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Cite as: AIP Conference Proceedings **1949**, 060006 (2018); https://doi.org/10.1063/1.5031552

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# Development of Composite Calibration Standard for Quantitative NDE by Ultrasound and Thermography

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**Abstract.** Inspection of aircraft components for damage utilizing ultrasonic Non-Destructive Evaluation (NDE) is a time intensive endeavor. Additional time spent during aircraft inspections translates to added cost to the company performing them, and as such, reducing this expenditure is of great importance. There is also great variance in the calibration samples from one entity to another due to a lack of a common calibration set. By characterizing damage types, we can condense the required calibration sets and reduce the time required to perform calibration while also providing procedures for the fabrication of these standard sets. We present here our effort to fabricate composite samples with known defects and quantify the size and location of defects, such as delaminations, and impact damage. Ultrasonic and Thermographic images are digitally enhanced to accurately measure the damage size. Ultrasonic NDE is compared with thermography.

## INTRODUCTION

NDE testing is done at various locations and by various personnel. These could be inspectors at the aircraft manufacturers or on the field working under very different conditions. These inspectors may have different levels of expertise, from novice to highly experienced. Along with this, the training of the technicians on actual damage samples is an important aspect of gaining experience. Technicians, during level practical training, require realistic defective samples to hone their skills. Based on all these scenarios it becomes important to have standard samples with known defects and standardized ultrasonic and thermographic signatures. This will help the trainees to gain experience on realistic samples and will reduce the variability between inspectors because they can compare their tests with standard samples. Keep in mind that this work is concerned with the development of standards samples.

Development of these standards is not easy and is especially true for composite materials. There are various types of defects and isolating one defect at a time is virtually impossible. As an example, in composites the delamination is preceded by micro-cracks, meaning that delamination without micro-cracks is not possible. Under impact load, the micro-cracks, delamination and possibly penetration occur in that order [1]. The material anisotropy of composites also can misguide the operators. Some of these problems can be eliminated or reduced if realistic damage can be engineered in samples.

Fabrication of samples with delamination is of major concern. The reasons are: (1) it is difficult to fabricate a delamination in the middle of a sample, (2) locating delamination in a particular lamina is difficult, (3) fabricating reproducible delamination defects is difficult, and (4) delamination without inducing micro-crack is difficult. A very common industry practice has been to put a layer of bagging film in between two laminas and cure the composite [2,3]. The hope is that this non-sticking foreign body will simulate a delamination. Plainly speaking, this practice simulates the existence of a foreign body (FOB) but not a delamination. So anyone who wants to make a delamination sample produces his or her own sample — there is no standard among the samples. As a result the inspection has no consistency and there is no way to compare the tests. Also, there is no standard that can be used to compare the results.

We present here our efforts to fabricate realistic delamination samples. The samples have realistic, controllable defects, and the defects are at different depths. Once the samples are produced, they are tested using both noncontact and contact ultrasonic inspection, and a damage map is produced. The samples are also tested using flash thermography [4,5] and the two techniques are compared. The received ultrasonic and thermographic images are also

*44th Annual Review of Progress in Quantitative Nondestructive Evaluation, Volume 37*
AIP Conf. Proc. 1949, 060006-1–060006-7; https://doi.org/10.1063/1.5031552
Published by AIP Publishing. 978-0-7354-1644-4/$30.00

digitally enhanced to make the defects visible to an untrained eye. The error between the perceived actual defect and measured defect size are compared to determine the margin of error.

## EXPERIMENTAL DETAILS

### Sample Preparation

The delamination was simulated by the following methods:

1. Bagging film insert
2. Baking soda layer
3. Aerogel/epoxy mixture layer
4. True delamination

### Testing Configuration

Contact ultrasonic investigation: Here the transducer is in contact with the part and generally is used in the reflection mode. The signal from backwall and the damage can be easily differentiated. Immersion ultrasonic investigation: Here the transducer is not in contact but separated by water that acts as the couplant to transmit the sound waves to the panel, also in reflection mode. These configurations are as shown in Fig. 1.

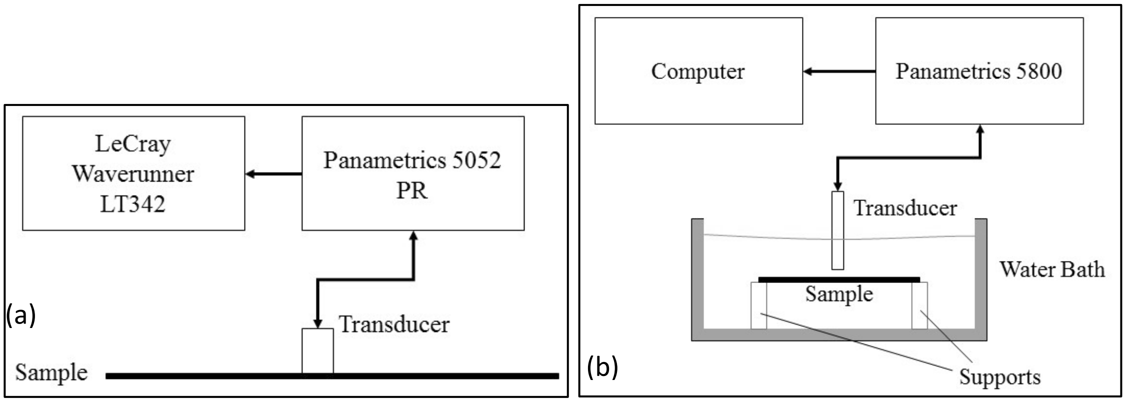


**FIGURE 1.** (a) Contact ultrasonic inspection, and (b) immersion ultrasonic inspection.

### Flash Thermography

The flash thermography setup is shown in Fig. 2.

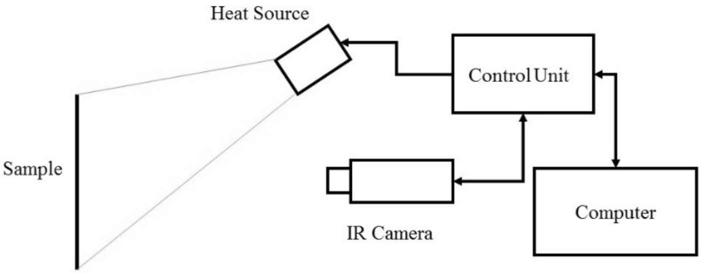
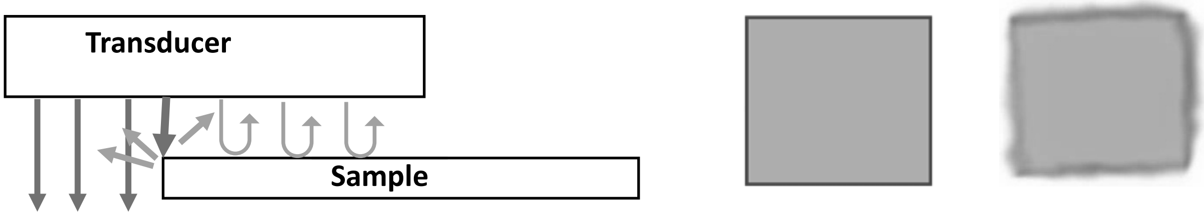


**FIGURE 2.** Flash Thermography configuration.

## Error Analysis and Digital Image Processing

The need for error analysis and image processing is shown in figure 3. Since the transducers are of finite size, when they are over the edge of the sample, then some of the signal passes through straight, while some reflect from the sample. The signal is averaged over the area of the transducer, hence near the edge the results will be a mix of the signal from the backwall and the signal from the defect. If the transducer is very small as compared to the sample edge then a clean scan as shown in Fig. 3b will be obtained. But if the signal at the edge is scattered then the scan shows up as shown in Fig. 3c. The edge of the defect cannot be clearly discerned and hence an error analysis has to be performed to measure the defect size. Digital signal processing is performed on all the images to enhance the defect and then the defect size is measured.



(a) (b) (c)

**FIGURE 3(a).** Transducer at the edge of samples, (b) scan if the transducer is very small, (c) edge scatter signal for a finite size transducer.

An example of the digital image processing is shown in Fig. 4, which helps in size characterization.

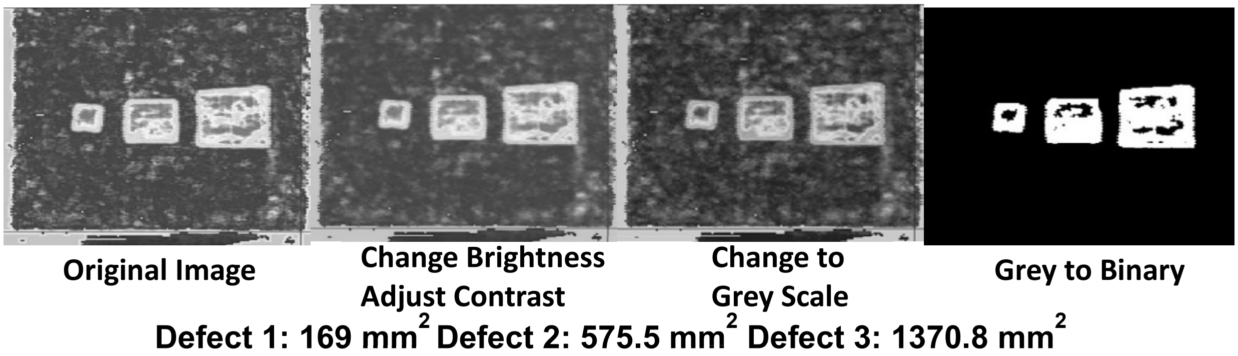


**FIGURE 4.** Example of image processing.

In the error analysis phase we have compared the engineered defects to the measured defects and the results are shown in Table 1.

Table 1: Error in size measured by ultrasound for bagging film insert and baking soda insert

| | Bagging Film Insert | | | Baking Soda Insert | |
|---|---|---|---|---|---|
| | Small | Medium | Large | Small | Large |
| | L x W | L x W | L x W | L x W | L x W |
| Actual Dimensions L & W (mm) | 13x13 | 25x25 | 39x39 | 13x13 | 25x39 |
| Error in L & W immersion (%) | 23.1x23.1 | 20x16 | 12.8x5.1 | 29.2x0.5 | -12.5x24.6 |
| Error in L & W Contact (%) | 22.3x22.3 | 14.4x14.4 | 5.9x5.9 | 27.6x-10.8 | 0.0x22.3 |

The results from Table I show that as the size of insert increases for the bagging film the error in measurement reduces. On the other hand even though the baking soda insert signals are fairly well defined the measurement errors are large since the powdery nature of the material.

## Transducer Selection

In any NDE inspection, transducer and frequency selection are an important inspection variable. Figure 5 shows two frequencies (5MHz and 10 MHz) and two diameters (6.35 mm and 12.7 mm). Results show that 5 MHz with a 6.35 diameter is a better choice for these tests. It should be emphasized that the transducer selection was not fixed and would change as the need changes.

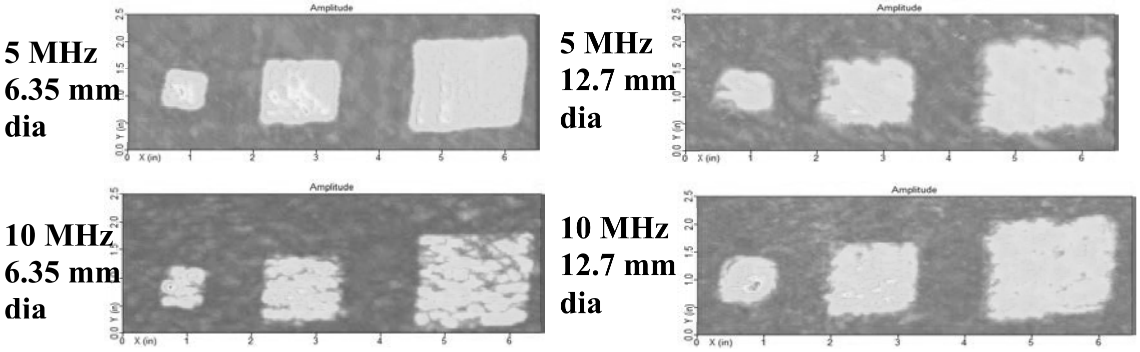
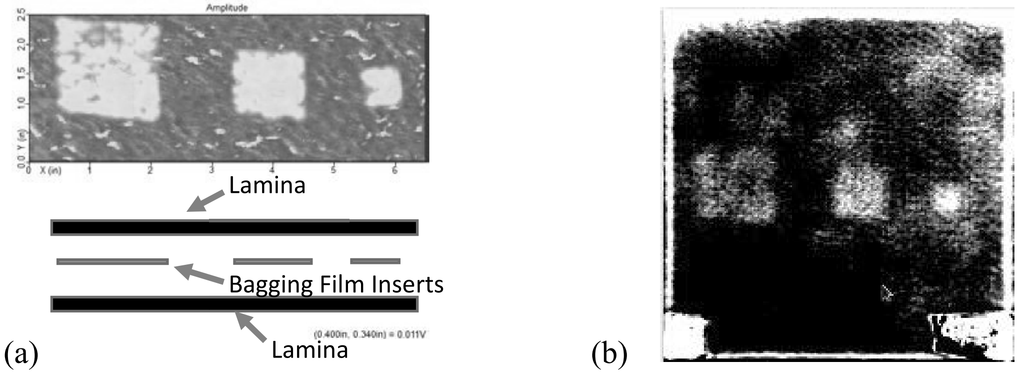


**FIGURE 5**. Effect of transducer frequency and diameter on received scans.

## RESULTS AND DISCUSSION

### Delamination Simulation by 2 Layer Bagging Film Insert

A two-layer pillow of bagging film was fabricated and the air was removed from between the film, so that epoxy could not seep in between the layers. It was placed in the laminate while the plies were assembled; the ultrasonic c-scan and thermographic images are shown in Fig. 6. This type of arrangement has been used for the simulation of delamination but can at best be a simulation of foreign body.



(a) (b)

**FIGURE 6.** Results of bagging film insert, (a) ultrasonic and (b) Thermographic.

It was observed that 0.5 MHz 0.25" dia transducers produced best results. The simulated delamination could be observed using flash thermography for a 1" square delamination, but anything small could not be discerned.

### Delamination Simulation using Baking Soda

Baking soda does not interact with the epoxy and so will stay as a powder in the laminate. A drawback of this simulation is that since soda is in powder form, it is difficult to control the shape of the delamination. Roughly 38mmx25mm and 13mmx13mm size simulations were tried and the results are shown in Fig. 7.

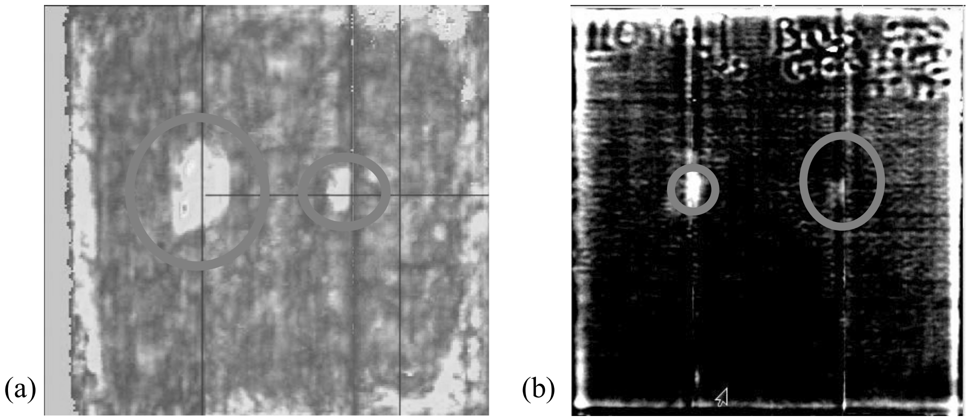


**FIGURE 7.** Delamination simulation using caustic-soda, (a) ultrasound, (b) flash thermography.

Both ultrasonic and thermography have no problem detecting the delaminations. But the sizing of delamination using thermography was difficult.

### Delamination Simulation using Aerogel

Aerogel is an extremely low density material [6], and so it is used to simulate delaminations. Since aerogel flakes are very light and are a health hazard, a mixture of aerogel and epoxy is prepared to contain the flakes and is smeared between the lamina to simulate the delamination. The ultrasonic and thermographic results for such a delamination are shown in Fig. 8.

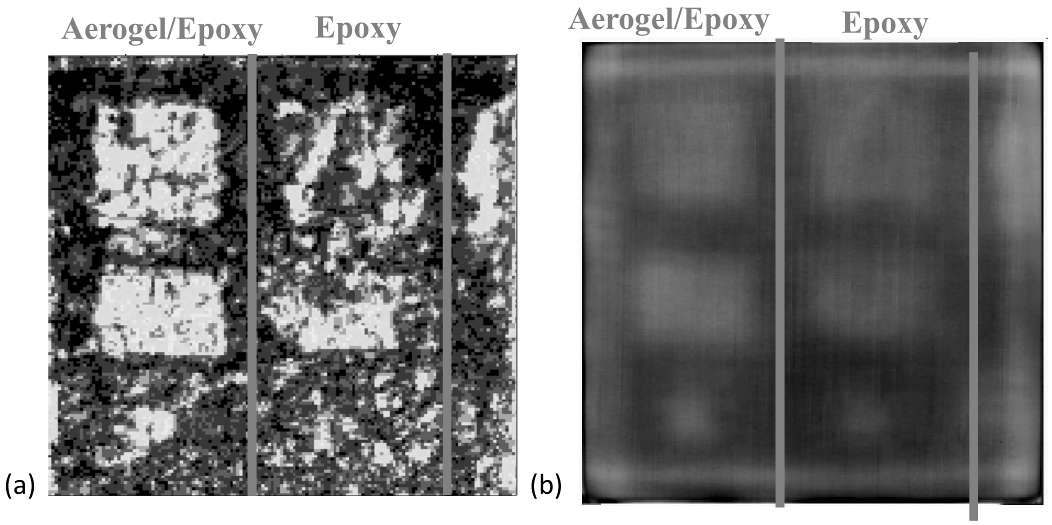


**FIGURE 8.** Delamination simulation using aerogel/epoxy blend, (a) ultrasound, (b) thermography.

Figure 8(a) shows the results for the aerogel/epoxy mixture; these delaminations are compared with the pure epoxy. It is evident that the aerogel/epoxy mixture, due to reduced density, is capable of acting like a reflector and can be a delamination simulator. Figure 8(b) shows the same laminate subjected to flash thermography. The difference between pure epoxy and aerogel/epoxy again is very clear. The epoxy layer gives a hazy uneven signature while the aerogel/epoxy delamination simulation is prominent and sharp.

## True Delamination Fabrication and Testing

Figure 9 shows the fabrication process: Fig. 9(a) shows a 0.01-inch thick sheet of aluminum placed between the composite laminas and cured. A cut-off line will be formed where the aluminum ends. After the cure is complete, the plies are pulled apart so that the separation of the laminas goes beyond the separation line. This region is now a true delamination. It has been observed that the plies are separated along with fiber bridging, which truly simulates a delamination. The only disadvantage of this delamination is that it is on the edge of a sample and very difficult to create inside a laminate.

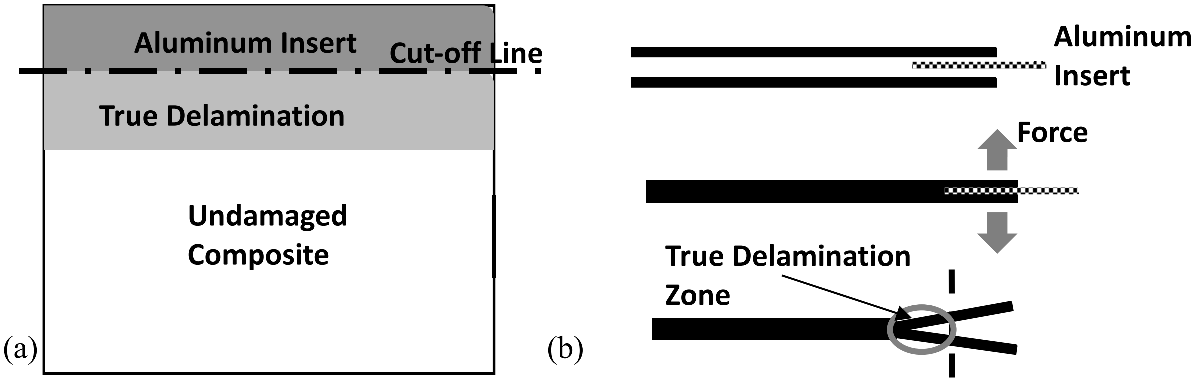


**FIGURE 9.** (a) Fabrication of the sample, and (b) formation of true delamination.

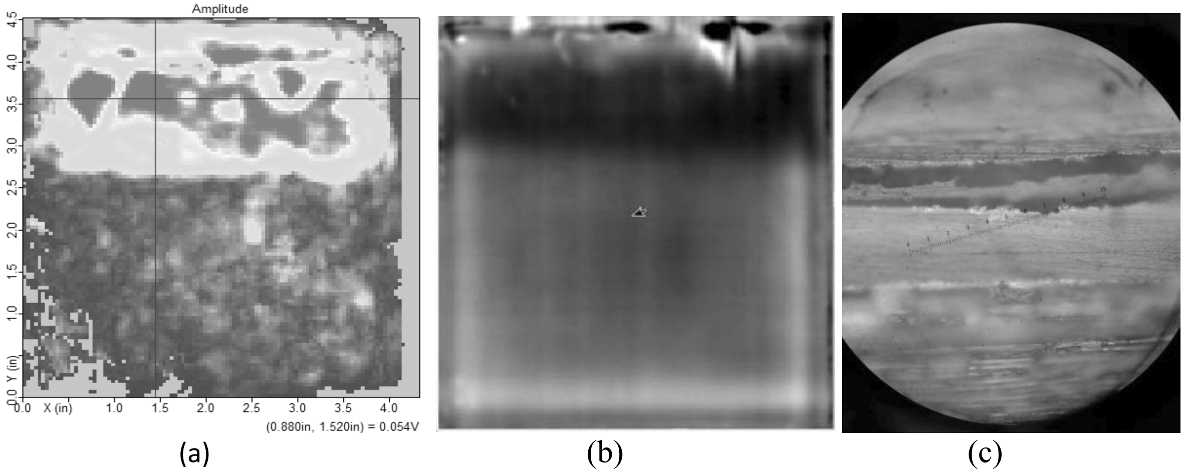


**FIGURE 10.** (a) 5 MHz 0.25"dia pulse-echo ultrasound, (b) thermographic image, and (c) edge micrograph.

True delamination was next subjected to ultrasonic and thermographic investigation. Figure 10(a) shows a very clear picture of delamination using pulse-echo ultrasound and is clearly visible using thermography 10(b). Figure 10(c) is a micrograph of the delamination and shows the clear demarcation of the damage. True delamination is very easy to fabricate with the only limitation being that it is not easy to produce in the middle. The edges of this sample can be filled by epoxy to hide the delamination and prevent water from entering when performing water immersion UT scanning.

## CONCLUSIONS

There are different ways to create a simulated delamination in composite laminate. Bagging film, caustic soda, aerogel, and true delaminations were fabricated and tested by pulse echo ultrasound and flash thermography. All the methods show the damage clearly by ultrasound and not so clearly by flash thermography. Aerogel/epoxy mixture is the most promising method as it is not very difficult to fabricate, the delamination can be located at any distance, and the fabrication is inexpensive. In a true delamination there is some contact between the delaminated surfaces and, due to kissing bonding, some energy is leaked through — this is correctly simulated in an aerogel/epoxy mixture. Further work is underway to study the mixture ratio of aerogel and epoxy to arrive at the best delamination simulation.

## ACKNOWLEDGMENT

This work is done under a Phase II sub-contract from Innoveyda Corp. Prime contract from U.S. Air Force No. FA8117-15-C-0007.

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