Damage Tolerance and Durability of Adhesively Bonded Composite Structures

04-C-AM-PU

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CT Sun (PU-AERO)

Administrative Outline

- PIs:

Research Outline: past years (also H. Kim)

- **Characterization of Adhesive Joints**
  - **Toughness**
  - **Strength**
  - **Environmental degradation**
  - **Bondline thickness**
  - **Size effects in joints**
- **Training**
  - **Computational Fracture Mechanics course (online offering in planning for Spring 09)**

Research Outline 2009

- Project #1 (Siegmund):
  - **Numerical Simulation of Fatigue Crack Growth: Cohesive Zone Models vs. XFEM**
- Project #2 (Sun):
  - **Development of Improved Hybrid Joints**

Numerical Simulation of Fatigue Crack Growth: Cohesive Zone Models vs. XFEM

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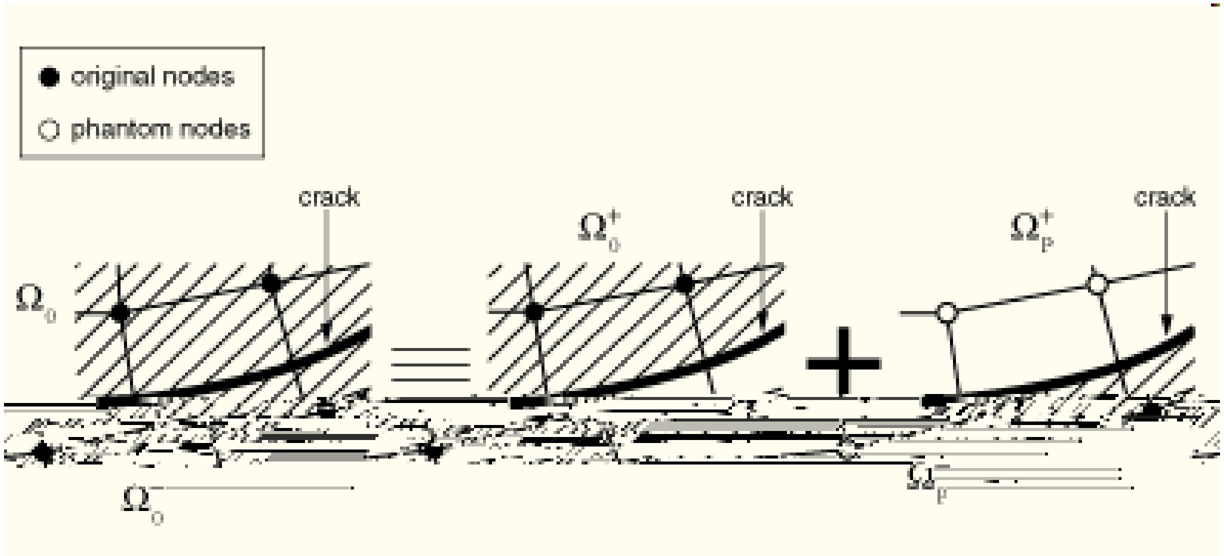
Research Accomplishments

- Tools for "Certification by Simulation"
  - Crack initiation and growth at arbitrary site and path (**adhesive**)
    - Compare cohesive zone model approach to XFEM
    - Implement fatigue crack growth in XFEM
    - Scenario: Failure from
  - Study contact fatigue failure (**rivets**)

XFEM-ABAQUS

- **eXtended Finite Element Method**
- Extension of conventional FEM based on the concept of partition of unity;



XFEM-ABAQUS

$$\mathbf{u} = \sum_{I=1}^{N} N_I(x)\left[\mathbf{u}_I + H(x)\mathbf{a}_I\right]$$

N_I shape function

$\mathbf{u}_I$ conventional nodal dispalcement

$\mathbf{a}_I$ enriched nodal displacements

Traction-Sparation Law

$$\begin{Bmatrix} T_{n,0} \\ T_{t,0} \end{Bmatrix} = \begin{bmatrix} K_0 & 0 \\ 0 & K_0 \end{bmatrix} \begin{Bmatrix} \Delta_n \\ \Delta_t \end{Bmatrix}$$

$$\max\left\{ \frac{\langle T_{n,0} \rangle}{\sigma_{\max,0}}, \frac{T_{t,0}}{\sigma_{\max,0}} \right\} = 1$$

$$T_n = (1-D)T_{n,0}, T_t = (1-D)T_{t,0}$$

$$D_m = \int_{\Delta_m^0}^{\Delta_m} \frac{T_{eff}\, d\Delta_m}{\phi_0 - \phi_{el}}$$

Monotonic Loading

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Example: CZM vs. XFEM

- Plate with a central hole
- Remote displacements
- CZ elements along several radial lines
- XFEM enrichment throughout

Damage Accumulation Rule

- Damage accumulation starts if a deformation measure, accumulated or current, is greater than a critical magnitude.
- There exists an endurance limit which is a stress level below which cyclic loading can proceed infinitely without failure.
- The increment of damage is related to

Damage Accumulation Rules

$$= \frac{\left|\Delta \quad\right|}{\delta_{\Sigma}} \; \frac{\quad}{\sigma} - \qquad\qquad = \int$$

σ_f…..cohesive endurance limit
δ_Σ….cyclic cohesive length

Cyclic Loading:
Damage Evolution in Mode I

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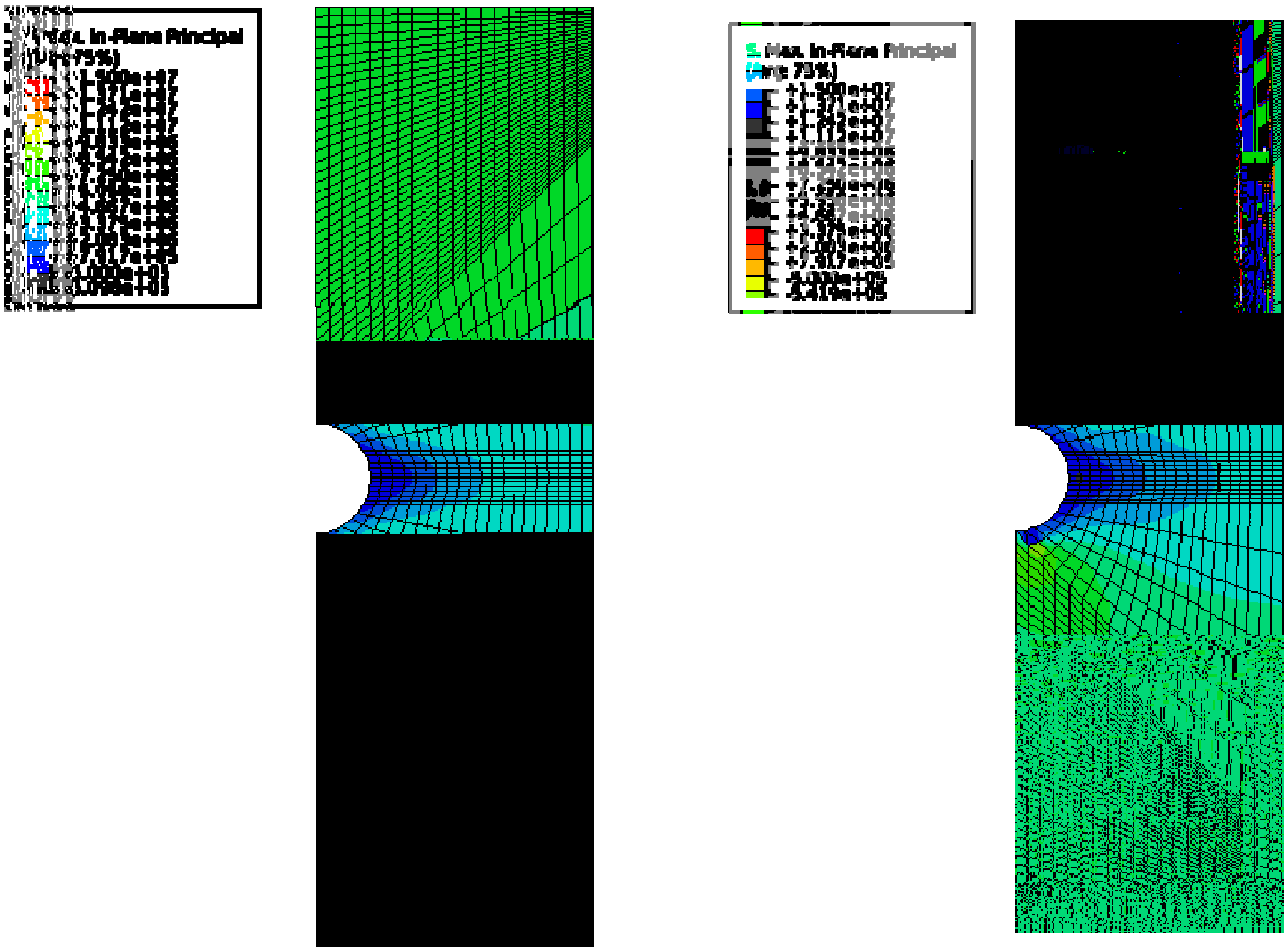
Cyclic Loading: Mixed Mode



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Contact Fatigue

- Multiaxial Fatigue Criteria:

Critical Plane Approach

E.g.: Findley Criterion:

$$\max\left\{\tau_a + \alpha_f \sigma_{n,\max}\right\} = \beta_f$$

τ_a shear stress amplitude on a plane

$\sigma_{n,\max}$ max. normal stress on that plane

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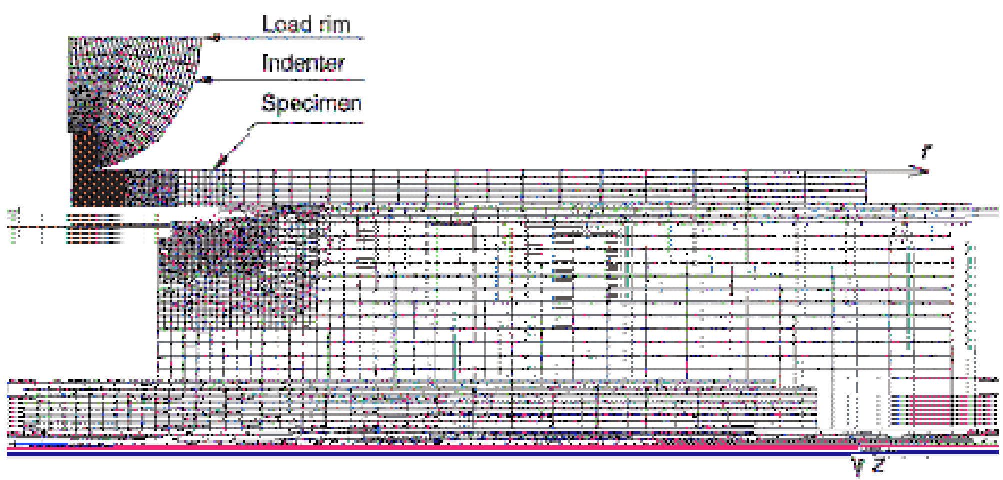
Example Result

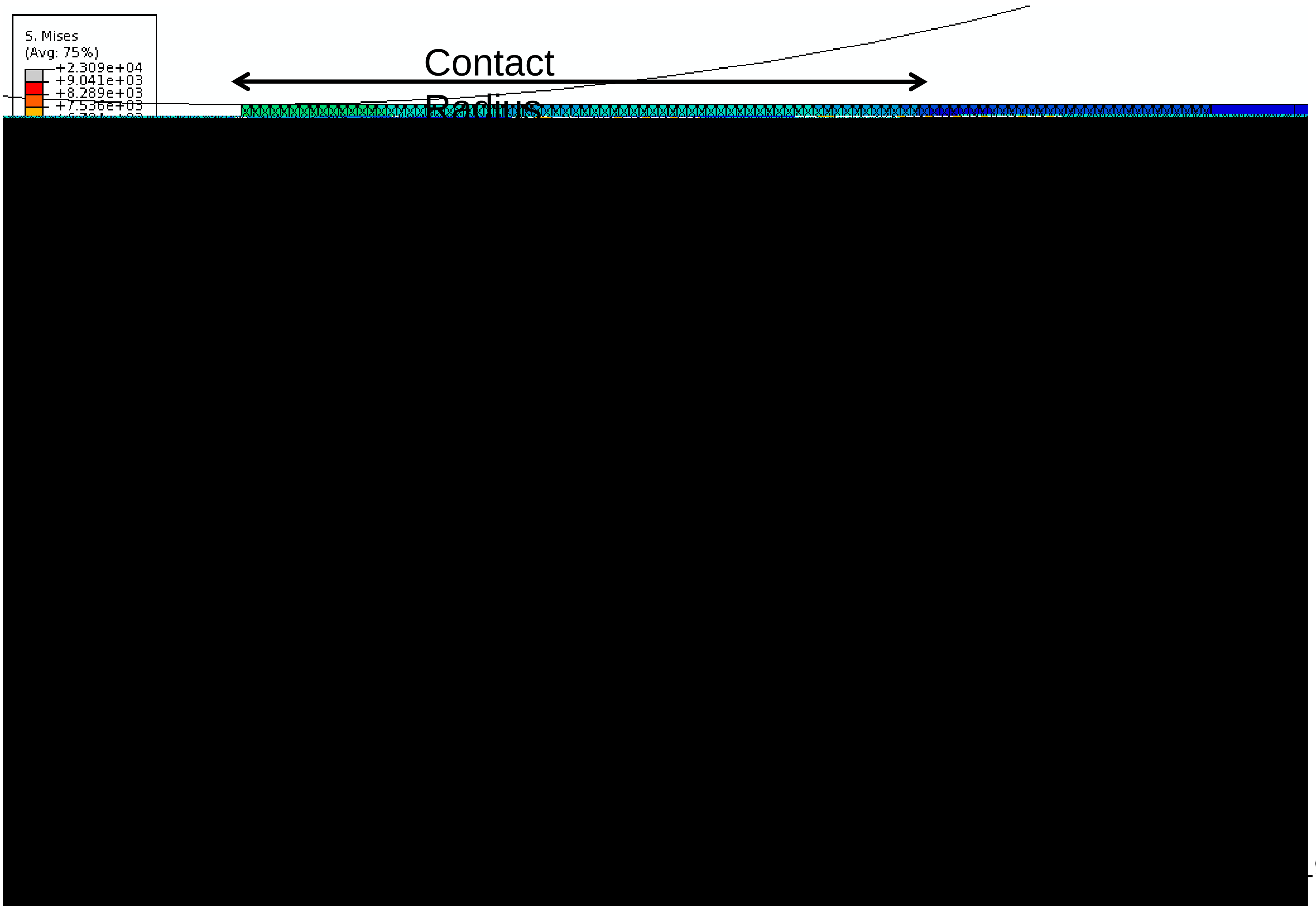
B. Alfredsson, M. Olsson / International Journal of Fatigue 23 (2001) 533–548



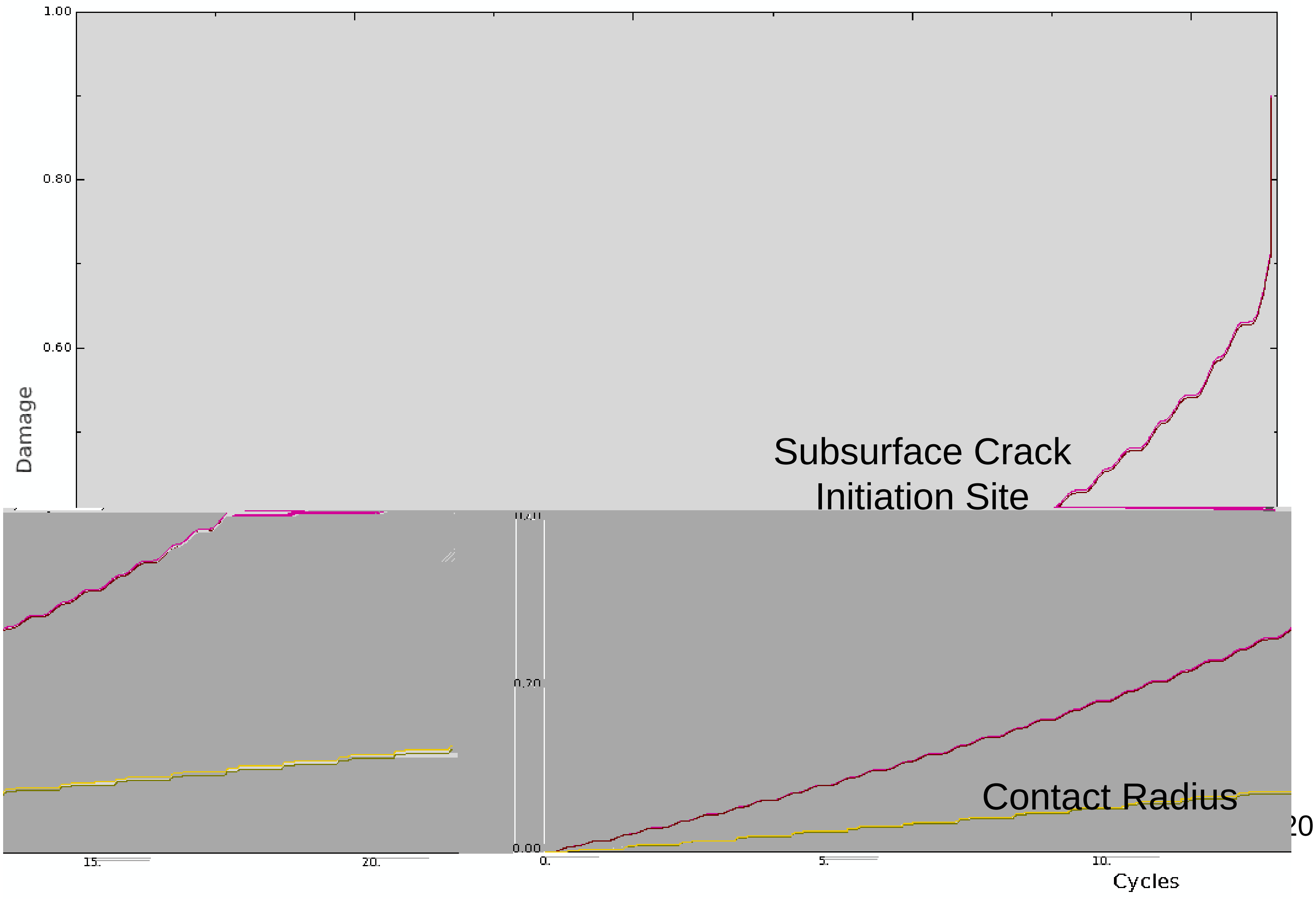
Provides location of crack initiation but not:
-- number of cycles to failure
-- not applicable to variable amplitude loading

Redefine: Effective Traction

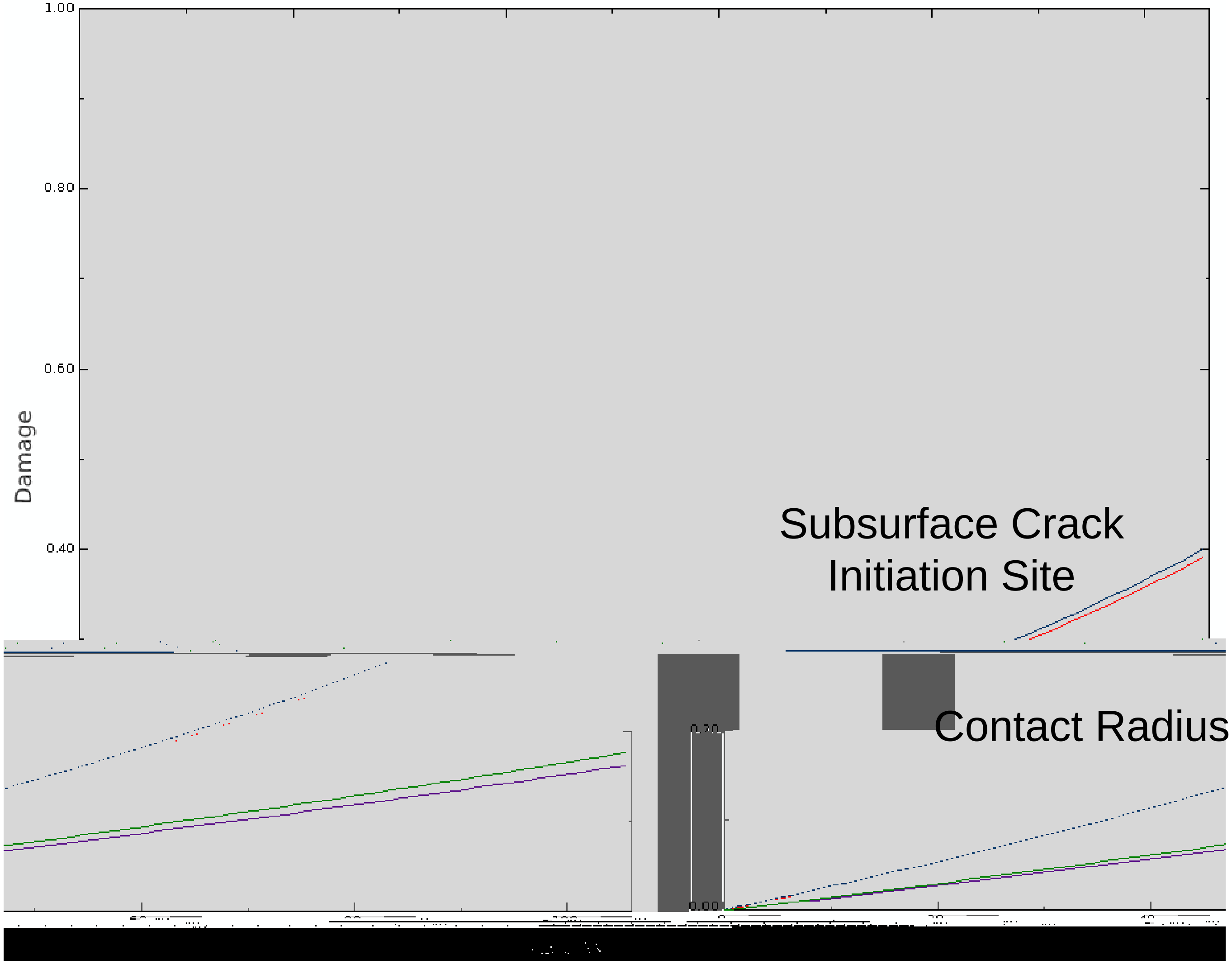
P_{max} = 16800 N at Failure



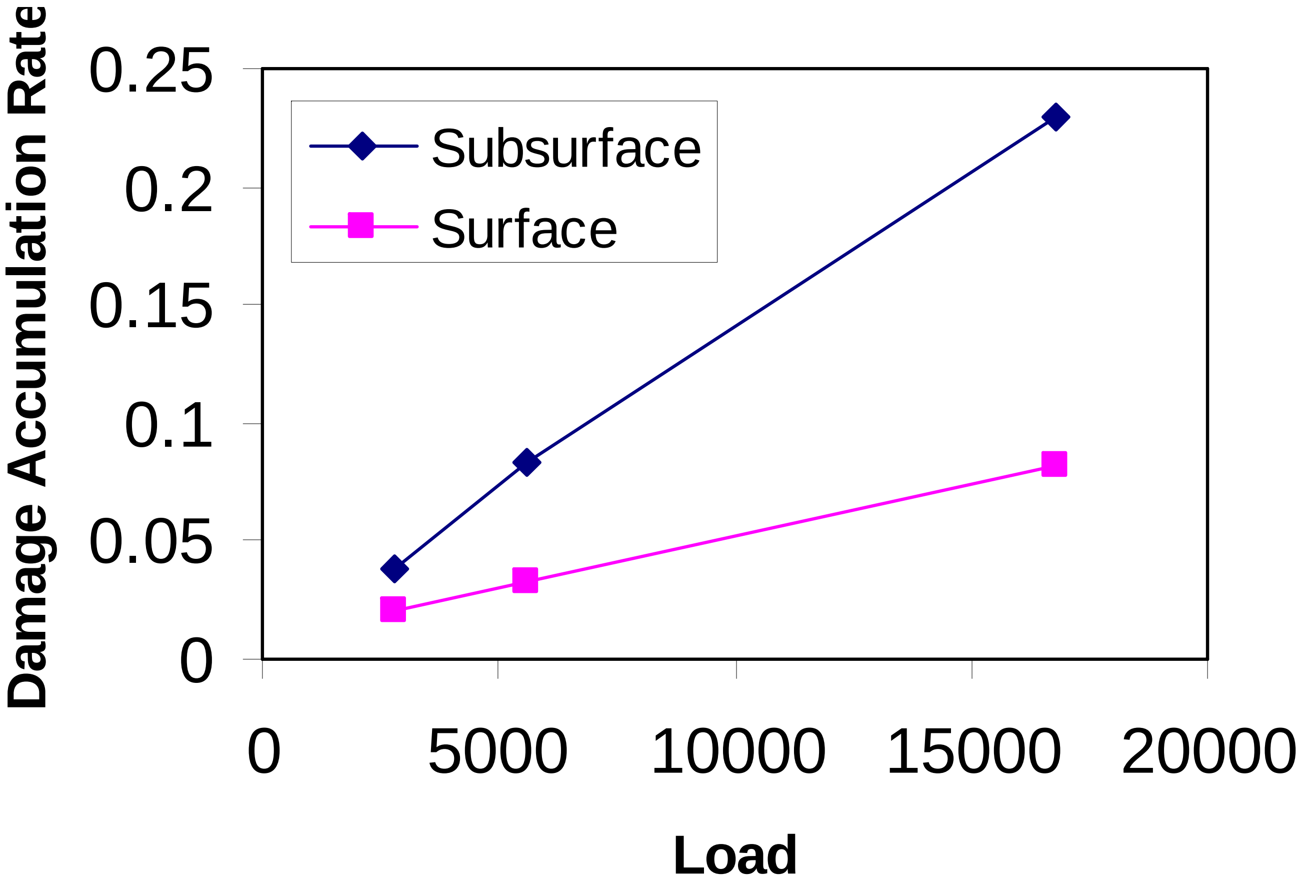
Damage Evolution



Damage Evolution
P_{max} = 2800 N



Comparison



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Summary

- CZM vs. XFEM:
  - Provide close results if correctly calibrated
  - CZM is mesh dependent, XFEM less
- Contact Fatigue:
  - Multifacet CZM
  - Effective traction
  - Variable amplitude loading or tilted geometry