Comparison between optical pulsed thermography and vibrothermography for the assessment of carbon fiber composite materials

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Pulsed thermography and vibrothermography are two active thermography techniques characterized by different heating methods of the specimen. In pulsed phase thermography, a sample is heated by two flash lamps for a short period to inject a Dirac impulse heat in the material. The cooling of the part is monitored with an infrared camera to detect thermal contrast in the image, characteristic of the presence of a defect. In vibrothermography, high frequency vibrations are injected into the sample causing an internal heating observed on surface right above the defect due to diverse phenomena as friction or viscoelastic hysteresis. If pulsed thermography is a well-known technique that has been integrated into the arsenal of industrial NDT methods, vibrothermography is a less common experimental method still subject to theoretical and practical investigations. This article aims to compare the effectiveness of the two methods in the case of different types of composites based on carbon fibers: carbon fiber reinforced plastic (CFRP) plates as well as a completely new material: carbon magnesium composite.

CFRP sample

Sample description:

The sample is a laminated rectangular plate containing 6 square size artificial delaminations of 25 mm made of different materials (Teflon film n°2, Teflon tape n°5, Kapton tape n°6, Flash breaker n°3, Mylar and Teflon film inserted into Kapton tape n°1&4). The tested composite is HexPly_6376C_HTS(12K)_10_35%.

Pulsed thermography:

Pulsed thermography set-up:

The experimental configuration for thermal infrared vision is illustrated in Figure 1. The radiation source is pointed towards the inspected object. The camera records images from the object surface. Data is stored and processed with a computer.

Results Analysis:

Data was processed by pulsed phase thermography (PPT). After the Fourier transform of the time signal, phase and amplitude images are obtained from which we can easily distinguish 5 of the 6 defects present in the sample. The defect made of flash breaker is not so well detectable using flash lamps as heat source.

Vibrothermography

Vibrothermography set-up:

An ultrasound controller sends the vibration signal to a piezo actuator. The actuator is pressed against the specimen (by a pneumatically-driven coupling system) via a coupling material as shown in Figure 2. A time pulse at constant amplitude (Pulse method) or amplitude modulated is used.

Results analysis:

Even if the chosen vibration frequency can affect visibility of each defect, we find that the 6 defects are as or more detectable as in phase thermography (see Figure 4). The Flash breaker defect may this time be easily detected but the Kapton tape insert is, in this case, a bit more difficult to reveal. Note that at 20 kHz, a standing wave has been observed between the two rows of defects and a limited heating zone is noticed in the area of the interface with the transducer.

Conclusion:

Results obtained by both, optical pulsed thermography and vibrothermography, were somewhat similar in this case. It is worth trying to verify if this equivalence is also true in the case of other composite sample types such as carbon magnesium one (CMg in abbreviated).

Carbon magnesium sample

Sample description:

The described metal matrix composites are magnesium matrix based (AZ91 alloy, 9 wt.% Al, 1 wt.% Zn) reinforced with about 45 vol.% high strength long carbon fibers. The used manufacturing technique is the semi-solid thixomoulding injection (Husky HyMet 650) used here with full liquid fraction. Hence, short contact times between fibers and liquid metal during infiltration can lead to bad fiber-matrix adhesion at interface. Further high speed injection requires sufficient geometrical pre-form stability to avoid undesirable defects such as porosity, bad orientation, deflection or fragmentation of the pre-form. The sample used here presents fibers deflection that induces bad impregnation between carbon fibers and magnesium.

Pulsed thermography:

Results Analysis:

There is unfortunately no indication appears on the thermographic images (Figure 5). Indeed, the thermal conductivity of magnesium is very high and the heat that may be trapped by defects is almost instantly dissipated into the magnesium. Therefore pulsed thermography is not useful in this case (at least using a 40 Hz video frame rate).

Vibrothermography:

Results Analysis:

By injecting a 25 kHz vibration signal for 6 s in the sample, it is possible to observe the surface where fibers are emerging out of the magnesium. We see a significant heating due to friction fiber against fiber (see Figure 6). But temperature contrast cannot be detected by observing the healthy face for the same reason that pulsed thermography failed to do so: the thermal conductivity of magnesium. However, if it was possible to reproduce an identical test on a healthy part and one in which the fibers are poorly impregnated, the internal heat source due to friction of the fibers would result on different global temperature gradient of both samples. Thus, detecting a variation of the temperature gradient would be indirect evidence of the presence of debonding and its extent.

Conclusions

Pulsed phase thermography and vibrothermography are useful and may be complementary in the case of conventional CFRP samples with equivalent performance. Note that in the case of vibrothermography, the technique is highly dependent of the conditions of the experiment like the excitation frequency and the coupling characteristics. The pulsed phase thermography is apparently not useful for CMg sample analysis. However, significant heating of bad impregnated carbon fibers in CMg sample has been observed using vibrothermography. Based upon this finding, attempts to evaluate and quantify the total fiber/matrix decohesion surface are currently in progress, even by an indirect method. This is essential because the manufacturing process of these CMg samples remains experimental and its effectiveness must be proven scientifically.

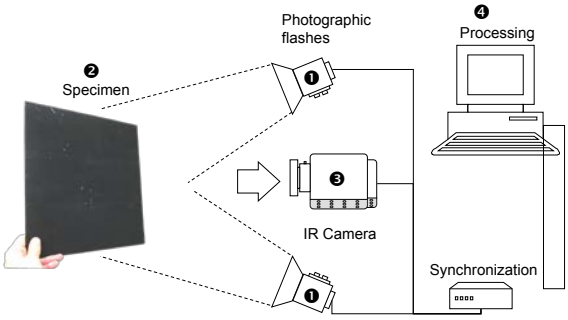

Figure 1: Typical experimental setup for infrared vision

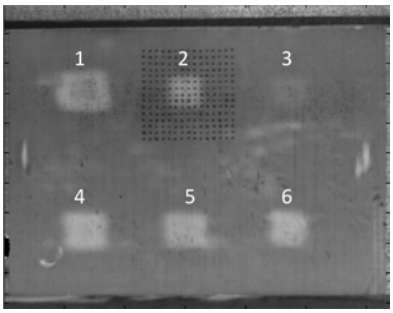

Figure 2: FFT phase thermography image of the sample using 2 flash lamps of 6.2 kJ by reflection for 5 ms

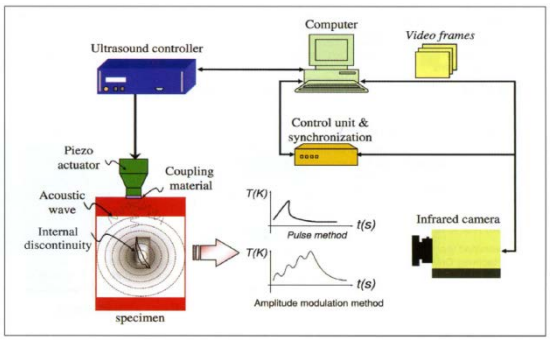

Figure 3: vibrothermography set up

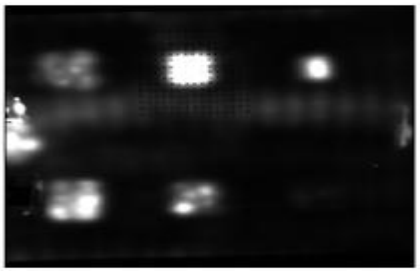

Figure 4: vibrothermographic FFT amplitude image using a 6 seconds 20kHz signal with modulated amplitude

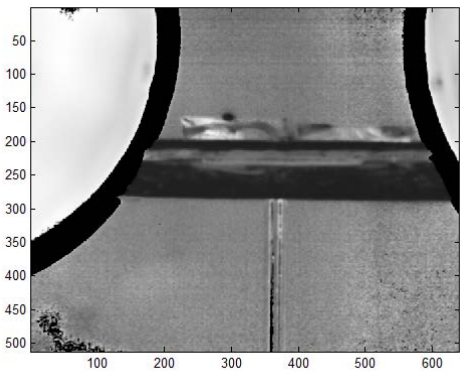

Figure 5: Pulsed thermographic image of CMg sample using 2 flash lamps of 6.2 kJ by reflection for 5 ms

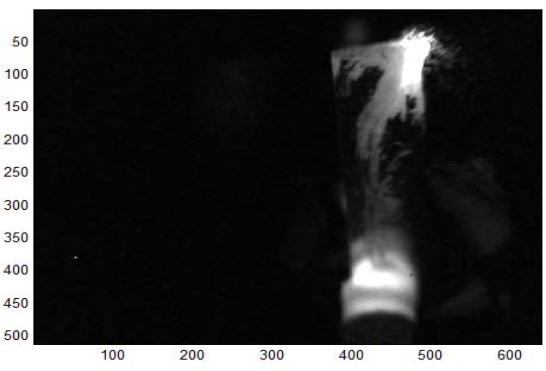

Figure 6: Vibrothemographic image of C-Mg sample(25kHz)