# Damage Evolution in Cross-Ply Laminates Revisited via CZM-Based Finite-Volume Homogenization


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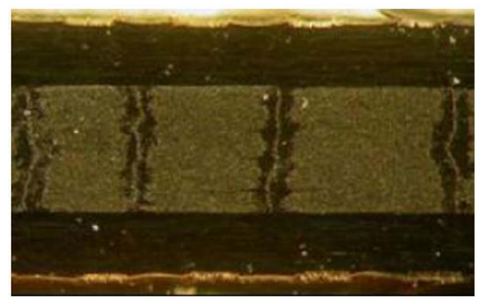
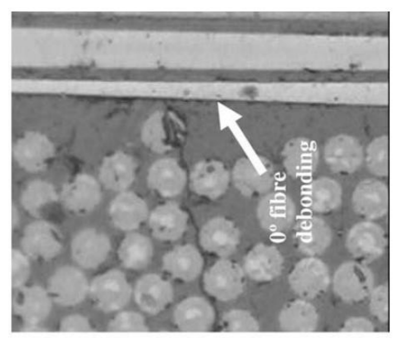
## Introduction:

**Q: Damage types in composite laminates?**

**A: Matrix cracking, fiber fracture, fiber/matrix debonding and delamination.**





**Damage simulation approaches based on FEA:**

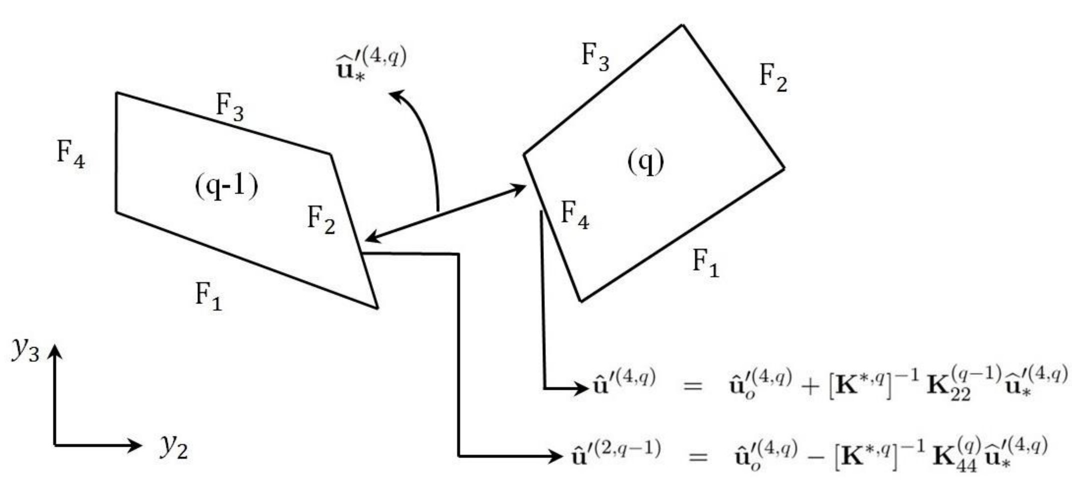
1) Re-meshing of analysis domain
2) Cohesive Zone Model (CZM)

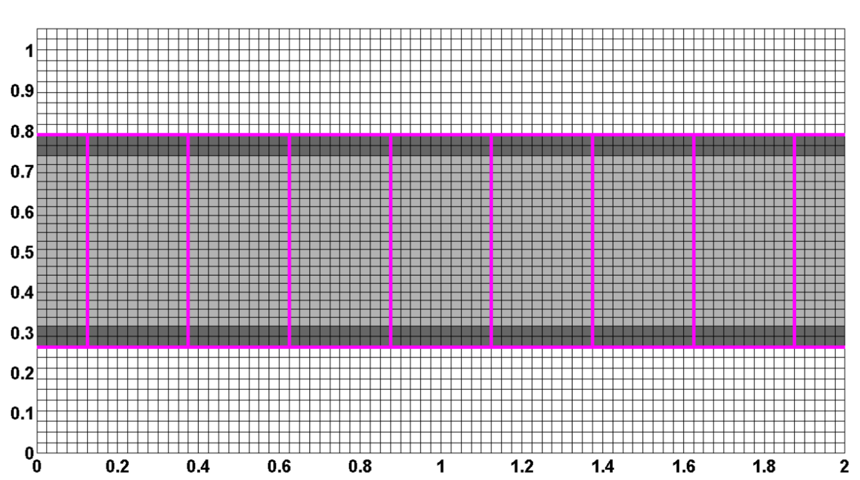
**Challenge in heterogeneous materials:** large modulus mismatch produces large stress gradient, especially in the presence of cracks.

**Finite Volume Direct Averaging Micromechanics** (FVDAM)→ an attractive alternative to FEA.

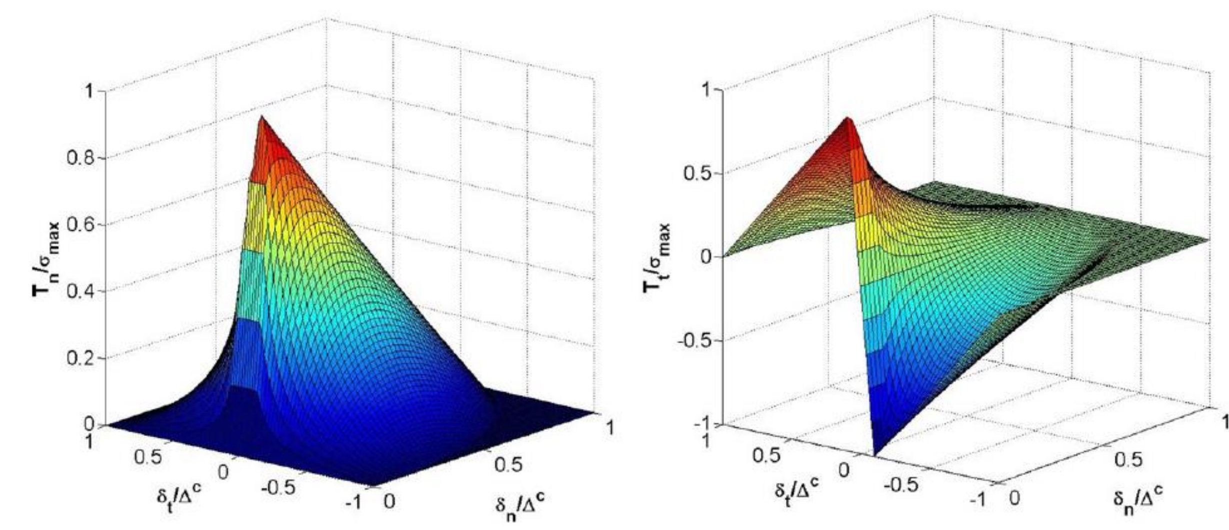
## CZM-Based Parametric FVDAM Theory:

**Parametric mapping and discontinuity:**

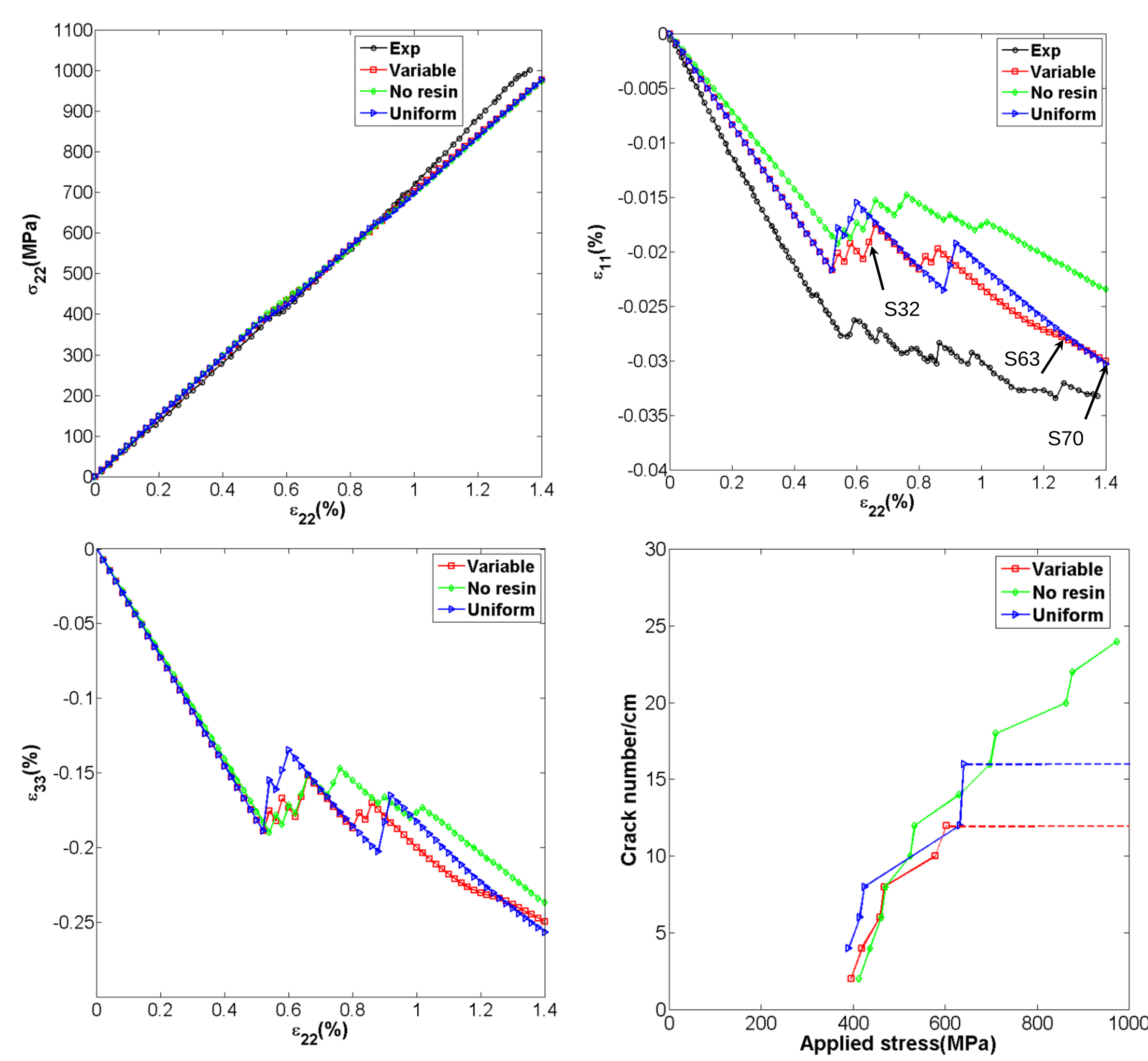


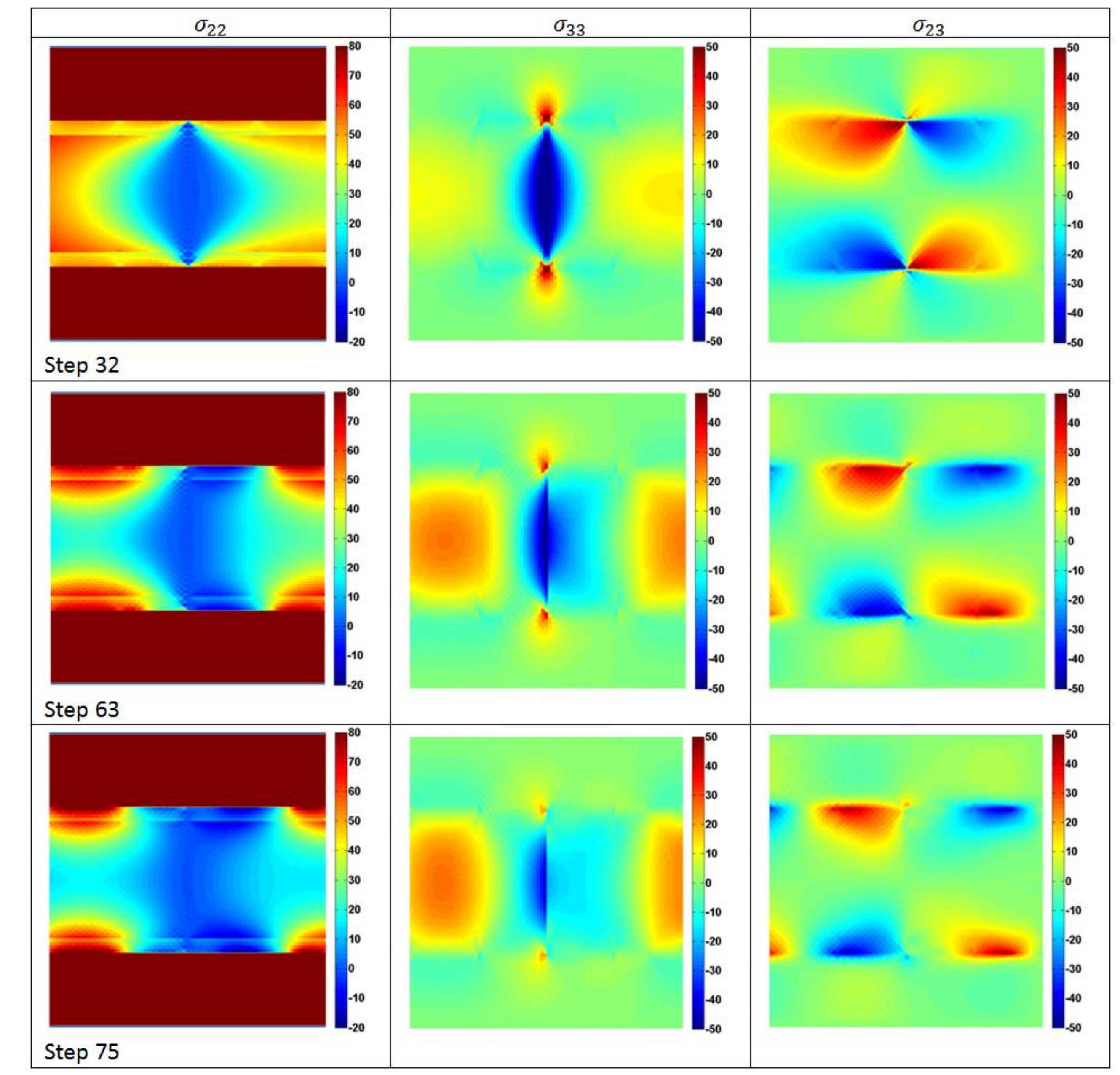
- **Displacement field :** $u_i^{(q)}(\mathbf{x},\mathbf{y}(\eta,\xi)) = \bar{\varepsilon}_{ij}x_j + u_i'^{(q)}(\eta,\xi)$
- **Fluctuating displacement:** $u_i'^{(q)} = W_{i(00)}^{(q)} + \eta W_{i(10)}^{(q)} + \xi W_{i(01)}^{(q)} + \frac{1}{2}(3\eta^2-1)W_{i(20)}^{(q)} + \frac{1}{2}(3\xi^2-1)W_{i(02)}^{(q)}$
- **Primary global system of equations:** $\mathbb{K}\hat{\mathbf{U}}_o' = \Delta\mathbf{C}\bar{\varepsilon} + \Delta\mathbf{\Gamma}\Delta T - \mathbf{L}\hat{\mathbf{U}}_*'$
- **Auxiliary system of equations:** $\mathbf{T} = \mathbf{K}^*\hat{\mathbf{U}}_*' + \mathbf{K}_o\hat{\mathbf{U}}_o' + \mathbf{C}\bar{\varepsilon} + \mathbf{\Gamma}\Delta T$
- **Homogenized Hooke's Law:** $\bar{\boldsymbol{\sigma}} = \frac{1}{\mathbf{V}}\int \boldsymbol{\sigma}(x)dV = \sum_{q=1}^{N_q} v_{(q)}\bar{\boldsymbol{\sigma}}^{(q)} = \mathbf{C}^*\bar{\boldsymbol{\varepsilon}} - (\bar{\boldsymbol{\sigma}}^{th} + \bar{\boldsymbol{\sigma}}^{d})$
- **Cohesive Law**



## Results: Homogenized response




**Stress field with evolving damage:**




## Conclusions:

- The newly developed framework offers a unified methodology for simulating damage in cross-ply composite laminates due to cracking or progressive interfacial degradation.
- Transverse and through-thickness Poisson's ratios are sensitive to different damage modes, which can serve as excellent damage detection indicators.

## Future Work:

- Incorporation of out of plane loading capability to simulate the dissipative response of unidirectional composites with two brittle constituents .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## References


1) W. Tu and M. J. Pindera, Cohesive Zone-Based Damage Evolution in Periodic Materials via Finite-Volume Homogenization, Journal of Applied Mechanics, 2014, 81: 101005(1-16).

2) F. Paris et al., Characterization and evolution of matrix and interface related damage in [0/90]S laminates under tension. Part I: Numerical predictions, Composites Science and Technology, 2010, 70: 1168–1175.