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Effects of Large Grain Size in Composite Overwrapped Pressure Vessels

The NASA Engineering and Safety Center (NESC) performed an assessment to characterize the effects of abnormal grain growth (AGG) within a metallic liner of a composite overwrapped pressure vessel (COPV). This effort focused on evaluating the mechanical response of the liner material, including the strain amplification factor (SAF), using a series of custom-designed coupons that incorporated both metal and composite overwrap. The study demonstrated that this approach was effective and practical to characterize strain localization under various conditions and showed strong correlation with modeling results. Additionally, preliminary investigations of phase coherence imaging (PCI), an ultrasonic technique, offered promise in detecting AGG microstructures, but further development is needed.

Background

Pressure vessels, especially those with thin walls, are susceptible to AGG due to the complexity of the thermomechanical processing history. In a COPV, the metal liner serves as the permeation barrier for the pressurized fluid and provides a structural interface for the pressure system and mounting points [ref 1]. AGG can result in the formation of a single grain across the entire wall thickness, significantly impacting the structural performance of the liner; this is especially true for designs where the liner deforms plastically with each pressurization cycle.

Findings and Best Practices

1. The use of materials and processes (M&P) controls, with specific grain size controls including grain size range, a maximum allowable grain size, and tailored requirements for various liner regions (e.g., dome versus boss), should be instituted for all designs.
2. M&P requirements for grain size and material flow are especially critical for spin forming and flow forming of liners.
3. AGG in spun formed liners is complex and non-uniform, making AGG initiation sites difficult to predict.
4. Liners with AGG will have highly variable microstructure-induced strain localization, which will be a significant obstacle to defining meaningful, statistically substantiated materials design values.
5. Full-field strain visualization on larger samples is required to quantify the strain localization behavior; this effect is much harder to discern in standard tensile tests.
6. The presence of microstructure-induced strain localization presents fundamental limitations on the use of conventional continuum-based stress analysis and thus has implications for the liner design process and damage tolerance assessment.
7. The effects of a disbond between large grain material and the reinforcement (e.g., composite overwrap) have a compounding influence on the magnitude of strain localization; therefore, maintaining bondline integrity is especially critical when large grains are present.
8. Conventional ultrasound and phased array ultrasound with full matrix capture using the total focusing method (TFM) were ineffective at detecting AGG in forgings.

Future Efforts

1. The NESC recommends further consideration of a standardized methodology for experimentally determining the SAF and evaluating its integration as part of the standard COPV structural analysis.
2. Development of such an approach should include a test series to investigate factors that may influence the SAF such as, but not limited to, bond integrity, liner and reinforcement thickness, and magnitude of global strain.
3. PCI, which focuses on phase information versus amplitude variation, has shown promise for detection of large grains, although further work is needed to refine the technique [ref 2].

References

1. McLaughlan, P.B., Forth, S.C., Grimes-Ledesma, L.R. (2011). "Composite Overwrapped Pressure Vessels, A Primer," NASA/SP-2011-573.
2. Orange, B., "ASNT Technical Discussion on (PCI) Phase Coherence Imaging and (TFM) Total Focusing Method," Evident Corporation.
3. NESC-RP-21-01688

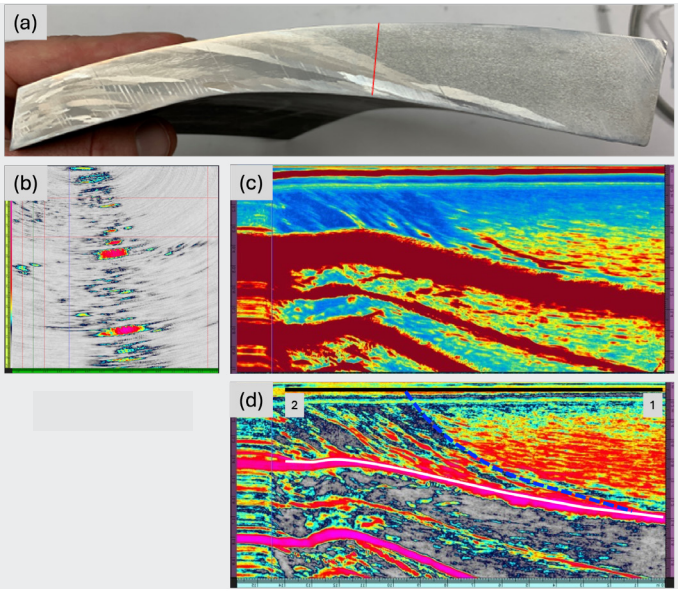

Illustration of PCI Inspection

(a) Etched dome cross-section
(b) A-scan contour plot
(c) TFM B-scan using amplitude of signal
(d) PCI B-scan using phase of signal

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