DETECTING COMPOSITE IMPACT DAMAGE DURING STORAGE AND HANDLING

Pamela Kay Strong[1] and Mackenzie Lynn Miller[2]

[1]United Launch Alliance
8100 Southpark Way
Littleton CO 80120

[2] University of Colorado
914 North Broadway Street
Boulder CO 80302

ABSTRACT

Composites used in aerospace parts have high strength and low weight properties; however, despite these benefits, impact damage is hard to visually assess or even identify since most delaminations are non-visual and subsurface. Faults or weaknesses in the composites do not become visually apparent until the surface ply is damaged. In this study, a film sensitive to pressure was used to identify the composite impact damage area. A calibrated hammer and a nondestructive ultrasonic A-scan were employed to test/evaluate a variety of impact sites. It was determined that the best impact indication film to use was the Pressurex® high rated (7,100-18,500 psi range) film with its matted side toward the composite. This provided the most accurate description of the location of possible impact damage. The film was investigated as to its capability to indicate the extent of the damage inflicted compared to that of the nondestructive testing (NDT) indication. The film only indicated that there was damage, but did not correlate the extent of the damage. The part in question required further NDT.

1. INTRODUCTION

Composites have revolutionized the aerospace industries with their high strength and low weight characteristics. Unfortunately, these advantages come with a difficulty in identifying ply impact damage. Composite damage is not visibly apparent until a sufficient force is applied to destroy the surface ply. Meanwhile, there is the potential for subsurface delaminations, undetectable without the use of expensive equipment, i.e., nondestructive (NDT) ultrasonic A-scan or C-scan and valuable time. Recently there have been advances in nondestructive evaluation of composites. Buschow, et al. (2001) [1] describe the most current methods of analysis and provide an overview of their uses. Methods of NDT evaluation still require extra time to find the damage and are not normally reapplied to parts already cleared for service or simply stored for future use. This paper analyzed the usefulness of a force-indicating film to illustrate the location and extent of damage done to composites. The film clearly indicated where the damage occurred; unfortunately, it neither indicated accurately the true extent of the damage nor designated the entire area of that damage.

2. METHODS

2.1 Materials

Sensor Products Inc. produces multiple different types of Pressurex®[2] pressure indicating films. These films are mylar-based and contain microcapsules that burst when force is applied to the film. The color intensity of the resulting mark on the film is related to how much force was applied to the film. The films differ based on their pressure ratings. For the lower pressure ratings, the films have separate transfer and developer sheets with the microcapsules on the transfer sheet and the color developing solution on the developer sheet. The higher pressure rated films combine these two sheets into one. The available ranges are the low (350-1400 psi), medium (1400-7100 psi) and high (7100-18,500 psi) film types. To test both the range at which the composite was damaged and the effectiveness of the film, samples of the low, medium, and high film types were tested. Samples of ultra low (28-85 psi) and super low (70-350 psi) were also included to illustrate the range of impact forces.

The sample composite pieces were scrap aerospace parts. They consisted of carbon fiber laminate sandwiched foam core composite in seven long strips and a circular piece. The long strips were 2” wide by 36” long with 3/8” Rohacell® core sandwiched by 1/8” graphite laminates. The circular piece was 15” diameter with ½” Rohacell® core sandwiched by 1/16” graphite laminates. Each sample piece of composite was labeled with a number to ensure identification. The circular piece was labeled #1 and the seven strips were labeled #2-8. All parts were first A-scanned to determine they were defect free.

Figure 1: Circular Piece #1

As is shown in Figure 1, the film was cut into strips and attached to the composite piece using red duct tape. Masking tape was used to label the composite pieces. A white pencil was used to mark the impact area/subsequent A-scan indicated impact damage on the composite.

2.2 Set-up

The experiment was to test Pressurex® film’s ability to indicate a composite impact. The results of the film, after a force was applied, were compared to that of an established nondestructive evaluation method, i.e. A-scan, see Figure 2. The ultrasonic A-scan method uses two transducers to detect any damage between them. This technique was the most accessible, cheapest available, and required the least amount of time for this type of experimentation. Damage was determined to be present using this device when the number of ultrasonic waves passing through the composite was fewer than the amount that went through an undamaged piece of composite. The transducers must be coated with enough couplant solution so this device does not identify false damage due to an air pocket between the transducer and the composite surface.

Figure 2: Ultrasonic A-Scan with 2 transducers

A known controlled force was required to create the impact damage that was then assessed by both the Pressurex® film and the A-scan. A calibrated hammer and a dynamic signal analyzer were used. The load cell in the hammer head measured the force in pounds. The dynamic signal analyzer measured, recorded and displayed force-time histories for each impact.

Figure 3: Dynamic Signal Analyzer (above) and Calibrated Hammer (below)

2.3 Procedure

Before testing the film, the sample composite pieces were submitted to A-scan to ensure that they were initially intact. The composite was wiped down with MEK solvent to remove dirt and residual A-scan couplant which might have adversely affected the results. Solvent wiping is also an established practice when working with aerospace parts. The designated impact indication film was applied to the composite sample in strips. The film was applied in a non-overlapping manner with the alternating film matte and glossy side towards the composite. This was to test which side; glossy or matte, best illustrated the damage. The strips of film were taped down and numbered, see Figure 4.

Figure 4: Strip #2 - entire length (left), close-up on one section (right)

The results were recorded as either glossy or matte along with the applied impact pressure. After it was determined that matte side toward the composite was a better arrangement of the film, the circular piece, with approximately ½" core sandwiched by 1/16" graphite laminates, was then tested with strips of the high rated film, matte side down and taped in place. Four strips of high rated film were also taped to the back of the circular composite piece to test whether the film would pick up the impact damage from the other side, see Figure 5.

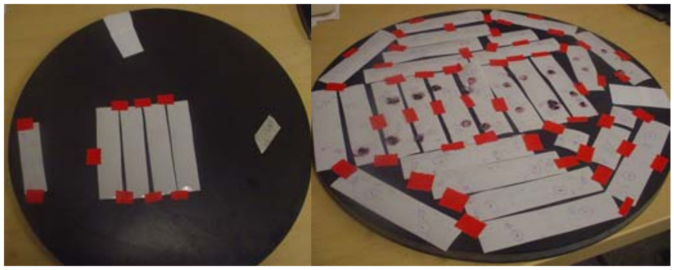

Figure 5: Circular piece #1- front (left), back (right)

The calibrated hammer and dynamic signal analyzer were used to collect all the impact measurements on the film samples attached to the composite samples, see Tables 1 and 2. The dynamic signal analyzer records how many pounds of force that the calibrated hammer impacted the composite. The film was rated in ranges of psi. The following formula was used to convert the measurement of impact force into psi (the area of the calibrated hammer head was 0.0298 in^2, ¼" hammer head diameter, for the higher rated film and 0.785 in^2, 1" hammer head diameter, for the lower rated films so that the appropriate psi ranges could be attained for testing):

$$PSI = \frac{lb_f}{area\ of\ impact} \rightarrow \frac{lb_f}{0.0298\,in^2} \qquad [1]$$

Or

$$PSI = \frac{lb_f}{area\ of\ impact} \rightarrow \frac{lb_f}{0.785\,in^2} \qquad [2]$$

Each film was impacted only one time per place, but in 2-3 places on the individual strip, with an appropriate amount of force depending on the film rating. After each impact, the area was circled and labeled with a consecutive impact number on the film. The dynamic signal analyzer also recorded this electronically by the same number. The film was removed and the impact areas were again circled and their impact numbers transferred onto the composite pieces with a white pencil. The final A-scan revealed where the composite had experienced significant impact damage. This information was compared to the force applied in each location. From this, the effectiveness of the various films was determined.

3. RESULTS

Four main outcomes became apparent after all testing was completed. First, when the film was impacted on the matte side, the impact was more obvious and clear. However, it was also easier to leave stray marks from handling along the matte film side. On the glossy side of the film, these stray marks showed less because the glossy covering prevented access to the pigment. The second outcome was the film failed to react to impact damage on the opposite side of the sandwich composite. The third and fourth outcomes became evident following the final A-scan. The A-scan confirmed where damage had occurred, but the area of actual impact damage was larger than the film indicated, as the third outcome. The fourth outcome was that the A-scan revealed the minimum force range for the composite pieces, using two different graphite sandwich thicknesses that had to be impacted with in order to be damaged. All damaged composite pieces that showed A-scan impact damage experienced 300+ pounds (10,067+ psi). The dynamic signal analyzer recorded the peak force before any damage was done to the ply (see Circle #39). At the point of damage, the signal was broken up and only the dissipation of the impact force was recorded appearing as noise (see Circle #17). The composite might have been struck with a larger force but the analyzer only documented up to the force it took to fracture the top ply. Not all pieces impacted with 300+ pounds were damaged; this therefore was indicated as a false positive by the high-rated film. However, there were no damaged composite pieces struck with anything less than 300 pounds and therefore there were no false negatives in which the high-rated film indicated no impact damage when there was damage present. The following tables display the composite impacts that did damage, Table 1, (all strikes within the range of the high rated film, 7,100-18,500 psi) and the rest of the composite impacts within that range of the high rated film that were determined undamaged by the A-scan, Table 2, dissipation of the impact force (see Circle #39):

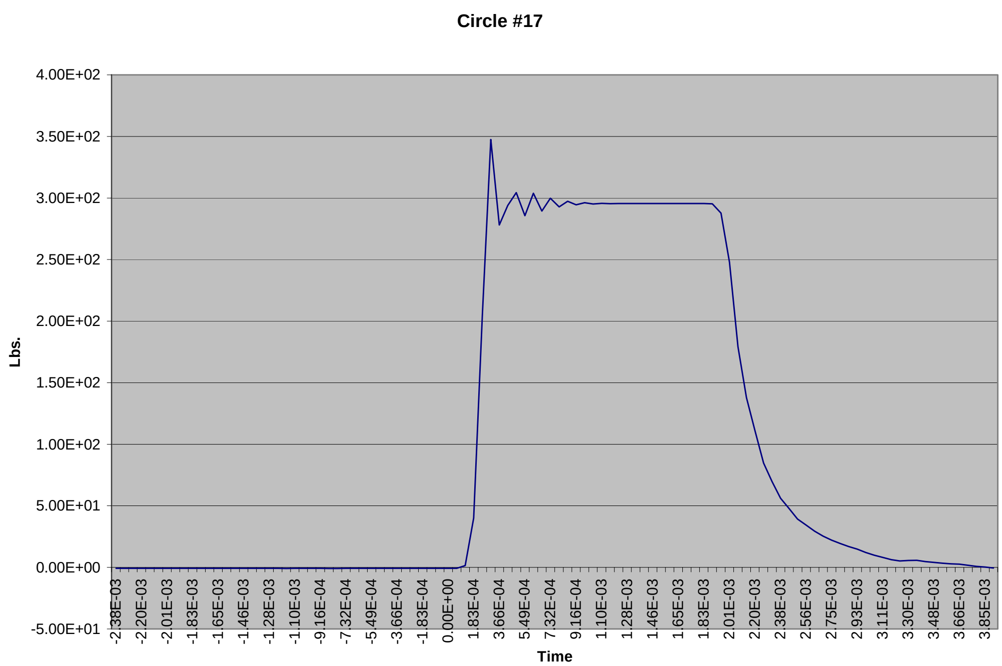

Figure 6. Impact Damage Table 1

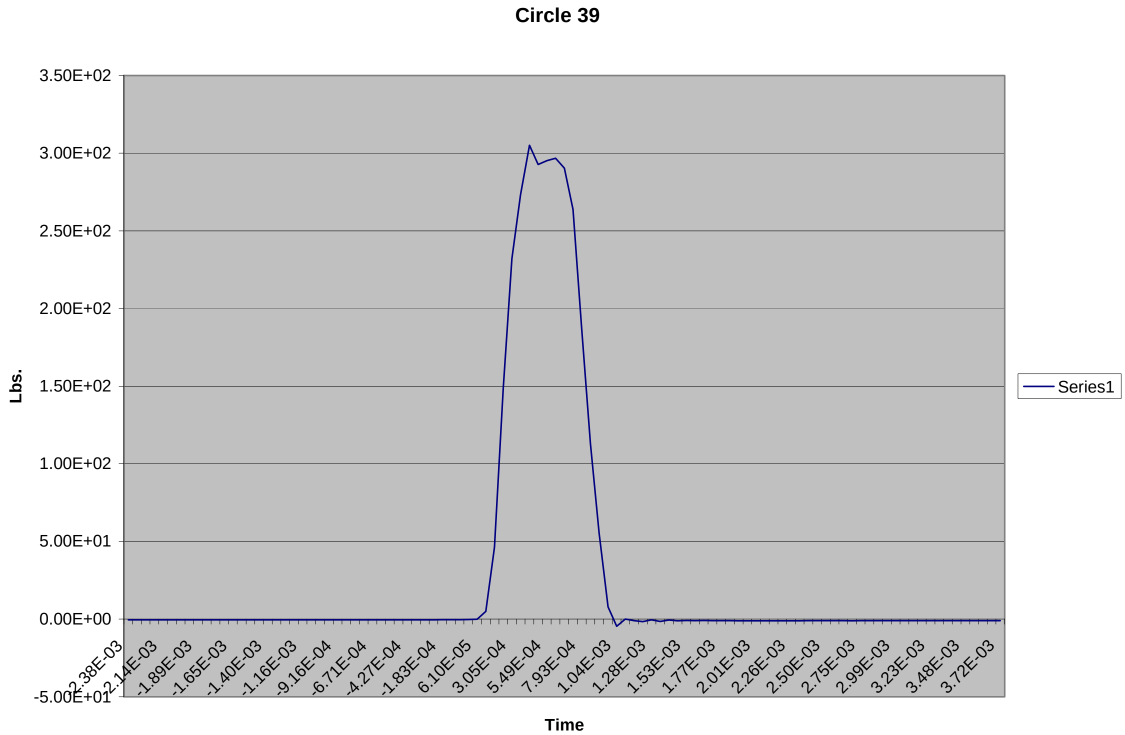

Figure 7. No Impact Damage Table 2

Table 1: Impact Damage to High Rated Film*

Impact #	**lb_f**	**PSI**	**Damage**
c10	298.25	10,008.22	yes
c5	313.75	10,528.52	yes
c19	315.04	10,571.88	yes
s87	319.92	10,735.47	yes
s88	319.92	10,735.47	yes
c4	320.13	10,742.68	yes
s90	325.77	10,931.91	yes
c9	326.30	10,949.63	yes
c24	326.44	10,954.23	yes
c2	329.63	11,061.31	yes
s94	331.02	11,107.99	yes
c18	331.27	11,116.51	yes
s93	332.94	11,172.35	yes
s82	333.78	11,200.60	yes
c14	333.95	11,206.51	yes
c23	333.99	11,207.82	yes
c8	335.89	11,271.54	yes
s95	335.91	11,272.21	yes
c13	336.36	11,287.32	yes
c11	337.13	11,312.95	yes
c22	337.19	11,314.93	yes
c16	340.49	11,425.94	yes
c1	342.96	11,508.72	yes
s77	343.33	11,521.21	yes
c15	344.00	11,543.56	yes
c12	346.90	11,640.77	yes
c17	347.52	11,661.78	yes
c7	347.84	11,672.32	yes
s84	348.48	11,693.99	yes
s83	349.30	11,721.58	yes
s96	349.38	11,724.19	yes
s92	350.77	11,770.84	yes
c3	351.34	11,789.90	yes
c20	351.52	11,795.81	yes
c6	354.08	11,881.88	yes

Table 2: No Impact Damage to High Rated Film*△

Impact #	lb_f	PSI	Damage
c41	303.65	10,189.53	no
c39	305.06	10,236.85	no
s72	308.72	10,359.70	no
s70	310.66	10,424.73	no
s78	314.67	10,559.40	no
s69	315.47	10,586.34	no
s85	319.86	10,733.49	no
s89	329.94	11,071.85	no
s73	329.96	11,072.48	no
s79	334.60	11,228.19	no
s71	335.40	11,255.13	no
s80	335.42	11,255.81	no
s74	335.83	11,269.60	no
s81	336.56	11,293.89	no
s86	337.93	11,339.87	no
s75	339.01	11,376.01	no
s76	347.48	11,660.47	no
s91	352.38	11,824.73	no

* ‘c’ denotes impact on circular composite piece;
‘s’ denotes impact on one of the strips of composite;

△ not all impacts displayed, just all those with damage or within the range of psi that showed damage on some composite

4. CONCLUSION

From the results of the testing, and with aerospace sandwich composite applications in mind, it was concluded that the high pressure rated Pressurex® film (7100-18,500 psi) would be a useful tool in indicating where there had been possible impact damage during storage and handling. An anomaly had been experienced with a composite aerospace part in the past, which was believed to have been caused by damage done to it by a forklift while it was in storage, although no visual evidence was apparent prior to its use. Composite aerospace parts are most susceptible to this type of accidental impact damage, while they are being stored and handled. They should be covered with this film, or similar material, so that it would be immediately apparent if there were any areas of concern/damage. This method would obviously not replace the routine ultrasonic scan required before parts are declared serviceable, but would ensure that the part was not subjected to impact damage after ultrasonic analysis. The film would be placed with its matte side towards the composite, so that light handling of the part would not give a false impact indication. The film would also have to be placed on both sides of a highly vulnerable part; since the film only shows damage from the side it is attached. The high rated film would work best given that the impact damage of the two tested graphite sandwiches were greater than 10,000 psi and the film's range is 7,100-18,500 psi.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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