Crack Growth Stress Level Sensitivity

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Background Regarding Stress Level Sensitivity (SLS)

- SLS predicted by strip yield at positive R-ratios ($R=K_{min}/K_{max}$) appears largely negligible in practice[1]
- Crack acceleration with reversed loading is typically attributed to the R-ratio, but K is valid only for $K \geq 0$.
- Getting it right involves stress-level effects aside from the usual ΔK driver, particularly with reversed loading
- The Newman closure equations, re-interpreted, can provide guidance—Let's look at some examples....

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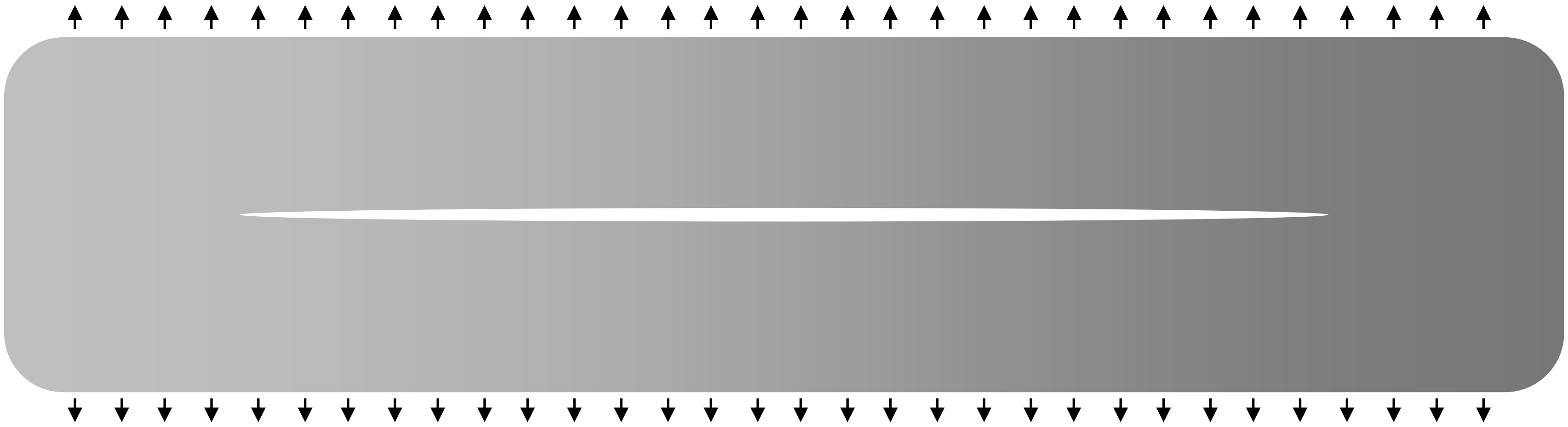
[1]NASGRO and other codes have had great success at +R despite this assumption. NASGRO is a registered trade name of Southwest Research Inst.

Case #1, -R Loading of Very, Very Long Crack



- An “infinitesimal” load in tension results in a sizeable K
- A compressive load at the same magnitude results in a closed crack at nearly zero contact stress (-K is aphysical)
- Would be expected to crack at the same rate at R=0 or -1 cyclic “test” condition. Strip yield solution/closure equation agrees if we use infinitesimal stress, though most implementations predict -R acceleration.
- Typically, however, we run –R ($R=S_{min}/S_{max}$) tests with fairly small cracks at high stresses—and see an acceleration associated with compressive loading[2]—what causes the acceleration, if it is not K_{min}?

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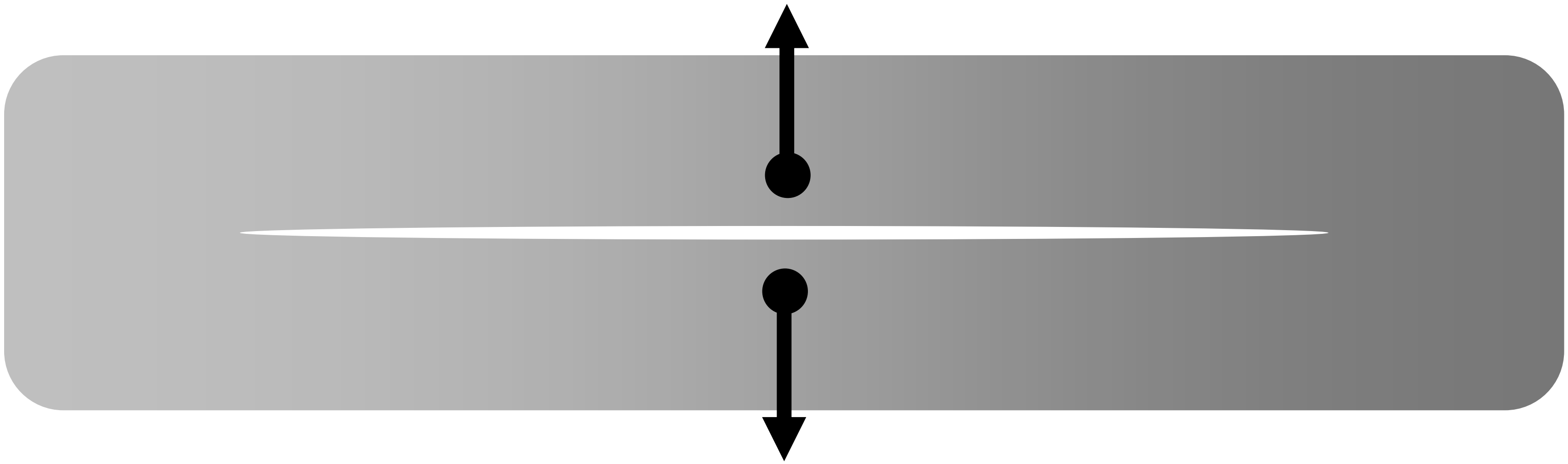
[2] J.C. Newman, J.J. Ruschau, *IJ of Fat.* 29 (2007) 1608-1615.

Case #2, Remote "Point" Loaded Crack



- A an opposing set of opposing tensile loads adjacent to the crack, but remote from the crack tip opens the crack and results in +K
- A compressive load at will result in local closing tractions on the crack flanks, which are remote from the crack tip, and can have no effect on it.
- The Crack **must** propagate at the same rate at R=0 or -1 cyclic "test" condition, but conventional crack growth codes using –K would erroneously predict an acceleration associated with R=-1.

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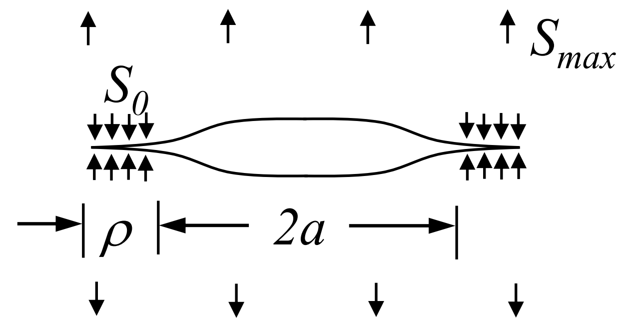
Potential Stress Level Sensitivity Mechanisms

During Tensile Portion of Load Cycle

The "far-field stress effect" is revealed by the Dugdale model for a center cracked panel which predicts that the plastic zone grows infinite as the far field tensile stress approaches the flow stress

Similarity Parameters:
R, Smax/So
(Smax is geometry specific)

$$\frac{a}{a+\rho} = cos\left(\frac{\pi S_{max}}{2S_0}\right)$$



During Compression Portion of Load Cycle

The residual stress/closure neutralization effect that occurs when the crack is globally closed and the crack tip is subjected to the local compressive stress (superposed on the residual stress left over from the prior tensile cycle)

Similarity Parameters:
Smin/So, defined at crack tip location

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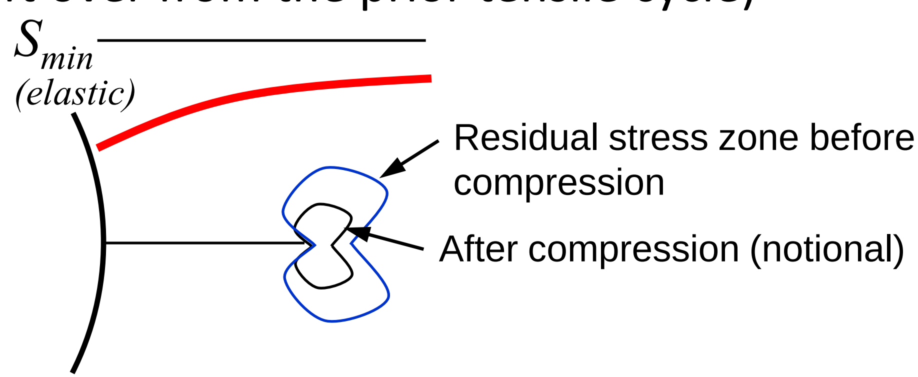
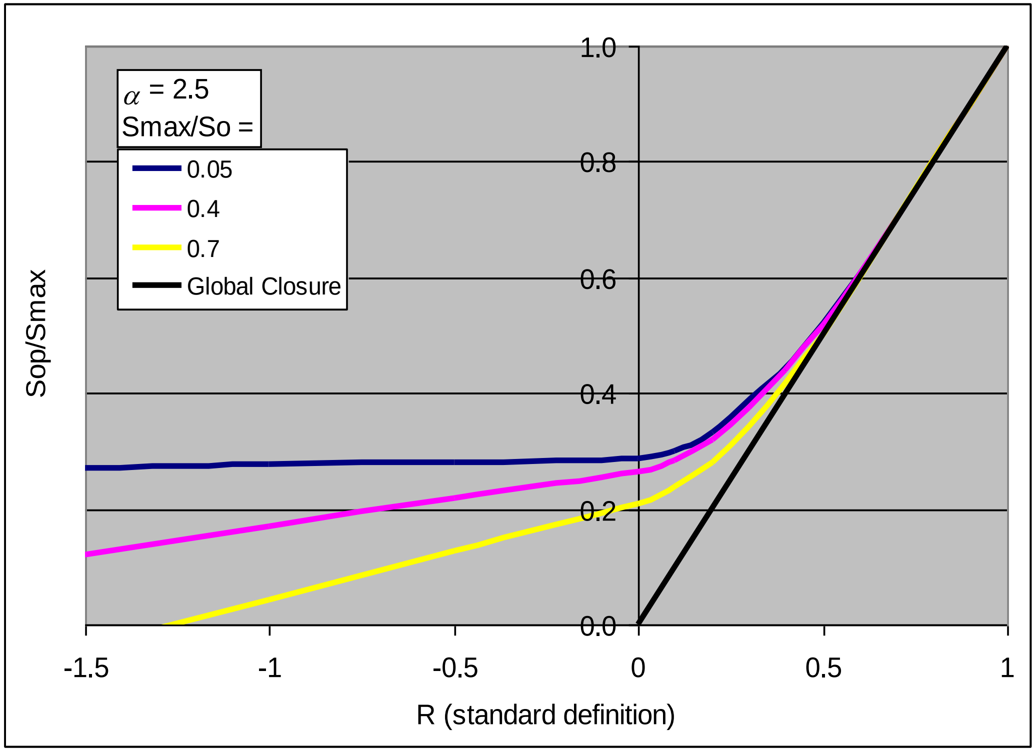
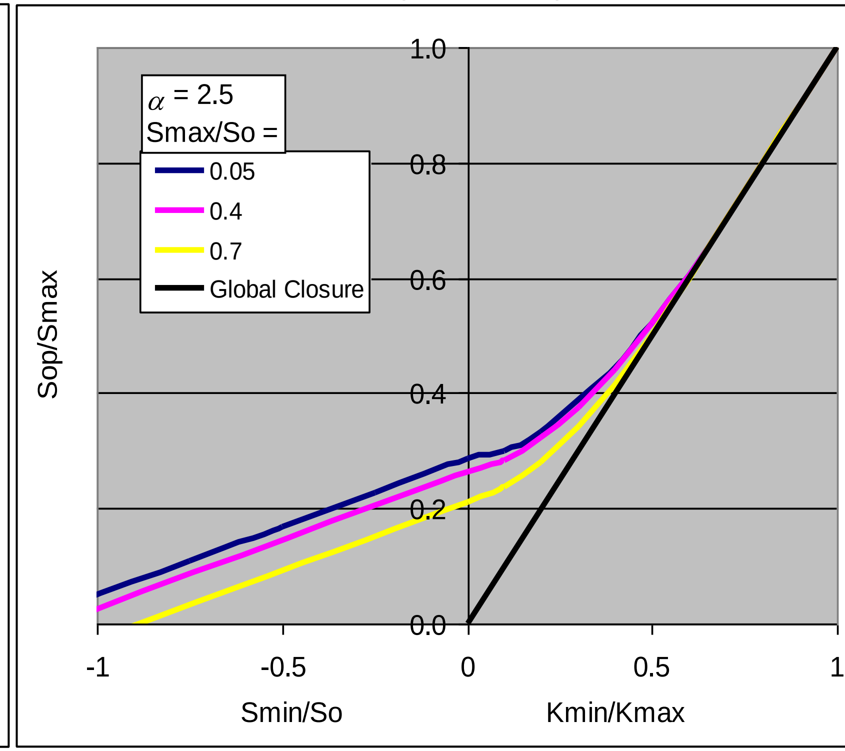


Proposed Method…a Simple Shift in Parameters

Standard closure plot



Same equations—new format[3] (no –K!)



- Plotting Newman closure equation in new format shows better collapse
- A constant "S_{max}/S_o ratio" can still be used for R+, but actual flow stress for R-

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[3]Use of Smin/So in place of –R was proposed by M. Lang, G. Marci, ASTM STP 1332, 1999, pp 474-495

Proposed Formulation

(Newman Closure Equations Revisited)

Empirical adjustment
(might still be needed)

$$S_{op}/S_{max} = \begin{cases} A_0 + C\,A_1 & for\ closed\ crack\ at\ min \\ MAX(A_0 + A_1 R + A_2\,R^2 + A_3\,R^3) & for\ R > 0 \end{cases}$$

Use actual elastic dieout stress and actual flow stress

$$A_0 = (.825 - .34\alpha + .05\alpha^2)\left[\cos\left(\frac{\pi}{2}\boxed{\frac{S_{max}}{S_0}}\right)\right]^{\frac{1}{\alpha}}$$

$$A_1 = \begin{cases} (.415 - .071\alpha)\,\boxed{S_{min}(a)/S_0} & for\ closed\ crack\ at\ min \\ (.415 - .071\alpha)\,\boxed{S_{max}/S_0} & for\ R > 0 \end{cases}$$

$$A_2 = 1 - A_0 - A_1 - A_3$$

$$A_3 = 2A_0 + A_1 - 1$$

Ratio may be treated as a constant (or use K-analogy method)

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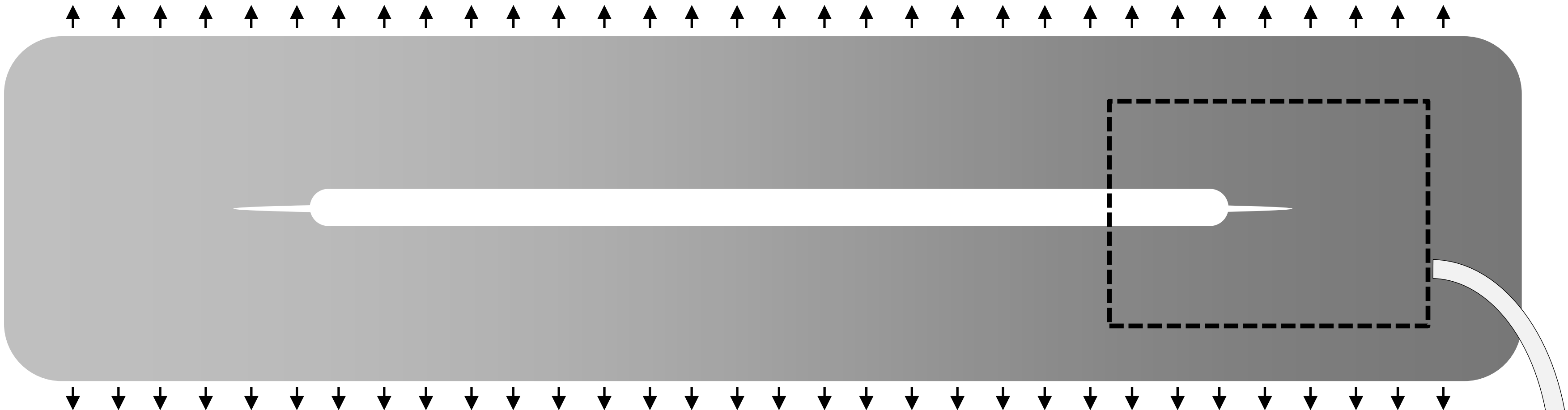
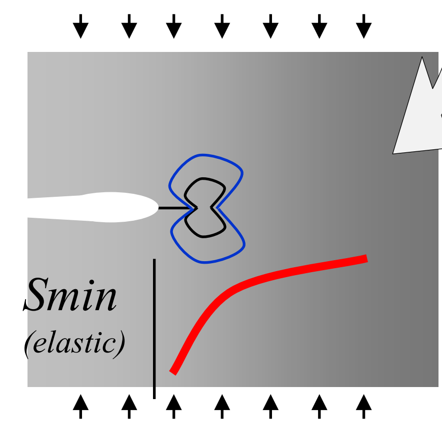
Case #3, -R Crack Growth Test from Sawcut



- A tensile load results in +K which becomes independent of sawcut width as crack grows beyond vicinity of sawcut tip
- A compressive load not only closes the fatigue crack, but loads the (open) sawcut in compression, resulting in a heavy compressive stress concentration near the sawcut tips.
- Because Smin(a)/So is what drives the closure, the compressive acceleration will diminish as the crack grows, even though the global load R-ratio is constant.



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Discussion

- Crack Growth codes often neglect stress level effects, which seems permissible for positive R-ratios, but hampers code performance for negative R-ratios.
- Use of the local elastic $S_{min}(a)/S_0$ in place of R for characterizing negative R-ratio data is more physically correct, and would better characterize this regime.
- A simple implementation of stress level sensitivity has been presented for the negative R-ratio regime only.
- SLS implemented in DARWIN 7.1

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Backup Slides

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SLS Walker Formulation

- In some situations, such as fatigue crack growth in a corrosive environment, plasticity induced closure formulations can fail, even as a surrogate for creating a curve fitting formulation.
- Even then, -K remains aphysical, and SLS must prevail for compressive loading
- Here is an SLS version of the Walker formulation

$$\Delta K_{eff}/\Delta K = \begin{cases} (1 - S_{min}/S_0)^{m^- - 1} & for\ closed\ crack\ at\ min \\ (1 - R)^{m^+ - 1} & for\ R > 0 \end{cases}$$

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