Crack Growth Under Long-Term Static Loads: Characterizing Creep Crack Growth Behavior in Hydrogenated Nitrile

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Context

1. Applications w/ large static loads and long time periods
   - Seals, packers, mud motors etc.
   - Combined cycle/time dependent crack growth

2. Purpose
   - Obtain crack growth rate law parameters
   - Efficient and reliable execution
**MATERIAL

MAT=NBR
ELASTICITY_TYPE=NEOHOEKEAN
C10=1.157E6 ! PA
BULK_MODULUS=1000.0E6 !Pa
FATIGUE_TYPE=THOMAS
SIZEPRE=20E-6 !M
SIZEEOL=1E-3 !M
RC=0.40E-6 !(M/CYCLE)
TCRITICAL=3050 !J/m^2
F0=2.55
QUASISTATIC_TYPE=POWERLAW
RQS=1.26E-6 !m/s
TQS=2540 !J/m^2
FQS=3.69
Precedents


Combining Cycle- and Time- Dependent Crack Growth Rates

\[
\frac{dc}{dN} = \left( \frac{dc}{dN} \right)_{cyclic} + \left( \frac{dc}{dt} \frac{dt}{dN} \right)_{steady}
\]

Testing Hardware
Quasistatic Strain Ramp Protocol
Crack Tip Imaging and Measurement
Crack Length history and curve fitting

\[
\frac{dc}{dN} = r_q \left( \frac{Wh}{T_q} \right)^F
\]

\[
c = c_0 + r_q \left( \frac{h}{T_q} \right)^F \int_0^t W^{F_q} dt = c_0 + A \int_0^t W^{F_q} dt
\]

\[
E = \left( c(t) - \left[ c_0 + A \int W^{F_q} dt \right] \right)^2
\]
Creep Crack Growth Rate Law
Time-dependent fatigue crack growth

\[ \frac{dc}{dN} = \left( \frac{dc}{dN} \right)_{cyclic} + \left( \frac{dc}{dt} \frac{dt}{dN} \right)_{steady} \]

\[ \frac{dc}{dN} = r_c \left( \frac{T}{T_c} \right)^F + r_q \left( \frac{T_q}{T} \right) \omega \left( \frac{T}{T_q} \right)^{F_q} \]

<table>
<thead>
<tr>
<th></th>
<th>Fatigue</th>
<th>Creep</th>
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</thead>
<tbody>
<tr>
<td>T</td>
<td>3.05 kJ/m²</td>
<td>2.54 kJ/m²</td>
</tr>
<tr>
<td>r</td>
<td>0.40 mm/cyc</td>
<td>1.26 mm/min</td>
</tr>
<tr>
<td>F</td>
<td>2.55</td>
<td>3.69</td>
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</table>
Conclusion

• Developed procedure for observing time-dependent creep-crack growth rate law

• Useful when designing against loads that must be supported over a long period, or when analyzing mixed cyclic and time-dependent crack growth

• The slope of the creep-crack growth rate law may differ from the slope of the fatigue crack growth rate law. Indeed, in the case of filled HNBR, the creep slope was significantly higher than the fatigue slope
Characterization Toolbox for Durability

- **Hyperelastic Module**
  Simple, Planar, and Equibiaxial tension, Mullins Effect

- **Core Fatigue Module**
  Fully Relaxing Behavior from both nucleation and fracture mechanical perspectives

- **Nonrelaxing Module**
  Quantify Strain Crystallization, Min and Mean Strain Effects

- **Thermal Module**
  Quantify dissipative properties, thermal properties, temperature dependence

- **Extended Life (>10^6 cycles) Module**
  Quantify endurance limit, estimate aging rate of stiffness, intrinsic and ultimate strength

- **Creep Module**
  Quantify Creep Crack Growth Rate Effects

- **Cyclic Softening Module**
  Quantify Cyclic Softening Effects

**Fatigue Property Mapping**
Know Your Material

- **Intrinsic Strength (>10^6 cycles) Module**
  Quantify endurance limits

- **Creep Module**
  Quantify Creep Crack Growth Rate Effects

- **Extended Life (>10^6 cycles) Module**
  Quantify endurance limit, estimate aging rate of stiffness, intrinsic and ultimate strength

- **Cyclic Softening Module**
  Quantify Cyclic Softening Effects

**Endurica**
Get Durability Right

**axel**
physical testing services

**Schlumberger**