New Developments in Nondestructive Evaluation for Composite Pressure Vessel Testing

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NASA White Sands Test Facility (WSTF) is supporting the recertification and life extension of aging Kevlar® and carbon composite overwrapped pressure vessels (COPVs). These vessels are directly associated with space shuttle orbiters and the International Space Station. WSTF is also helping to address the special issues associated with the application of carbon COPVs to Orion and future spacecraft. This task is challenging because the COPVs have varying criticalities, usage histories, damage and repair histories, times at pressure, and numbers of pressure cycles. The application of effective nondestructive evaluation (NDE) technologies is important to this effort and, in many cases, requires that techniques be refined and new standard processes be developed. Areas we are addressing include: the implementation of NDE into manufacturing to detect any defects and reduce variation; the development and application of effective impact detection methods; inspection for composite-to-liner interface issues; in-service structural health monitoring (or in-situ NDE); and evaluation of global material property changes as the vessels age and potentially progress toward a phenomenon known as "stress rupture." Stress rupture could result in a failure at operation pressure after an extended period of use.

One example of hardware development is a laser profilometer that maps variations in liner profile that could involve liner and composite interaction issues. Laser profilometry allows examination of areas not inspectable by other methods. When our engineers observed liner ripples with a videoscope (see the lower right image in figure 1), the amplitude and frequency could not be accurately measured to determine whether discrepant conditions exist. We developed laser profilometers to scan the inside of spherical vessels at 0.001 to 0.002 in. accuracy (depending on vessel diameter). Measurements provided from this technique allow analysis using modeling and analytical methods to quantify anomalies. The laser head, located at the center point of the vessel (indicated by the solid model in figure 1), fully maps the surface from near the lower port to near the upper port, allowing the entire surface to be viewed at once.

Profilometry is being used with other methods such as shearography to give a more complete characterization of vessel indications. Figure 2 illustrates a shearography image of multiple NDE indications taken from the outside of a vessel. These images are shown aligned with profilometry images taken from the inside. The profilometry data give the amplitude and frequency of the multiple ripples, as revealed in the plot. Shearography, on the other hand, images the resulting external "out-of-plane" deformations as the vessel is slightly pressurized. These deformations can also be measured using shearography analysis

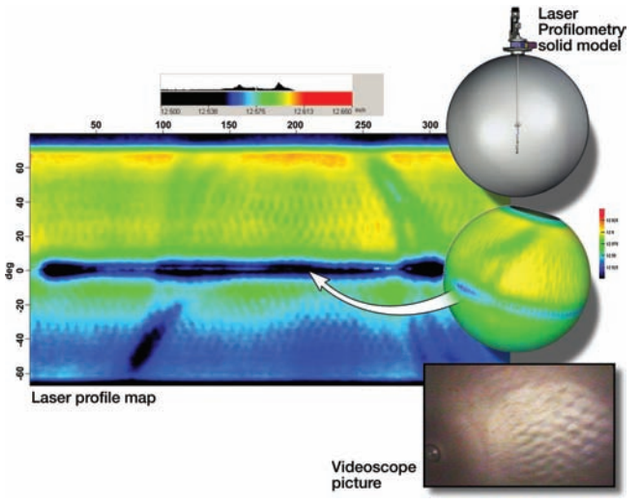

Fig. 1. *Laser profilometry of a COPV interior surface.*

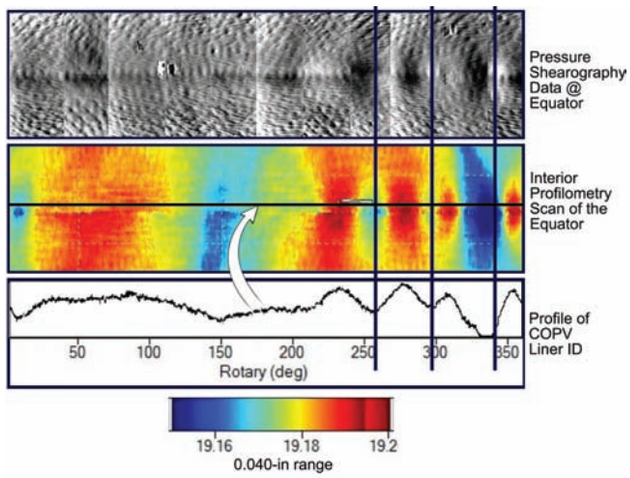

Fig. 2. *Laser profile map and measurements correlated to shearography images.*

software. Our next goal is to develop more complex laser profilometers to scan and map cylindrical vessels. The equipment will support several upcoming test programs and evaluation of flight vessels over the next few years.

Other projects include a correlation between impact damage, NDE response, and the associated reduction in burst pressure; development of NDE that can be implemented into manufacturing to reduce risk; in-situ NDE characterization of carbon composite micromechanics (for improved COPV health monitoring); and composite stress rupture NDE development. Composite stress rupture NDE involves extensive COPV testing to correlate NDE response to the various indicators of stress rupture progression. Further details on many of these projects can be found on our Website (http://nnwg.org/current/index.html) under "White Sands Test Facility." Although we manage these projects, other NDE specialists and experts from several NASA centers, industry, and academia are involved.

Among our new innovative endeavors is the Carbon Stress Rupture NDE Development Project. This project seeks to extend the success of a previous Kevlar® stress rupture NDE project by developing and demonstrating NDE techniques applicable to carbon COPVs. Testing will increase the data available for stress rupture characteristics of T1000 and IM7 carbon COPVs, and will provide NDE to help evaluate stress-rupture-related degradation. T1000 is a grade of carbon fiber produced by Toray Industries, N.Y., and IMF is a grade of carbon fiber produced by Hexcel, Stamford, Conn. T1000 is a premier fiber with fewer defects per unit length and currently being used on more performance-critical COPVs; IM7 is a somewhat older, weaker, and yet more economical grade used on lower-cost vessels and other structures where a lower cost and sometimes more available fiber are desirable.

For this project, 100 carbon-wrapped vessels will undergo stress rupture aging using an elevated stress technique at ambient temperature. To support this effort, a new stress rupture test facility is being built at WSTF that will house 20 vessels at a time in a Lexan®-covered blast enclosure (figure 3). The Lexan® enclosure will allow continuous, 360-deg visual inspection of the vessels to monitor for the onset of fiber failure.

The new system will hold the vessels at a constant elevated pressure while various NDE and specialized monitoring instrumentation record vessel stress rupture progression. We tracked the spools of carbon fiber used to wrap the vessels, and will evaluate representative carbon test specimens to set vessel stress levels for test. Techniques

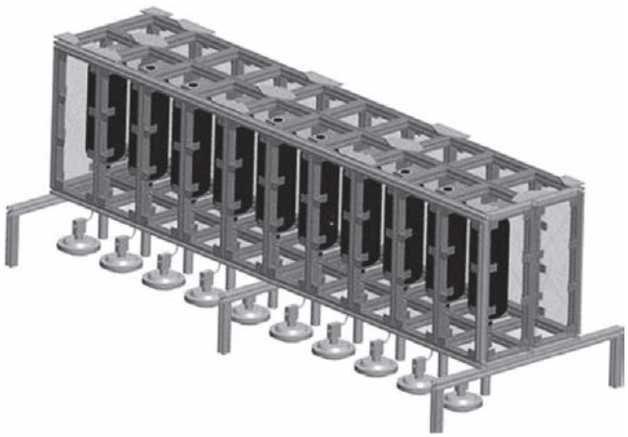

Fig. 3. *Enclosure design for carbon vessel aging, showing only one side populated with COPVs.*

such as visual inspection, acoustic emission, portable in-situ Raman spectroscopy, fiber Bragg gratings and conventional strain gauges, belly bands, and a wireless distributed impact detection system are to be applied. Following stress rupture aging to various levels, we will remove the vessels in lots and apply other methods (e.g., scanning Raman spectroscopy, laser-induced ultrasound testing (UT), other conventional scanning UT and UT-guided wave techniques, shearography, and thermography) to the test vessels.

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