center of each delamination region for the low energy impacts.

Figure 3 shows the results obtained when the time gate is set at those delays which showed a delamination indication on a B-scan through the impact site for the graphite/epoxy 10 and 20 ft-lb impact specimens. In both specimens the delaminations near the front surface are much smaller than those on the back, and shadows of these delaminations are seen in the images near the back surface. For the delamination on a given level to be identified, the total cumulative area of delaminations in the images for the levels above must be subtracted.

Figure 4 shows the same type of results for the graphite/PEEK specimens. In this case it may be noted that the shock wave which produces the delaminations does not spread out nearly as much as it does in the graphite/epoxy specimens, and only small amounts of new delamination progressively appear at each successive level.

In order to verify the ultrasonic results further, a destructive examination was performed. The results of this examination for the 10 ft. lb. impact in graphite/epoxy are shown in Figure 5. The arrow points out the delamination which corresponds to the small cigar-shaped delamination found ultrasonically at the 0.015-inch level shown in Figure 3. Careful examination of these photomicrographs showed equally good correspondence with the other delaminations shown in the ultrasonic images. It may be noted that a great deal of information is missed in the ultrasonic images due to the shadowing effect.

In the final figure we show the results of two scans with simultaneous data collection at seven different time delays. Transducer frequencies were 5 and 25 MHz with the gate width being set to 1/2 cycle of the rf period. In the figure the 25 MHz images have the stronger signals indicated as black while the 5 MHz images have the stronger signals indicated as white. At 25 MHz it is easy to see the delaminations on each layer, while the 5 MHz results contain some ambiguity due to the width of the gate. However, even in this case it is easy to distinguish new delaminations. For example, note the additional white area in the figure at the 0.02-inch level compared to the 0.015-inch level.

CONCLUSIONS

The value of digitized ultrasonic data with software processing has been demonstrated in this paper. The images of the delaminations resulting from impact damage are considerably sharper when the software gated rf signal is used rather than the detected, filtered ultrasonic signal. In addition, the multiple gated images demonstrated the ability to resolve closely spaced delaminations.
GRAPHITE/EPoxy COMPOSITE
10 MHz transducer, 3 inch focus

Figure 2
PLY-BY-Ply IMAGES
OF IMPACT PRODUCED DELAMINATIONS
USING
ACCURATE TIME-GATED FOCUSED C-SCANS

GRAPHITE/EPOXY COMPOSITE
10 FT. LB. IMPACT

GRAPHITE/EPOXY COMPOSITE
20 FT. LB. IMPACT

Figure 3
PLY-BY-PLY IMAGES
OF IMPACT PRODUCED DELAMINATIONS
USING
ACCURATE TIME-GATED FOCUSED C-SCANS

GRAPHITE/PEEK COMPOSITE
10 FT. LB. IMPACT

GRAPHITE/PEEK COMPOSITE
20 FT. LB. IMPACT

Figure 4
Figure 5
PLY-BY-PLY IMAGES
OF IMPACT PRODUCED DELAMINATIONS
USING
ACCURATE TIME-GATED FOCUSED C-SCANS

GRAPHITE/EPOXY COMPOSITE
15 FT. LB. IMPACT

![Figure 6]

25 MHz TRANSDUCER
2' FOCAL LENGTH

0.015 inch
0.020 inch
0.025 inch
0.030 inch
0.050 inch
0.065 inch

5 MHz TRANSDUCER
4' FOCAL LENGTH

0.015 inch
0.020 inch
0.025 inch
0.035 inch
0.055 inch
0.070 inch

(distance from front surface)
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REFERENCES