INSPECTION OF IMPACT DAMAGE IN HONEYCOMB COMPOSITE PLATE BY ESPI, ULTRASONIC TESTING, AND THERMOGRAPHY

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Abstract

This paper describes an optical nondestructive testing technique for honeycomb composite material, which has been used as structural material in aeronautics and space transportation. The inspection of a honeycomb composite structure by the conventional NDT technique is difficult and complex. Optical NDT can give a solution about problems of previous technique. Optical NDT basically provides non-contact, whole-field inspection and easy interpretation. Representative techniques are X-ray, Thermography, Electronic Speckle Pattern Interferometry (ESPI), Shearography, Neutron Radiography and so on. They each have strengths and weaknesses with respect to system preparation, field application and inspection target. ESPI, ultrasonic testing and Thermography in this paper are applied to detect an artificial defect of 30 mm in diameter and an impact-induced delamination inside the honeycomb composite plate, which consists of an aluminum core and carbon fiber reinforced plate skin. Inspection conditions in the experiment are compared with each other, and results are discussed.

1. Introduction

The performance of honeycomb composite materials has been advanced by their widespread application in aerospace structures over that of conventional materials. However, their mechanical properties may degrade severely in the presence of various types of damage. Impact damage, which is most common, and can lead to significant degradation of the mechanical properties and to the complete failure of a structure. It may occur either at the manufacturing level or during in-service application of a material. As the primary cause of delamination, impact damages must be detected early and their extent characterized to evaluate the integrity of a structure. Therefore, the non-destructive techniques (NDT) for reliable detecting of manufacture or in-service defects (disbonding, defects from impact, etc.) are necessary [1]-[3]. Disbonds, impacts or other defects in composite structures are detected by many techniques such as Radiography, Shearography [4], Thermography [5], [6], Electronic Speckle Pattern Interferometry(ESPI) [7], Ultrasonics, and they continue to be advanced and extended. The main in-service demands on NDT methods are simplicity, rapid application and reliability[8], [9]. In this respect, ESPI and Thermography can overcome the limitations of conventional techniques. Two methods for nondestructive evaluation (NDE) are aimed at the discovery of subsurface features such as abnormal inclusion, delamination, thanks to relevant temperature difference or relevant deformation observed on the surface with ESPI or Thermography. To detect subsurface defects, an external stimulus is necessary which is called active technique. Thermal excitation in ESPI and Thermography is widely applied and is known as reliable technique. In which, object is heat up by high-power lamp. Because it is difficult to maintain uniform thermal loading in case of broad surface, thermal excitation has some limitation in out-door application. This paper proposes a coolant injection technique for honeycomb composite plate, which supplies easy to application and high repeatability. ESPI and Thermography, based on the proposed technique, are applied for the delamination detection of honeycomb composite plates and compared with each others.

2. Principles and experimental setup

2.1. Electronic speckle pattern interferometry

The fringe pattern from ESPI can be used for the detection of damage in composite materials and is associated with the surface displacement of a specimen under external loading. Two states, before and after deformation, are compared, and the dynamic variation of the fringe pattern during deformation of an object can be readily monitored in real time. Optical phase information extracted from fringe patterns can be equally employed to quantitatively evaluate defect size and location. Phase distribution can be determined by many phase extraction techniques. Time-dependent phase shifting technique [10] is a common example.

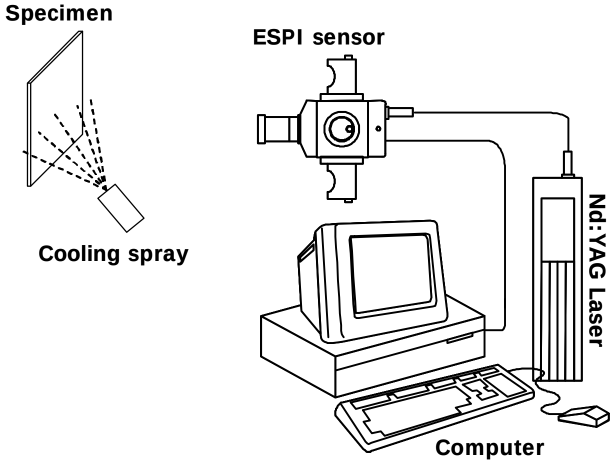


Figure 1: *ESPI measures the surface deformation under thermal loading and the difference of thermal expansion coefficient between sound part and defect part indicates the detect size and location.*

Phase map can indicate damage's size and location with high visibility and clarity. In this paper, a commercial ESPI system shown as Fig. 1 and software, Ettemyer GmbH, is used. The laser source is Nd:YAG laser with 532 nm wavelength. Out-of-plane displacement sensitive interferometer and 4-step phase shifting technique are employed. The phase information is demodulated to surface displacement by unwrapping technique. Honeycomb plate is deformed by thermal loading from the front side and ESPI directly measures the displacement between the defect and the sound part, which results from the difference of thermal expansion coefficient between these parts.

2.2. Infrared Thermography

Thermographic NDT technique has been used in a variety of applications, i.e. inspection of subsurface defects and features, identification of thermo-physical properties, detection of coating thickness and hidden structures. The technique has been successfully applied for delamination detection, and fiber-reinforced plastic inspection. In the 1980s, Vavilov and Taylor [11] discussed the principles of thermal NDT expressing the ability to provide quantitative information about hidden defects or features in a material. When a material presents voids or pores in its structure, its thermal conductivity and density decreases, and its thermal diffusivity is altered, so the conduction of heat transfer within the material is affected [12]. Thermography, contrary to ESPI, measures the surface temperature of an object and the temperature difference between the defect and the sound part indicates the defect size and location.

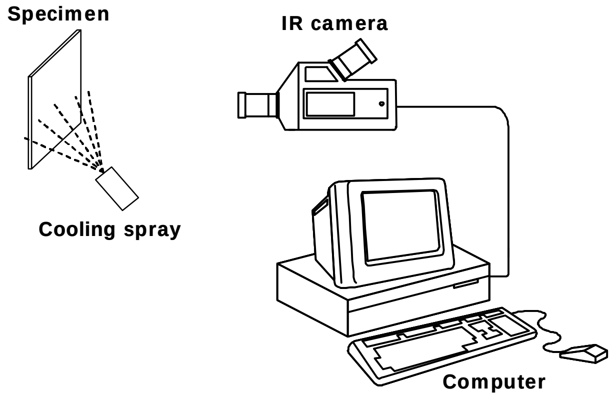
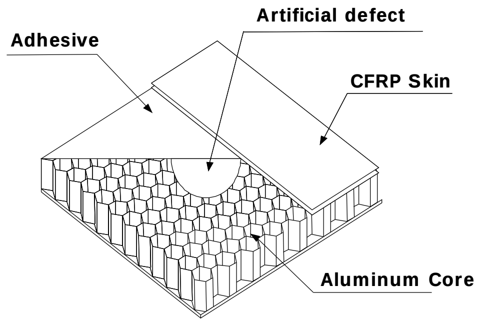


Figure 2: *Thermal loading gives temperature change due to thermal conductivity. If temperature difference between sound part and defect is large enough, the defect size and location can be recognized by 2 dimensional thermal image.*

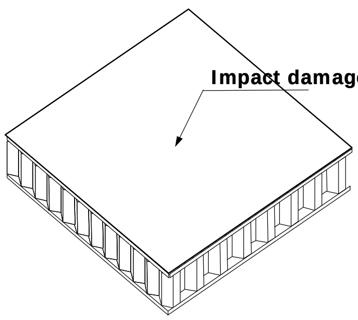
For effective detection, Thermography requires that the test object be heated effectively, but effective heating is often difficult. The IR camera, data processing software, and application techniques for detecting and imaging subsurface defects have been greatly enhanced. In this paper, IR camera (model: SC 2000), manufactured by FLIR System Co., and ThermaCAMTM Researcher software are employed. Two detection techniques are applied. In one technique, the surface of the specimen is sprayed with coolant; in the other technique, the backside of the specimen is heated with a heater, which is controlled by the power supply. Figure 3 shows the Thermography inspection system for a honeycomb composite plate.

2.3. Preparation of honeycomb composite

The honeycomb composite materials in aerospace applications are made of thin and rigid skins bonded on a thick and light core. The prepared specimens have cores made of aluminum and skins made of carbon fiber reinforced plate. Sandwich materials may induce some debonding defects between the skin and core due to lack of pressure or adhesive during curing or due to the presence of an inclusion. In this paper, one of two specimens has an artificial defect of Teflon film with diameter of 30 mm between the skin and core. The other has impact damage inside the plate, as shown in Fig. 3. The skin of a honeycomb plate is a unidirectional laminate at 90°.



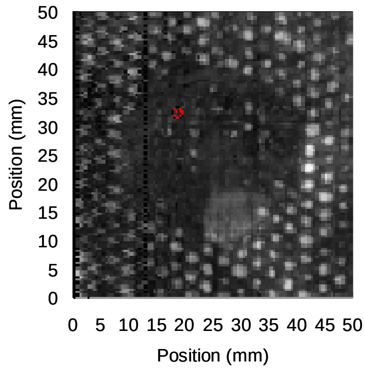
(a) Artificial delamination defect-specimen A



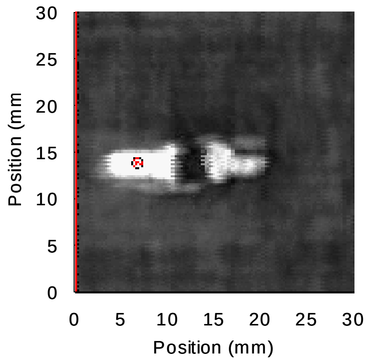
(b) Impact-induced delamination defect-specimen B

Figure 3: *The core of prepared specimens is made of aluminum and the skin is carbon fiber reinforced plate. one of two specimens has an artificial defect of Teflon film with 30 mm diameter between skin and core. The other has impact damage inside of plate.*

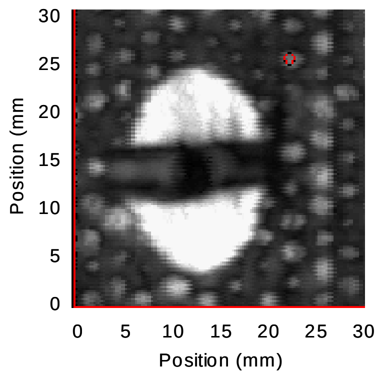
The panel with the impact damage is square of 100 mm by 100 mm, 8 mm thick, and the specimen with film disbanding is 250 mm by 100 mm, 6 mm thick. Artificial defect size and location are verified by ultrasonic testing. During the C-Scan process, the 3-axes fine manipulator with PC controlled ultrasonic probe in immersion liquid (water) scans the surface of the sample. Figure 4 shows the inspection results of artificial delamination and impact damage by ultrasonic testing. Damage area on back face of honeycomb composite is much larger than that on front face, which is compared with optical non-destructive testing techniques.



(a) UT image of specimen A



(b) Impacted side of specimen B



(c) Back side of specimen B

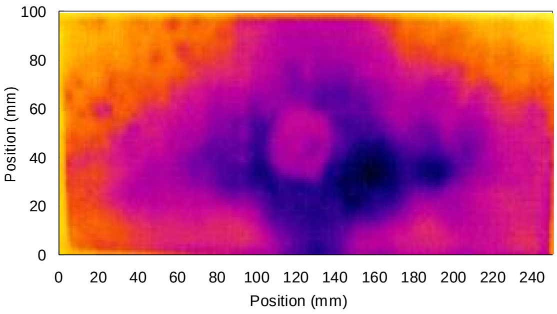
Figure 4: *The inspection results by ultrasonic C-scan show that the size of delamination is estimated as 30.68 mm at specimen A, 16.45 mm x 4.76 mm at the impacted side of specimen B, and 14.06 mm x 20.8 mm at the backside of specimen B.*

3. Experimental results

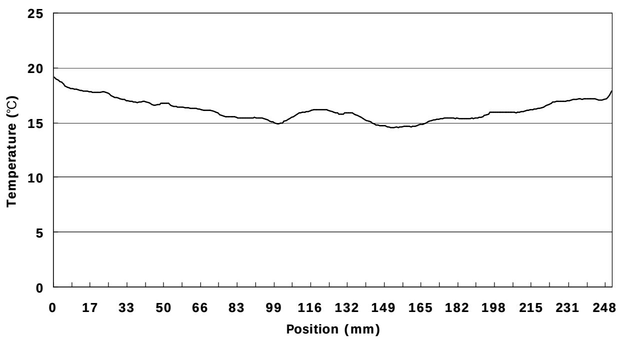
3.1. Inspection results of Thermography

Figure 5(a) shows the thermal image of inside artificial delamination by Thermogrpahy.

The circular spot on the image is identified as artificial defects, which have been detected earlier by other techniques. The computer processes the temperature distribution to evaluate the defects as 31.4 mm, which has good agreement with that of ultrasonic testing and the original size. Temperature distribution of Fig. 5(b) show internal delamination, made of Teflon film, disturbs thermal conduction and temperature on defect is higher than sound part.

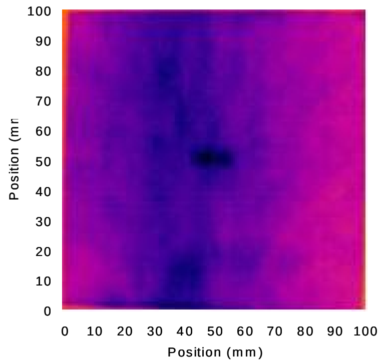


(a) Thermal image of artificial delamination defect

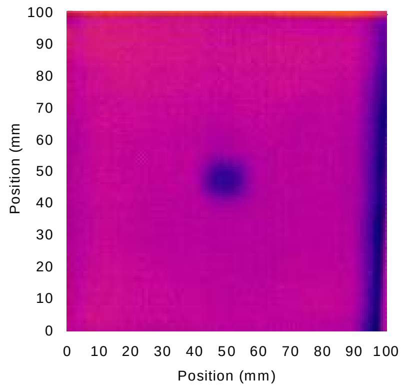


(b) Temperature profile on the surface

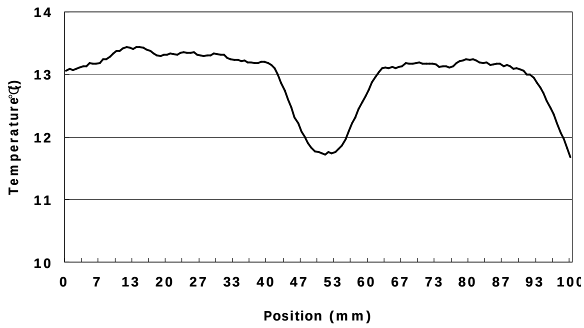
Figure 5: *Thermography result of artificial defect shows the shape and location of the defect is readily recognized due to the temperature difference and the estimated size is 31.4 mm.*



(a) After 1 second



(b) After 3 seconds



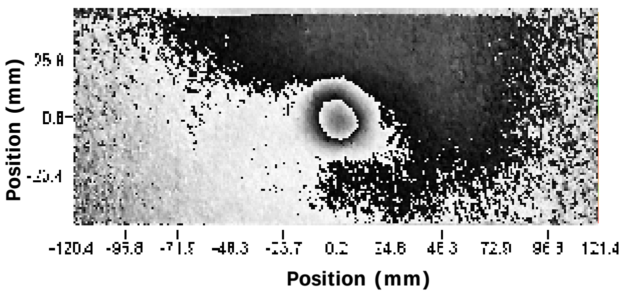
(b) Temperature profile on delamination of (b)

Figure 6: *Thermography result at the impacted side of honeycomb composite*

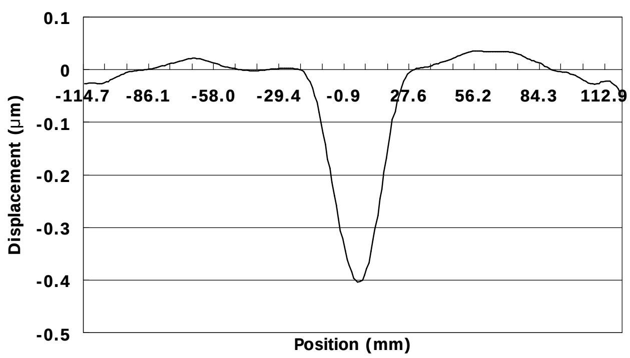
Figure 6 show inspection results for the impact-induced delamination of specimen B by Thermography. The black spot in Fig. 6(a) and 6(b) is readily identified as a defect. Defect shape of Fig. 6(a) and 6(b) is different according to the detection time after coolant injection. When one second is gone after coolant injection, peanut-shaped defect is recognized and defect after 3 second is shaped with circular type. Based on composite mechanics, peanut-typed defect is more reasonable due to fiber direction. The size of the impact damage is detected as 13 mm in the x-direction and 4.3 mm in the y-direction. Compared with those of ultrasonic testing, Fig. 4(b) in x-direction, the estimated size is 21 % higher. The reason is that the thickness of delamiation at edge has not influence on the difference of surface temperature. In temperature distribution of Fig. 6(c), the temperature on the defect, contrary to Fig. 5(b), is less than temperature on the sound part. Since the impact damage is filled with air and the heat conduction of air is much lower than those of sound part and Teflon film, the temperature of air-coupled damage decreases. When the temperature difference between defect and sound part in two experiments is more than 1 ℃, defects can be easily detected.

3.2. Inspection result of ESPI

The honeycomb composite plate is cooled for a short time with the coolant injection. The deformation during the cooling of the specimen is measured. Figure 7 shows the ESPI inspection result of the artificial defect. According to temporal phase shifting technique, phase maps are recorded at two different temperature of the object. The subtraction then yields the phase map of modulo 2π shown in Fig. 7(a). The circular fringes clearly indicate a defect. Surface deformation distribution is shown in Fig. 7(b), and deformation profile of the defect is shown in Fig. 7(c). In the deformation profile, the deformation of the defect is lager than that of sound part, which means that the thermal expansion coefficient of the defect is much larger than that of the sound part.



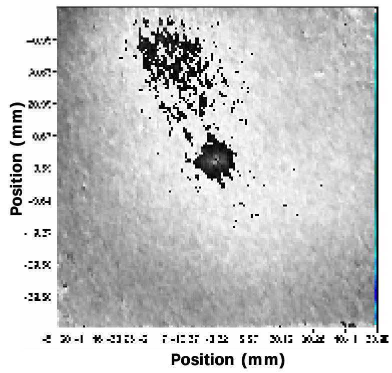
(a) ESPI phase map



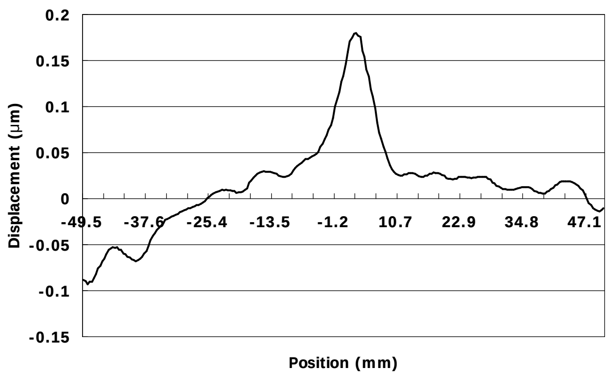
(b) Surface deformation profile

Figure 7: *ESPI result of the artificial delamination*

The defect is evaluated from Fig. 7(b) and 7(c) qualitatively and quantitatively. The size of the inspected defect which is estimated as 29.95 mm shows good agreement with that of ultrasonic testing.



(a) ESPI phase map



(b) Surface deformation profile

Figure 8: *ESPI result of the impact induced delamination*

Figure 8 shows the inspection result of the impact damage, which is more difficult to detect it than an artificial defect probably because the carbon fiber has a very small thermal expansion coefficient, which disturbs the out-of-plane thermal expansion of the defect. The defect size is estimated as 5.5 mm in the x-direction and 3.1 mm in the y-direction. The deformation difference between the defect and the sound part in line profile is small, compared with that shown in Fig. 7(b). This small difference means that the thermal expansion coefficient of the air gap by impact damage is similar to that of the sound part. Since the thickness of delamination between layers is not uniform, the defect boundary in the line profile of Fig. 7(b), compared with Fig. 6 (c), is not clear to determine the size. The location of defect in Fig. 6(c) and Fig. 7(c) is agreed with high accuracy. When the defect sizes of the two techniques are compared, Thermography's results of two defects are larger than those of ESPI.

3.3. Comparison of each method

Three different NDI techniques are compared to evaluate their ability to detect the artificial and impact defect in honey composites and reveal the magnitude of affected area. The size determination of delaminations is realized by means of the C-Scan, Thermography and laser ESPI. From the results, it could be proposed that C-scan, although it gives high resolution and the depth of defect, is not suitable for industrial application.

On the contrary, Thermography and ESPI have the high measuring sensitivity and relative simplicity of use, which are much closer to the reality. Table 1 shows the quantitative evaluation of defects. Referred to C-scan, two techniques detect the location with high accuracy and in quantitative analysis of impact delamination, Thermography gives lower error than ESPI.

Table 1: Comparison of defect size in each method (unit: mm)

	Artificial Defect	Impact defect	
		x	y
Thermography	Ø 31.4	13.0	4.3
ESPI	Ø 29.9	5.5	3.1
UT	Ø 30.7	16.4	4.7

4. Conclusions

This paper describes the ability to determine the size and location of defects in honeycomb composite plates by ESPI and Thermography and the loading technique is proposed for versatile application in composites in which the temperature of plate surface is lowered by a coolant injection. In the loading technique, front loading and inspection technique supplies a highly-efficient application of composite material structure. Compared with previous heat up technique, coolant is cool down on surface and heat flux is maintained in same direction with detector. This technique is more powerful to apply composite structure, because most of defect is resultant from outside strike – bird, small stone and something. Also, Coolant injection can be sprayed on wide range of surface uniformly and coolant can be selectable, according to kinds of object. However, this technique is difficult to apply steel structure, because most of defect is started from and propagate to outside. In inspection results, the impact-induced delamination is more readily detected by Thermography and ESPI is more usable to detect the artificial delamination of honeycomb plate. However, ESPI is more sensitive to external environmental disturbance. The defect location is detected with high accuracy in comparison with the designed location. The quantitative analysis of defect has good agreement in comparison of artificial defect. However, there are difficult to determine defect's size of impact-induced defect due to the ununiform thickness of delamination.

5. References

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