INSPECTING ADVANCED COMPOSITE MATERIALS AT ULTRASONIC FREQUENCIES FROM 2 MEGAHERTZ TO 2 GIGAHERTZ

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INTRODUCTION

Ultrasonic nondestructive evaluation is an effective method of evaluating various types of composite materials for defects such as porosity, resin rich areas, fiber misalignment and delaminations. This paper discusses the role ultrasonic nondestructive evaluation performed in studying the impact tolerance of composite materials. The composite specimens were ultrasonically inspected to determine their integrity before and after exposure to impact. Traditional low frequency (2.25 to 10 megahertz) C-scan techniques evaluated an assortment of large composite panels which were made of several organic matrix resins including thermosets and a thermoplastic. After specimens were cut from these panels an ultrasonic microscope scanned them for cutting damage. After the composite specimens were impact loaded, they were again ultrasonically scanned. From the images, the extent of the damage was calculated and compared with the impact level. A damaged composite specimen was sectioned and an end view of the damage was imaged with a scanning acoustic microscope. The composite specimens were also destructively analyzed, and the results were compared with the ultrasonic inspections.

SAMPLE PREPARATION

Several composite panels were provided by Fiberite. There were four different resins combined with the T300 graphite fiber, five fibers (T300, P75, IM6 are graphite, W107 is Kevlar (Dupont), and S2 is glass) combined with the 934 epoxy resin, and two samples made of pure resin. The material selection was designed to evaluate the influence of the two constituents, fiber and matrix, on the impact resistance of organic matrix composites. These composite specimens were impacted at different energy levels and their toughness was determined by microstructural examination, ultrasonic inspection, and mechanical property measurement.

ULTRASONIC EVALUATIONS

The composite specimens were ultrasonically evaluated three times during this study. The first inspection was conducted on the 18" x 18" plates received from the supplier. An ultrasonic C-scan was performed with 2.25 and 5 megahertz focused transducers with an automated multi-axis ultrasonic scanner. This scanner produced color images which displayed the amplitude of the reflected signal from the back wall of the composites and detected porosity, delamination, and resin rich areas. Figure 1 is an example of a composite plate image. Once the composite plates were inspected, two inch square specimens were cut from good areas on the plates. These specimens were then ultrasonically inspected to detect cutting damage. The two inch square specimens were impact loaded with an aluminum flyer plate which uniformly impacted the composite samples on one side. Three impact levels were applied to each type of composite. The damaged samples were ultrasonically inspected with a high resolution ultrasonic microscope to image delaminated and cracked plies. A photograph of identical composite samples exposed to the three levels of impact loading and the resulting damage is displayed in Figure 2. The images in Figure 2 were generated by mapping the amplitude of the internal reflected energy. Thus, for these images the high amplitude areas represent defective areas. Images of the impact damaged specimens were stored on a VAX 11/750 for processing and automated damage assessment. To confirm the ultrasonic results, one of the composite specimens was sectioned through an indicated defect and, as shown in Figure 3, there was delamination present. Another capability of the ultrasonic evaluation is to image defects at a particular depth. Figure 4 is four images of the same specimen where each image is displaying defects at four different depths. Here it is clearly shown that the majority of the damage occurs near the surface. This technique could be extended to possibly view individual plies.

IMAGE ANALYSIS

Once the impact damaged specimens had been evaluated and the ultrasonic images were stored on a VAX 11/750 computer, an image analysis algorithm was developed to calculate the extent of damage. The algorithm processed each composite image and determined the percent of damaged area. To determine which areas were damaged, a comparison was made of the reflected amplitude of each pixel in the image with a predetermined damage reflection amplitude. If the pixel's amplitude was above the level, that pixel was judged to represent a damage location. The pertinent amplitude level was specified by comparing the ultrasonic results with damage seen in the sectioned samples.

ACOUSTIC MICROSCOPE STUDY

A high frequency scanning acoustic microscope provided magnified images of the damage areas on the sectioned samples. The acoustic microscope operates at frequencies up to 2 gigahertz and can magnify features up to approximately 2000 times. At these frequencies, the acoustic microscope's magnification can provide an end-view image of individual fibers and display the condition of the resin. Two acoustic microscope images are shown in Figure 5. They were made at 1.3 GHz on a composite damaged by impact loading where the delamination is shown as a dark band across the photograph. We see features in this acoustic image similar to those after polishing and optical viewing.

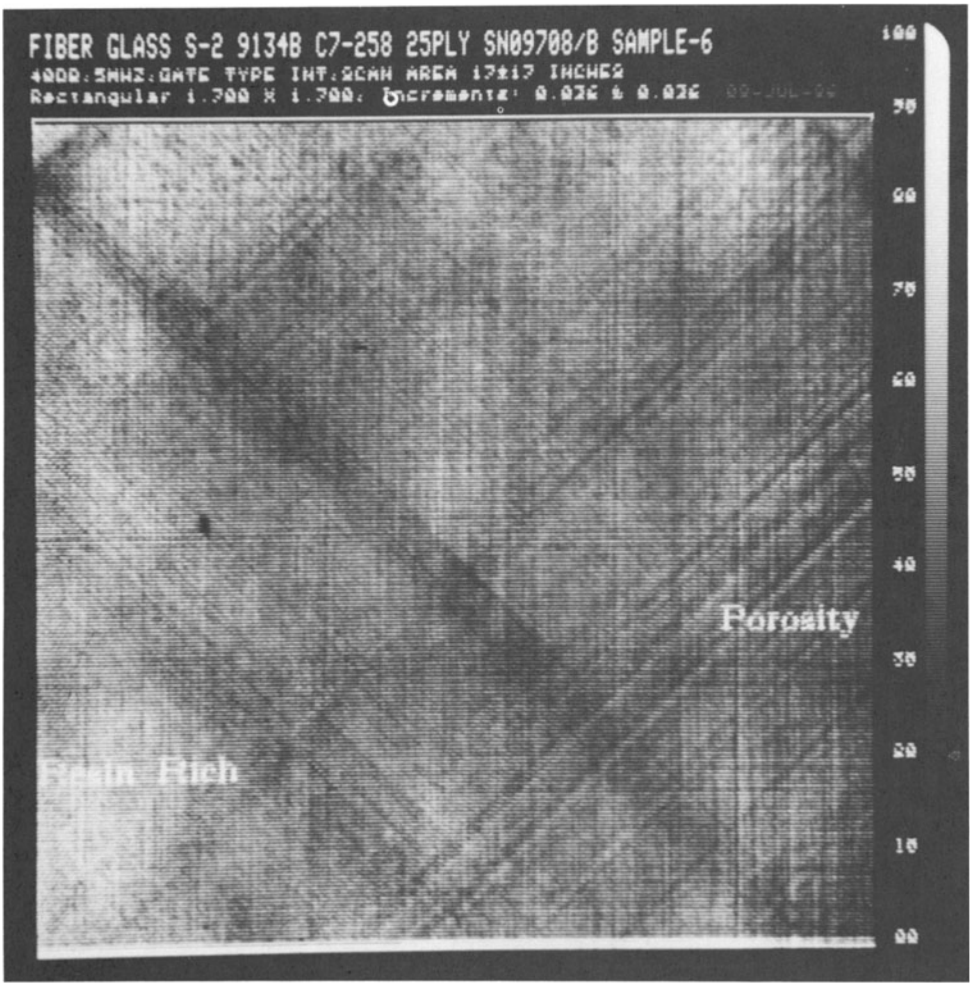


Figure 1. Example of ultrasonic C-scan on 18" x 18" composite panel.

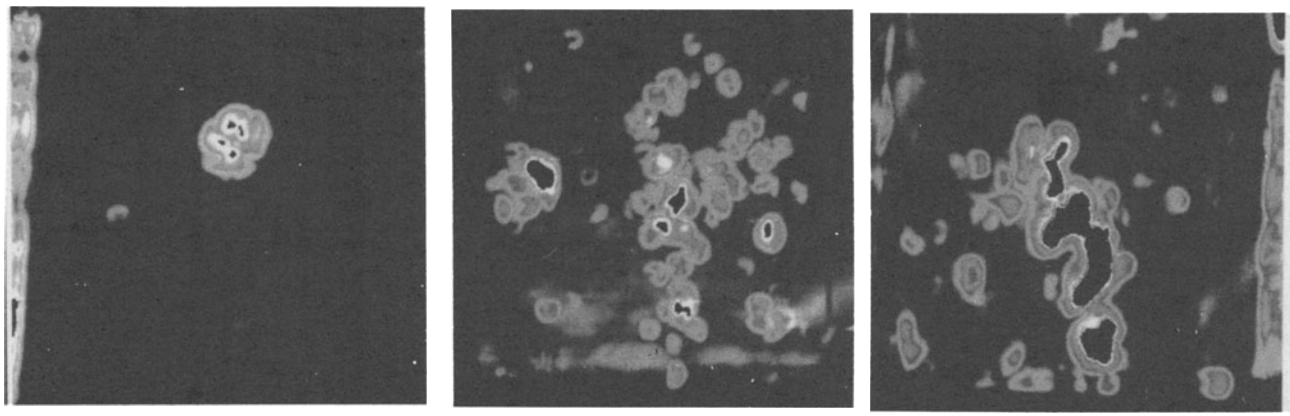


Figure 2. Ultrasonic inspection of a T300/934 composite following impulse loading at 0.58, 0.74, and 1.15 KTAP.

BOOKFACE
DELAMINATION

TRANSPLY
FRACTURE

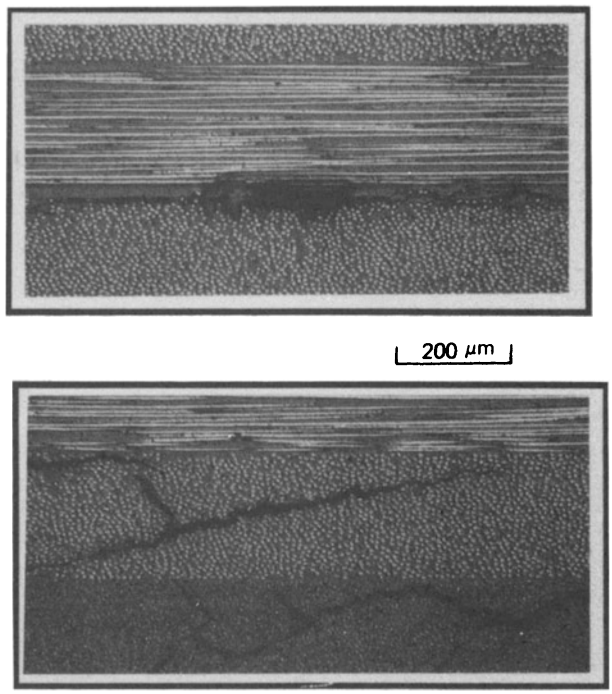


Figure 3. Microstructural damage produced by impact loading.

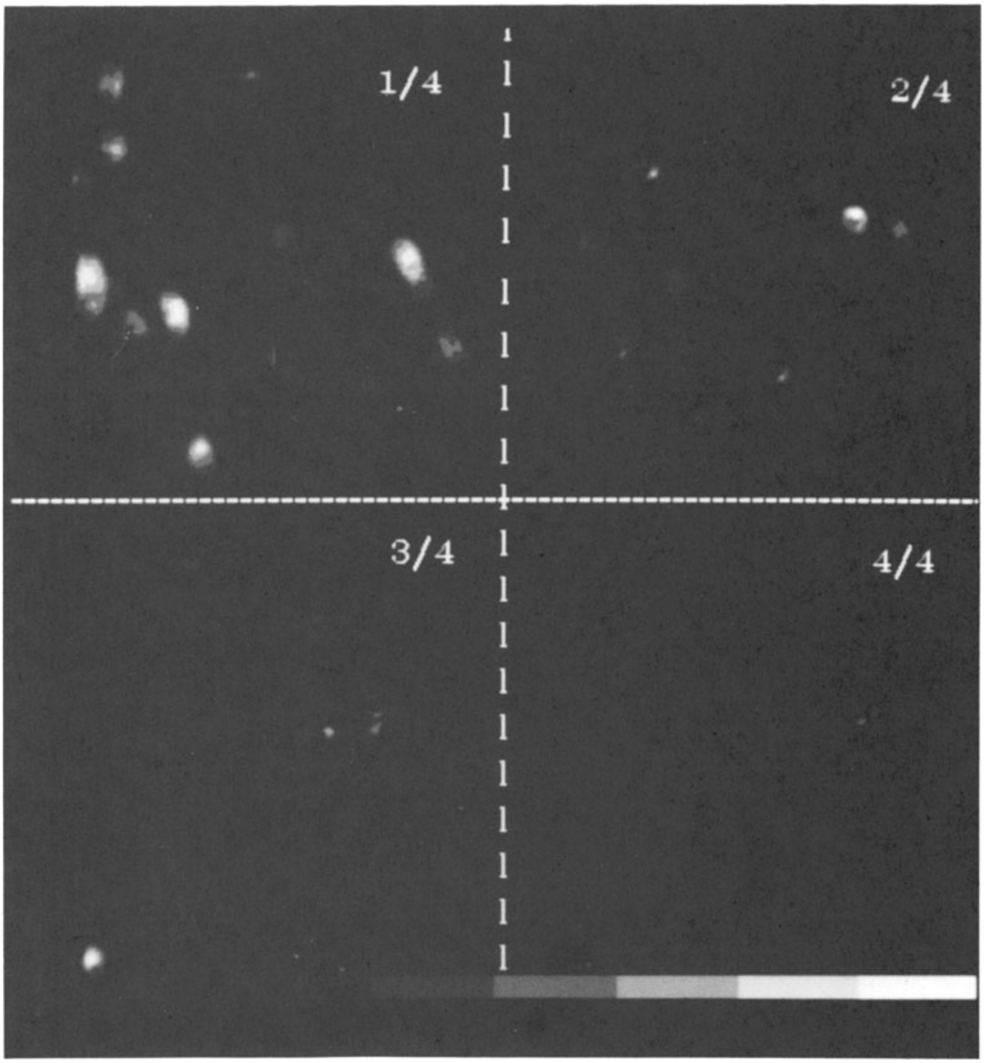
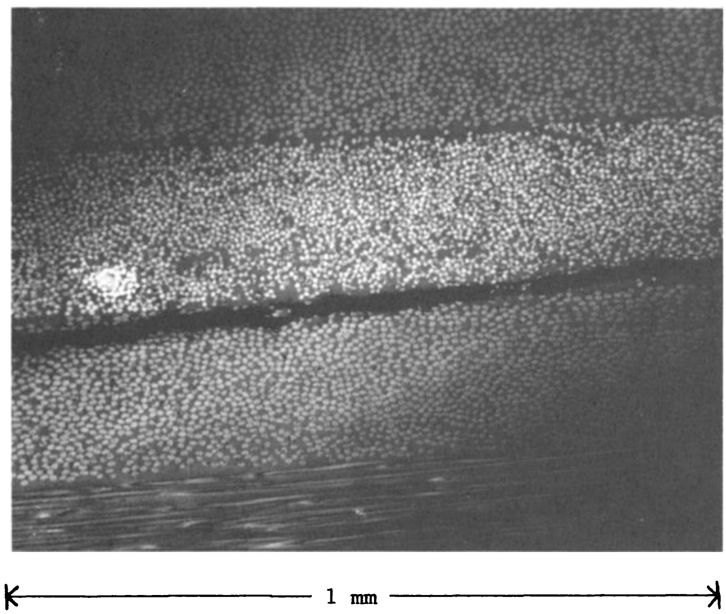
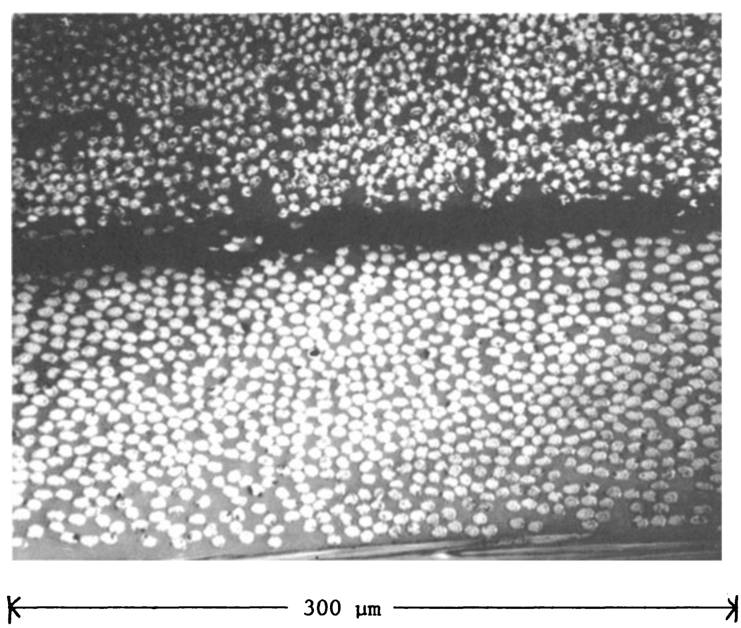


Figure 4. Four ultrasonic C-scans of same impact damaged specimen. Each image displays damage at different depth in plate.



a)



b)

Figure 5. Acoustic image photograph of delamination in composite specimen subjected to impact leading.

SUMMARY

Ultrasonic nondestructive evaluation was an integral part of a study to measure impact tolerance in advanced composites. Low frequency acoustic scans first assured the quality of the as-received composite and then provided images of impact damage. From the ultrasonic images an automated damage assessment algorithm calculated the percent of damaged area in each composite specimen. High frequency ultrasonic microscopy displayed the impact induced delamination in sectioned samples and confirmed the ultrasonic scanner results.