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Aerospace NDT

Part 2: Inspection of Composite Materials

Editor's Note: The following is the second of a two-part series on nondestructive testing (NDT) for the aerospace industry. The text and figures have been excerpted from Aerospace NDT, an ASNT Industry Handbook (2014). Part 2 focuses on the NDT of composites, which are widely used in aircraft and spacecraft structures. This article touches on the key NDT methods and techniques that are commonly used.

Development and use of composite materials in aerospace applications originated during World War II. Material scientists were attempting to develop materials with good specific strength and stiffness that surpassed existing structural materials. One of the earliest uses of composite materials was in glass fiber reinforced polymers for rocket motors (ASM 2001). Plastics were a material type that consisted of organic polymers combined with hardeners, fillers, and reinforcements. The polymer and its additions are typically processed at elevated temperatures that produce flow of the polymer to help achieve the final shape, which is retained upon cooling to a solid state. Plastics are categorized into either thermoplastics or thermosets.

Thermoplastic materials are capable of being repeatedly softened by increasing the temperature and then hardened with a decrease in temperature. When heated, thermoplastics can flow and be molded or extruded into a new shape and, after decreasing the temperature, the material hardens and retains the shape until it's heated again. The sequence of heating/softening/flowing/shaping can be performed repeatedly and the material characteristics always remain the same after cooling/hardening. Thermoset plastics, on

the other hand, differ in that after the initial flow and formation of a shape, they cannot be softened and reshaped by increasing the temperature—in essence, their shape is set (ASM 2001). The selection of a thermoplastic or a thermoset for an application can depend on the optimization of a number of factors. Thermosets have been more widely used in aerospace because of performance, manufacturing, and cost trade-offs in material selection.

Initial applications of composite materials in aircraft structures were primarily simple shapes that were not primary structure. Eventually composite materials migrated into doors, fairings, and control surfaces, and finally into the primary load-carrying structure. The selection of which NDT method to use to inspect composite structures (either at the time of manufacture or later in service) will be based on the sensitivity and resolution of the method(s) to the features or discontinuities of interest, the ability of the method(s) to meet the required rate of coverage, and the overall cost.

Visual Testing

Visual testing is the first evaluation a carbon fiber reinforced polymer (CFRP) structure receives after manufacture and plays an important role in the application of other methods of NDT. This may be simply a quick evaluation of the condition of the structure after removal from the autoclave. After removal of the tooling and bagging materials, the surfaces of the component may be viewed for excessive wrinkles, holes, gaps between adjacent plies, surface voids, cracks, buckling, and other conditions. This visual check is normally done without magnification. Just as the actual part itself is viewed,

the tooling and bond forms may be viewed for discontinuities and alignment problems. These evaluations are normally performed by manufacturing personnel. A more thorough evaluation may be required by engineering personnel. This may entail looking for resin-rich or resin-starved areas, blisters or delaminations in the exterior plies, surface voids, and edge separations. If the matrix material is semitransparent, this evaluation may also include looking for internal voids by shining a high-intensity light through the structure and viewing it in a darkened area.

Visual testing of CFRP composite materials is more difficult than that of most other engineering materials because the CFRP is heterogeneous (ASNT 1993). A perfectly good structure may have variations in resin, causing color variations on the exterior surface, surface roughness, or waviness due to woven materials used to apply pressure during the layup or due to benign surface features such as small voids or wrinkles.

Preparation of the part to be viewed is important in visual testing of composites. Often, structures cannot be viewed immediately after manufacture. Edges and bag side surfaces must be trimmed extensively to remove excess resin. After trimming operations conclude, there may be dust and residue on the surfaces. Sanding or polishing of the edge may be necessary if the edge of the structure must be viewed. After the cleaning, good lighting is essential. Straight-on lighting may be needed to see the features at the bottom of a void; oblique lighting may be needed to distinguish between a protruding or concave surface feature.

Because of heterogeneity, it is important to choose an appropriate scale factor for viewing composite materials with magnification. Many visual tests are performed with 5× to 10× power. This relatively low power evaluation is a balance of close viewing of the small surface imperfections and retention of the ability to view a significant surrounding area for perspective and comparison. Figure 1 shows matrix cracks in CFRP (notice the prominent crevice).

Because a visible light image can be readily viewed, documentation of an evaluation is important. Often the visual test will be requested and documentation will be required because of an anomaly detected with another form of NDT. Low magnification imaging is useful to document surface discontinuities, as shown in Figure 2. Microscope photography is useful in imaging discontinuities that have been cross sectioned and polished.

In-service visual testing is performed on large aerospace structures to identify damage at the visible impact damage detection level. Visual testing is the first opportunity to detect damage to an aircraft from hail impact, runway debris, or lightning strikes. Looking at the structure for dents, buckled areas, or discoloration is part of preflight inspection. Depending on the size of visible damage, more extensive nondestructive inspections may be applied to determine the required repairs. Some aircraft radomes (antenna housings)

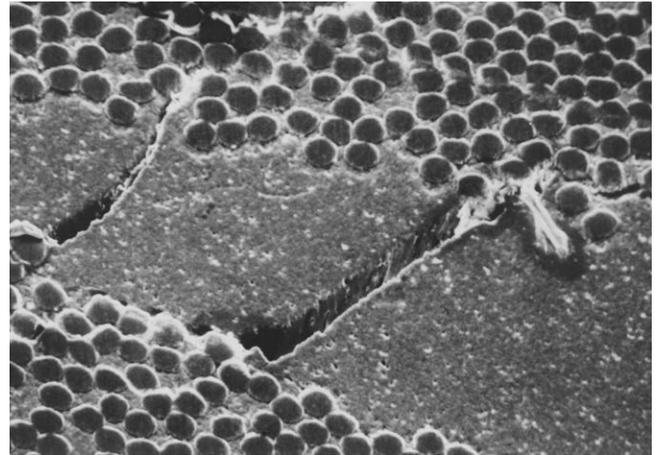


Figure 1. Actual matrix cracks in CFRP.

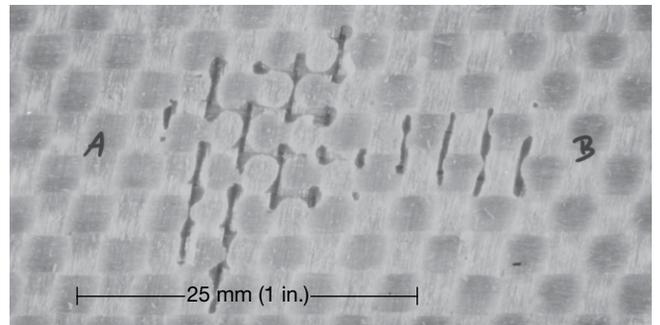


Figure 2. Voids exposed on composite surface.

have had excessive static discharges that have resulted in burns to the composite. These burns are visually detected and then the composite structure is measured by ultrasound and radiography. These visual evaluations often are required at fixed in-service intervals. The visual indication is the first sign of something wrong that the follow-up NDT reveals.

Ultrasonic Testing

Ultrasonic testing (UT) is used extensively for the detection of cracks, corrosion, delaminations, and disbonds in aerospace structures. The ultrasound method of NDT consists of a mechanical wave that is transmitted and reflected through a material and is therefore particularly effective for testing the consolidated quality of composite materials. Given the size of many aircraft structures, large-scale automated scanning systems have been developed to inspect various aircraft structural components (Figure 3). Aerospace inspection involves both inspections at manufacture



Figure 3. Gantry scanner inspection of a large aircraft component.

and periodic inspections in the field. Many UT designs, such as squirter systems, require the disassembly of the component from an aircraft for inspection. Over the years, mobile UT equipment has been developed and used in depot maintenance environments for on-aircraft inspection (Figure 4).

For composite inspection, UT is used to validate the consolidation of the material following the cure cycle. Ultrasonic beam theory and system technology are used to focus energy and provide coverage based on the geometric configuration of the aerospace components. The major concerns for composites are the detection of porosity, foreign material inclusions, disbonds, and delaminations. The UT system will be qualified for the inspection based upon the ability to detect the discontinuity criteria defined by structural requirements and built into test standards. Figure 5 shows a multiple-axis squirter UT system for the inspection of complex contoured aircraft structures. Such systems can align to the surface at the proper angle for the desired inspection. Both through-transmission and pulse echo tests can be performed simultaneously. Similar systems can be designed for very high scanning rates by the addition of transducer arrays and surface-following transducer technology. Typical production data spacing will be set at one-third the minimum discontinuity size to be detected by the specification. This means that, for a 0.25 in. (6 mm) discontinuity, data spacing will be set at 0.080 in. (2 mm). Single transducer systems can operate at about 20 ft²/h (1.9 m²/h) of coverage, depending on part complexity. Array based systems can test faster than 100 ft²/h (9 m²/h), and some systems can operate at over 1000 ft²/h (90 m²/h).



Figure 4. Example of a portable scanner.



Figure 5. Multiple-axis squirter UT system for inspection of composite structures with complex contours.

Once a composite structure is in service, there is normally no requirement for periodic ultrasonic inspection. However, if visual inspection shows surface damage or suspected significant impact is known, then UT may be employed. These in-service ultrasound inspections can check for the extent of subsurface delaminations, disbonds, cracking, and heat or chemical damage.

Radiographic Testing

Penetrating radiation inspections are applied to composite structures for the detection of variations in resin and fiber content and also when composites are joined with other materials. The radiographic

methods are useful for detecting density variations and cracking. Computed tomographic (CT) imaging is particularly advantageous to show internal material variations and details. Figure 6 shows a CT image of a composite J stiffener, where the variations in the consolidation and the ply layups can be evaluated, particularly at the T junctions. CT can also image wavy or crimped fibers after curing, which are difficult to detect using other methods.

Thermal/Infrared Testing

Thermography or thermal/infrared testing (IR) uses changes in the surface temperature of parts under inspection to detect subsurface anomalies. The heat transfer properties of composite materials are well suited to the application of IR inspection. Both passive (using ambient temperature effects) and active (using stimulation) can be usefully employed on composite materials.

IR has been implemented by numerous military and commercial organizations for the detection of trapped water in honeycomb sandwich structures (used in rotor blades and fixed wing rudders), elevators, ailerons, and other control structures. Various forms of excitation are used, including heat guns and lamps, flash excitation, direct contact, and passive heating. Thermographic detection of water is based on the uniquely high heat capacity of water relative to other materials in aircraft construction. Water absorbs incident heat but changes temperature far less than composite or metallic materials. As a result, surfaces in contact with trapped water appear

to be cooler than surrounding dry areas. The success of a trapped water inspection will vary, depending on several factors: contact between water and the inspection surface, the extent to which the honeycomb cell is filled, the number of adjacent filled cells, the core material (for example, aluminum, fiberglass, or foam), the presence of excess adhesive or sealant, and skin thickness.

In severe cases of water entrapment (for example, if several adjacent cells are nearly full and water is in contact with the test surface), the inspection is relatively simple and can be conducted using a heat gun or lamp while the technician inspects the surface directly with an infrared camera. Cool spots associated with trapped water are readily identifiable; they persist long after the heat source has been removed. Figure 7 shows an example of finding water in honeycomb by using a hot air gun and an infrared camera on a rotor blade.

The inspection becomes more challenging for smaller amounts (both cell fill volume and number of cells) of water; for water not in direct contact with the inspection surface; and where the presence of excess adhesive or sealant also absorbs incident heat, which generates a false “cold” indication that resembles water. With additional instrumentation, the inspection can be performed quickly and with validation of the presence of water. For example, using thermographic signal reconstruction derivative analysis of flash thermography data, a partially filled single cell can be detected and confirmed in less than 20 s (Figure 8).

In the process of manufacturing composite structures, stray pieces of polymer or paper backing material may adhere to a prepreg sheet and become inadvertently embedded in the layup. Once the part is cured, such foreign objects compromise the strength and integrity

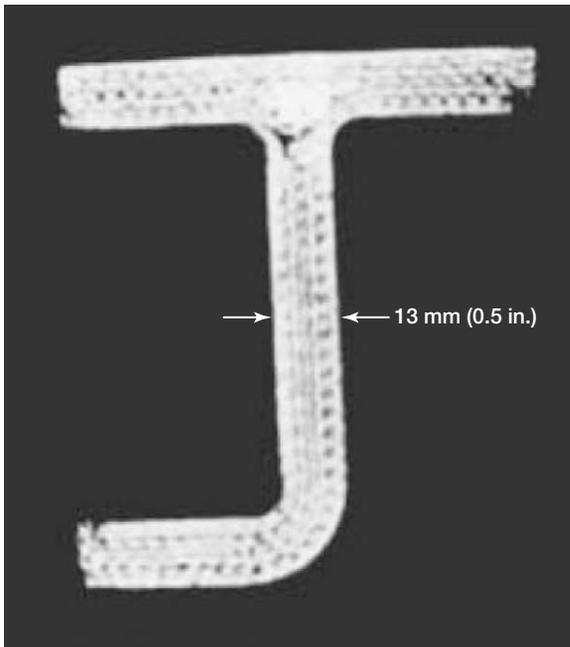


Figure 6. Computed tomography (CT) image of graphite epoxy woven J stiffener showing ply condition and consolidation.



Figure 7. Infrared image of helicopter rotor blade during heating by hot air gun.

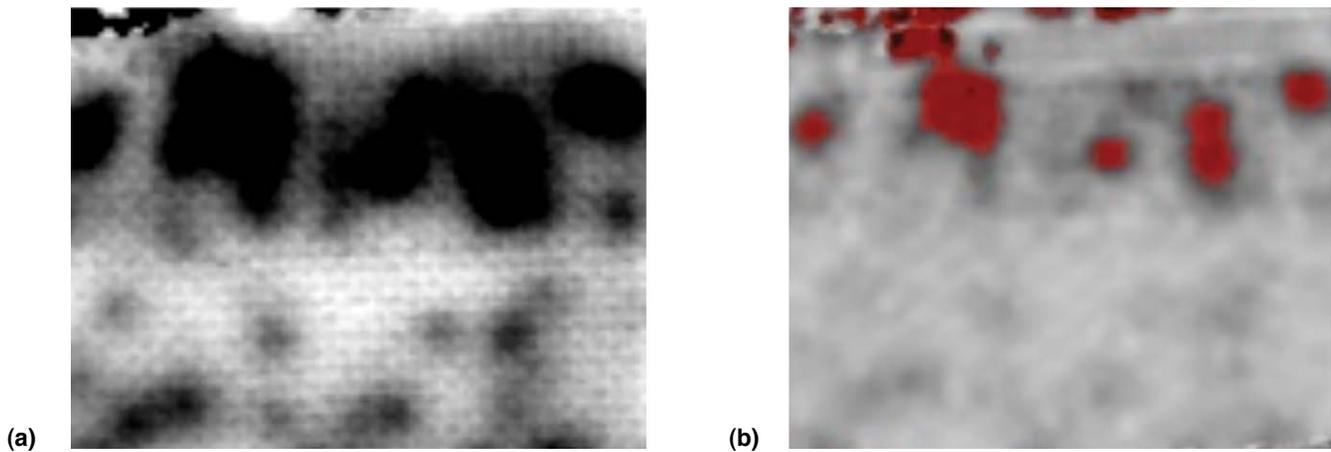


Figure 8. Flash thermography of composite aircraft spoiler with trapped water: (a) the raw thermal image acquired 11 s after flash shows dark spots due to water and excess adhesive; (b) the thermographic signal reconstruction first derivative image identifies water entrapment sites.

of the structure. Detection before deployment of the finished part is essential. Thermography may be performed on either the green (uncured) part or after the part is cured. In the green state, the low density of the prepreg material limits the depth penetration of the applied heat. Active thermography with optical excitation may be effectively performed on the first four to six layers of the layup. In practice, this thickness often coincides with the compression (“debulk”) process that is performed after the addition of every few ply layers to remove wrinkles and air gaps. In the green state, small voids, delaminations, or foreign objects may be masked by the fiber structure, which is quite apparent in the thermography results. Signal processing may be required, in addition to two-dimensional image processing to minimize fiber clutter.

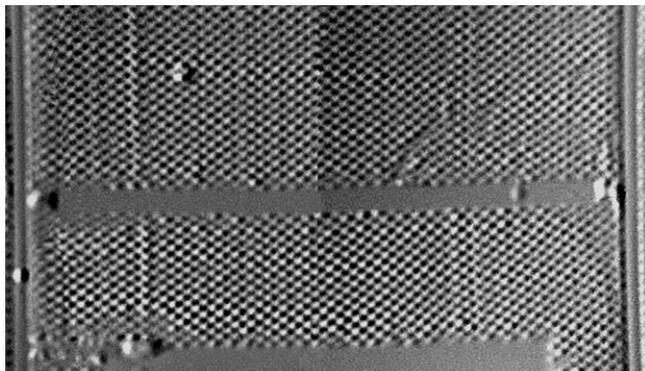


Figure 9. Shearogram of a honeycomb panel showing cells, disbands, embedded tubes, and metal inserts.

Laser Methods Testing

The shearography laser method technique uses the measurement of small surface displacements due to stress loading to identify subsurface material variations. Shearography has been found to be particularly useful in composite honeycomb manufacturing inspection where a slight external pressure change is able to induce surface deformation due to internal issues such as delaminations, disbands, and inserts. Figure 9 shows an example of a honeycomb panel inspection using laser shearography. Shearography has been successful in both manufacturing and in-service inspection of composite honeycomb structure. ●

REFERENCES

- ASM, 2001, *ASM Handbook 21: Composites*, ASM International, Materials Park, OH.
- ASNT, 1993, *Nondestructive Testing Handbook, Vol. 8: Visual and Optical Testing*, 2nd edition, American Society for Nondestructive Testing, Columbus, OH.

EDITOR'S NOTE

Aerospace NDT, An ASNT Industry Handbook, is available for purchase from the online ASNT Store at asnt.org.

Figures 1 and 2 first appeared in ASNT's *Nondestructive Testing Handbook, Vol. 9: Visual Testing*, 3rd edition (2010). Figure 6 first appeared in *Nondestructive Testing Handbook, Vol. 4: Radiographic Testing*, 3rd edition (2002).