Fatigue Damage Analysis of an Elastomeric Tank Track Component

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14. ABSTRACT
-Demonstrate simulation-based design qualificaiton capability for fatigue of elastomers -Application to the elastomeric backerpad operating as a part of the M1 Abrams track system -Estimate failure location and crack nucleation life

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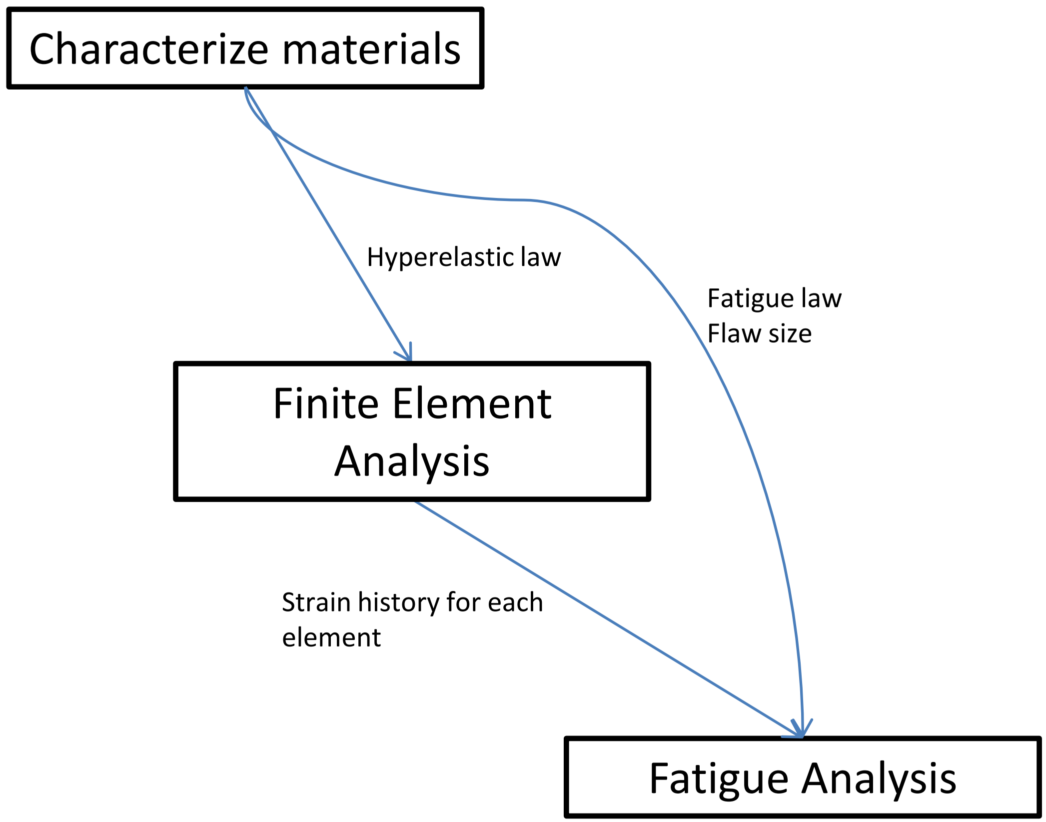
M1 Abrams Tank

Purpose

- Demonstrate simulation-based design qualification capability for fatigue of elastomers
- Application to an elastomeric backerpad operating as a part of the M1 Abrams track system
- Estimate failure location and crack nucleation life
  - Elastomeric material behavior
  - Realistic duty cycle

Plan



fe-safe/Rubber™

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Fatigue Analysis Strategy

$$T = g(\varepsilon_{ij}, \theta, \phi) a$$

ERR of a small probe crack scales linearly with crack size, and depends on strain state and crack orientation

$$\frac{da}{dN} = f(T_{\max}, R)$$

Crack growth rate for an individual event-pair

$$r = \sum_{i=1}^{M} f_i(T_{\max}, R)$$

Crack growth rate per application of given duty cycle

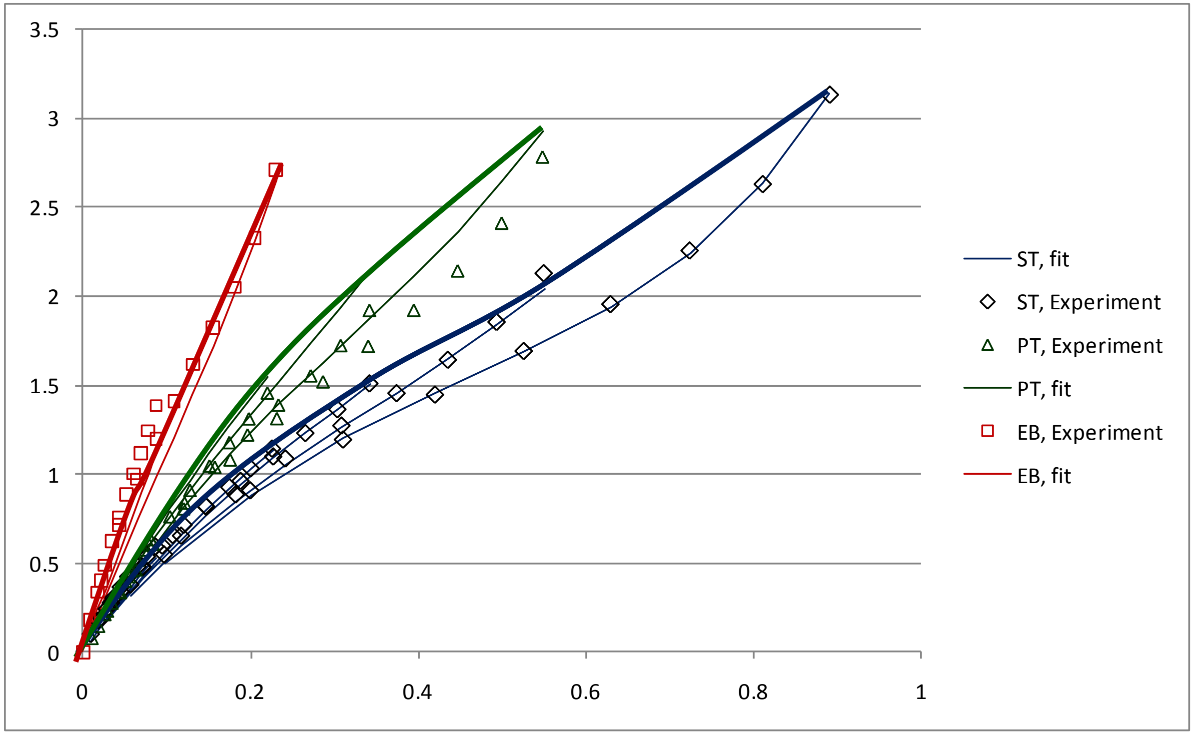
$$N_{\theta,\phi} = \int_{a_0}^{a_f} \frac{1}{r(T(a,t))} da$$

Number of repeats of duty cycle required to develop a crack

$$N_f = \min_{\theta,\phi}(N_{\theta,\phi})$$

Life minimization to identify critical plane

Stress-Strain Behavior




```
MU1=2.275319  ! MPa
MU2=0.054452  ! MPa
ALPHA1=-1.00837
ALPHA2=7.863497
MULLINSR=6.641545796
MULLINSM=0.558478587  ! MPa
MULLINSBETA=0.029639767
BULK_MODULUS=140.7 ! MPa
```

$$W = \sum_{i=1}^{N} \frac{2\mu_i}{\alpha_i^2}\left(\bar{\lambda}_1^{\alpha_i} + \bar{\lambda}_2^{\alpha_i} + \bar{\lambda}_3^{\alpha_i} - 3\right)$$

$$W = \eta \widetilde{W}(I_1, I_2) + \phi(\eta)$$

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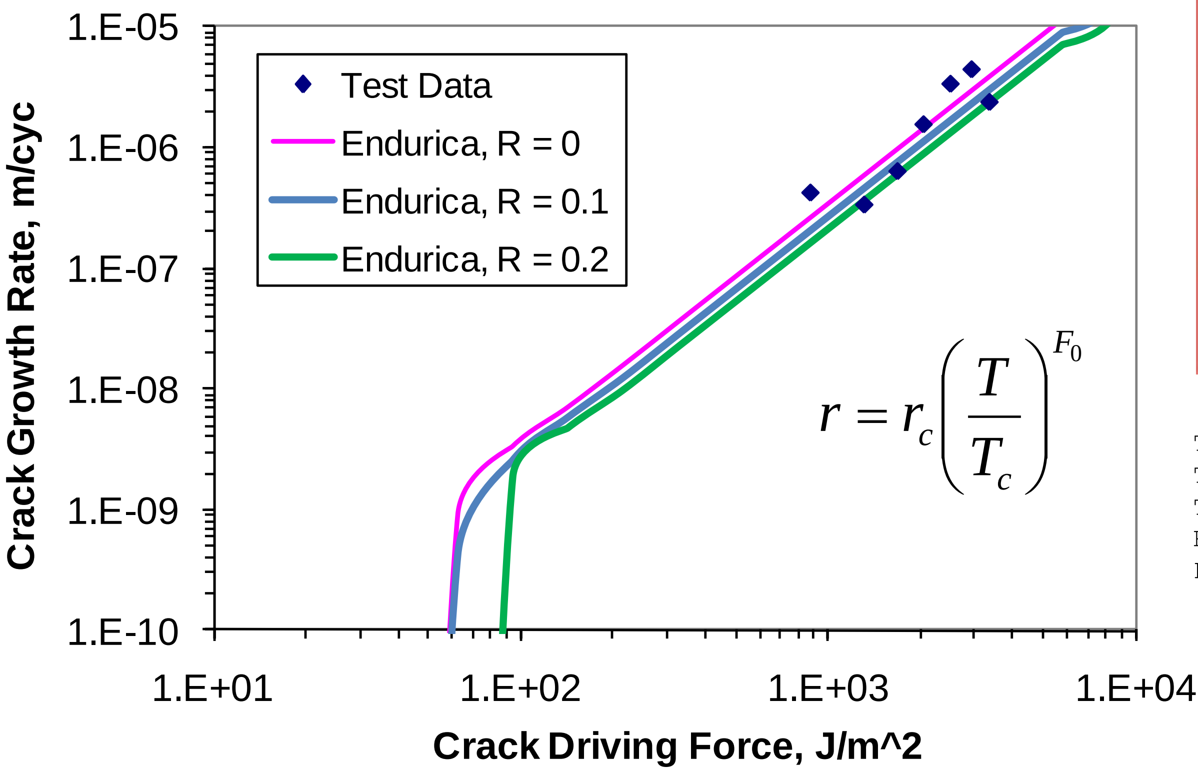
axel physical testing services

Fatigue Crack Growth Law

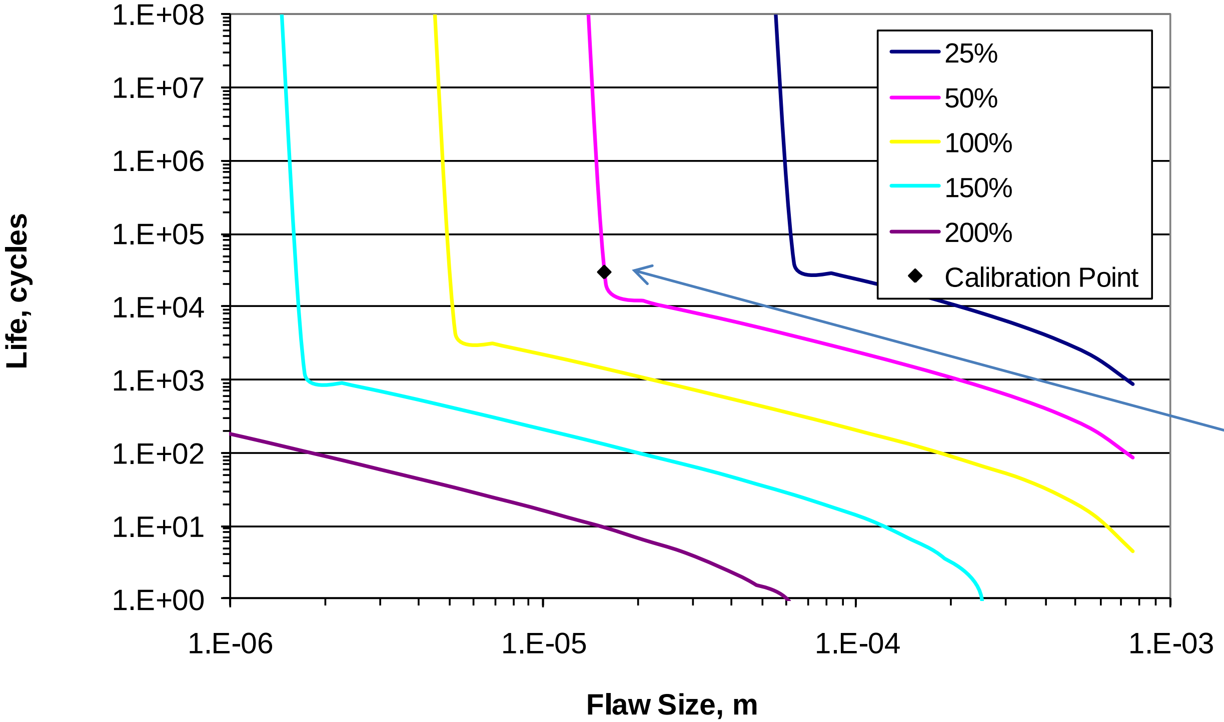


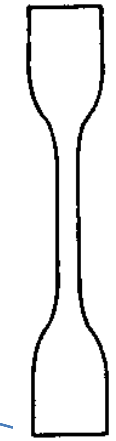
$$r = r_c \left(\frac{T}{T_c} \right)^{F_0}$$

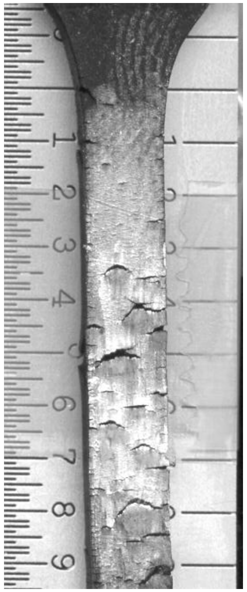
Courtesy Axel Products

```
TCRITICAL=10e3 ! J/m^2
THRESHOLD=50 ! J/m^2
TRANSITION=150 ! J/m^2
RC=3.42E-5 ! m/cyc
F0=2
```

Material Microstructural Feature Size





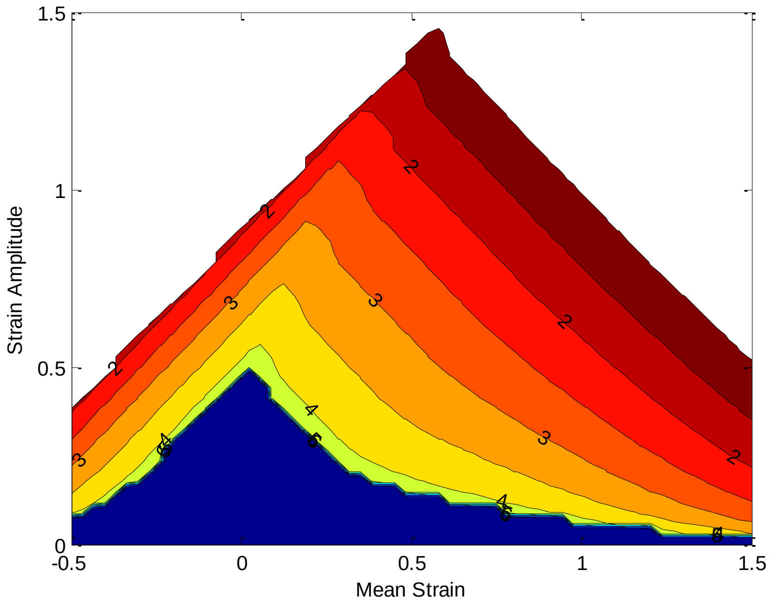


Simple Tension

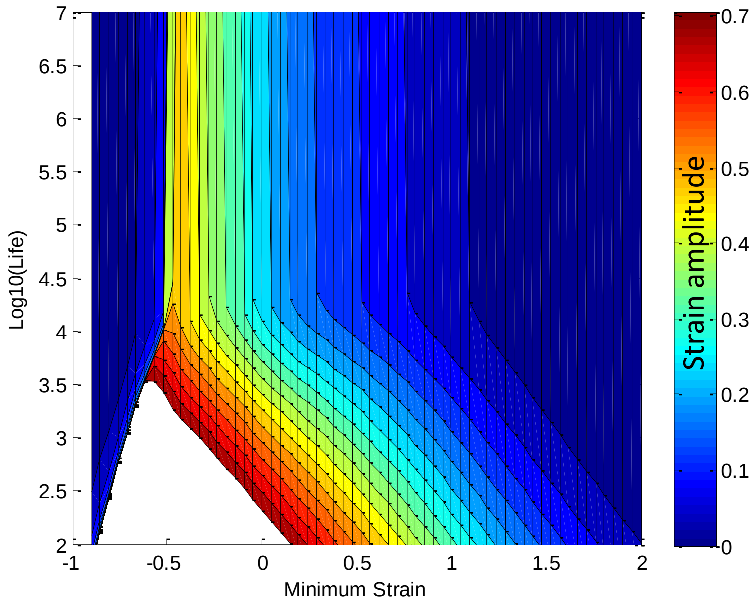
$$N_{\theta,\phi} = \int_{a_0}^{a_f} \frac{1}{r(T(a,t))} da$$

Computed Fatigue "Design Envelopes"

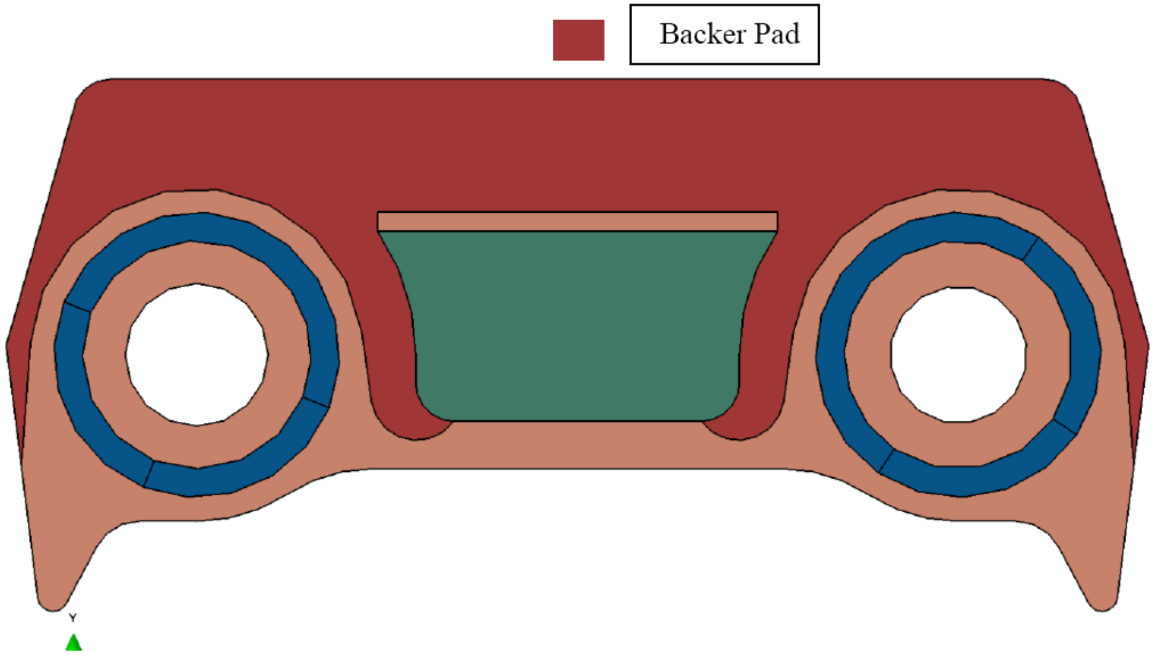
Haigh Diagram



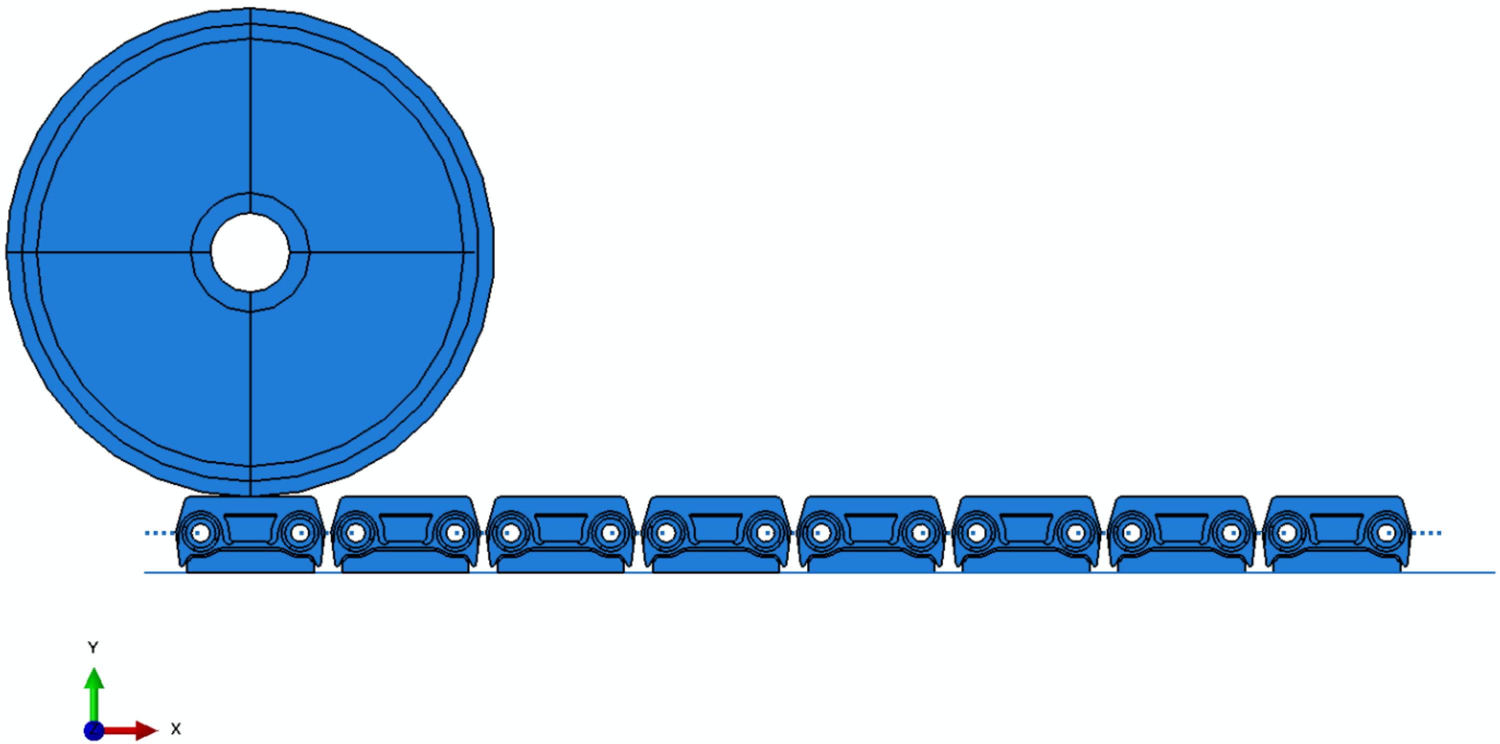
Cadwell Diagram



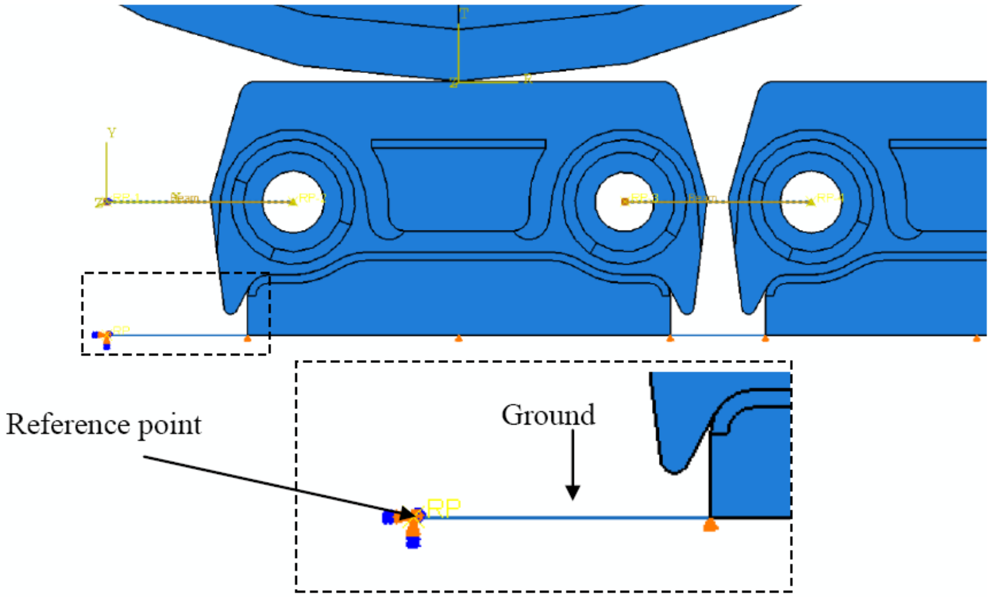
Backerpad Geometry



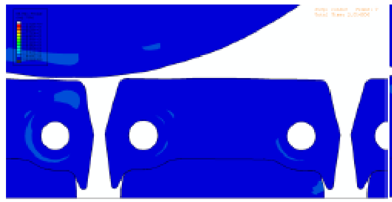
Operating Scenario



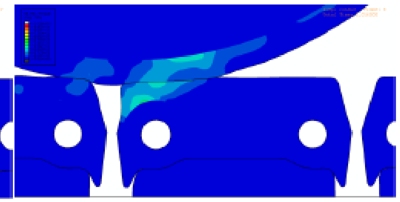
Boundary Conditions - Detail



Typical rollover event highlights



t = 2.014



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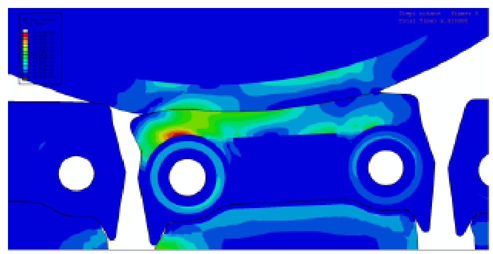
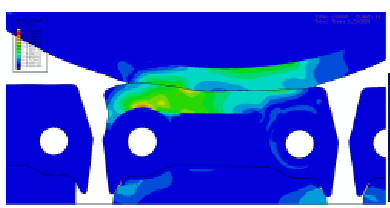
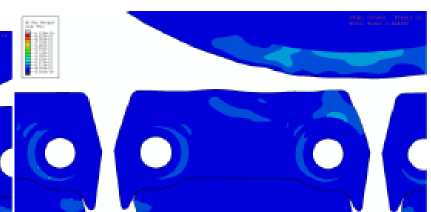


t = 2.018



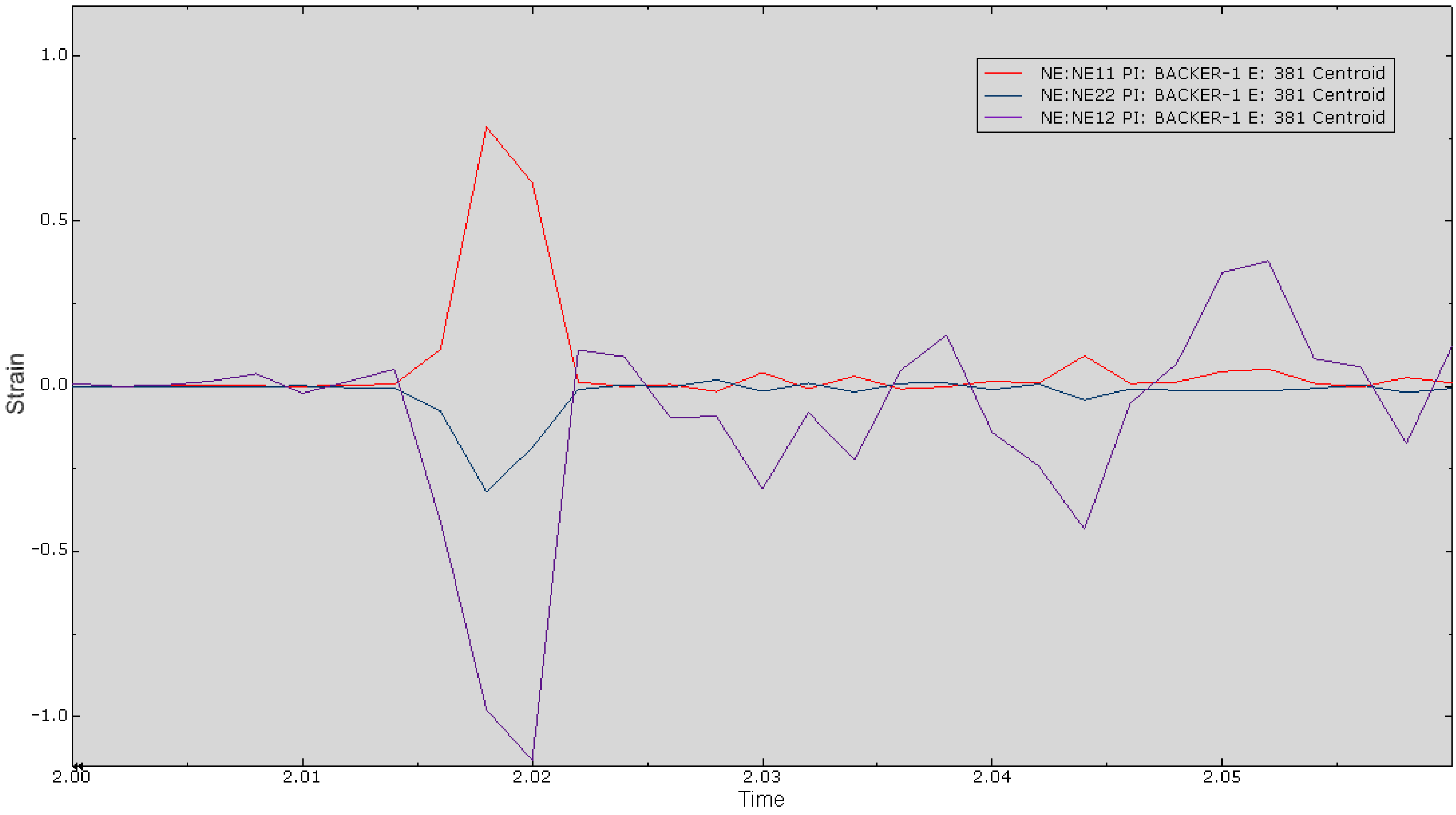
t = 2.020



t = 2.022

Contours of max prin strain

Strain history at typical location



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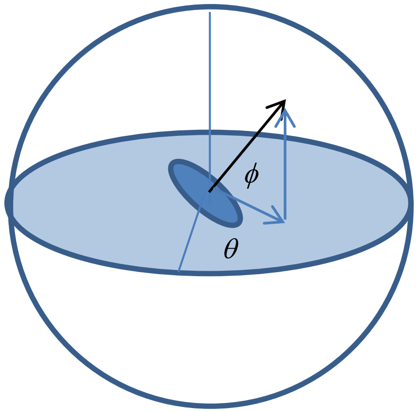
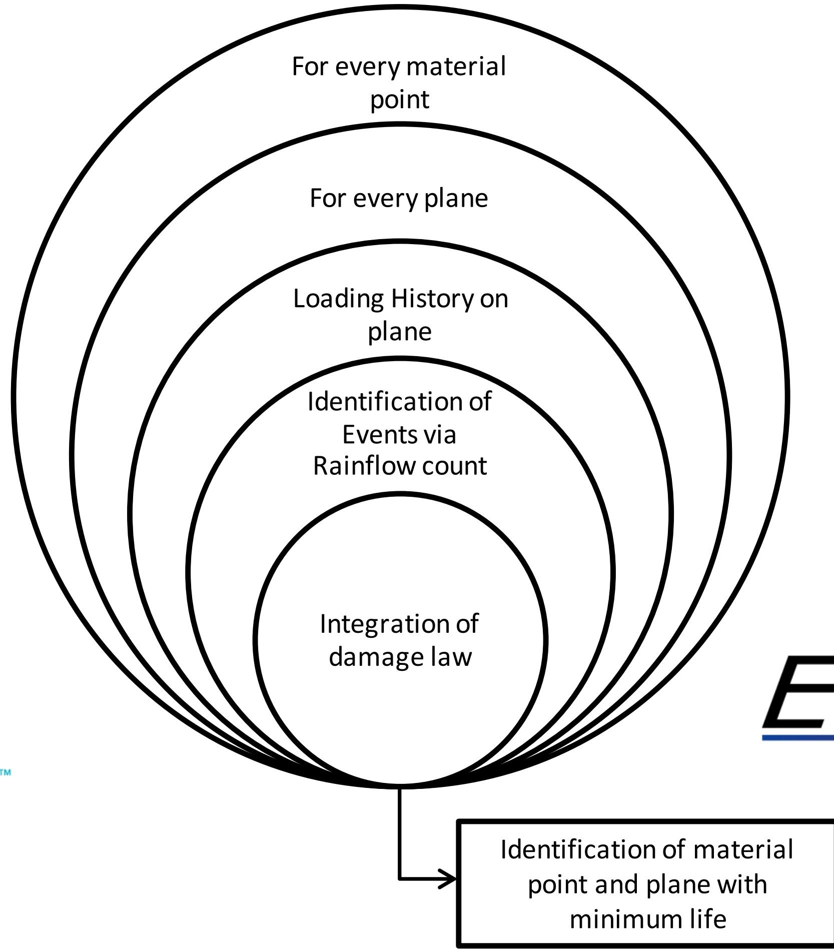
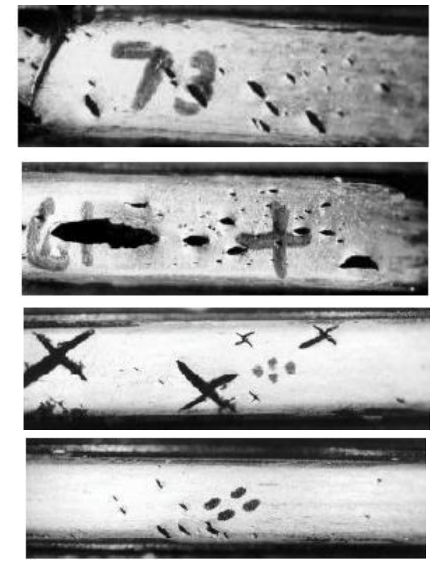
Critical Plane Analysis







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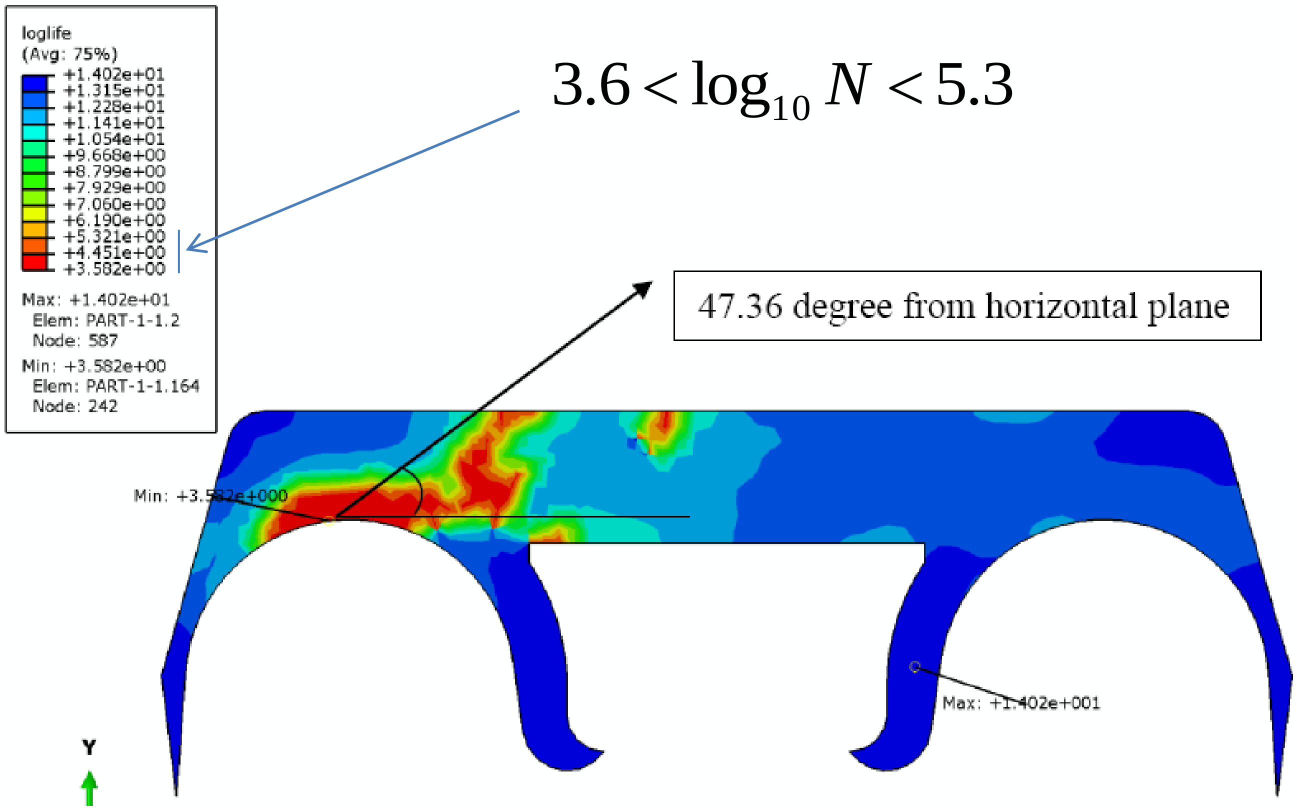
Accelerating Reliable Design

US PATENT NO. 6,634,236 B1

Results

$$3.6 < \log_{10} N < 5.3$$



Typical damage development

New 500 miles 1000 miles

$$\log_{10}\left(90\,\frac{revs}{mile}\times 500\,mile\times 7\,\frac{cycles}{rev}\times\frac{1}{3}\frac{mm}{mm}\right)=5.02$$

Conclusion

- Introduced a simulation-based approach for estimating elastomer fatigue crack nucleation life under complex dynamic loads
- Demonstrated
  – characterizing rubber’s fatigue behavior via fracture mechanics procedures
  – computing damage accumulation under complex service conditions using a critical plane analysis strategy
  – encouraging comparison to reality

Outlook

- Army funded SBIR Phase II project to expand features, validation, and application of the code.
- Partnership with Axel Products now offers Fatigue Design Envelope characterization service.
- Partnership with Safe Technology offers post-processing solution Fe-safe/Rubber (coming soon).

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Abstract

- *Abstract: The backerpad on the Abrams tank track system is an elastomeric cushion that protects the track and has direct contact with the tank's wheels. The backerpad's service life is limited by harsh operating conditions, and system designers are challenged to extend that limit. Accordingly, an analysis is demonstrated here of an experimental backerpad's fatigue performance under the action of a tank roadwheel repeatedly rolling over the pad. First, the elastomer is characterized via tests that define its fatigue behavior. Next, the multiaxial, variable amplitude duty cycle of the pad through a representative rollover event is computed in ABAQUS/Explicit. Finally, the material characterization and duty cycle are analyzed via the fe-safe/Rubber fatigue life solver to estimate damage accumulation in each finite element of the model. The calculation identifies the location and number of duty cycle repeats associated with the first appearance of 1 mm cracks for the selected duty cycle, providing an example of how fatigue analysis may be applied to understand damage development in elastomeric components.*
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- *Keywords: Damage, Fatigue, Elastomer, Material Characterization, Postprocessing*