

# Inspection of subsurface defects in honeycomb structure composites using infrared lock-in thermography

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## Introduction

Safety is critical for aeronautics and astronautics, and it could be improved if continuous inspections were guaranteed during in-service nondestructive testing for honeycomb structure composite of aircraft and aerospace flight. Active infrared thermography is widely used to inspect composite material for nondestructive testing and evaluation (NDT&E) [1,2].

Lock-in thermography (LT) is based on thermal waves generated inside a specimen and detected remotely. Phase image is relatively insensitive to local optical surface features (such as non-uniform heating) [3].

The finite element modelling (FEA) is developed to investigate the behaviour of thermal waves in the honeycomb composites. The FEM phase difference produced by subsurface defects is predicted and utilised to obtain the optimum inspection parameters for different aluminium sheet thickness. The lamp light incident angle is investigated to improve the phase image signal-to-noise ratio, and the profile of the differential phase distribution is used to estimate the boundary and location of subsurface defect.

## FEM of aluminium skin honeycomb sandwich structure panel by lock-in thermography

Finite element modelling is used to simulate the transient heat transfer in an aluminium skin honeycomb sandwich structure panel. The aluminium specific heat is  $904 \text{ J/(Kg}^\circ\text{C)}$ , the thermal conductivity is  $107 \text{ W/(m}^\circ\text{C)}$ , the density is  $2710 \text{ Kg/m}^3$ , and the glue thermal properties are such that the special heat is  $1300 \text{ J/(Kg}^\circ\text{C)}$ , the thermal conductivity is  $0.2 \text{ W/(m}^\circ\text{C)}$  and the density is  $1700 \text{ Kg/m}^3$ . The Teflon is inserted as defect, the Teflon specific heat is  $1200 \text{ J/(Kg}^\circ\text{C)}$ , the thermal conductivity is  $0.14 \text{ W/(m}^\circ\text{C)}$  and the density is  $000 \text{ Kg/m}^3$ . The modulated frequencies are varied from  $0.1 \text{ Hz}$  to  $0.4 \text{ Hz}$ , and the aluminium skin thickness is set to  $0.3 \text{ mm}$ ,  $0.5 \text{ mm}$ ,  $0.8 \text{ mm}$  and  $1.0 \text{ mm}$ .

## Experimental

### Materials

One specimen was made from a CFRP sheet honeycomb structure panel, and the skin thicknesses are  $0.5 \text{ mm}$ ,  $1.0 \text{ mm}$  and  $1.5 \text{ mm}$ .

Another specimen was made from an aluminium sheet honeycomb structure panel, and the skin thicknesses are  $0.3 \text{ mm}$ ,  $0.5 \text{ mm}$ ,  $0.8 \text{ mm}$  and  $1.0 \text{ mm}$ .

### Experimental system

The experiment system consisted of the infrared camera, a thermal stimulation unit (function generator and power amplifier), a controller unit, a lock-in unit and a heat source (2 halogen lamps, one with a lamp power of  $1 \text{ KW}$ ). The heat source was driven by a power amplifier, and the heat source and infrared camera was synchronised using the sinusoidal function of the function generator and the lock-in unit modulus. The phase angle data were calculated using a lock-in unit modulus at the modulated frequency.

## Results and discussion

It is shown that the computation phase difference is about  $1.68$  degrees between the defective area and the healthy area for skin thickness  $0.5 \text{ mm}$  and the experimental phase difference is approximately  $1.73$  degrees from Fig.1.

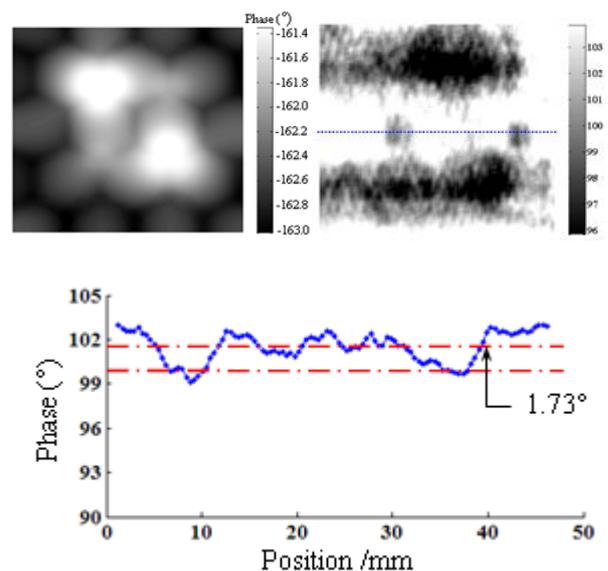


Fig.1 FEM and experimental phase difference

We can calculate the computation deviation between the

FEM and the experimental results to be approximately 2.9%, and this demonstrates that the FEM calculation can be used to predict the inspection parameters (such as modulation frequency) for lock-in thermography.

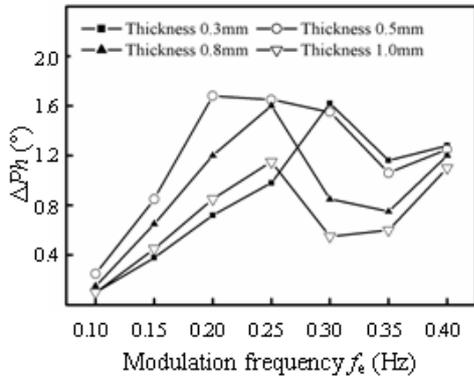


Fig.2 The relation between phase difference and the modulation frequency

It can be found that the modulation frequency should be selected from a different range to obtain the maximum phase difference for different skin thicknesses, and there exists an optimum modulation frequency range for a skin thickness of 0.3 mm, the selected frequency was 0.3 Hz, for a skin thickness of 0.5 mm, a range of 0.2~0.3Hz was selected and for skin thicknesses of 0.8 mm or 1.0 mm, a range of 0.2~0.25 Hz was selected from Fig.2.

For the engineering applications of lock-in thermography, the thermal stimulation lamp light incident angle should be selected in the range of  $\theta < 60^\circ$  to obtain better inspection results from Fig. 3.

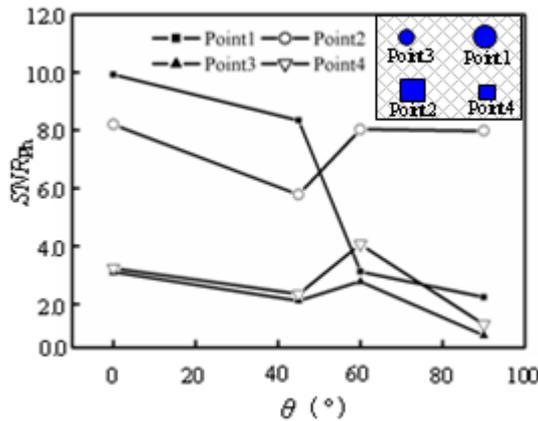


Fig.3 Image of the SNR of the local defective region The entire round defects forming the subsurface at a depth of 1.0 mm are detectable from the phase image shown in Fig. 4a and the differential phase image shown in Fig. 4b at the modulated frequency of 0.1 Hz. The differential phase at line of the specimen is plotted in Fig. 4c, and the defect locations and boundaries (sizes) can be

obtained from the differential phase profile.

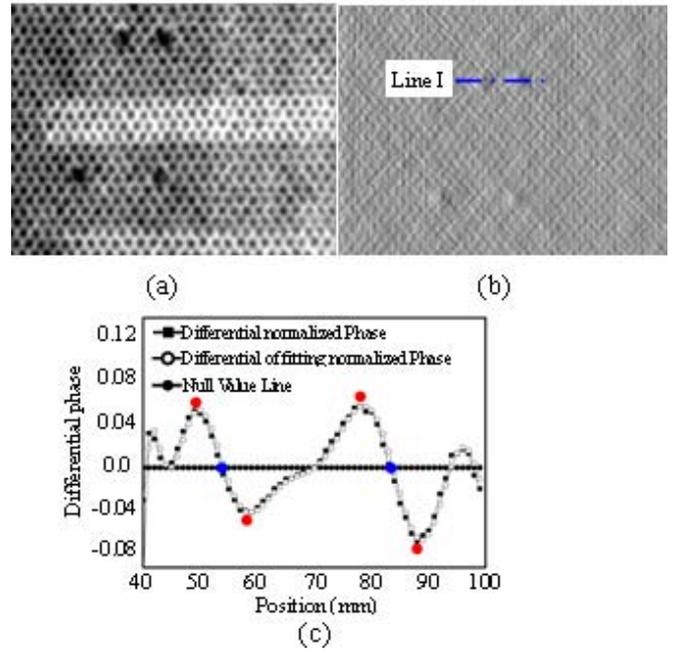


Fig. 4 Phase and differential phase images

**Conclusions**

The subsurface defect of honeycomb structure composite inspection is deep studied using lock-in thermographic technique. The FEM analysis is valid to investigate the behavior of thermal waves in the honeycomb structure composites and to predict inspection parameters. It is noted that the lamp light incident angle should be located less than 60 degrees. Experimental results demonstrate that lock-in thermography is very available for subsurface defects of honeycomb composites nondestructive testing.

**Acknowledgement**

Authors are grateful for the Chinese National Natural Science Foundation (No.60776802 and No.51074208), the Fundamental Research Funds for the Central Universities under Contract No.HIT.NSRIF.2009025.

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