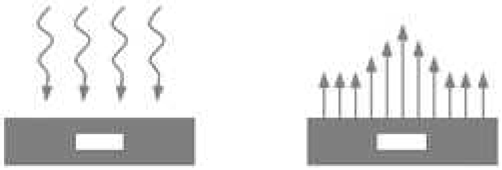
Flaw Detection for Composite Materials Improved by Advanced Thermal Image Reconstruction Techniques

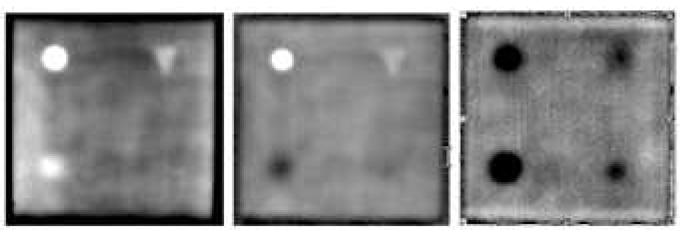
The development of advanced composite materials for use in space and propulsion components has seen considerable growth over the past few years. In addition to improvements that have been made in material properties and processing techniques, similar growth must be seen in the development of methods for the detection of flaws, either generated in service or during manufacturing. Thermal imaging techniques have proven to be successful for the nondestructive evaluation (NDE) of composite materials, but their detection capabilities decrease as flaw depth increases. The purpose of this research is to investigate advanced thermal imaging methods and thermal image processing technologies to increase the maximum depth below surface that a flaw can be detected and improve the contrast between flawed regions and sound regions.

One of the more widely used methods for the thermographic inspection of materials and components is pulsed thermography. As the name implies, the technique imparts a pulse of thermal energy, usually provided by a photographic flash lamp, on the surface of a specimen. The thermal energy on the surface is conducted into the cooler interior of the sample. In turn, there is a reduction of the surface temperature over time. This surface cooling occurs in a uniform manner as long as the material properties are consistent throughout the specimen. Subsurface defects that possess different material properties (thermal conductivity, density, or heat capacity) affect the flow of heat in that particular region. This resistance in the conductive path causes a different cooling rate at the surface directly above the defect, when compared with the surrounding defect-free material. The change in the subsurface conduction is seen as a nonuniform surface temperature profile as a function of time (see the following figures). Unprocessed, as-received data are typically displayed sequentially on a computer monitor in a movie fashion. Images are then visually inspected for signs of a subsurface defect by locating areas with anomalous surface temperatures. Since the method depends on the interaction of the defect with the advancing thermal front, defects that are located at greater depths show up later in time. Because of lateral diffusion, deeper defects tend to have less contrast than flaws near the surface do.



Flash thermography setup. Left: A specimen is heated with a pulse of thermal energy. Right: As the thermal front conducts through the material, defects such as delaminations prevent the flow of heat and result in a higher surface temperature directly above the specimen.

A new technique for the processing of thermal image data has been applied at the NASA Glenn Research Center to improve detection capabilities. This method involves the creation of a set of mathematical equations that represent the time response of each pixel in the raw data set. This “reconstruction” process exploits certain general features of the thermal response of materials to pulsed heating, and has been shown to significantly improve the detection of subsurface features without the use of a reference. The three images shown in the final figure illustrate this improvement. The image to the left represents an unprocessed thermal image of a C/SiC test specimen after the application of the flash input. The specimen contains four seeded defects, located at various depths below the surface. Using the raw thermal data, three of the four defects were identified, with the deepest defect undetected. The center and right images were created using the image-reconstruction algorithms and represent derivatives of the original thermal signal. The instantaneous slope information generated from the reconstructed data set was used successfully to locate the deepest defect. In addition, the contrast between defect locations and defect-free areas was improved dramatically. We expect that these improvements will greatly enhance the inspection capabilities of composite materials used in the Ultra-Efficient Engine Technology (UEET) Program, Reusable Launch Vehicle (RLV) program, and Higher Operating Temperature Propulsion Components (HOTPC) project.



Pulsed thermography results for a C/SiC specimen with seeded flaws. Left: Raw thermal image data. Center and right: First and second derivative images generated from the reconstructed thermal data.

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