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PREDICTION OF PROCESS-INDUCED DEFORMATIONS USING DEEP LEARNING INTERFACED FINITE ELEMENT CONSTITUTIVE MODELS

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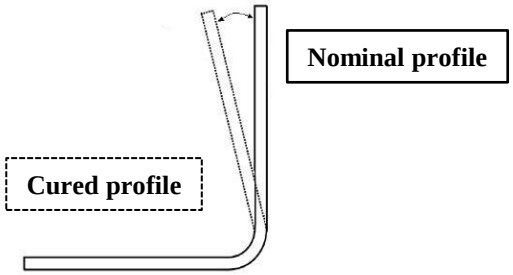
Problem Description:

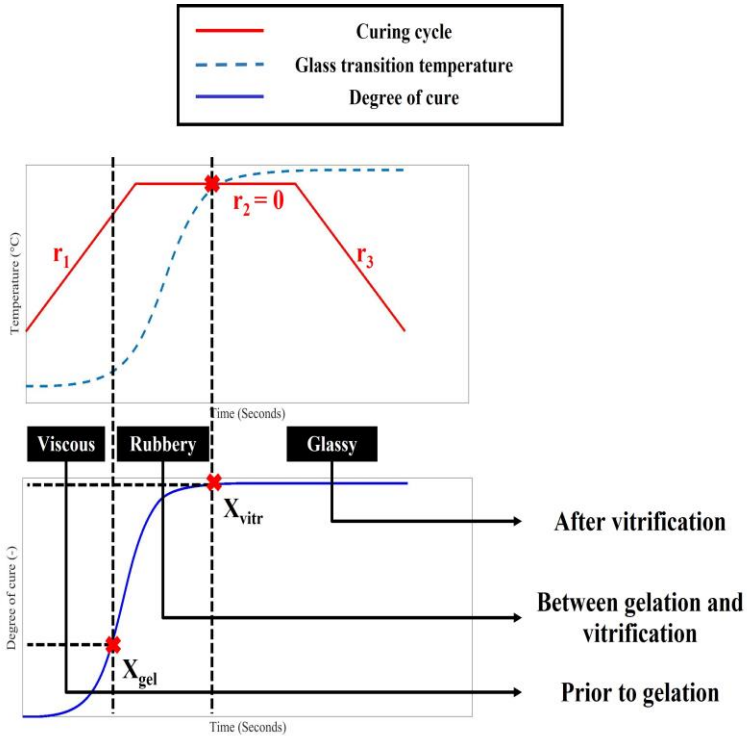
Process induced deformation in thermoset parts



Example of process induced deformations in L-shaped part (cross-plies)

Process induced defects arises due to:

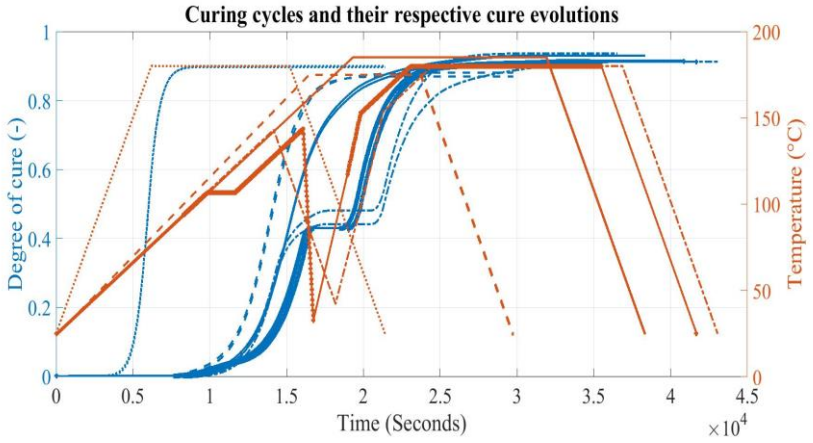
- Thermal expansion
- Chemical shrinkage
- Lay-up configuration, mold material, composite part thickness etc.,



The cure state variables are

- **The degree of cure,** X
- **The glass transition temperature,** T_g

Non-parametric cure model:



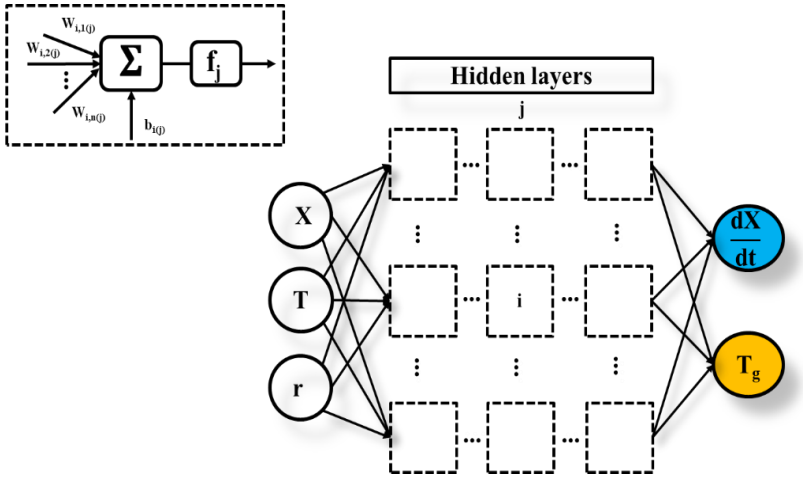
Characterization tests at rates of 1.5°C/min, 0.55°C/min, and 0.5°C/min & with isothermal dwells at 180°C, 175°C, and 185°C, respectively + some with partial curing

Diffusion Cure Kinetics (CK) Model (Cole, et al. [2005]) and DiBenedetto's model (Stutz, et al. [1990])

$$\left(\frac{dX}{dt}, T_g\right) = f(X, T)$$

Drawbacks:

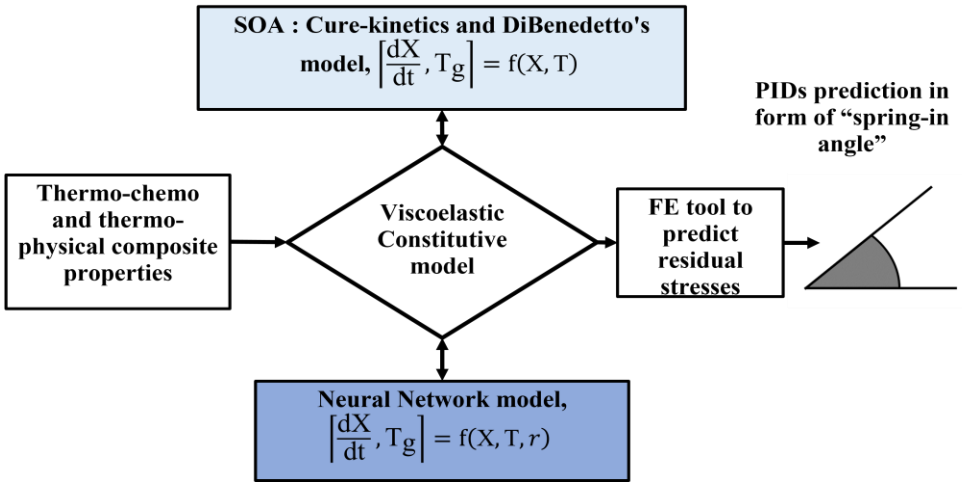
- No dependency on process condition variables.
- The part often follows different temperature profile.
- CK model parameters treated deterministically.

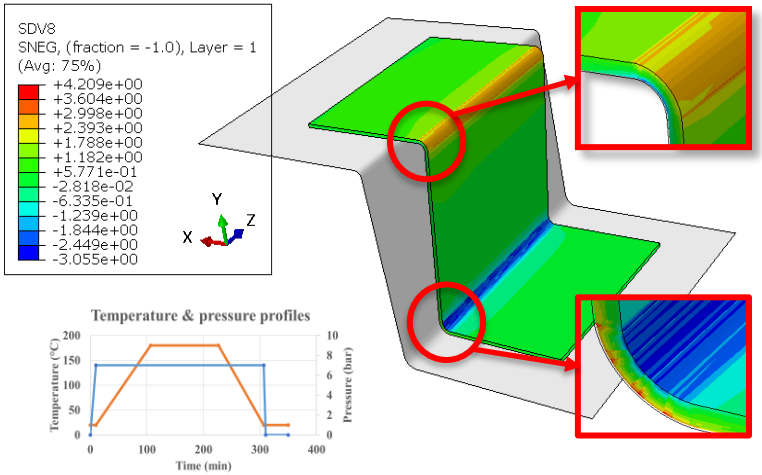


Non-parametric neural network model

$$\left(\frac{dX}{dt}, T_g\right) = f(X, T, r)$$

Case study: Curing of Z-shaped part ($[\pm 45°/0\text{-}90°]_{4s}$) made of 15 plies on Invar mold

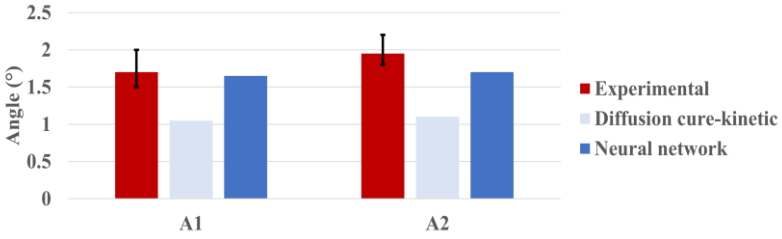




Residual stress in X direction upon demoulding (deformation scaling factor = 5)

Residual stress field prediction based on visco-elastic constitutive model (Svanberg, et al. [2004])

- Validation of the internal residual stress field is achieved through a comparison of process induced deformations (PIDs).



Comparison of PIDs

Summary and Conclusions:

- The non-parametric model makes accurate state transitions predictions considering the influence of process conditions.
- The proposed model when interfaced with the constitutive model predicts the PIDs that correlates more closely with experimental laser scan measures for the case of Z-shape thermoset part.

Outlooks:

- The model is implemented to conduct stochastic curing simulations, allowing for the quantification of uncertainties associated with cure temperature cycles.
- Characterization of complex resin formulations for newer thermoset materials.