Space Environments and Thermal Vacuum Effects on Composite Overwrapped Pressure Vessels

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Since 1978, the NASA Johnson Space Center White Sands Test Facility (WSTF) has been active in testing and evaluating composite overwrapped pressure vessels (COPVs) in support of NASA human space exploration missions. WSTF has developed new approaches for test and evaluation of COPVs in simulated space flight environments of thermal vacuum. Specifically, COPVs are being evaluated to determine the effect of vacuum, shelf life, and thermal effects on cycle, stress rupture, and residual static strength.

Partnerships

Several NASA organizations are contributing funding and support to this project. The partnership includes:

- NASA Headquarters Safety and Mission Assurance, which has provided overall guidance
- The In-Space Propulsion Program, which has donated test articles
- The NASA Engineering Safety Center (NESC) Composite Pressure Vessel Working Group (CPVWG), which has provided technical support for development of finite element analysis (FEA) models at WSTF
- The NASA Jet Propulsion Laboratory, which has provided guidance on experiment planning
- Lawrence Livermore National Laboratories, which has provided technical support and composite coupon-level vacuum environment test data

Test System

The test chamber (figure 1), located in the WSTF Laboratories Building, has been uniquely designed to perform long-term durability components and materials testing using parallel vacuum systems. During testing, one vacuum system can be isolated and maintained with the other system in operation, which allows testing of components and materials that continuously outgas for multiyear durations. Typical test chambers lose high vacuum as soon as out-gassed products contaminate vacuum equipment, resulting in loss of test integrity.

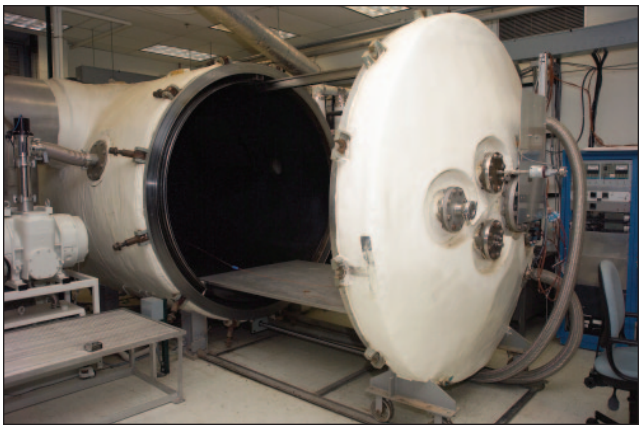

Fig. 1. *White Sands Test Facility thermal vacuum cycle and stress rupture test chamber.*

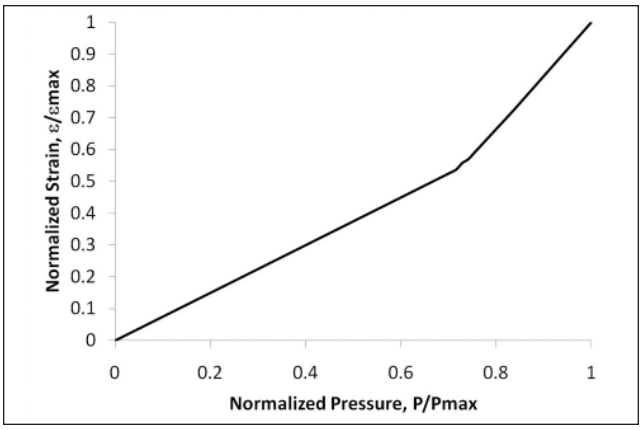

Fig. 2. *White Sands Test Facility finite element model of composite overwrapped pressure vessel strain and pressure.*

Results

WSTF has developed FEA models of test articles using GENOA-PFA (AlphaSTAR Corporation, Long Beach, California) software. Stress ratios have been established for the vessels (figure 2). The vacuum chamber and the blast enclosure with COPVs have been validated to achieve stabilized vacuum levels of 10^{-7} Torr with 18 vessels (figure 3). Visual inspection and flash thermography inspections (figure 4) have been performed on COPVs to establish the as-manufactured condition.

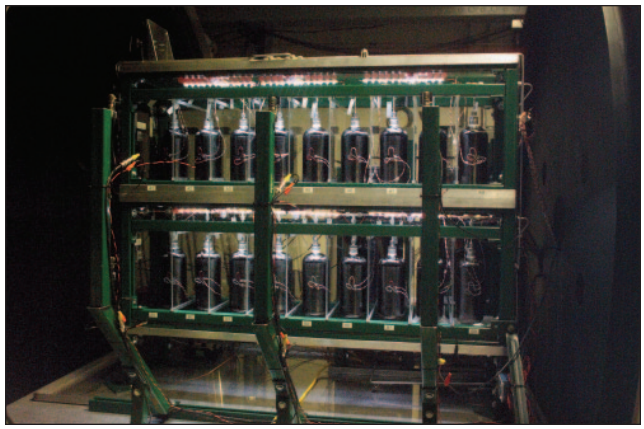

Fig. 3. *Blast enclosure with 18 composite overwrapped pressure vessels installed.*

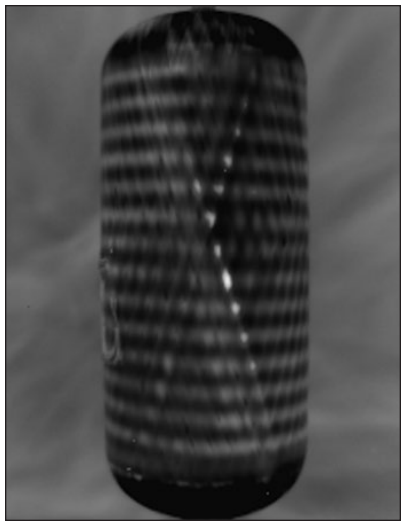

Fig. 4. *Flash thermography image of composite overwrapped pressure vessel.*

Testing in vacuum has been conducted to check out strain, pressure, and temperature instrumentation at vacuum levels between 10^{-7} to 10^{-9} Torr. Also, the chamber heating capability has been exercised from 21 to 49°C (70 to 120°F), and baseline strain, pressure, and temperature data have been collected.

Findings

Several findings were made about the structural response of COPVs in a simulated space vacuum environment during system validation. These findings have affected the methodology NASA applies in testing vessels for determination of long-term durability. Findings include the following:

- The first measured creep response of COPVs during autofrettage, resulting in new understanding of proof strain offset and vessel stress ratio
- The first measured carbon COPV fiber creep strain data to failure, thus allowing for a new carbon creep-life model to be developed and a new method to measure vessel health (strain/pounds per square inch) that is now used by NASA and was implemented in the NESC and the Space Shuttle Orbiter Program to assess space shuttle Kevlar® (E. I. du Pont de Nemours and Company, Wilmington, Delaware) COPV health beyond the manufacturer certification
- The first measurement of COPV vessel-to-vessel variability in stress ratio affecting reliability assessment approach and accuracy
- The first carbon COPV stress rupture structural response data, used in analysis by NESC CPVWG to compare current COPV FEA modeling approaches
- New baseline information for testing COPVs, including fixtures, barriers, pressurization capability, and instrumentation requirements

Ongoing and Future Work

Testing is being performed at on-orbit simulated thermal (-60 to 200°F [-51 to 93°C]) and vacuum (10^{-7} Torr) conditions on COPVs. Results will provide data on long-term durability of COPVs, and will involve cycle, stress rupture, and static strength burst testing.