PREDICTING CRYSTALLIZATION-DEPENDENT RESIDUAL STRESS DEVELOPMENT IN THERMOPLASTIC COMPOSITES

UNIVERSITY OF DELAWARE | CENTER FOR COMPOSITE MATERIALS

Nithin K. Parambil, (P. D.) [1], Branndon R. Chen, (Ph.D.M.S.E) [2], Dr. Joseph M. Deitzel[1], and Prof. John W. Gillespie, Jr. [1,2]
University of Delaware | Center for Composite Materials[1] | Department of Materials Science and Engineering[2]

Introduction

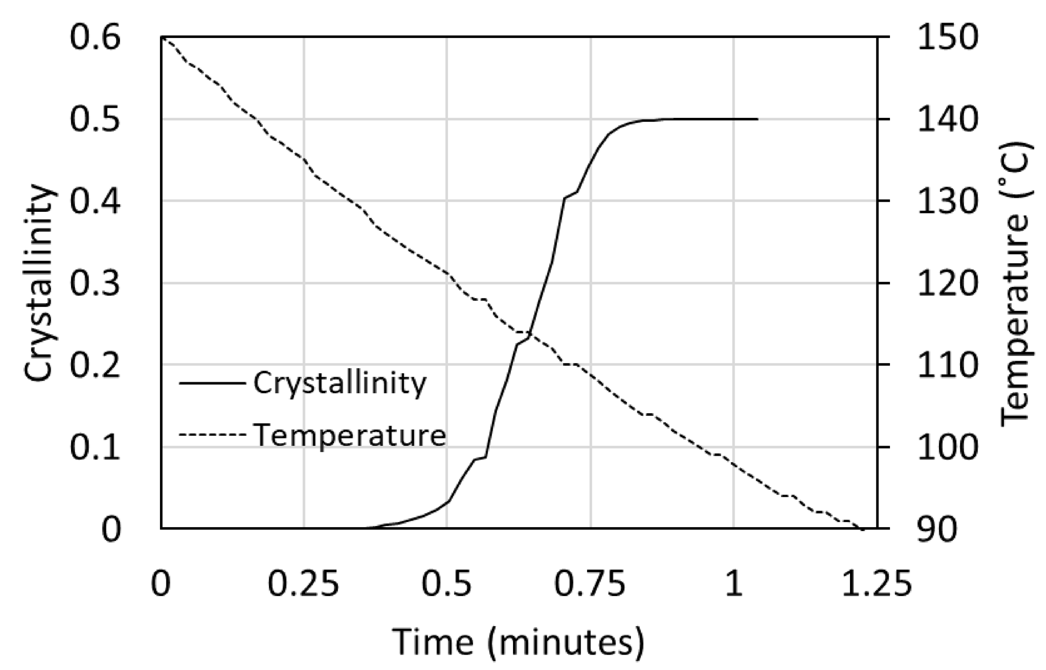
- The prediction and validation of residual stress development in AS4 carbon fiber in a polypropylene (PP) matrix at the microstructural length scale is the focus of this work.
- In the previous study, we made a simplifying assumption to define the stress–free temperature (Tsf) as the end of the crystallization temperature (cooling rate dependent) for the residual stress calculations.
- In the present study, we relax this assumption by starting the residual stress calculation in the melt and include non-isothermal crystallization effects to predict processing-induced residual stress.
- Residual stress predicted at different preloads (pre-defined weight at the end of fiber ends) was validated using the Raman spectroscopy method in the present study.

Factors Responsible for the Causes of Thermal Residual Stresses

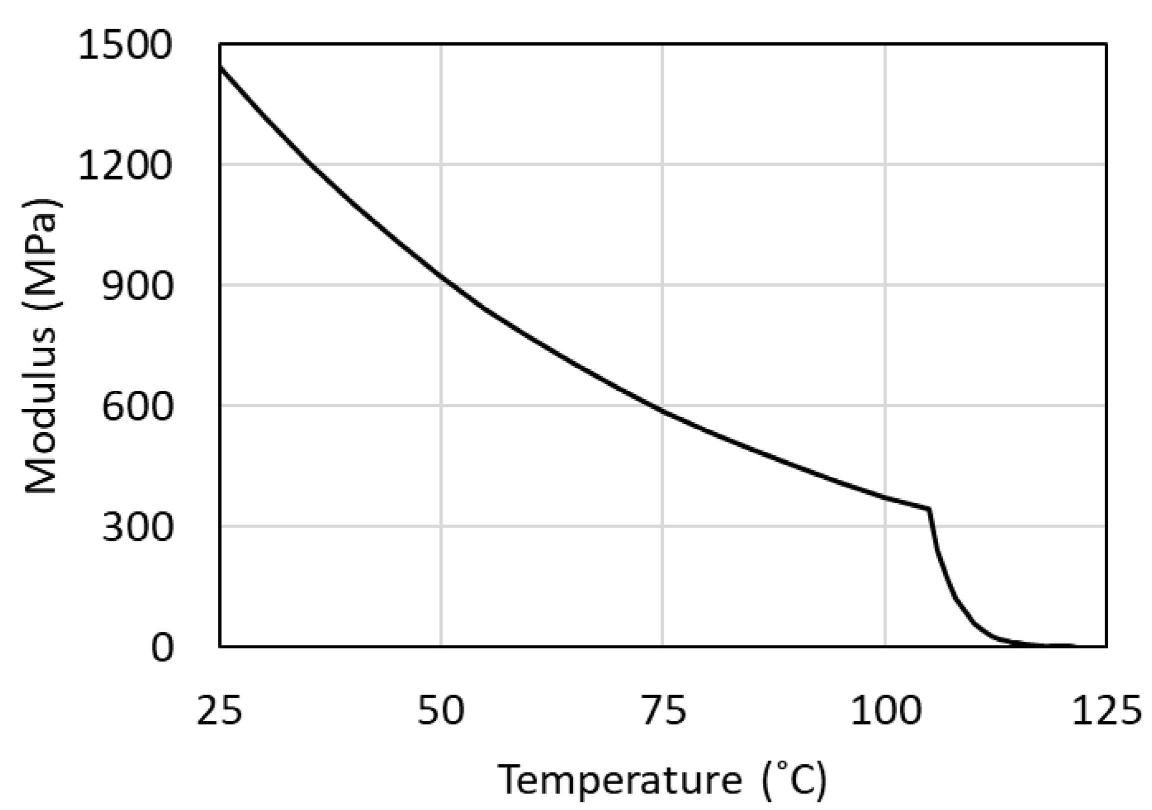
- PP's cooling-rate-dependent crystallinity
- Temperature-dependent elastic modulus
- Temperature-dependent coefficient of thermal expansion (CTE),
- Crystallization-dependent shrinkage, elastic modulus and CTE
- CTE mismatch of PP and carbon fiber (AS4)

Crystallization Prediction Versus Time for the Thermal Histories in the Single-Fiber Thin Film Sample

- Crystallinity at the termination of the crystallization process is almost 50% for the non uniform cooling rate in the single fiber thin film sample thermal processing



The Temperature-Dependent Modulus including Crystallization Effects Using the Thermal History in the Single-Fiber Thin Film Sample



The Predicted Processing-Induced Resin Shrinkage Strain and CTE

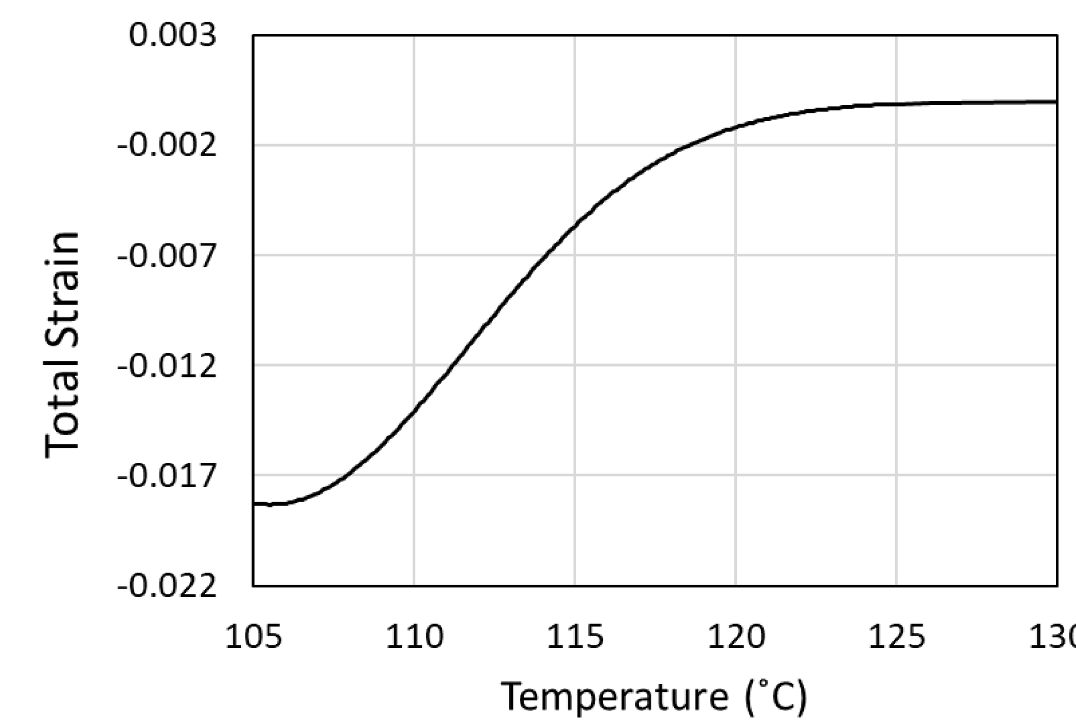
- The isotropic shrinkage strain of a unit volume element of resin, $\Delta\varepsilon_r^{cry}$, resulting from an incremental volume resin shrinkage, ΔV_r^{cry}, may be calculated as

$$\Delta\varepsilon_r^{cry} = \frac{-1+\sqrt{1+4/3\Delta V_r^{cry}}}{2}$$

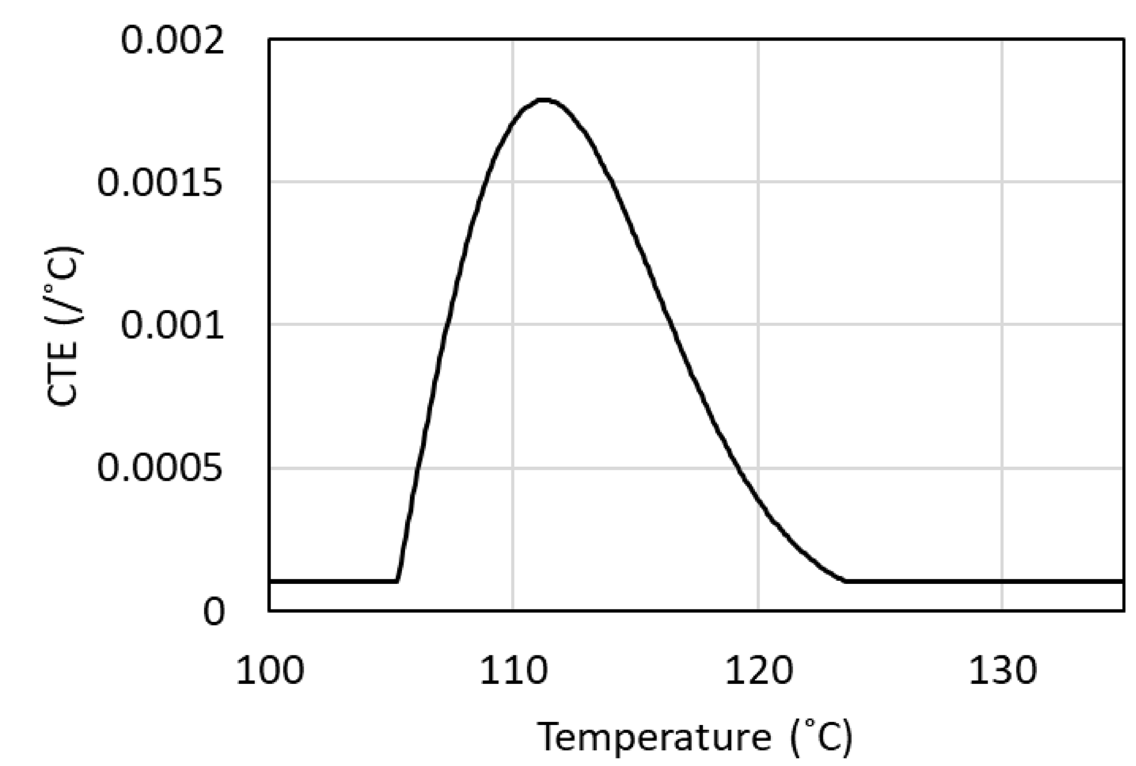
- The incremental thermal shrinkage strain is determined from the instantaneous, temperature-dependent resin thermal expansion coefficients and the temperature increment between time steps, as

$$\Delta\epsilon^{cte} = \alpha(T).\Delta T$$

- The total processing-induced resin shrinkage, $\Delta\epsilon^{th} = \Delta\varepsilon_r^{cry} + \Delta\epsilon^{cte}$



- The effective CTE during processing induced resin shrinkage is $\alpha_{\text{eff}}(T) = \frac{\Delta\epsilon^{th}}{\Delta T}$



Experimental Processing for Residual Stress

- Buckling must be avoided to ensure accurate Raman strain measurement
- Varying free-hanging pretension weight to change residual fiber stress (1g, 4g and 8 g)

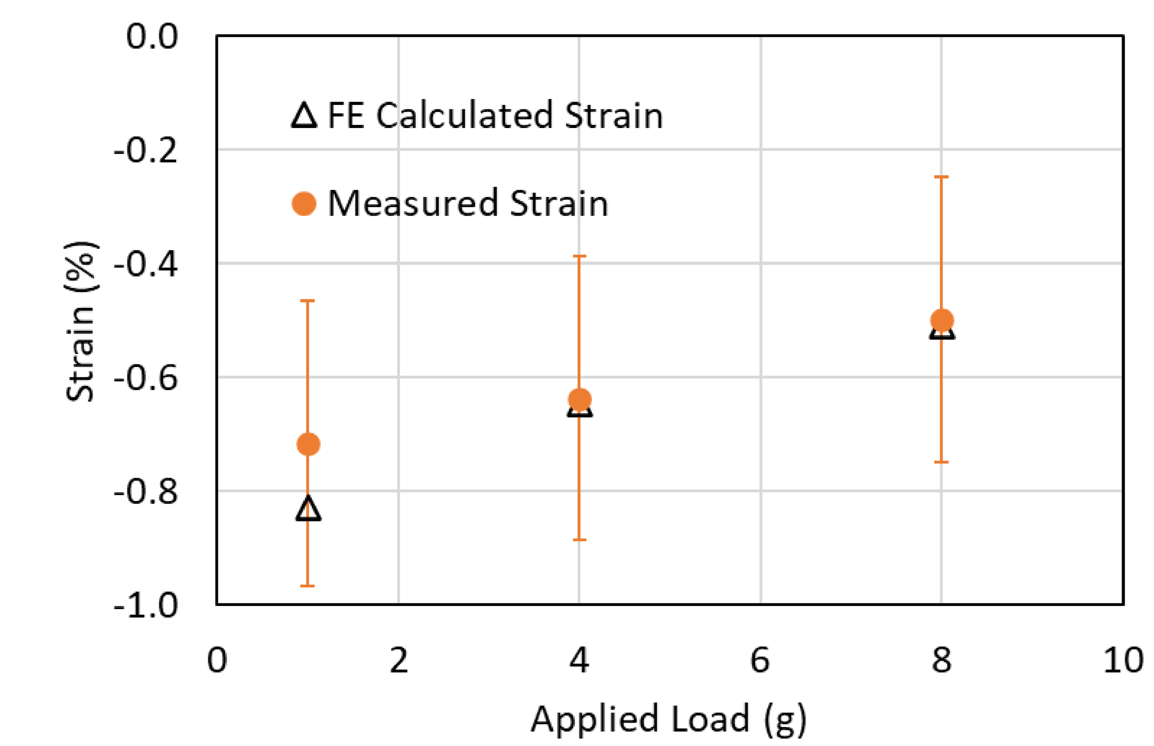
Residual Stress Calculation of SFFT Model

To mimic the experiment

1. Applying preload to the fiber (to make sure fiber is straight)
2. With the preload, cooling down the temperature to the room temperature (Δt = (120˚C to 25˚C)
3. Removing the preload

Bulk Residual Stress via Raman and Validation with Model

- Raman Spectroscopy
  - Using 633nm laser line scan
  - 3-4 measurements in the middle



Discussion

- The Raman strain measurement technique provides good overall correlation with the FE model predicted residual stress.
- Having validated a simple case with the FE model, we can apply it to more complicated geometries, such as the pullout test geometry where residual stress greatly influences the mechanical response.

Acknowledgements

This material is based upon work supported by the National Aeronautics and Space Administration under Grant and Cooperative Agreement No. 80NSSC20M0164, issued through the Aeronautics Research Mission Directorate, Transformative Aeronautics Concepts Program, University Leadership Initiative.