APPLICATIONS OF THERMOGRAPHY AND ULTRASONICS FOR DETECTION OF DEBONDING IN CARBON FIBRE-REINFORCED COMPOSITE PANELS

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Abstract

Carbon fibre reinforced plastic (CFRP) composites are widely employed in modern aerospace structures. Due to the involved and lengthy manufacturing processes, several types of defects can occur during production. There are various non-destructive testing (NDT) methods used to identify defects within composite components. In this paper, the performances of pulse phase thermography and the ultrasonic C-scan methods were used to assess the integrity of a bonded panel with a contaminated bond line. The pulse phase thermography method is a ‘dry’ and quick approach whereas the ultrasonic C-scan method is usually a ‘wet’ and slow approach. The two CFRP assemblies that were used were made by bonding together two sets of panels with paste and film adhesive. This was done in order to assess the performance of the two NDT methods for each of the adhesive bonding techniques. Artificial defects were introduced into the panels using different contaminants including, a release agent, release film, pre-cured adhesive and barrier cream. Both transmission and reflection techniques were employed in the experimental tests using the pulse phase thermography method, whereas only the transmission technique was used for the ultrasonic C-scan method. The pulse phase thermography method has been observed to be highly effective for detecting insertion-type defects. However, from the results of this experiment it was shown that pulse phase thermography is less sensitive to defects as a result of contamination similar to those used in this trial.

Key words: Disbond; thermography; ultrasonic testing; carbon fibre reinforced plastic;

1. Introduction

Advance structural composites are usually made of high-strength fibre embedded in polymeric matrix. Carbon fibre reinforced plastic (CFRP) composites are widely employed in modern aerospace structures due to their improved material properties compared to aluminum and titanium alloys. Due to the involved and lengthy manufacturing processes, several types of defects can occur during production. Defects such as disbond during the manufacturing process may cause dramatic reduction in the strength & fatigue life of aerospace structures (Irving and Soutis, 2014). Therefore, there is a need for a reliable, accurate and quick non-destructive testing (NDT) method for quality control in both the manufacturing and in-service phases.

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Currently, various NDT methods have been employed to identify subsurface defects of fibre reinforced composites such as ultrasonic testing, wave propagation, vibration testing, thermography, shearography and radiography (Diamanti and Soutis, 2010). For laminated composite structures, the ultrasonic method (e.g. through-transmission) has been extensively used during the manufacturing phase due to its high sensitivity to porosity and disbonds. Other dynamic methods like wave propagation (Worlton, 1957; Kessler et al., 2002) and vibration testing (Pardoen, 1989; Valdes and Soutis, 1999) have also found application in bonding quality inspection for in-service structures. Thermography has found wide application for in-service quality inspection in laminated and sandwich composite structures for bond failure and core failure due to impact damage (Maldague, 2001; Meola and Carломagno, 2004). For in-service structures, shearography has been found to be an effective method in the identification of delaminations and disbonds (Newman, 2005; ASTM, 2007). Radiographic methods, such as x-ray transmission and computed thermography (CT), show high sensitivity in both porosity and volume type defect identification. However, the method manifests less sensitivity in planar defect detection which limits its application in laminated structures.

Among the existing NDT methods, ultrasonic testing is currently the predominant inspection technique for advance composite laminated structures in the aerospace industry. Nevertheless, the long inspection period and complex requirements for surface preparation limits its operational efficiency in the manufacturing process. The literature has reported the significant time saving improvement associated with pulse thermography approaches compared to other approaches in NDT testing for in-service laminated composites structures, such as wind turbine blade (Amenabar et al., 2011) and aircraft fuselage (Genest et al., 2009). However, most of the previous studies focus on the in-service phase application, the performance of pulse thermography approach in manufacturing phase NDT assessment for disbonds is not well studied. In addition, insertion-type defects (embedded PTFE sheet) have been widely studied in the research papers for pulse thermography approach (Vollmer and Mollmann, 2010; Maierhofer et al., 2014), other type of defects which do not contain an insertion layer has not received enough attention. It is worth noting that due to the variation of thermal properties associated with different types of artificial defects, the performance of thermography approach depends on the defect types studied.

In this paper, a comparative study has been carried out to understand the performance of the pulse thermography approach compared to through-transmission ultrasonic C-scan for various types of disbonds identification in the manufacturing process. Pulse Phase Thermography (PPT), as a commonly used quick NDT approach, has been investigated for the assessment of the integrity of a bonded CFRP panel with a contaminated bond line. The two CFRP assemblies that were used were made by bonding together two sets of panels with paste and film adhesives. Artificial defects were introduced into the panels using different contaminants including, a release agent, release film, pre-cured adhesive and barrier cream. Both transmission and reflection techniques were employed in the experimental tests using the pulse phase thermography method, whereas only the transmission technique was used for the ultrasonic C-scan method. The panels containing each type of adhesive have been tested using the two NDT techniques and the results have been compared. Some key features in the study are highlighted at the end of the paper.

2. Sample preparation

Fig. 1 shows the bonded CFRP panel samples employed in this investigation. The dimensions of each panel are 550 mm x 550 mm x 4.5 mm in length, width and thickness. The two panels used were made by bonding together two sets of panels with paste and film adhesives. To investigate the effect of different types of artificial contaminant in the bond line, five types of defects were introduced into the panels. Fig. 2 shows the arrangements of the defects embedded in the panel, including, cured film removed (left top), pre-cured adhesive (left bottom), release film (right top), chemical release agent (right bottom) and release cream (middle). The results of C-scan and thermography tests are produced according to the same arrangement of defects shown in Fig. 2 in the following sections.
3. Pulse thermography test

Fig. 3 (a) shows the experimental setups of a transmission pulse thermography test. The sample has been mounted vertically by adhesive tapes on the metal frame. Two flash lamps are arranged symmetrically at the back of the sample at a distance about 0.3 m to ensure the light illumination is uniformly distributed on the sample surface. The thermal camera is set at a fixed location which provides the full view of the sample. The experimental setup of the reflection pulse thermography test is shown in Fig. 3 (b). The flash lamps are arranged at the front face of the sample at the same angle of inclination to the panel surface at a distance of about 0.3 m. The IR camera is placed at 2.5 m from the sample front surface with an adjustable lens to cover the full size of the CFRP sample. Fig. 3 (c) presents the data acquisition module of the testing system.
4. Results and discussion

4.1 Paste adhesive CFRP sample

From Fig. 4, the two pre-defined defects with inserted release film (upper right) and pre-cured adhesive (lower left) were clearly identified by the C-scan test. In addition, the outline of the supporting paste adhesive beads is also clearly shown in the C-scan. Nevertheless, the defect with removed release film (upper left) is not clearly indicated in the results. The defect section with applied release agents (contaminants – lower right) showed slight attenuation above the background level. However, its contrast ratio with respect to the bonded region is relatively small. In addition, the barrier cream applied in the centre region is not detected from the C-scan.

Figs. 5 (a) and (b) show the transmission and reflection configuration of PPT for the paste adhesive CFRP panel, respectively. From Fig. 5 (a), the transmission PPT shows the outline of the paste adhesive beads. A slight dark spot occurs in the bottom left ellipse which is related to the pre-cured adhesive. The other defects, including the inserted release film, release agent, barrier cream and removed release film, are not clearly shown in the phase thermal images. In addition, a certain degree of random noise is manifested in the corner of the transmission results. This may be due to the ambient/background light during the exposure by the IR camera.
The original reflection PPT phase image is shown in Fig. 5 (b). The reflection configuration shows less sensitivity to ambient light effect which is due to the relatively large infrared intensity from the flash lamp during recording duration. Similar to the transmission test, the adhesive bead outline is clearly seen from the phase results. The pre-cured section again shows a slight darker region in the phase image, while the other types of defects are not well identifiable in the image.

4.2 Film adhesive CFRP sample

It is seen in Fig. 6 the C-scan clearly identifies four of the five defects. The inserted release film and pre-cured adhesive, exhibited the highest sensitivity in the test. This corresponds with the results of the paste adhesive CFRP sample in the previous sub-section. Slightly lower intensity is shown in the defect caused by the release agent. The defect with removed release film (after curing) is partially detected in the film adhesive sample. The barrier cream is not identified in the C-scan test, although there may still be an area of contamination which may produce a weaker bond. In addition to pre-defined defect features, a certain degree of noise is shown in the C-scan results which might have been caused by the inhomogeneity in the bonding layer.

Figs. 7 (a) and (b) show the transmission and reflection configuration of PPT for the film adhesive CFRP panel, respectively. The defect of pre-cured adhesive produces a dark region that can be seen in the phase image. The defect made by inserting release film is partially detected with a relatively low contrast ratio. The release agent, barrier
cream and removed release film, are not seen in the phase image. This is similar to that observed with the paste adhesive for the same defect types shown in Fig. 5 (a). Noise from ambient/background light is visible in the corners of the image.

The original reflection PPT phase image is shown in Fig. 7 (b). Compared to the transmission configuration, the reflection PPT has less background noise in the phase image. Similar to the transmission test, the pre-cured adhesive defect is observed in the phase image of the reflection PPT. The contrast ratio of the inserted release film is relatively low and the size and shape of the defect is difficult to assess. The release agent, barrier cream and removed release film, are still not observable as seen in the transmission PPT result.

Sections 4.1 and 4.2 compared the pulse thermography and ultrasonic C-scan test results for various types of defects that frequently occur in the manufacturing process. The results in those sections suggest that the NDT method used depends on the defect type and bonding method. As an initial NDT approach, the infrared thermography method has been increasingly applied in aerospace and related fields. Its ability to detect defects related to pre-cured adhesive and release films has been demonstrated in this study. The results of this study can be employed as a guide to find a suitable NDT approach to apply in practical applications. For the application of the thermography method, as a NDT tool, in manufacturing of composite structures, a preliminary test is helpful to understand the limitation of the method, in particular the inspection configurations.

5. Conclusions

In this paper, a comparative study has been carried out to understand the performance of the Pulse Phase Thermography approach compared to ultrasonic C-scan, for identifying various types of defects, present in composite manufacturing. Pulse Phase Thermography, has been used for the assessment of bonded CFRP panels with a variety of defects. The result of the thermography approach in both transmission and reflection is compared with through-transmission C-scan. The effectiveness of the thermography approach has been demonstrated for defects of voids, pre-cured adhesive and release film.

Certain limitations are also revealed from the comparative study. The defects of removed release film (cured), release agent and barrier cream, the thermography approach is not effective. Detection is slightly better in film adhesive than paste. Less variation of the detection performance occurs between transmission and reflection configurations of thermography. In addition, some of the other signal processing methods are not employed in the analysis. Further study may require characterising the performance of the thermography approach completely in terms of measurement and post-processing procedures.
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