Evaluation of Defects in FRP Composites by NDT Techniques

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ABSTRACT

The very fast developments of technology of composite materials have led to newer and wider applications of such promising materials. Composite materials offer a number of potential advantages in the aerospace field, particularly in safety-critical structures such as primary and secondary aircraft components. The presence of several types of defects such as voids, inclusions, debonds, improper cure and delamination are almost common during the manufacture and use of composite materials. The proper assessment of such defects is necessary to utilize the full potential of these materials. This present work has been taken up to detect and characterize of such defects using thermal imaging technique. The technique is found to be deterministic in the acceptable level for the assessment of defects in polymer composites. The thermography, ultrasonics (A-Scan and C-Scan) and also microscopy (photo-microscope and scanning electron microscope) methods were used here to assess the defects. The detection and characterization of the wide range of defects requires a number of specialized nondestructive methods. The proper assessment of defects is an essential, particularly in safety-critical structure such as primary and secondary aircraft components to avoid catastrophic failure.

KEYWORDS: Composite materials, Defects, NDT, Thermal Properties, Thermography, Ultrasonography, Micrography

NTRODUCTION

The composite products are too many and cover a very wide domain of applications ranging from an engine valve or a printed circuit board laminates to a longer size boat level or an aircraft wing. Equally there can be an enormous variation in the thickness and overall size of the components, from small carbon-fiber composite panels on satellite structure, which might be only 0.25mm thick, to the 30m long and 25mm thick, hull of a naval miniature. The ample evidence can be found of the growing confidence in composite materials and of increasing penetration in many applications. But the full potential of composites can not be explored without a significant improvement in manufacturing reliability and reproducibility. The presence of different types of defects such as voids, inclusions, debonds, improper cure and delamination are almost common during the manufacture and use of composite materials. A reduction in void content from 40% to 10% increases the flexural strength by nearing three times, and almost doubles the modulus [1]. The characterization of defects is addressed in the present investigation for fiber-reinforced plastic (FRP) composites. The presence of voids is almost inevitable during the manufacture of polymer composites. A high void content results in (i) weaker interfacial strength due to inadequate adhesion, (ii) mutual abrasion of fiber; and (iii) crack initiation and growth due to void coal essence. The present investigation has been taken up to assess the defects by non-destructive testing (NDT) techniques; ultrasonic (A-Scan and C-Scan), thermal imaging and photomicroscopy to provide assurance on the quality and structural integrity of a particular component. It is frequently alternative to repair the composite structure than to undertake complete replacement. Foils of different metals with different thickness were chosen to introduce artificial defects in the laminated composites during fabrication. The thermography can detect local small variations in thermal diffusivity arising from inhomogeneities in composite materials. The presence of metallic foil in the laminate has raised the thermal diffusivity and the defect is detected as a local hot spot.

EXPERIMENTAL

The high modulus impregnated carbon fibers with epoxy resin were used to prepreg laminated composites. Samples comprise of 15 layer of unidirectional preparing carbon fiber, were made by lay-up method with autoclave vacuum begging (Moores Press, 310 mm diameter, 20 ton capacity with resistance heating arrangement). Different types of materials with different thickness (copper foil of 0.1mm, aluminum foil of 0.015mm, gold leaf of 0.0075mm, zinc foil of 0.38mm thickness etc.) were chosen to introduce artificial detects in the laminated composites during fabrication. The curing of the sample was performed at 120^{o}C temperature for 20 minutes under 551.6 kPa pressure.

The thermal imaging was performed with Land, Cyclops TI 35+ thermal imager. The imager has scanned system using 8 facet polygonal mirror of having 12 elements HgCdTe detector and also having 0.5m to infinity focusing range. Thermographic method may be conveniently divided into two main types: passive – where there is an externally applied heating or cooling source and active – where there is internally generated heating effect. In both the cases, the surface temperature distribution is monitored and examined for anomalies that indicate the presence of detects.

The ultrasonic waves passing through a composite material interacts with the various defects. These defects in turn affect the wave velocity and attenuation. The A-scan experiment was carried out with double-probe in pulse-echo mode by the ultrasonic flaw detector, USM 2. The C-scan produces a real image of the defect. The C-scan test was performed with a Krautkramer USD 10 instrument.

The optical photo-micrographs and scanning electron microscope (SEM) studies have been conducted on carbon/epoxy and Kevlar/epoxy composites to evaluate the defects.

RESULTS AND DISCUSSION

The active method, however has only really found application in the monitoring of fatigue tests where heat is generated by fretting effects at a site of internal damage [2]. In the passive method, which has been much more widely employed, the surface of a component is subjected to a rapid temperature change and the subsequent heat flow is monitored. The way in which the heat is dissipated depends on the thermal conductivity of the composite and on the nature and location of defects. If there is a delamination, in a composites then less heat will be transmitted through the defective area resulting in a hot spot on the heated surface, and a cold spot on the back surface. The performance of thermographic system is, of course, strong affected by the thermal conductivity of the particular composite. Thermography is capable of detecting the presence of impact damage and debonds in composite structure [3]. Figure 1 and Figure 2 show the presence of defects in laminated carbon/epoxy composite by thermal imaging technique.

The A-scan results show the present of defects were detected except gold leaf and aluminum foil of 0.015 mm thickness. This difficulty may be due to more scatter, strong attenuation and ultrasonic damping [4]. It yields a one-dimensional trace of the defect. Figure 3 shows the detection of presence of metallic foil in carbon/epoxy composites by ultrasonic C-Scan. The only limitation is that the defect with intricate shapes is not properly monitored. The methods are better suited to metal matrix composites than to polymer matrix composites because ultrasound is rapidly attenuated by polymeric materials. The attenuation of 7 MHz ultrasound by glass/epoxy composites is 3 dB cm^{-1} compared with about 10^{-3} dB cm^{-1} for metal matrix composites [5]. The possibility of determining the size of delamination type defects smaller than the probe diameter has been investigated but it was found to be of low accuracy [6].

The optical micrographs reveals the ‘resin rich’ and ‘resin starved’ regions of carbon/epoxy composites in Fig. 4 and Fig. 5. The debonds and delaminations of Kevlar/epoxy composites are shown in scanning electron micrographs (Figures 6 and 7). The delamination here occurred because of thermal shock conditioning. The scanning study also confirms the presence of very fine delamination in the same conditioned specimens. The microscopy techniques are found to be useful in investigating the manufacturing defects and also defect percentage and fiber/resin distribution.

CONCLUSIONS

Thermal imaging was found to be very consistent and fast in detecting the different defect in the composite materials. The temperature distribution profile images clearly indicate the shape and location of the defect area. The ultrasonic method (A-Scan and C-Scan) were applied to the same samples and it was found that this non-destructive was not that consistent in polymer composites for detecting defects with very sharp corners. But non-destructive findings are only characterization unless they are correlated with results from destructive tests and with data from theoretical investigations describing which kind of flaw results in failure and why? Only this combination allows for reliable predictive maintenance where unnecessary replacement of good components is avoided while critical ones are replaced early enough to avoid failure.

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REFERENCES

1. Boey, F.Y.C. and Lye, S.W. (1992). Composites, 23, 266.
2. Papadakis, E.P., Emmanuel, P. and Mack, R.T. (1997). Materials Evaluation, 55, 2.
3. Livingston, R.A. (1996). Materials Science Forum, 210-213, 751.
4. Matiss, I. (1996). Polymer and polymer Composites, 4, 181.
5. Ashbee, K. (1993). Fundamental Principle of Fiber Reinforced Composites, Technomic Publication, Lancaster, Pennsylvania, P.402.
6. Wong, B.S., Tui, C.G., Tan, K.S. and Kwan, K.W. (1997). Insight, 39, 257.

FIGURE CAPTIONS

Figure 1. The circular region indicates the presence of metallic foil in laminated composites.

Figure 2. The temperature profile indicates the presence of defect in thermograph.

Figure 3. The C-Scan reveals the defect as a white circular regions in FRP composites.

Figure 4. Optical micrograph shows the 'resin starved' region in carbon/epoxy composites.

Figure 5. 'Resin rich' area is revealed in optical micrograph.

Figure 6. Debonding and matric crackings in Kevlar/epoxy composite are shown in scanning electron micrograph.

Figure 7. Delamination of Kevlar/epoxy laminate is revealed.

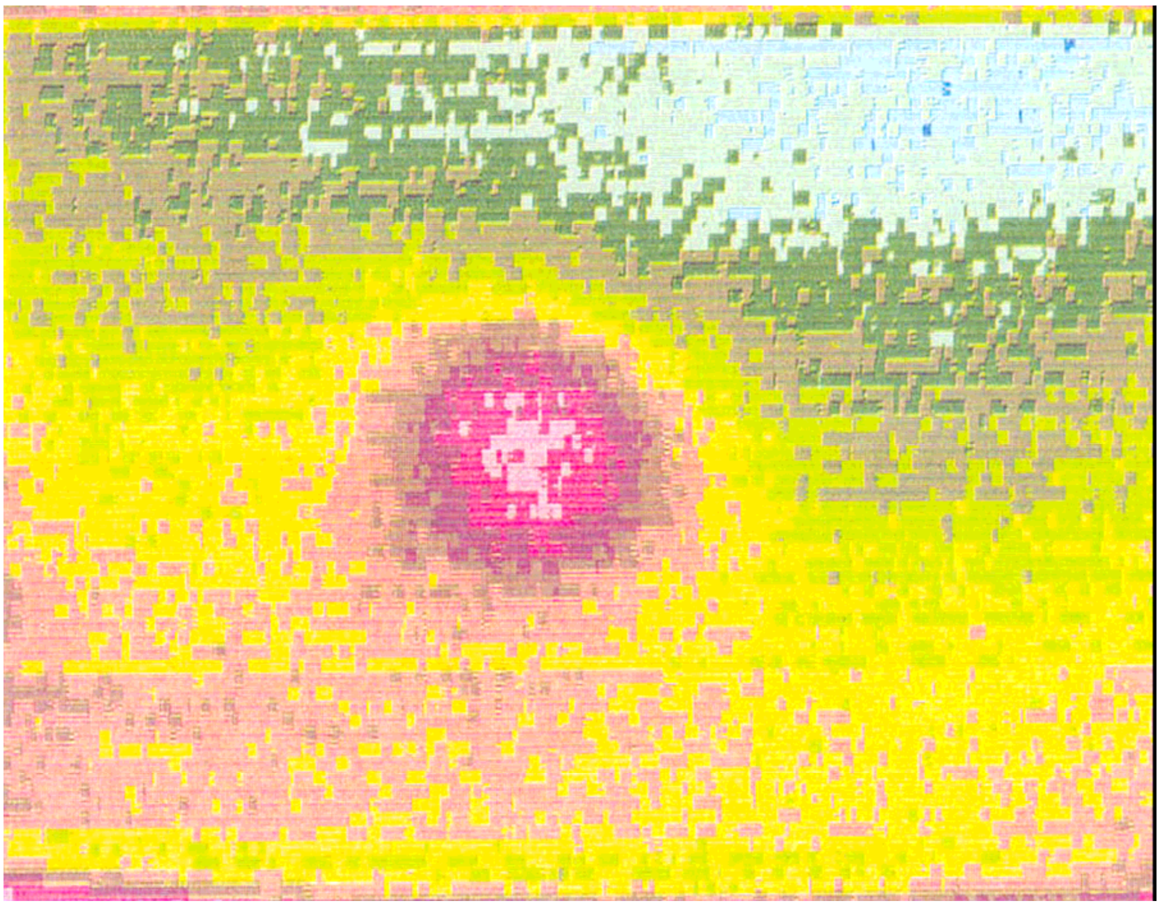
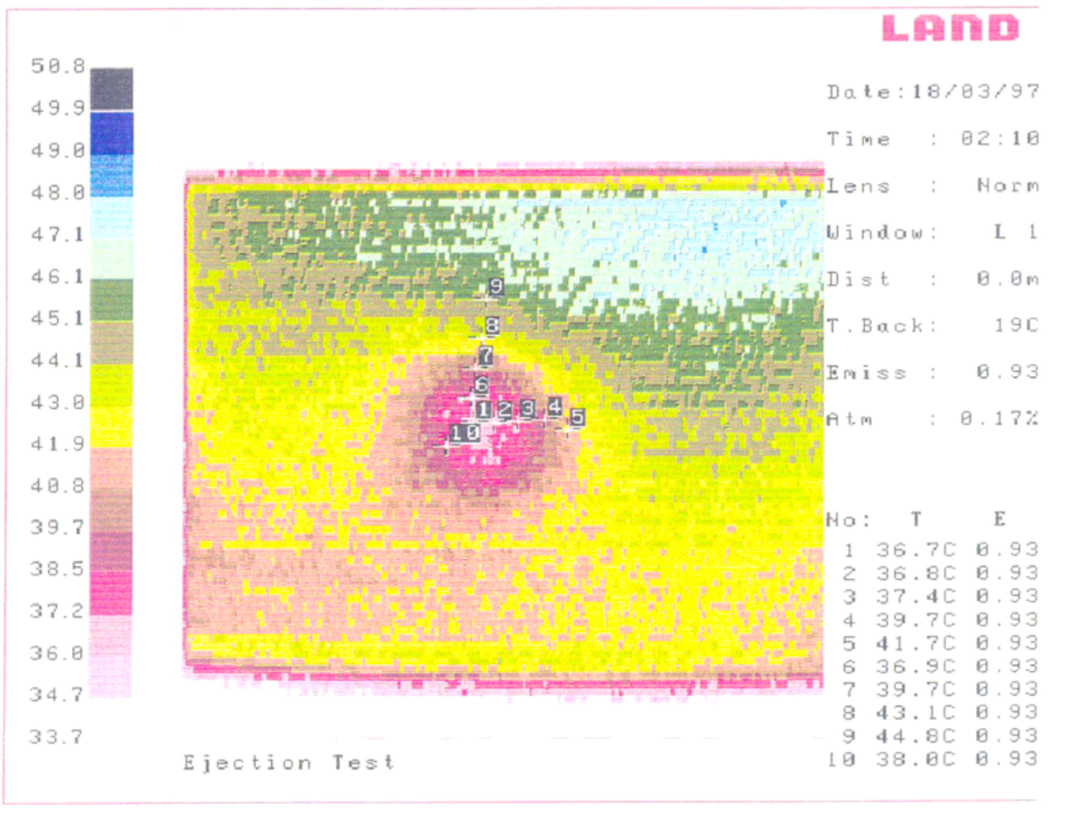


Figure 1.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39.7
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37.2
36.0
34.7
33.7
Date:18/03/97
Time : 02:10
Lens : Norm
Window: L 1
Dist : 0.0m
T.Back: 19C
Emiss : 0.93
Atm : 0.17%
No: T E
1 36.7C 0.93
2 36.8C 0.93
3 37.4C 0.93
4 39.7C 0.93
5 41.7C 0.93
6 36.9C 0.93
7 39.7C 0.93
8 43.1C 0.93
9 44.8C 0.93
10 38.0C 0.93
Ejection Test

Figure 2.

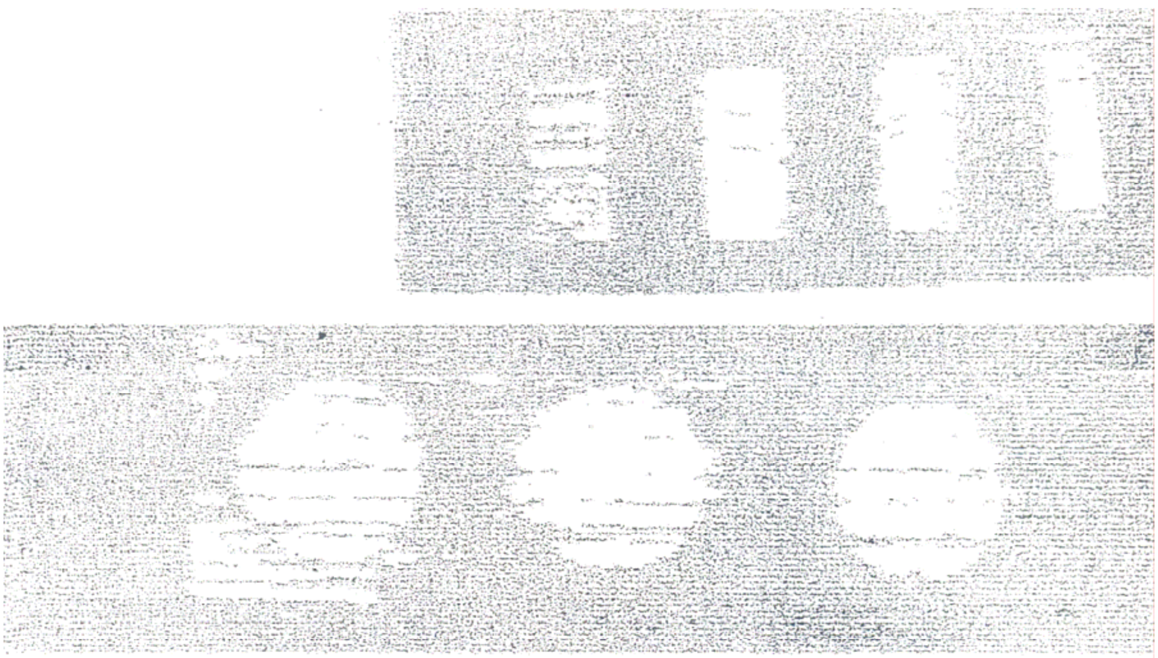

Figure 3

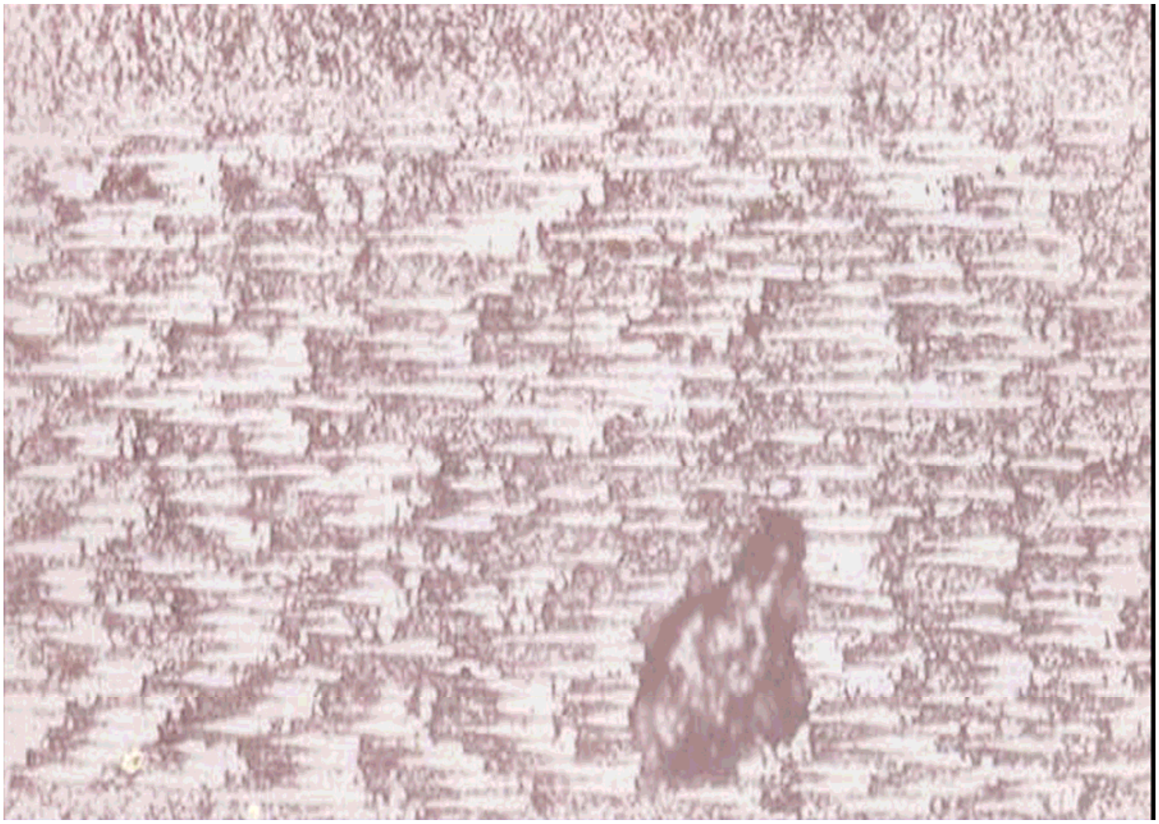

Figure 4

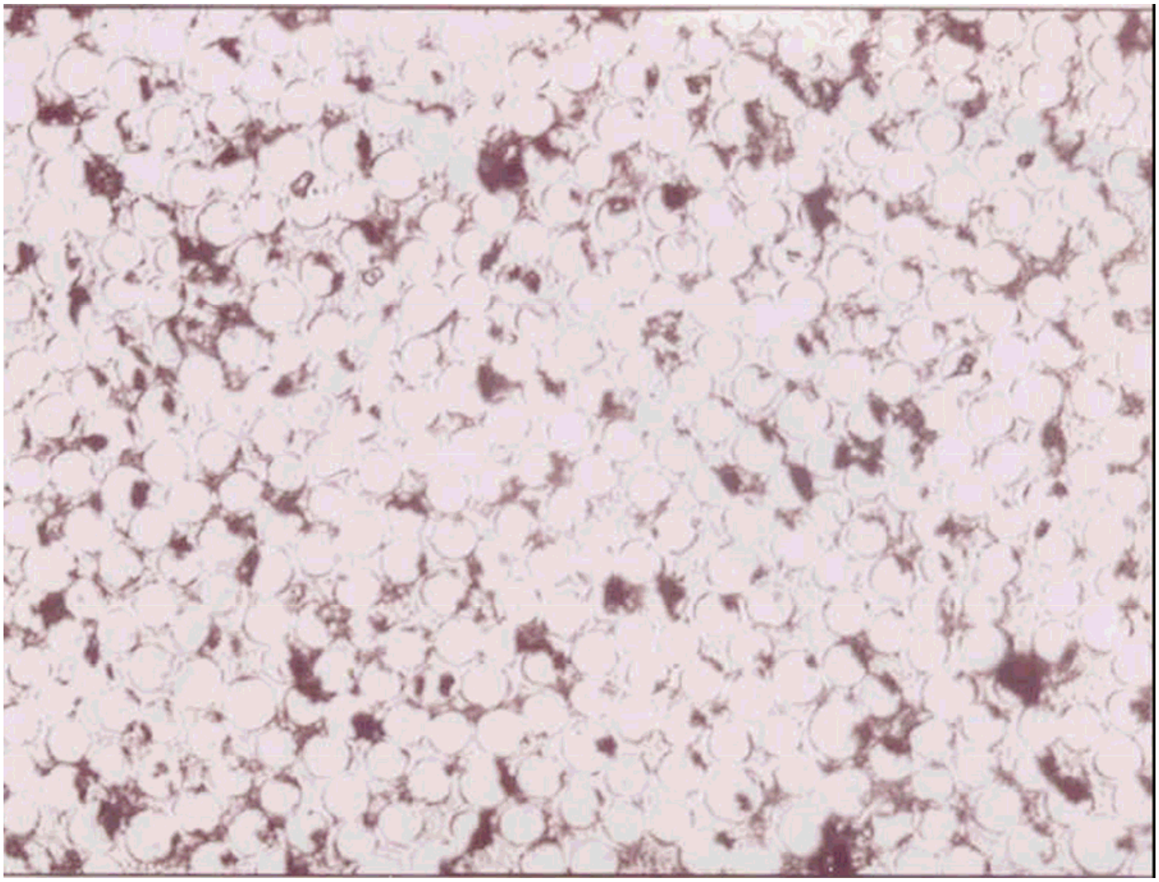

Figure 5

Figure 6.

Figure 7.