RESIDUAL STRAIN MEASUREMENT IN COMPOSITES USING CURE-REFERENCING METHOD

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Residual stress results from thermal mismatch between fiber and matrix

Also results from chemical shrinkage of matrix on polymerization

Thermal characteristics of composites are directional and depend upon fiber orientation.

These behaviors influence the fiber and matrix differently and are based upon fiber orientation angle.

If thermal and chemical characteristics are not taken into consideration during stacking the laminate may warp significantly.
Materials Tested

- AS4/3501-6 graphite/epoxy and plain weave fabric
- 4 cases tested
- Unidirectional - $[0_{16}]_T$
- Cross-ply $[0_2/90_2/0_2/90_2]_S$
- Angle-ply $[0_2/45_2/0_2/45_2]_S$
- 18-ply woven panel
A diffraction grating is attached to the composite to view chemical shrinkage after solidification of the matrix.

The grating in a stress-free state is known and serves as reference.

The grating is applied and cured with the composite then observed using moiré interferometry to view residual stresses.
Moiré Interferometry

- Measures orthogonal in-plane displacements, U and V
- Two beams of light are impinged upon specimen and react forming an interference pattern consisting of light and dark bands
- This is known as reference grating or virtual reference grating because it is just lighting
- The specimen grating and the fixed reference grating interact to form the moiré pattern
Experiments at Elevated Temperature

- Specimen must be heated to cure temperature to remove residual strains that are due to contraction.
- Residual strains left are due to chemical shrinkage and stress relaxation.
Unidirectional Fiber

- U field pattern (Fiber/ x-direction) is nearly zero
- V field pattern (Transverse/ y-direction) is quite large
- A large compressive strain was found in y-direction
Unidirectional Fiber

- Strain transverse to fiber direction at the cure temperature was not zero.
- Demonstrates that a significant portion of residual strain is related to chemical shrinkage in matrix.
Cross-Ply Composite

- Gradients in both fields are nearly equal.
- As expected because of equal number of plies in 0-deg and 90-deg direction
- No detectable residual strain due to chemical shrinkage
Angle-Ply Composite

- U field gradient is small, consistent with direction fiber dominance.
- V gradient is inclined, indicating strong vertical and horizontal gradients.
- Both normal and shear strains did not return to zero.
Conclusion

- This paper covers the experimental techniques used to measure strain due to residual stresses.
- Subsequent papers describe how to calculate stresses with Laminate theory.
- Residual Strains and Thermal Analysis are covered in Chapter 3 of “Design and Optimization of Laminated Composite Materials.”
References

- Key phases- composite materials, residual stress, cure-referencing method, moiré interferometry
- Dr. Peter Ifju