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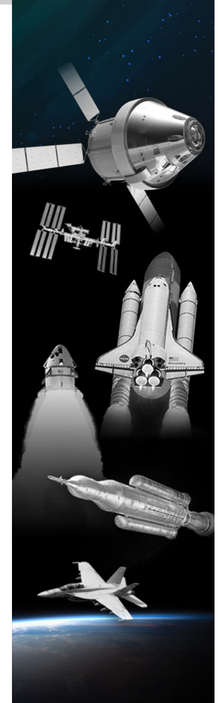

NESC tech bulletin

Evaluating and Mitigating Liner Strain Spikes in COPVs

Unexpected cracking and leaking in bonded composite overwrapped pressure vessel (COPV) liners occurring in recent test programs have been attributed to liner strain spikes observed through measurement and predicted by analysis. Diminished load transfer between the liner and composite overwrap can lead to localized excessive liner yielding in the dome section. This diminished constraint can occur due to yielding of the adhesive or a manufacturing unbond defect. COPVs should be assessed for susceptibility to this new failure mode.

Background

COPVs are often designed with a bond between the liner and composite. The purpose of the bondline is to provide load transfer continuity between the liner and overwrap during pressurization and depressurization cycles throughout the lifetime of a COPV. In the cylinder region the liner and overwrap longitudinal strains are often similar; therefore, the bondline is not highly strained in shear. However, longitudinal strains are not similar in the dome, leading to development of bondline shear stress. This shear stress can concentrate in the liner at geometric transitions such as at a liner thickness taper near the boss.

Bondline Strain Mechanisms

If the liner taper does not smoothly transfer load into the overwrap from the liner, stress concentrations can result in both the liner and the bondline. For example, if the taper is too short, then geometric stress concentrations in the liner occur near the thin end of the liner taper along with an abrupt increase of adhesive shear stress between the liner and overwrap as the liner thickness increases. These stress concentrations can result in larger plastic strains than intended in both the liner and adhesive and when these large plastic strains occur at the same location in the liner and the adhesive, the liner deforms independently from the overwrap. This allows the plastic strain in the liner to localize and the resulting strain spike can increase quickly with additional deformation. The figure shows large plastic strains in the adhesive associated with the strain spike in the liner can lead to failure of the adhesive, increasing the independence of the liner. A similar plastic strain concentration in the liner can occur in regions where the composite and liner are unbonded due to a manufacturing error.

Recommendations to Mitigate Bondline Strain Spikes

Liner strain concentrations from adhesive and liner yield interaction or manufacturing defects can lead to crack nucleation and growth or development of a liner buckle. To evaluate the risk, the margin of safety should be determined at design burst. If it is positive, then examine strain distributions for evidence of alignment of adhesive and liner yield. If the adhesive is predicted to yield or disbond at a location concurrent with net section liner yielding, perform one of the following:

1. Explicitly model the bondline with elastic-plastic properties and re-evaluate the development of the liner strain spike. Determine the magnitude of any strain spike that develops in this new model. If adhesive strains approach the shear failure criterion of the bondline, then a local disbond should be modeled and strain spikes re-evaluated.
2. Add a disbond only at the location where the adhesive exceeds yield and determine the magnitude of any strain spike that develops in the liner.

Note that simulating a disbond over the entire bondline either by releasing nodes or diminishing shear modulus is not necessarily conservative. To evaluate the significance of the strain spike for all pressure conditions of the COPV, include the magnitude of the strain spike in all required verification activities associated with crack nucleation, crack growth, and liner buckling failure modes in ANSI/AIAA S-081B Space Systems-Composite Overwrapped Pressure Vessels (sections 5.2.13 Fracture Control Design, 5.2.14 Fatigue Life Design, 5.2.6 Negative Pressure Differential Design, and 5.2.10 Stability Design). The potential for local normal deflection reversals (oil-canning) at a disbond should be considered in crack nucleation and growth failure modes.

If the magnitude of the liner strain spike is too large to be robust to these failure modes, then the design can be modified to reduce the shear stress in the adhesive below yield. For example, increasing the taper length could be considered. In addition, process control measures should be implemented to ensure that the risk of unbonds is acceptably low.

Analytical Results: Explicitly Modeled Elastic-Plastic Adhesive, Disbond Not Included