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On the Nondestructive Evaluation of Composite Structures by Liquid-Crystal Thermography

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Abstract

Due to their specific characteristics, the usage of composite materials is extended everyday. In order to prevent the catastrophic failure of composite structures, several non destructive test methods have been developed. In this study, a new technique to evaluate these structures by using liquid-crystal thermography is presented. Temperature gradients produced by sensitive liquid-crystals are used to detect invisible defects of composite structures. The effect of constituent materials and defect location is investigated and advantages/disadvantages of the new method are discussed. Based on the results from this study it can be concluded that the liquid-crystal thermography can be used as an inexpensive method in inspection of composite structures.

Keywords: Non destructive testing, liquid crystals, thermography, composite

Introduction

Due to their high specific modulus and strength, composite materials have widely used in aerospace, marine, chemical and electrical/electronic industries as well as infrastructures and bio applications. Generally speaking, defects can be produced in any structure and component during manufacturing, handling or under service conditions. To avoid catastrophic failure of composite structures, it is necessary to find appropriate inspection techniques in order to obtain information about the integrity of these structures. Non destructive testings (NDTs) can offer a solution. Among well known techniques in NDT field applied to composite structures are radiography, thermography and ultrasound methods. Delamination is one of the usual defects in composite components. Although these types of defects can be easily detected by using ultrasound techniques, however, the necessity of using an intermediate material in these techniques, is putting a limitation on their usage. It is possible for the intermediate material to penetrate into the structure and degrade or even destroy the fiber/matrix interfacial strength [1, 2].

Considering radiography, a long term usage of *x*- or γ-radiation can reduce the life time of resin. In addition, low contrast of images and high initial investment for labs and dark rooms are some of the other disadvantages of radiography techniques [1,2]. Due to these limitations, other NDT methods such as low frequency or thermography techniques are mostly preferred ones in composite industries. In this work, a new method of thermography [3] by using thermochromic-liquid-crystals (TLC) to evaluate the integrity of composite structures is introduced. TLCs change color with temperature due to a change in their molecular structure. The liquid crystals change from transparent at low temperatures, to red, yellow, green, blue and violet as the temperature is increased. At higher temperatures, the liquid crystals return to the transparent state. Based on the sensitivity of TLCs to temperature, it is possible to detect invisible defects including delamination in composite structures. In order to investigate the capabilities of this new method and to study the effect of constitutive materials, several samples using different combination of fibers and resins with an artificial defect were manufactured.

Principles of TLC Thermography

Thermography provides a description of the surface temperature changes and consequently allows detection of defects or anomalies in the underlying material due to changes in the surface temperature. The difference between thermal coefficients of defects and the surrounding materials influences the temperature distribution. Depending on how the thermal load is supplied to the sample, there are two types of thermography, the so called passive and active methods [4-6]. The passive approach examines structures which are naturally at different (often higher) temperature than ambient, while in the case of the active approach, an external stimulus is necessary to induce relevant thermal contrasts. In this work, the active method was used.

The development of liquid crystal based thermography over the past 30 years has provided researchers with a relatively inexpensive technique for visualizing and measuring surface temperature. Scientists have successfully used TLC thermography to investigate various thermal phenomena in a wide variety of applications [3]. At the heart of LC based thermography systems are thermochromic liquid crystals. These are materials which change their molecular and optical properties with temperature. Most TLC surface temperature measurement applications require that the object be coated with a thin layer of contrast enhancing black paint before applying the TLC material.

Fundamentally, a liquid crystal is a thermodynamic phase that is between the pure solid and pure liquid phases of matter and exists in some organic compounds under certain conditions. At temperatures below the TLC's event temperature, a TLC will be in the solid state and will appear transparent. At its event temperature, a TLC will reflect a unique wavelength of visible light (i.e., color) that can be readily captured by a color camera. As the temperature rises through the TLC bandwidth, the reflected color of the TLC will change. The TLCs will change from transparent at low temperatures, to red, yellow, green, blue and violet as the temperature is increased. A simple, two color-temperature designator typically describes this behavior. For example, R40C10W, the TLC used in this study, is one of TLC formulation. The R40C signifies that the red, 'R' start or event temperature of the TLC is 40^{o}C. The 10W signifies that the blue-start temperature is at 10^{o}C above the red-start temperature and this provides users with a crude estimate of the formulation's active bandwidth. These color changes are repeatable and reversible as long as the TLCs are not physically or chemically damaged. Finally, when the temperature exceeds the TLCs clearing point temperature, the material will enter the pure liquid state and will revert back to being transparent [7-10]. TLC formulations with activation temperatures ranging from -30^{o}C to 120^{o}C and bandwidths ranging from 0.5^{o}C to 30^{o}C are commercially available [11].

Preparation of Samples

The most common defect which can be created during manufacturing or under service conditions is delamination. In this study, samples with artificial defects including delamination and air bubbles were manufactured. Hand-layup was used to fabricate composite laminates containing 8 layers. Glass, carbon and Kevlar fibers with epoxy and/or polyester resin were used in this work. Two layers of Kevlar/resin were used as skin for hybrid composite with 6 layers of glass/resin as their core. The dimensions of samples with glass fibers as well as hybrid samples were 15×15 cm while specimens manufactured by carbon fibers were 10×10 cm. The final thickness of composite laminates with glass and carbon fibers was 4 mm while for hybrid samples it was 6.5 mm. Creating artificial defects was done based on ASTM D 2734-70 standard [12]. Using a piece of Teflon tape, an artificial delamination was created between forth and fifth layers in all specimens. All samples then were cured at room temperature for 24 hours.

To prepare specimens for LC thermography, one side of them were coated with a very thin layer of black paint. Using an air brush, R40C10W liquid crystal was then sprayed on the black side of the specimens. An isothermal container was used to apply a steady-state heat flow to the unpainted side of the specimen, as shown in Figure 1. Changes on the surface temperature of the samples due to the existence of defects was then recorded using a digital camera. A commercial image processor software was used to create more clear pictures from recorded images.

Results and Discussion

In order to evaluate the results from LC thermography, all specimens were also examined by IR thermography. Figures 2 and 3 show the results from both thermography methods. As it can be seen from these figures, the results obtained from LC thermography are in close agreement with those observed by IR thermography. It should be noted that due to the existence of defects and consequent differences in heat conduction coefficients between composite laminate and delaminated area (air), different behavior was observed by IR and LC thermography methods. In IR technique, since the heated and scanned surface of the laminate is same, therefore, the surface temperature of delaminated area will be higher than other parts of the laminate, i.e. the heat conduction coefficient of air is less than surrounding material. On the other hand, in LC thermography, the heated surface is not same as the scanned one. For this reason, the temperature of delaminated area should be less than surrounding area without any defect.

As it can be seen from the Figure 2, the effect of resin material on the detection of delaminated area is not significant. Both thermography methods were able to detect the interlaminar defects in both epoxy and polyester reinforced composite laminates. The only difference in applying LC method was the time required to reach the activation temperature of the LC, i.e. 40^{o}C in this study, in composite laminates with epoxy and/or polyester resins. This was because of the difference in heat conduction coefficients of these two samples.

Based on the observations from this study, it is possible to list the characteristics of TLC thermography in evaluation of composite laminates integrity. Among advantages, its low initial investment as well as lower ongoing expenses compared to other NDT techniques can be mentioned. The surface temperature gradients can be saved using a normal digital camera. In addition, it is possible to repeat the test as long as the LC is not damaged. It should be noted that, it is possible to calibrate and measure the temperature of different area using TLC thermography results. However, black painting of a surface of the laminate structure and the necessity of having access to both side of the laminate are among disadvantages of TLC thermography.

Conclusions

LC thermography is offering an inexpensive method to nondestructive evaluation of composite laminates. The results from this study indicate that this technique can be successfully applied to the detection of delaminated areas in composite structures. However, some of the limitation of this method may restrict its usage in every composite structure. Among them one can refer to the preparation procedure and the necessity of having access two both sides of the composite structure during the inspection. From economical point of view, on the other hand, it is offering an inexpensive alternative method for accurate evaluation of composite laminates. Generally speaking, the accuracy of this new method is comparable to other NDT techniques. However, the suitability of TLC thermography for the detection of small cracks needs more studies.

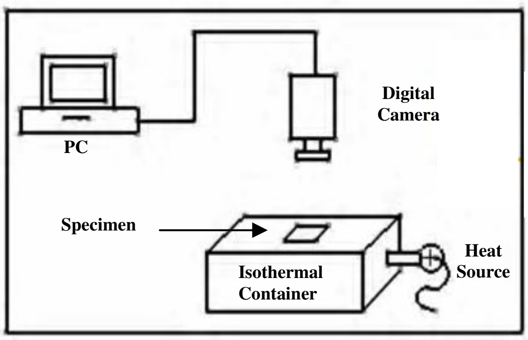

Figure 1: Schematic arrangement for LC thermography

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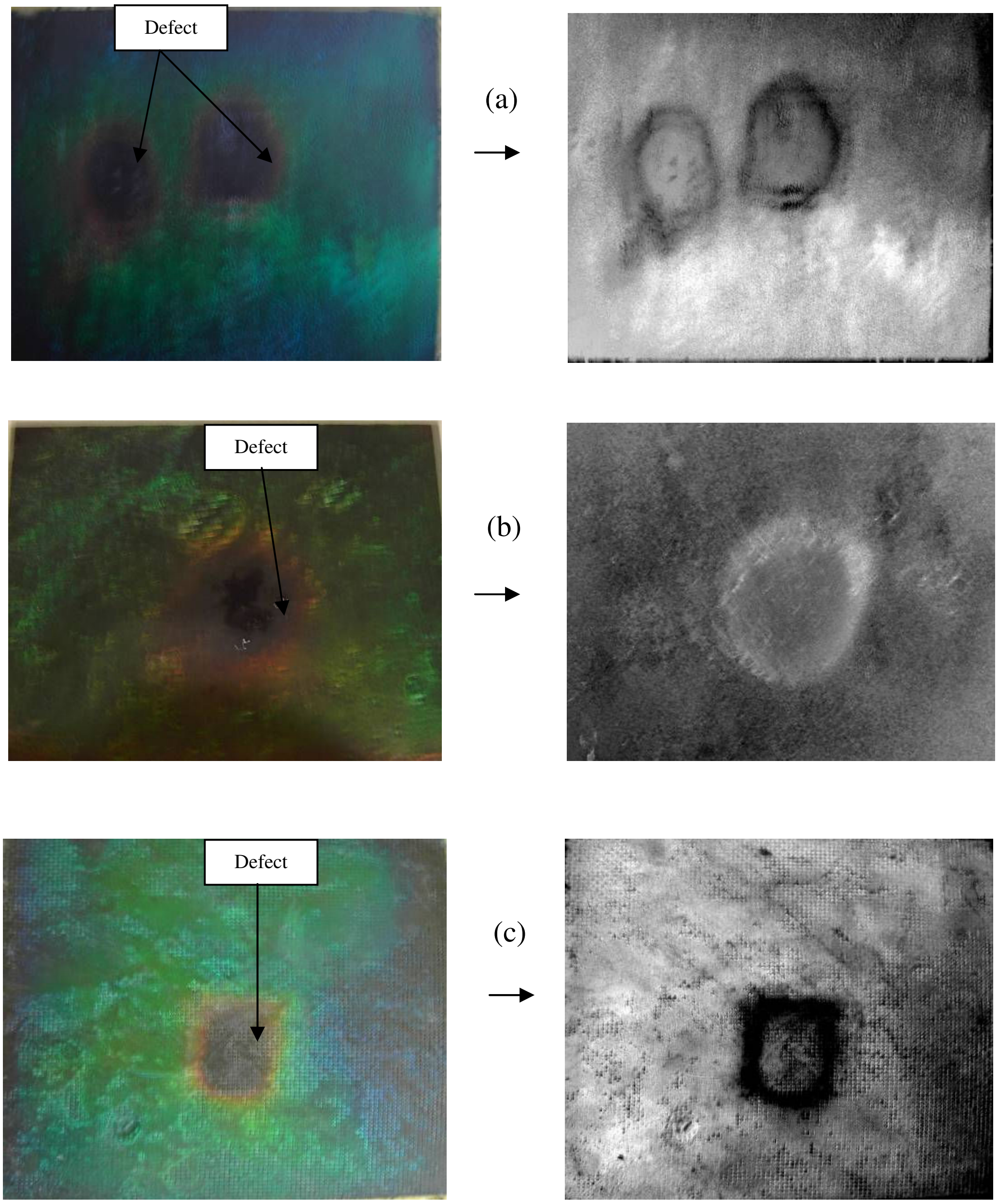

Figure 2: Results from LC thermography for specimens of (a) E-glass/epoxy, (b) carbon/polyester and (c) Kevlar/E-glass/epoxy

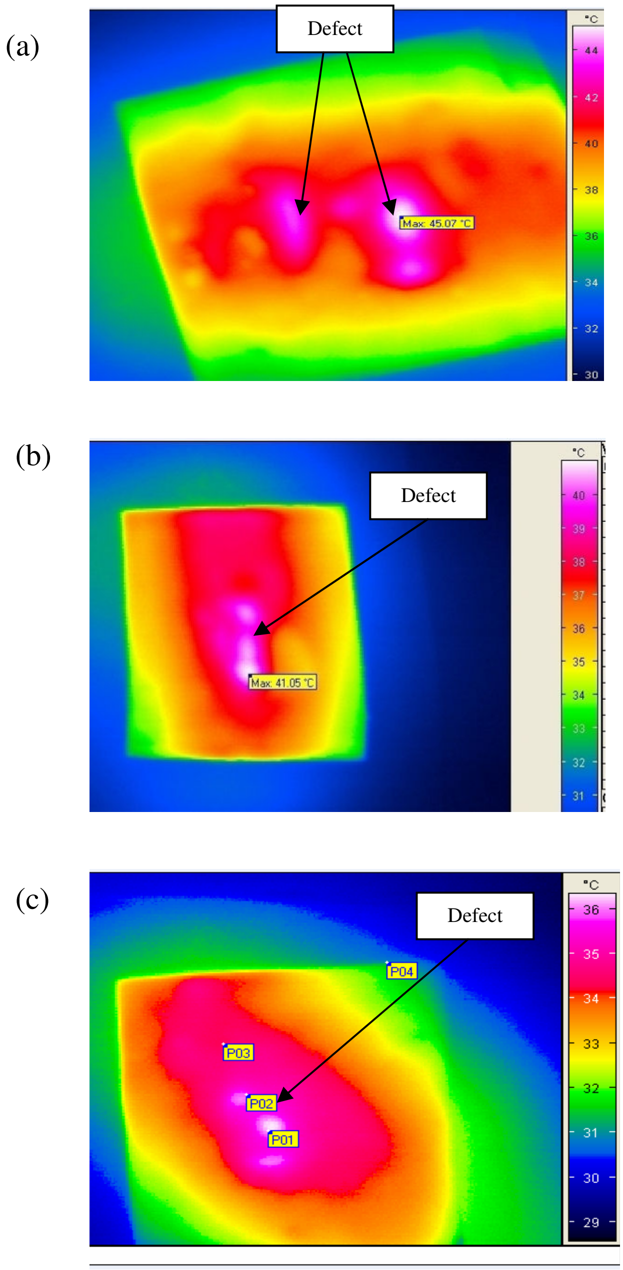

Figure 3: Results of IR thermography for specimens of (a) E-glass/epoxy, (b) carbon/polyester and (c) Kevlar/E-glass/epoxy

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