17th International Conference on
Flow Processes in Composites Materials (FPCM17)
Sheffield, United Kingdom, 30 June to 02 July 2026.

Numerical methods of predicting induced residual stresses during processing of thermoplastics composites

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Fiber reinforced thermoplastic composites are attractive for aerospace and automotive industries due to their rapid processing and high mechanical properties when compared to thermosetting composites. Processing of thermoplastic composites are carried out at higher temperatures, above the glass transition temperature and are subsequently allowed to solidify to room or service temperature [1]. This cooling step can induce internal residual stresses resulting in undesirable deformation of the composite product.
Accurate prediction of residual stresses and distortions in thermoplastic composite laminates requires a robust understanding of the coupled thermal-mechanical response after processing. This study presents a multiphysics modelling framework developed through user-defined subroutines UMAT and UEXPAN in Abaqus, enabling simultaneous consideration of temperature-dependent material properties and geometric nonlinearity in composite laminates. The formulation employs an incremental tangent approach for thermal strain (UEXPAN) and stress evaluation (UMAT), overcoming the limitations of the conventional secant based Abaqus implementation.
The framework was validated using two experimental benchmarks. The first, based on Barnes et al. [2], examined free thermal expansion of PEEK/IM8 [$0_4/90_4$] laminates, where curvature evolution was predicted as a function of temperature-dependent moduli and coefficients of thermal expansion. The second case reproduced the Flanagan [3] study on unsymmetrical unidirectional laminates, investigating curvature and residual stresses during cooling from 315 °C to 25 °C. Numerical predictions were compared with experimental data and Classical Laminate Theory (CLT) under both geometrically constrained and unconstrained cooling conditions.
Results demonstrate that the proposed UMAT–UEXPAN implementation accurately captures the nonlinear thermo-elastic response, curvature evolution, and stress relaxation behavior following constraint removal. The inclusion of geometric nonlinearity (NLGEOM) had minimal effect on stress prediction in constrained cases but proved critical for reproducing in-plane shrinkage and out-of-plane bending observed experimentally in unconstrained conditions.

References

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