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Infrared thermography and ultrosonic C-scan for nondestructive evaluation of aerospace materials: A comparative study

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Abstract

Ultrasonic C-scan is a well established nondestructive evaluation (NDE) technique which has the ability to detect defects or damages in all thicknesses of materials. However, it has the distinct disadvantages of being intrinsically slow and requiring a coupling agent.[1] The use of infrared (IR) thermography techniques for the NDE of aerospace materials has progressively increased in the last few decades. It offers noncontact, rapid detection of subsurface defects. In this paper, comparative experimental results and analysis are presented; it shows that infrared thermalgraphy can be used as a complement or alternative to ultrasonic C-scan inspection technology in many practical applications.

1. Introduction

In ultrasonic C-scan, a pulser/receiver and a digital oscilloscope are used for the signal acquisition. During scanning, the sender emits ultrasonic waves, while the attenuation through the receiver is recorded at each point, stored on the internal buffer of the oscilloscope, and transferred to the computer hard disk once the buffer is filled. Then the computer processed the dates to reconstruct the echo signals that represent the internal structures. [2]This type of point testing is very time consuming for the inspection of large area components since the transducer must be scanned over the whole area to be tested. Besides, in order to reduce the attenuation of ultrasonic before it goes into the detected material the coupling agent is required. Water is commonly used in ultrasonic C-scan.

As the development of new aerospace materials, the availability of effective, rapid, reliable NDE techniques able to discover defects in complex materials and structures are required. In this context, infrared thermography seems attractive because of non-contact character and high inspection speed. [3] The main disadvantage of infrared thermography is that it can only detect damage near surface(within≈4mm, depending on materials' thermal diffusivity and defects size). However, as we know in order to reduce the aircraft weight, advanced alloy plate-like, sandwiched structures and fiber reinforced laminates instead of cumbersome metals are widely used in aircrafts. Infrared thermography techniques have proven to be an effective way to detect and, in many cases, to quantify the subsurface defects and damages in some materials.

There are two approaches for infrared thermography: passive and active. In active infrared thermography there are several ways to inject a heat source to the specimen. Normally excitation forms can be divided in four types [4]: optical, mechanical, electromagnetic or other. In this paper, both optical pulsed thermography (PT) and vibrothermography (VT) are mentioned. In PT, high energy flash lamp is used to generate a uniform plane heating source on the sample surface. The heat travels through the inspected material to the subsurface anomalies (defects or damages) and back to the surface. In VT, the solid sample is excited with high energy, low-frequency ultrasound; heat generated at the defect interface and then travels to the surface. An infrared camera is used to captures the signals of surface temperature field in both PT and VT.

In this study, titanium alloy belting, sandwiched structures and carbon fiber reinforced laminates used widely on aerospace parts were tested by infrared thermorgraphy and ultrasonic C-scan method. In addition a kind of sintered metal mesh material which is used in liquid rocket was also tested by infrared thermography. Ultrasonic C-Scan and other conventional NDE methods have difficulties in detecting the delamination defects in this special material.

2. Inspection of titanium alloy belting

Titanium alloy is an attractive material to aerospace designers due to its high strength to weight ratio and excellent corrosion resistance. This material is widely used in aircraft engine parts and some other aerospace structures. Titanium alloy belting made of rolled plate is a component of a satellite. Like other metal plates, delaminations are very common defects in these components. The three rectangle specimens that will be detected are the sections of the belting. They are all 87mm long, 28mm wide and 1.8mm thick with delamination flaws. The specimens' front surface were painted in black, and inspected by vibrothermography. They were also detected by ultrasonic C-Scan.

Figure 1 shows the comparative testing results of three different titanium alloy specimens by ultrasonic C-Scan and VT. The red rectangular frames indicate the regions that contain delaminations.

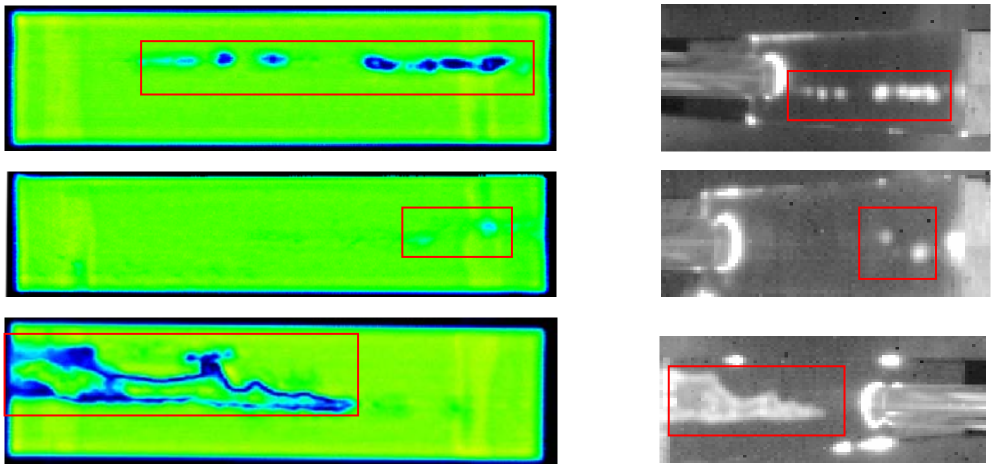

(a) (b)

Fig.1. Comparative results of three different titanium specimens by: (a) Ultrasonic C-Scan, and (b) VT

Both the VT and ultrasonic C-Scan obtained satisfying inspection results. However, it is difficult to inspect all parts of the titanium alloy belting by ultrasonic C-scan. Because the both ends of the belting bend up, which produce blind areas for ultrasonic C-scan. Figure 2 is the diagram of the bending part of the belting, and the inspection results of the bending part by

VT. The high energy, low-frequency ultrasound was well absorbed, but there was no delaminations can be seen in either front or back side testing. The thermal anomaly marked by a blue frame is caused by the friction of contact area of the belting.

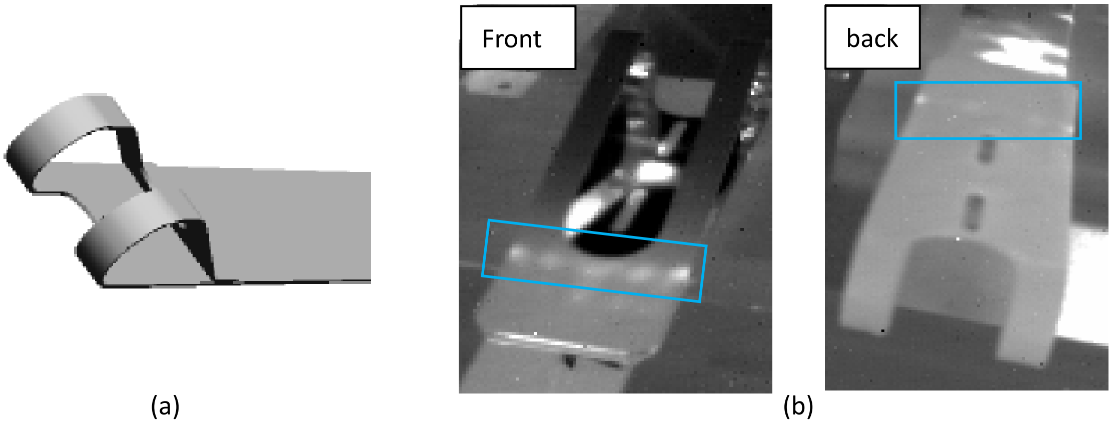


Fig.2. (a) diagram of the bending part of the belting, and (b) VT inspection results shows anomalous heating due to the horn tip and the friction at the contact area of the belting

3. Inspection of sandwiched structure materials

Sandwiched structures made of a honeycomb core between two multi-layer are very common in aerospace parts. The skin materials can be aluminum, carbon or glass fiber reinforced plastics and some other composites. The honeycombs are commonly made of paper, aluminum or polymer materials. This kind of structure is normally affected by anomalies such as delaminations (between plies in the facesheet), disbonds (between the inner facesheet and the core), core crushing, etc..

Ultrsonic C-san is widely used in these materials inspection. Figure 3 shows the inspection results of a sandwiched structure material made of paper honeycomb and two glass fiber reinforced plastics skins. In the C-scan map the six artificial defects simulate disbonds and the honeycomb structure can be seen clearly.

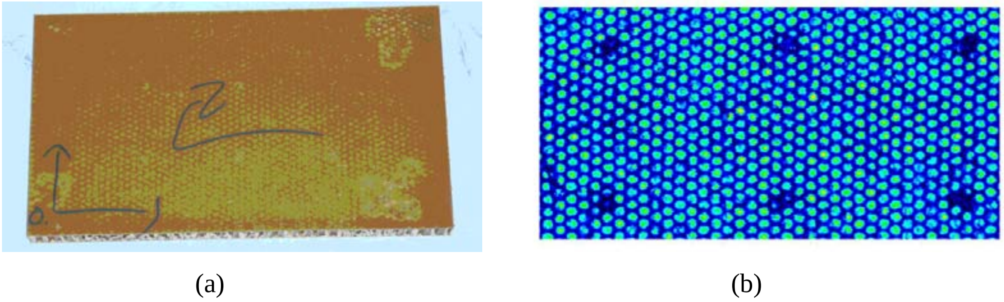
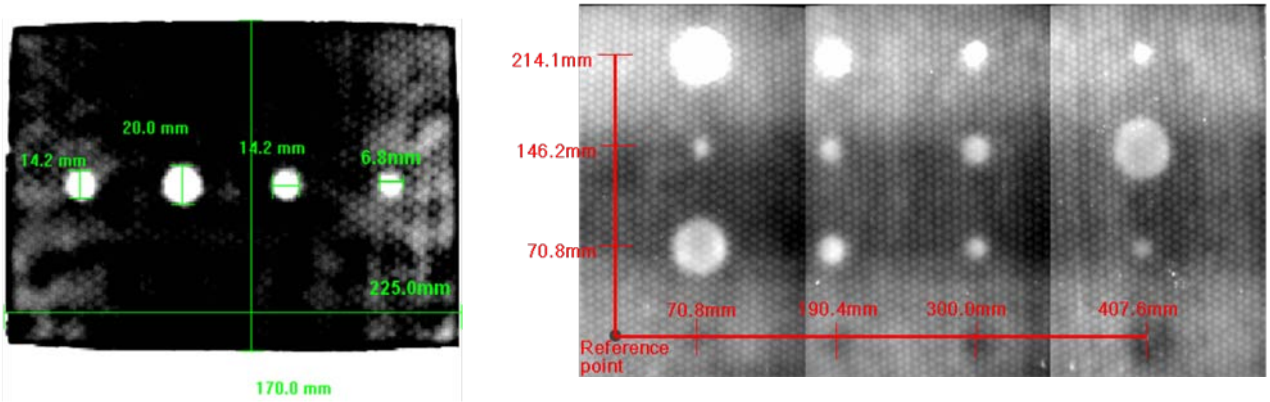


Fig.3. (a) Specimen photograph, and (b) inspection results by ultrasonic C-scan

However, a continuing problem with these composites inspection is the need to cover large areas of structure and in situ inspection. Figure 4 is the inspection results of another two sandwiched structures by PT. The measurements of the four simulated disbonds were marked out on the thermogram, as shown in figure 4(a). The dimension of the sample was treated as a known size, the actual size for each pixel a can be calculated, then the defects size (diameter D) can be determined using the following equation: $D = \Delta n \times a$. Δn represents the pixel points of the defect. Figure 4(b) is the thermogram with horizontal and vertical distance measurements from the defects to the reference point. It is a part of testing results of a large area sandwiched structure. The inspection results by PT show perfectly the inner defects and the honeycomb structure, which let us to believe that PT could provide rapid and satisfying in situ inspections.



(a) *(b)*

Fig.4. Inspection results by PT. (a) Thermogram with defects measurements, (b) Thermogram with horizontal and vertical distance measurements from the defects to the reference point

4. Inspection of carbon fiber reinforced laminates after impacting

Four carbon fiber reinforced laminates specimens of dimensions 89×55×1.5mm3 were inspected. All the specimens were made of laminates with ply stacking sequence [0° /45° /90° /135°], see figure 2. Low velocity impact was conducted using a Falling Weight Impact Tester, and the specimens were struck by a 20-mm diameter hemispherical steel impact head, weighing 4.0 kg. The impact head fell down from different heights; the impact energies were 2J, 3J, 4J, 5J. All impacts occurred at the center of the specimen and multiple impact was prevented. There were no obvious damages on the surface of specimens.

Ultrasonic C-scan is routinely used in the assessment of the carbon fiber reinforced laminates after impacting. The specimens were immersed into the water. The transducer that focused and had a 5 MHz output frequency received the reflection echo from the specimen back-face. The projected images of the internal damages obtained by ultrasonic C-scan are shown in figure 5.

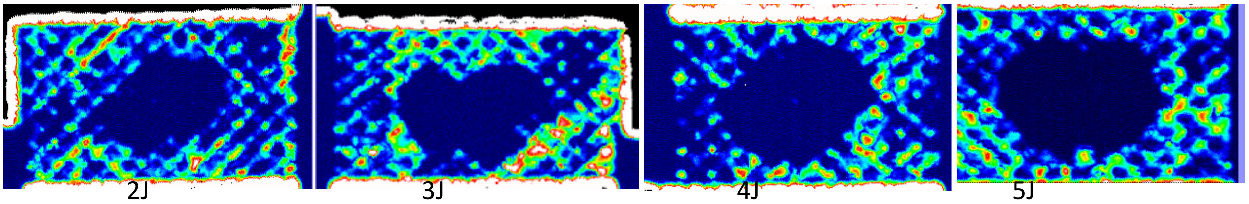


Fig.5. Ultrasonic C-scan inspection results of the specimens impacted with energies from2J to 5J

Pulsed thermography shows an interesting result for carbon fiber reinforced laminates after impacting. Figure 6 shows first derivative images at different times. The image sequences demonstrates that the inner damages twist around the impact point and extend along the fibers directions[0° /45° /90° /135°]. Figure 7 shows the schematic of impact damage in the specimen.[5] Damage area increases with the impact energy in turn increases, which is demonstrated by both the ultrasonic S-scan and PT inspection results. Figure 8 shows the PT inspection results of the specimens impacted with energies from 2J to 5J. Comparing with the ultrasonic S-scan, PT obviousely gives more informations about the inner damages in this case.

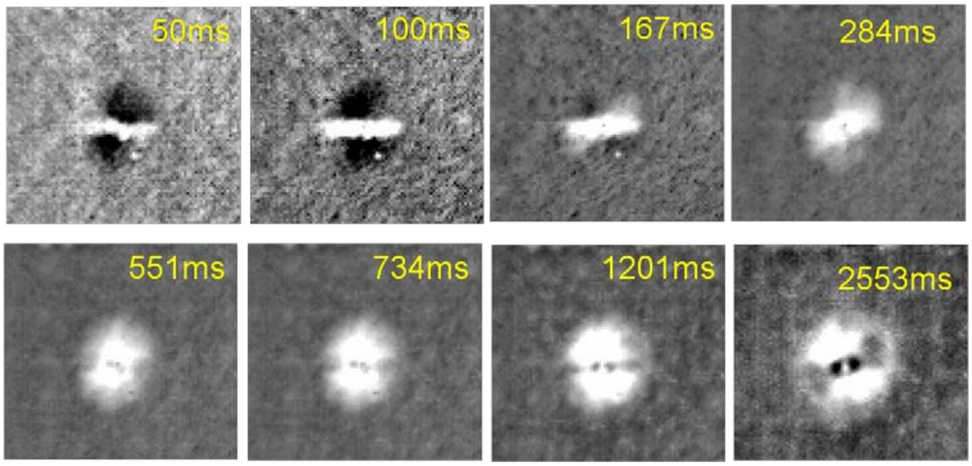


Fig.6. First derivative images at different times by PT

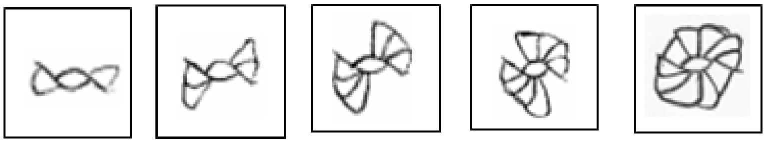
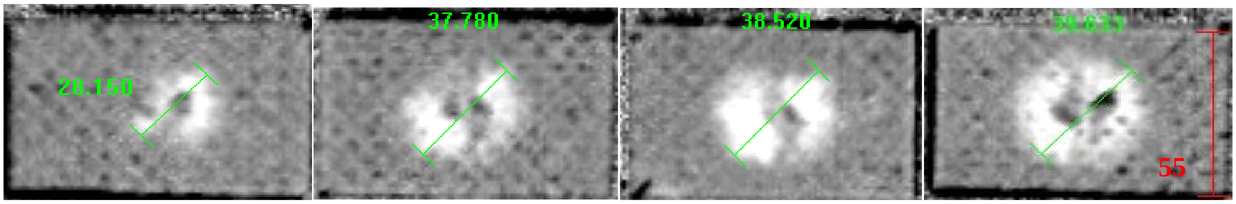

0^0 45^0 90^0 135^0 0^0

Fig.7. Schematic of impact damage in the specimen

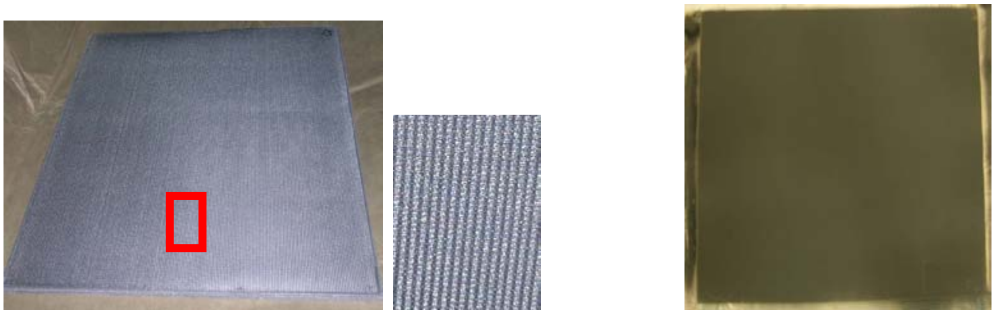


2J 3J 4J 5J

Fig.8. PT inspection results of the specimens impacted with energies from2J to 5J

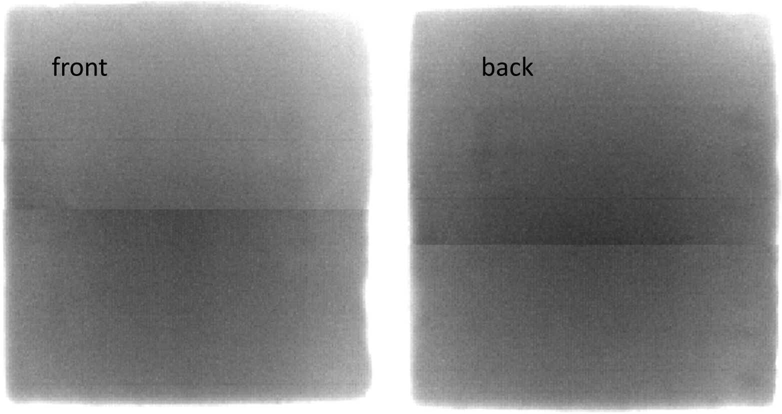
5. Inspection of sintered metal mesh materials

Sintered metal mesh materials is made of multi-layer wire mesh under the conditions of high temperature and pressure. It is used as the diffuser panel in a liquid rocket engine. Like other multi-layer composite material, delaminations are the common and concerned defects. We inspected a group of panel products. The one of the inspected products shown as figure 9 (a); the partial enlarged drawing is shown as figure 9 (b). The thickness of the products is about 6mm; the surface of the material has metallic luster and uniform meshes. Ultrasonic C-scan is not suitable, because immersing into the water is not allowed for this material. In PT, the problem is we cannot do surface paint, which is necessary to image in the IR spectrum at room temperature for low IR emissivity surface. We chose covering thin black film before inspecting by the PT system, see figure 9(c). Figure 10 shows the inspection results of two sintered metal mesh products.



(a) (b) (c)

Fig.9. (a) The one of inspected products, b) The enlarged drawing of red rectangle region in a), and (c) Photograph after covering black film



(a)

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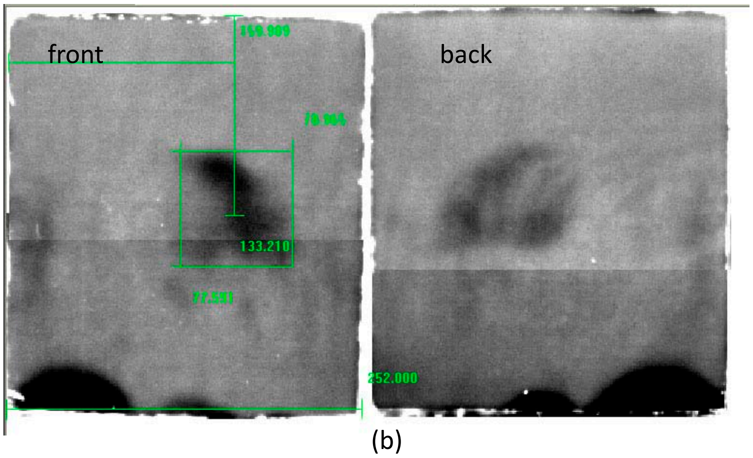

(b)

Fig.10. The derivative images: (a) Front and back side inspection results of a product without delaminations, and (b) Front and back side inspection results of a product with delaminations

6. Conclusions

For some components geometrically complex which is difficult to conduct a comprehensive inspection by ultrasonic C-scan, VT have proven to be a complementary method to detect. In most cases, because of non-contact character and high inspection speed, PT become to be a practical way in detecting and quantifying the subsurface defects and damages in many composites, such as sandwiched structures and fiber reinforced laminates. PT often provides more information about inner structures and defects through time-varying thermal image sequences. And in many cases, PT offers the possibility of inspecting some special materials, which cannot be easily inspected by using ultrasonic C-scan and other methods. Infrared thermalgraphy can be used as a complement or alternative to ultrasonic C-scan inspection technology in many practical applications.

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