Ultrasonic Guided-Wave Scan System Used to Characterize Microstructure and Defects in Ceramic Composites

Ceramic matrix composites (CMCs) are being developed for advanced aerospace propulsion applications to save weight, improve reuse capability, and increase performance. However, mechanical and environmental loads applied to CMCs can cause discrete flaws and distributed microdamage, significantly reducing desirable physical properties. Such microdamage includes fiber/matrix debonding (interface failure), matrix microcracking, fiber fracture and buckling, oxidation, and second phase formation. A recent study (ref. 1) of the durability of a C/SiC CMC discussed the requirement for improved nondestructive evaluation (NDE) methods for monitoring degradation in these materials. Distributed microdamage in CMCs has proven difficult to characterize nondestructively because of the complex microstructure and macrostructure of these materials. This year, an ultrasonic guided-wave scan system developed at the NASA Glenn Research Center was used to characterize various microstructural and flaw conditions in SiC/SiC (silicon carbide fiber in silicon carbide matrix) and C/SiC (carbon fiber in silicon carbide matrix) CMC samples.

Ultrasonic guided-wave inspection can be an attractive alternative to scanning because a single transducer, or a line of transducers can be used to excite guided waves at one location of a structure, with returning echoes indicating the presence of defects (ref. 2). This type of inspection has successfully detected flaws and degradation in many types of materials and components, and in some applications, over significant distances. The guided-wave signal in raw form is very complex (many dispersive and interfering modes traveling at different velocities) with significant coherent noise that cannot be averaged out. As a result, guided-wave methods seem to be most successful when they control coherent noise by tuning for a minimally dispersive or nondispersive mode of ultrasound, at a particular excitation frequency, in just one direction. The guided-wave method used at Glenn takes a different approach by utilizing the total (multimode) ultrasonic response in a scanning configuration and by employing specialized signal-processing routines to extract parameters of the time- and frequency-domain signals. These parameters, which have proven to be sensitive to changes in microstructural conditions and to the presence of defects, appear promising in monitoring the degradation in CMCs.

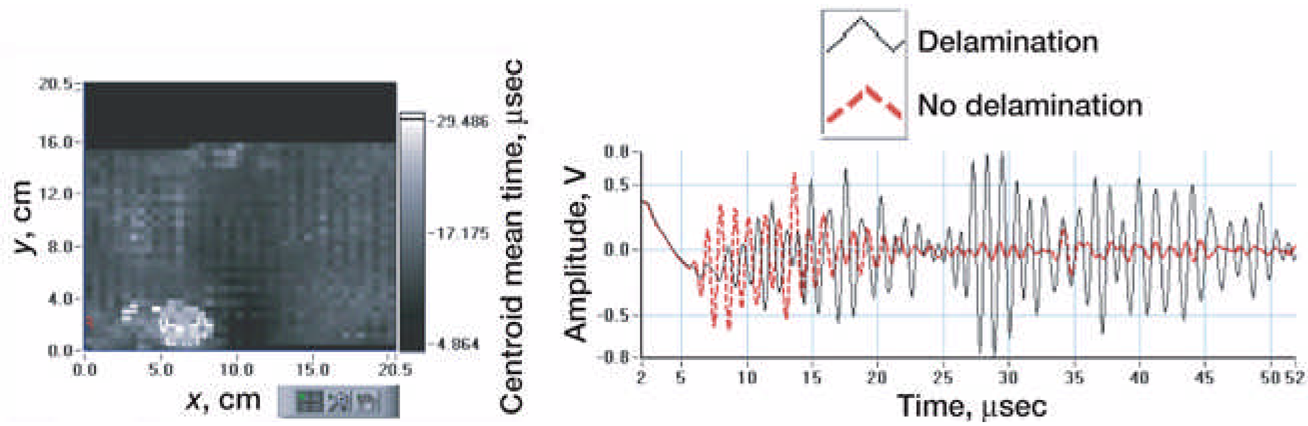
Guided-wave scanning may have several further advantages over conventional ultrasonic methods.

1. Guided-wave scanning can be performed directionally, allowing correlations to be made between ultrasonic parameters and directionally dependent material properties (such as for unidirectional composites or in testing the nondirectionality of properties).

2. The sample under test does not have to be immersed in fluid (as for most conventional ultrasonic characterization).

3. Guided-wave scanning is potentially applicable to components with mildly curved surfaces.

4. Guided-wave scanning is potentially more versatile in characterizing local modulus changes than resonant frequency methods since the resonant frequency methods require nodal excitation and generation and, thus, are not applicable for scanning.



Left: Centroid mean time image (in µsec) of SiC/SiC sample. The lower left whitish area is delaminated. Right: Time-domain waveforms associated with delaminated and nondelaminated areas.

The figure shows an ultrasonic guided-wave scan image of a SiC/SiC composite sample containing delamination. The delamination was most easily discriminated in the centroid mean time image (whitish areas in image; the signal processing performed allows over 20 parameters of the time and frequency domains to be calculated for image formation). Centroid mean time can be thought of as the time in the raw waveform demarcating the location of energy balance. The time-domain waveforms associated with the delaminated and nondelaminated areas are shown in the figure. The shift in the centroid mean time away from the origin is quite apparent for the delamination.

References

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Glenn contact: *Don Roth, 216-433-6017, Donald.J.Roth@nasa.gov*
Authors: *Don J. Roth, Laura M. Cosgriff, Richard E. Martin, Michael J. Verrilli, and Dr. Ramakrishna T. Bhatt*
Headquarters program office: *OAT*
Programs/Projects: *UEET, RLV*