46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-7008

THE EFFECT OF DEFECT SIZE ON THE QUANTITATIVE ESTIMATION OF DEFECT DEPTH IN COMPOSITE STRUCTURES USING SIR NDE

Omar Obeidat[1] , Qiuye Yu and Xiaoyan Han
Department of Electrical and Computer Engineering,
Wayne State University
Michigan, USA

ABSTRACT

Sonic Infrared (SIR) NDE is hybrid nondestructive testing technique that uses ultrasonic excitation along with infrared imaging to detect defects in the structures being inspected. This technology can detect defects of different types in a wide range of materials such as metal alloys, ceramics and composites. Recently, composites have become genuine components in modern aerospace industry. Due to their light weight and robust properties, composites continue to replace traditional materials like steel and aluminum. However, composites are prone to impact damage; such damage is a source of mechanical weakness and may lead to structure failure. Quantitative defect depth estimation can help aid repair assessments and reduce maintenance costs. In last year's QNDE, we presented a model that can be used to describe heat diffusion from impact damage in composite structures during SIR inspection. The model uses certain aspects of the temperature-time curve for defect depth profiling, namely, half-maximum power point, the peak slope point and the second derivative peak point. In this study, we investigate the effect of defect size on the quantitative estimation of defect's depth.

Keywords: Sonic IR, Thermal Imaging, Depth profiling

1. INTRODUCTION

Sonic Infrared (SIR) NDE is a relatively new nondestructive testing method; it is a combination of ultrasonic excitation and thermal imaging; while a short pulse of ultrasonic excitation generates heat in the defected area, a thermal imager will detect the generated heat and thus expose hidden defects in the structures being inspected [1-2]. In SIR, a defect will act as a heat source. Heat is attributed to different heating mechanisms that work simultaneously to make a defect detectable to the thermal imager in use. By subtracting the ambient temperature, defects are recognized as bright spots on a dark background [3-9].

Composites have become genuine components in modern aircraft designs. They are desired due to their excellent mechanical properties such as light weight, high strength and high specific stiffness. However, composites are prone to impact damage. Although impact damage can leave minimum visible effect, it is potentially a source of mechanical weakness which may lead to structure failure. Defect depth quantification is of great importance in quantitative NDE; precise depth estimation can aid repair assessments and reduce maintenance costs. In [10] we introduced a theoretical model for a circular subsurface heat source in an orthotropic structure. This model can be used to describe heat diffusion from impact damage in composite structures during SIR inspection. In this paper, the investigation on the effect of defect size for quantitative flaw characterization is presented.

2. MATERIALS AND METHODS

2.1 Analytical Model

An analytical model that describes heat diffusion from a circular subsurface defect in a composite structure is presented in [10]. The model gives the surface temperature of a point overlapping with the defect center located at depth d in a panel of total thickness L. The defect radius is R and the pulse duration is τ.

$$T(\vec{0},t) = \begin{cases} a\sum_{n=-\infty}^{\infty}\left\{\left[\sqrt{t}e^{-\frac{B^2}{t}} - \sqrt{\pi}B.erfc\left(\frac{B}{\sqrt{t}}\right)\right] - \left[\sqrt{t}e^{-\frac{C^2}{t}} - \sqrt{\pi}C.erfc\left(\frac{C}{\sqrt{t}}\right)\right]\right\} & t \le \tau \\ a\sum_{n=-\infty}^{\infty}\left\{\begin{matrix}\left[\sqrt{t}e^{-\frac{B^2}{t}} - \sqrt{t-\tau}e^{-\frac{B^2}{t-\tau}} + B\sqrt{\pi}\left(erfc\left(\frac{B}{\sqrt{t-\tau}}\right) - erfc\left(\frac{B}{\sqrt{t}}\right)\right)\right] - \\ \left[\sqrt{t}e^{-\frac{C^2}{t}} - \sqrt{t-\tau}e^{-\frac{C^2}{t-\tau}} + C\sqrt{\pi}\left(erfc\left(\frac{C}{\sqrt{t-\tau}}\right) - erfc\left(\frac{C}{\sqrt{t}}\right)\right)\right]\end{matrix}\right\} & t > \tau \end{cases} \quad (1)$$

[1]Omar Obeidat, Department of Electrical and Computer Engineering, Wayne State University, Michigan, USA; E-mail: fj9807@wayne.edu

Where
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$$a = \frac{2\sqrt{2}}{\rho c} \frac{1}{(\pi\alpha_z)^{1/2}} \qquad (2)$$

$$B = \sqrt{\frac{(d-2nL)^2}{4\alpha_z}} \qquad (3)$$

$$C = \sqrt{\frac{(d-2nL)^2}{4\alpha_z} + \frac{R^2}{4\alpha_x}} \qquad (4)$$

$$erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-t^2} dt \qquad (5)$$

Three features are used for depth profiling, these are: half-maximum power time, first derivative peak time and the second derivative peak time [10].

2.2 Experimental Setup

The set of experiments conducted aim to understand the effect of defect size on defect characterization. The conducted experiments simulate subsurface circular defects of different sizes located at different depths. A combination of optical heat source and insulating masks of different sizes were used to mimic SIR procedure. The material chosen was a DERLIN panel of length 30.6 cm, breadth 16 cm and thickness 1.2 cm. It is a hard-plastic material, isotropic with diffusivity of 0.21 mm^2/s. Flat-bottom holes defects with radius of 19.05 mm at different depths were machined as depicted in Fig. 1. Defects depths are shown in table 1. Defect size is set by controlling the openings in the insulating mask. openings have radii of 19.05, 15.88, 12.70, 9.53 and 6.35 mm. The heating duration (τ) is 5 ms. A thermal camera is used to observe the heat on the other side of the plate. Figure 2 shows the experimental setup. The video sequences collected during the inspections were used to construct temperature-time curves of the defect signature at the surface. The constructed curves were processed, and the features of interest were collected accordingly.

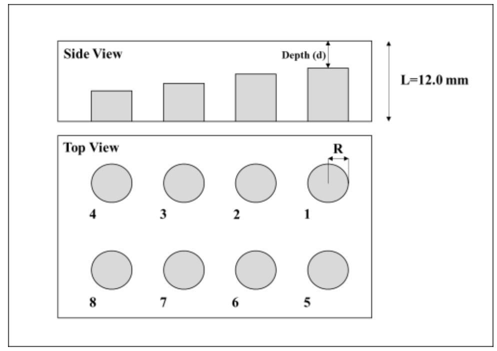

FIGURE 1: SCHEMATIC DIAGRAM OF A PLASTIC SAMPLE HAVING EIGHT BACK-MILLED FLAT-BOTTOMED HOLES OF THE SAME SIZE AT DIFFERENT DEPTHS BENEATH THE FRONT SURFACE

TABLE 1: DEFECTS' DEPTHS USED IN THE EXPERIMENTS

Index number of defect depth	Depth (mm)
1	1.17
2	1.68
3	2.08
4	2.61
5	3.18
6	3.63
7	4.11
8	4.62

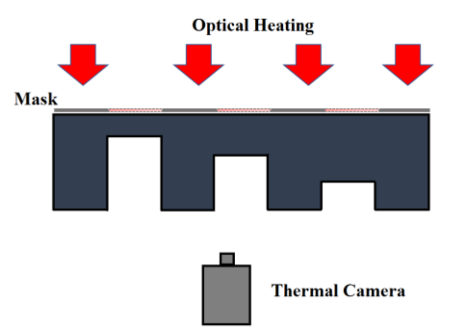

FIGURE 2: EXPERIMENTAL SETUP

3. CONCLUSION

The effect of defect size on defect characterization in SIR NDE is investigated. Preliminary results suggest that the features of interest are affected differently by the change of the defect size.

ACKNOWLEDGEMENTS

This work was sponsored by Wayne State University

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