PROBABILITY OF DETECTION STUDY ON IMPACT DAMAGE TO HONEYCOMB COMPOSITE STRUCTURE USING THERMOGRAPHIC INSPECTION

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ABSTRACT

A probability of detection study was performed for the detection of impact damage using flash heating infrared thermography on a full scale honeycomb composite structure. The honeycomb structure was an intertank structure from a previous NASA technology demonstration program. The intertank was fabricated from IM7/8552 carbon fiber/epoxy facesheets and aluminum honeycomb core. The intertank was impacted in multiple locations with a range of impact energies utilizing a spherical indenter. In a single blind study, the intertank was inspected with thermography before and after impact damage was incurred. Following thermographic inspection several impact sites were sectioned from the intertank and cross-sectioned for microscopic comparisons of NDE detection and actual damage incurred. The study concluded that thermographic inspection was a good method of detecting delamination damage incurred by impact. The 90/95 confidence level on the probability of detection was close to the impact energy that delaminations were first observed through cross-sectional analysis.

KEY WORDS: Impact Damage, Delamination, Nondestructive Evaluation.

1. INTRODUCTION

The NASA Constellation program will make use of large composite structures. As part of a demonstration to the Constellation Upper Stage program a probability of detection study was performed on an existing composite structure to establish the reliability of nondestructive evaluation in finding impact damage.

In the late 1990s a NASA Research Announcement (NRA) program built and tested a composite intertank as a technology demonstration. The intertank remained in storage until 2007 when it was to be dismantled. Prior to dismantling a nondestructive evaluation (NDE) probability of detection (POD) study was performed on the tank. The intent of the study was to demonstrate NDE capability in detecting impact damage on full-scale composite hardware.

The intertank was 244 cm in diameter with a height of 193 cm. The intertank was fabricated from IM7/8552 carbon fiber/epoxy facesheets and 0.635 cm (0.25”) cell aluminum honeycomb core that is 2 cm (0.8”) thick (CRIII-1/4-5052-.0015P-3.4). AF-191 epoxy film adhesive was used to co-cure the facesheets to the core. The facesheets were eight plys with a total thickness of 0.127 cm (0.05”) providing a cured ply thickness of ~0.016 cm (0.006”).

For the thermographic images presented here, a FLIR Phoenix imager run under Thermal Wave Imaging (TWI) software control was used, Figure 1. The system utilizes pulse heating from a flash hood to uniformly raise the surface temperature of the structure under test. As the structure cools, regions with low through-thickness thermal diffusivity such as a void or delamination will remain hotter than good regions of the sample which conduct heat better. Table 1 summarizes the test set-up.

Table 1. Thermography parameters

Parameter	Value
Imager	FLIR Phoenix
Frame Rate	30 Hz
Lens	25 mm
Thermal Source	TWI Flash hood
Field of View	20 cm x 20 cm (8” x 8”)
Camera to Lens Distance	45.7 cm (18”)
Number of Frames	500 (16.6 seconds)
Detector Size	640 x 512 pixel image

Figure 1. Thermography System

2. TESTING

The intertank was first inspected with thermography to identify any preexisting indications. Low velocity impacting was then performed with a pendulum type impactor. Two phases of impact testing were performed. The first phase of impact testing was for sizing purposes. The impact testing was performed on the intertank to gain an understanding of the structure's damage resistance and the sensitivity of the nondestructive evaluation (NDE). Impact locations were known by NDE personnel and inspected with thermography prior to cross sectional analysis. The cross sectional analysis provided the energy level that initially damaged the facesheet by delamination. This initial test series provided the range of impact energies needed for the probability of detection study. The second phase of impact testing was performed as a blind study with the location and number of impact sites unknown to NDE personnel.

2.1 Low Velocity Impact Testing. A simple pendulum type fixture (Figure 2) was developed to impart an impact onto the intertank wall. Various diameter steel balls were used to provide differing weights for the pendulum. The length of the pendulum and weight of the steel ball were varied to produce the desired range of impact energies. The impact fixture was not instrumented and relied solely on control of the impacting weight and height to provide a given impact energy. The impact energy is determined from the gravitational potential energy equation:

$$E = mgh = Fr(1-\cos\theta) \qquad 1$$

where r is pendulum radius (wire length plus half of ball diameter) and F is pendulum weight (neglecting wire weight).

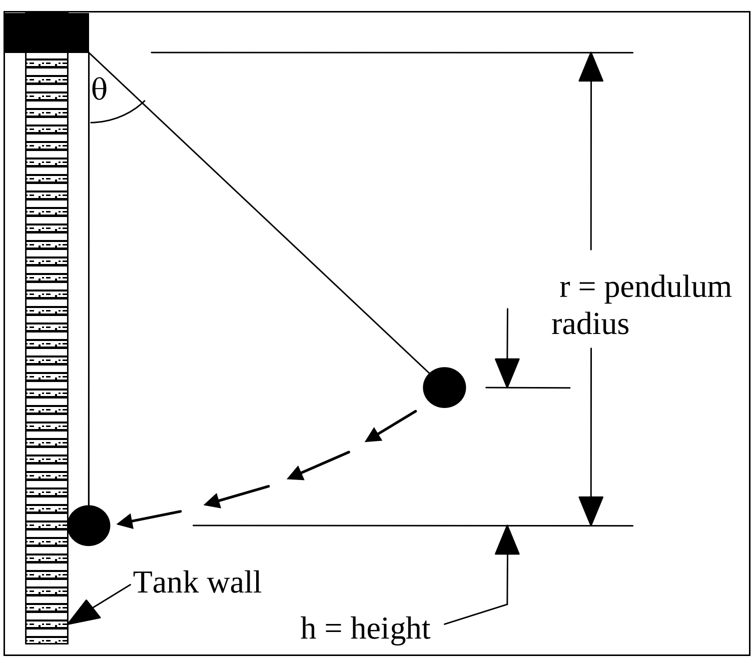

Figure 2. Illustration of Impact Pendulum

The Phase I tests impacted the intertank at a range of 0.1 to 5.4 Joules. Thermographic inspection was then performed on the impact locations. Although none of the impacts were visibly detectable, all impact locations greater than 0.5 Joules were easily detectable with thermography. Cross sectional analysis of the impact locations indicated that impact energies as low as 0.5 Joules created a delamination within the facesheet. This initial testing provided an estimate of impact energies necessary to perform a probability of detection (POD) study.

A random number generator was used to select impact locations for thirty impacts ranging from 0.3 to 1.4 Joules. Table 2 identifies the location and energy level of the impacts used in the POD. Each grid represents squares of 18 cm per side. NDE personnel were not informed of the location or number of impacts.

Table 2. POD Impact Locations and Energy Levels (Joules)

	Column											
Row	A	B	C	D	E	F	G	H	I	J	K	L
1			0.3								0.5	
2						0.7						
3			1.1			1.1				0.4		
4			0.7	0.8					0.3		1.2	
5			0.9	0.8		0.8				0.3	0.4	
6				0.9	0.7					0.8	1.2	0.5
7				0.5	0.4						0.4	1.4
8			0.5	0.3		0.4			0.5		1.4	0.5

2.1 Thermographic Inspection. Following impact testing, two NDE technicians independently performed thermographic inspection on the intertank. Thermography was performed with a FLIR Pheonix with 25 mm lens using Thermal Wave Imaging software. None of the impacts of 0.4 Joules or smaller were detected, half of the impacts of 0.5 Joules were detected, and all impacts of 0.7 Joules or greater were detected. A 90/95 probability of detection for impact energy is 0.62 Joules (Figure 3). Figure 4 contains typical thermography images of indications at various impact sites.

Cross sectional analysis indicated that facesheet delamination began at a threshold of 0.5 Joules. Although, core crushing was evident at lower impact energies, the threshold of NDE detection began with the onset of delamination. Figure 5 shows the threshold of delamination and illustrates the core crushing.

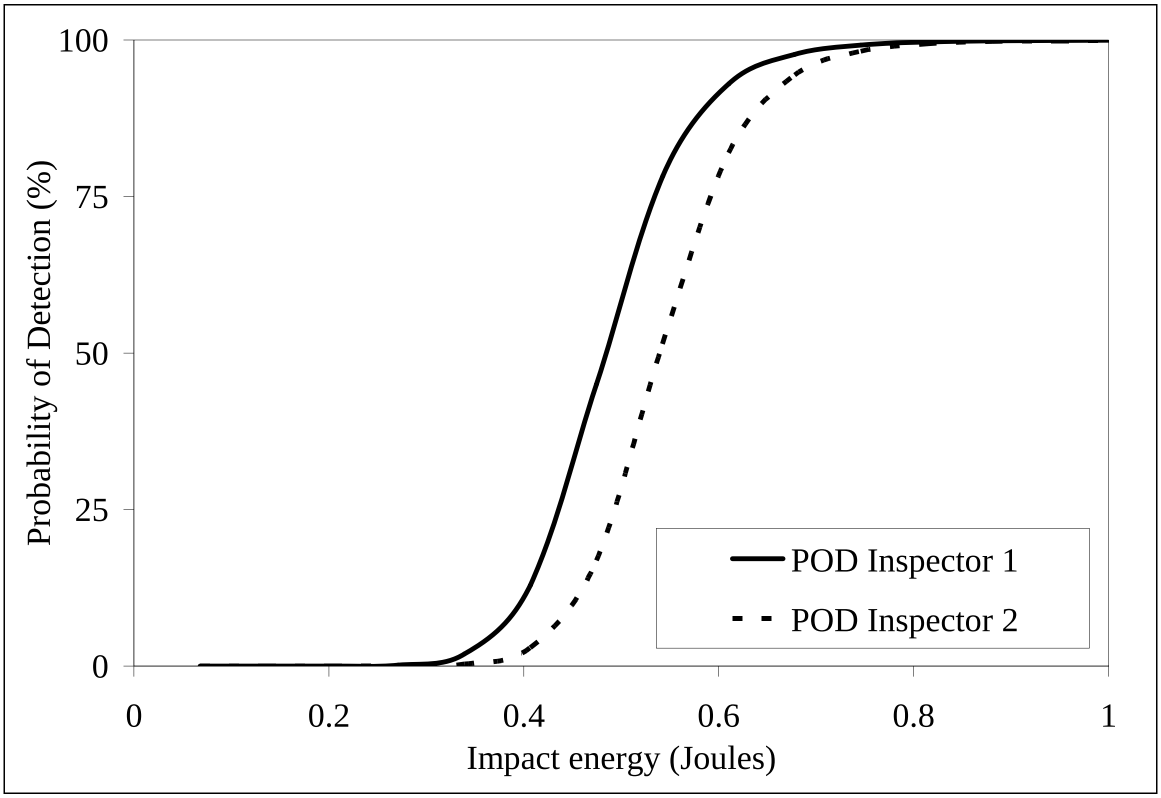

Figure 3. Probability of Detection for a Given Impact Energy

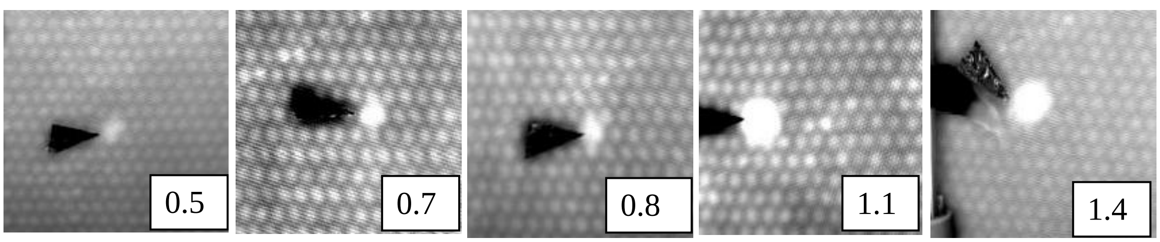

Figure 4. Thermography images labeled with impact energy (Joules)

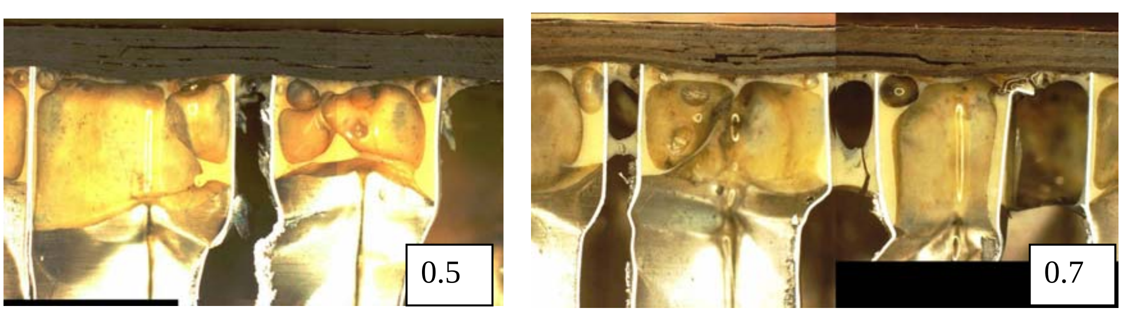

Figure 5. Cross Section of Specimens Impacted with 0.5 and 0.7 Joules of Energy.

3. DISCUSSION AND AREAS OF FURTHER RESEARCH

One observation noted during the cross sectional analysis was the high level of drape resulting in facesheet dimpling and porosity over individual core cells. While the thermography was able to find delaminations close to the threshold of delamination initiation, a higher quality composite facesheet (reduced porosity and dimpling) would likely result in improved NDE detection capability.

No attempt was made to evaluate the damage tolerance of the composite structure. The damage resistance appeared quite low, with impact energy of 0.5 Joules causing core crushing and delamination. However, no strength testing was performed to evaluate the mechanical effects the damage had on the structure.

Typically a POD is performed with known defect sizes. This study was an attempt to use defects generated by impact to perform a POD. However, the minimum size delamination produced by low velocity impact is quite likely greater than the detection capability. Thus, it is incorrect to suggest that for an impact energy of less than 0.62 Joules the probability of detection is less than 90 % with 95% confidence given the impact may be below the threshold that produces damage. Subsequent sizing of the delaminations produced from the impacts in this study would need to be performed. The important demonstration of this study was that thermographic inspection detected delamination due to low velocity impact at the threshold of delamination initiation.

4. CONCLUSIONS

Demonstration of a probability of detection study with thermography was performed on a full scale test article. Rather than using preexisting defects, impact damage was initiated on multiple locations on the structure. The capability of finding delamination due to impact in a blind study was demonstrated with thermographic inspection. The threshold of detection was at the threshold of the onset of delamination.

5. ACKNOWLEDGEMENTS

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References

1. Nondestructive Testing Handbook (3rd edition); Volume 3, “Infrared and Thermal Testing”, 2001.

2. Metals Handbook (8th edition); Volume 11, “Nondestructive Inspection and Quality Control”, 1976.