Using Open Source Software to Predict Crack Initiation and Crack Propagation for the F.D.E. Total Fatigue Life Project

Al Conle, Univ. Windsor, Canada

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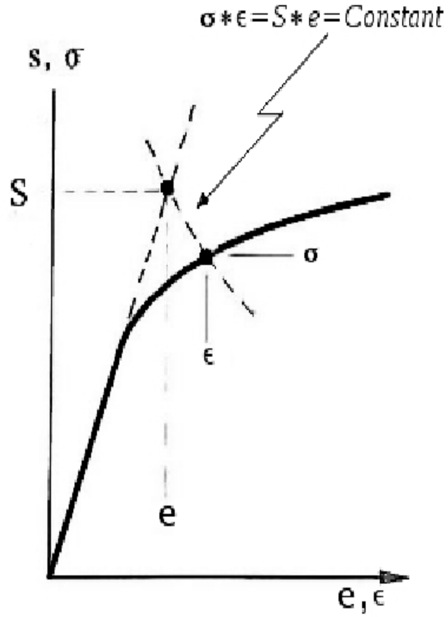
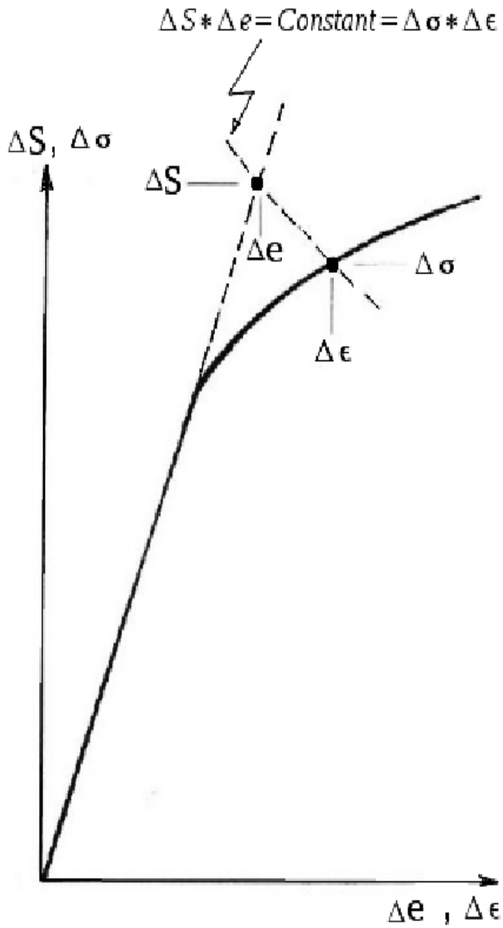
Part 1: Review of Local Stress-Strain loops

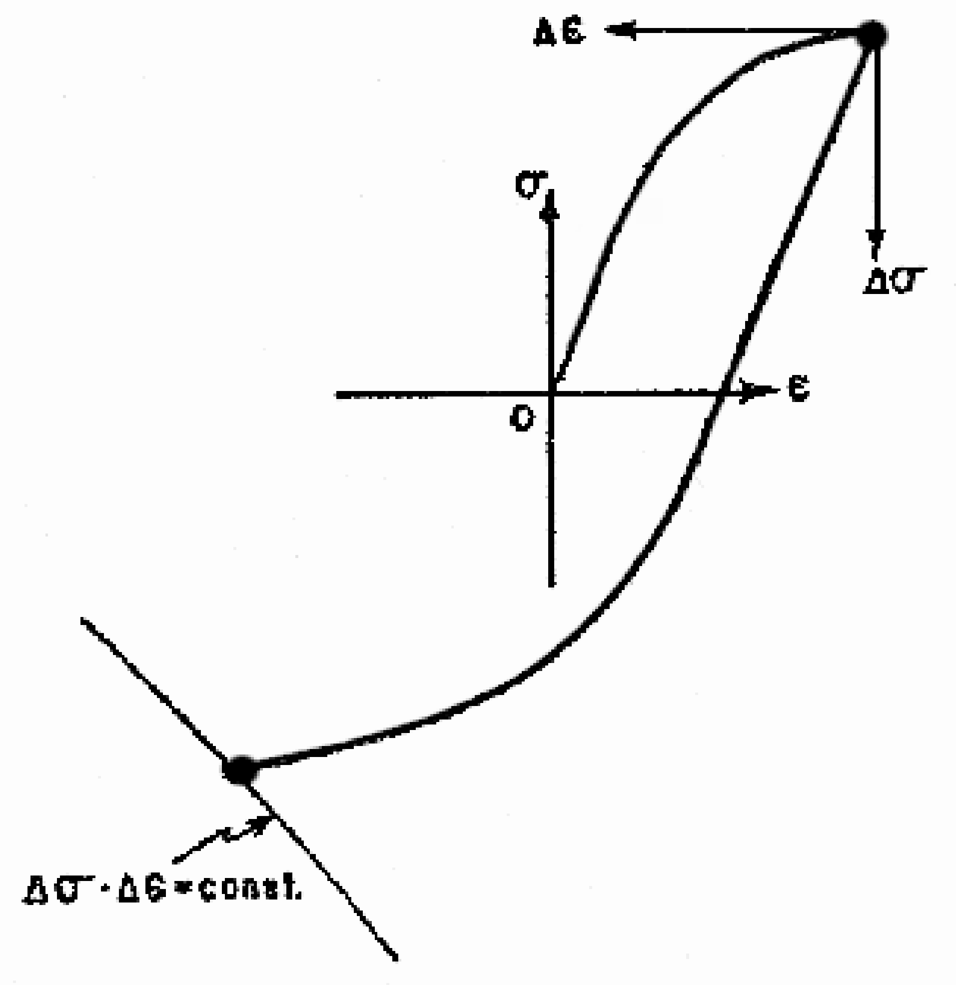
Neuber plasticity correction is used to convert the nominal elastic calculated stresses to local hot-spot stresses and strains. Note difference between first loading curve and subsequent “doubled” shape



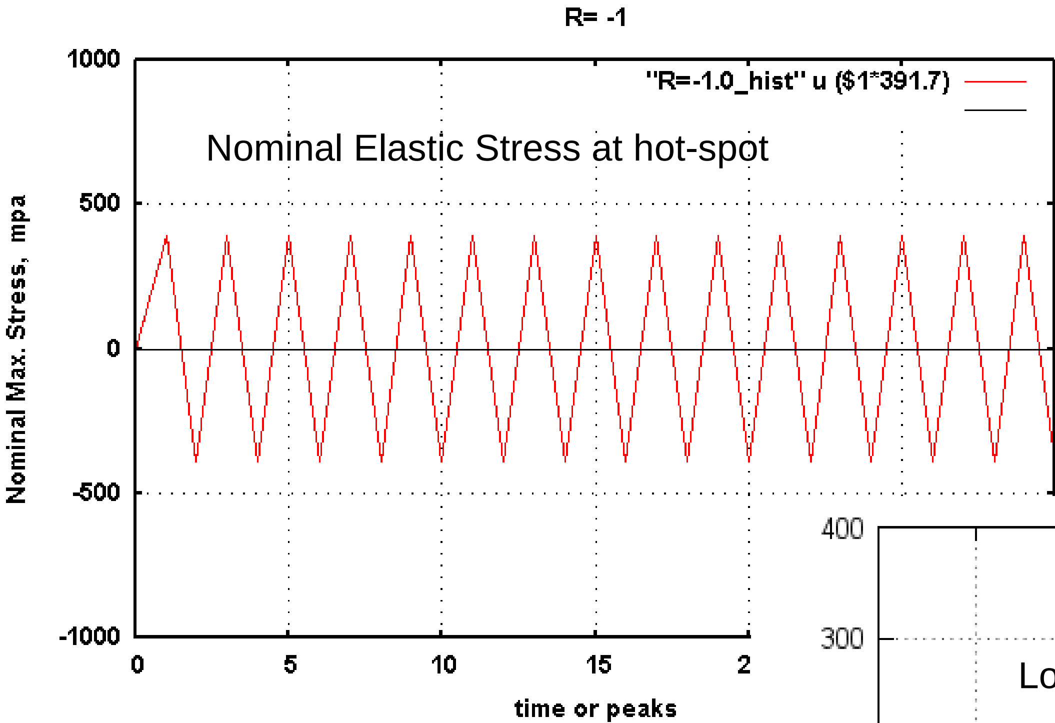


1^{st} Loading shape
(cyclic Stress-Strain curve)

Subsequent shape
(doubled)

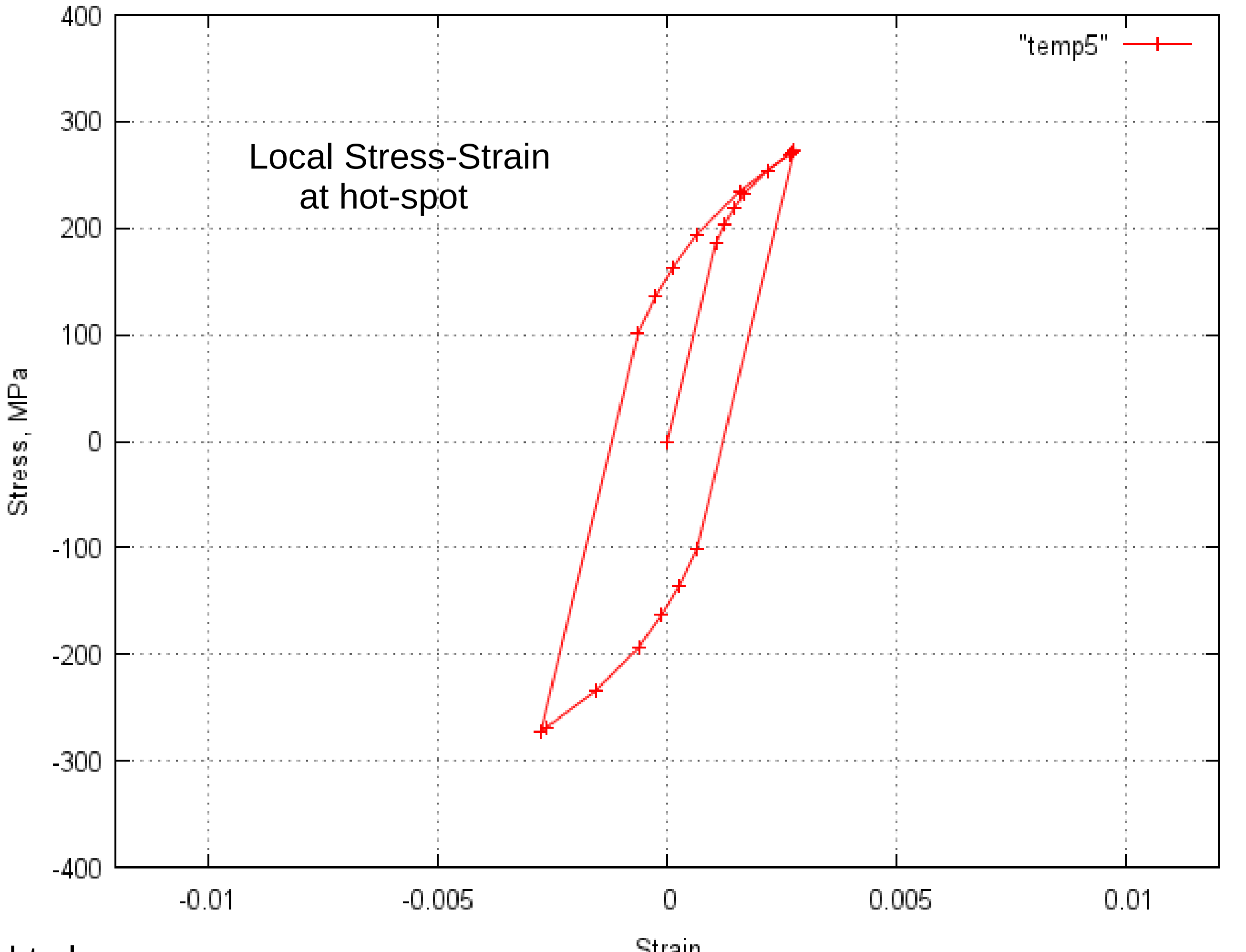


Further information:
http://fde.uwaterloo.ca/Fde/Notches.new/neuber.html



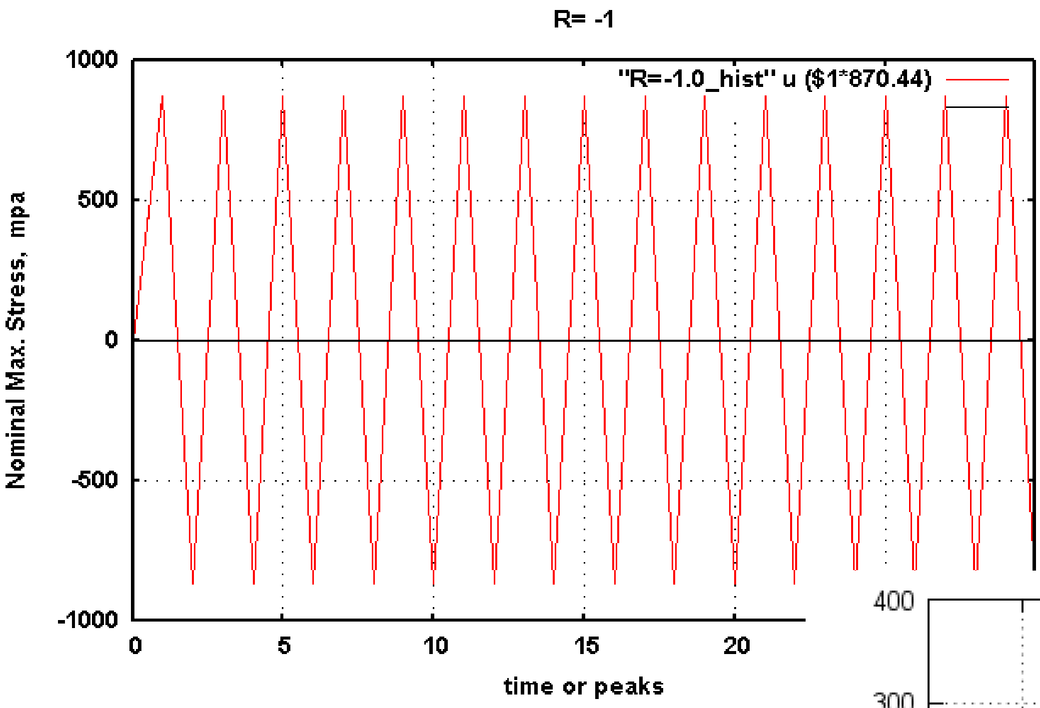
E.g.: 10.8kN R= -1 test, Kt= 1.784

A fully reversed (Zero mean) nominal loading will result in a Zero mean plasticity corrected local hysteresis loop

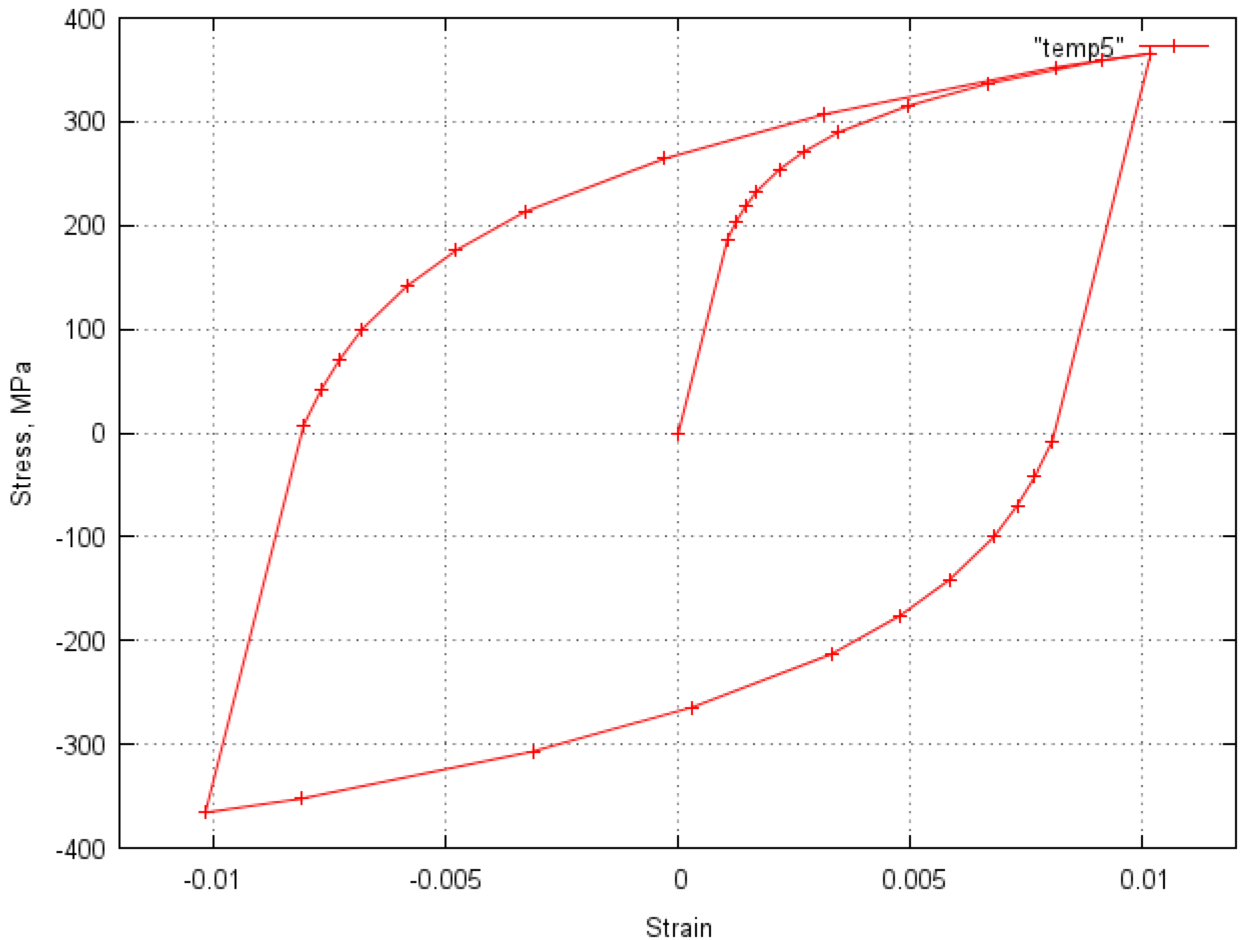


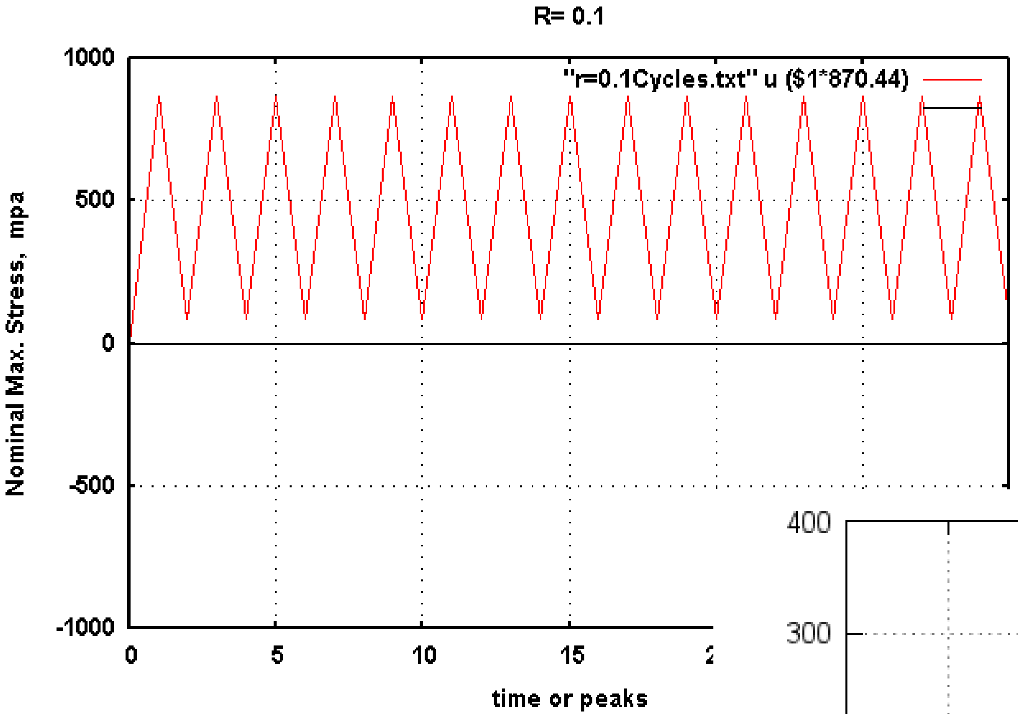
Open Source Crack Initiation software used:

http://fde.uwaterloo.ca/Fde/Calcs/saefcalc2.html



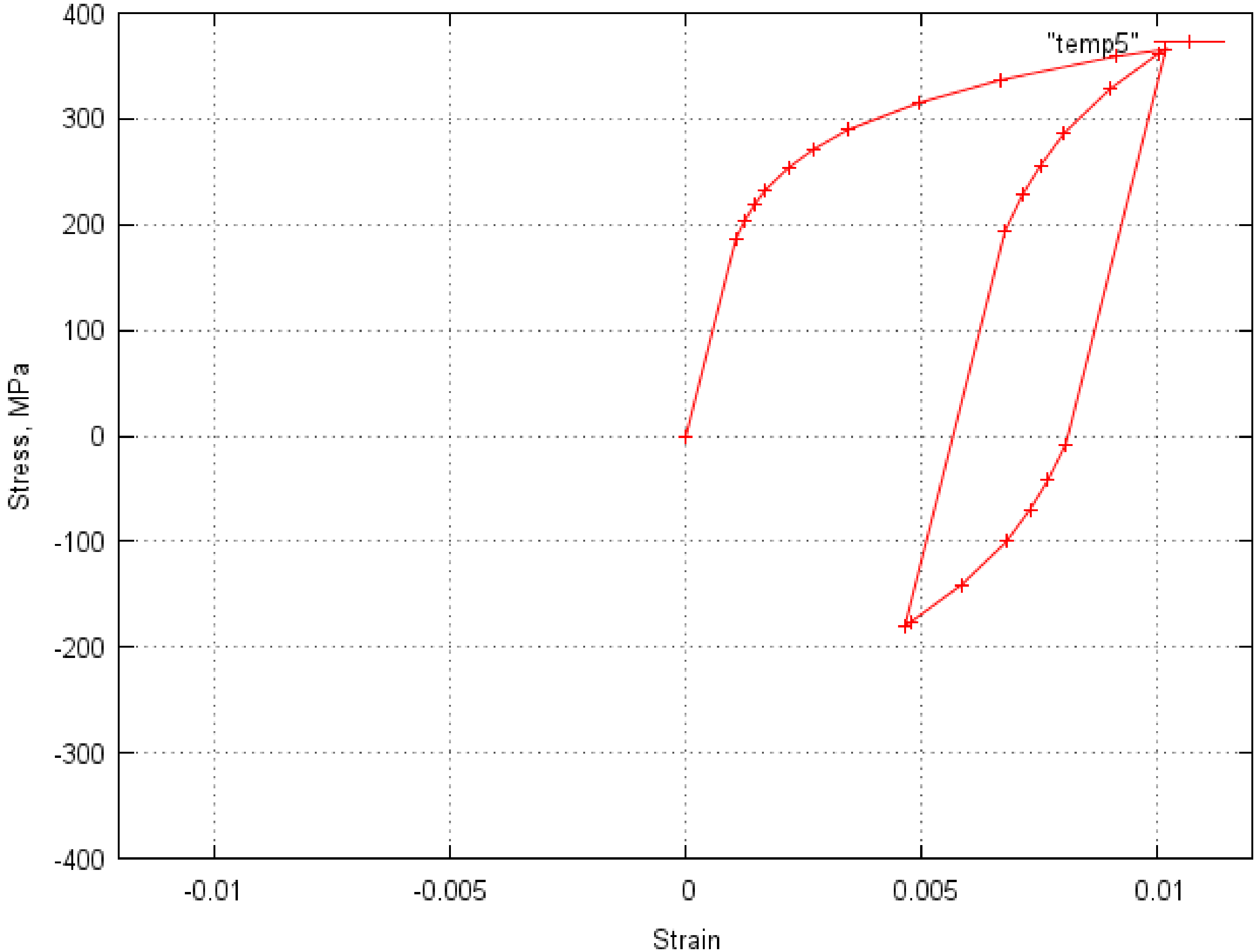
Similar simulation for what would be a +/- 24kN test. (Sim. only no test was done at this level)





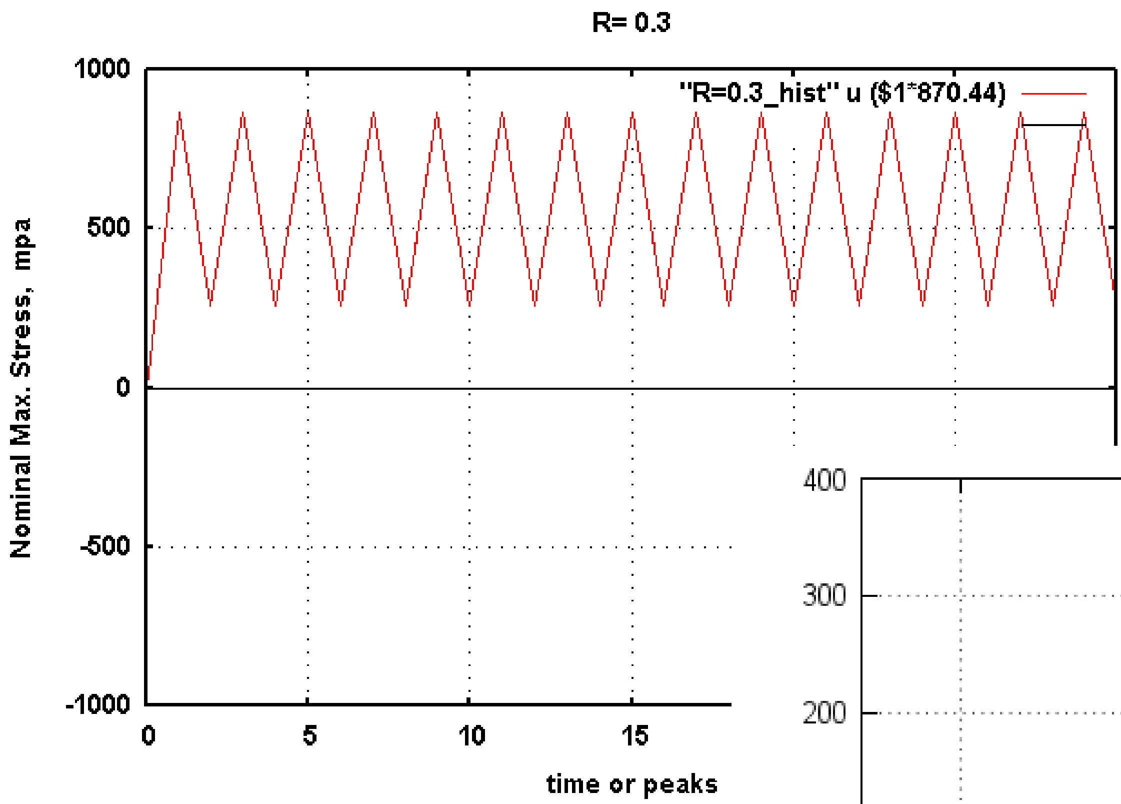
24kN test R= 0.1

Nominal stress history and simulated local hysteresis loops using Kt= 1.784

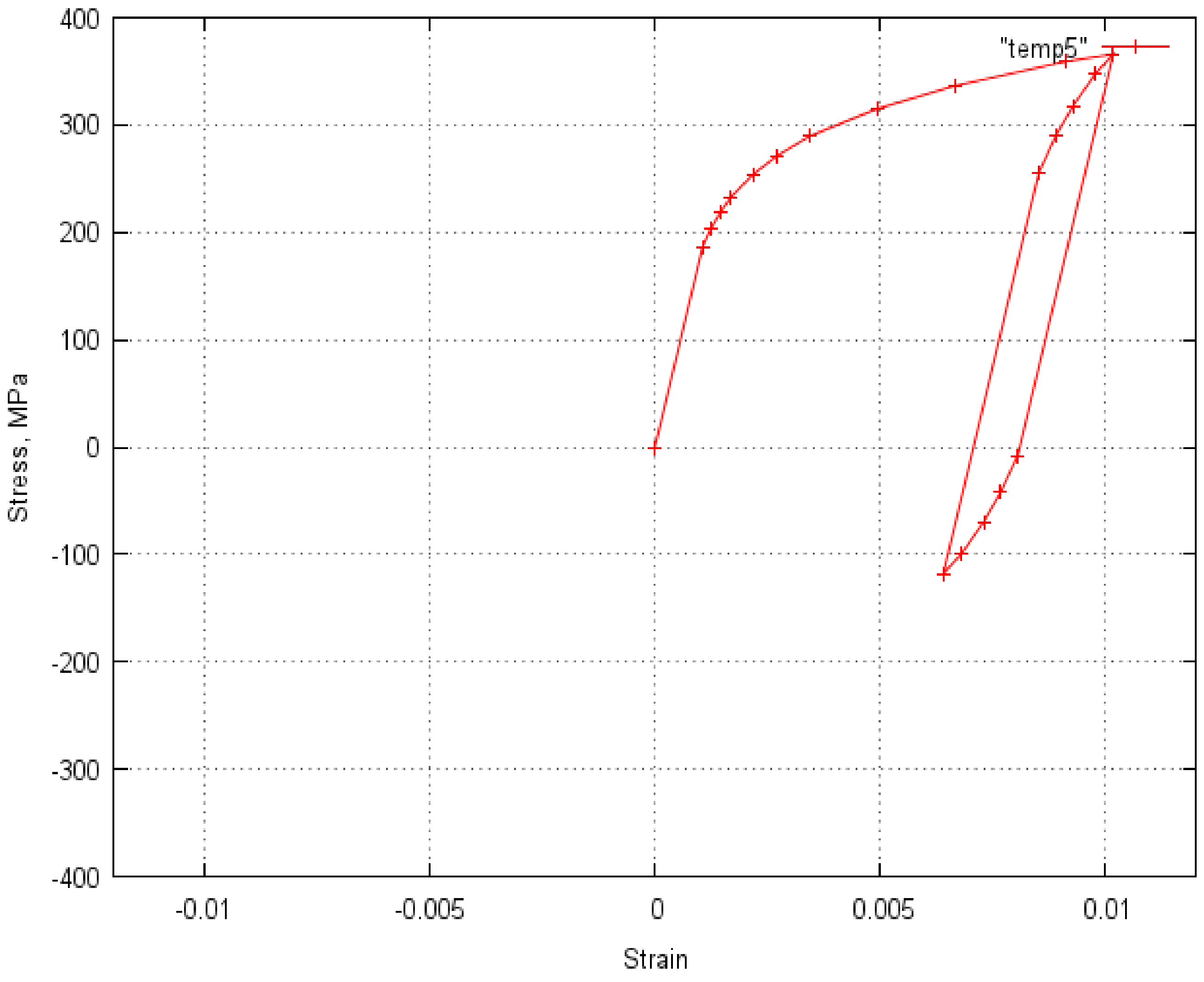


Note that the non-zero mean loading results in a cyclic loop that has a mean stress. This mean stress may wash out during the life due to cyclic mean stress relaxation

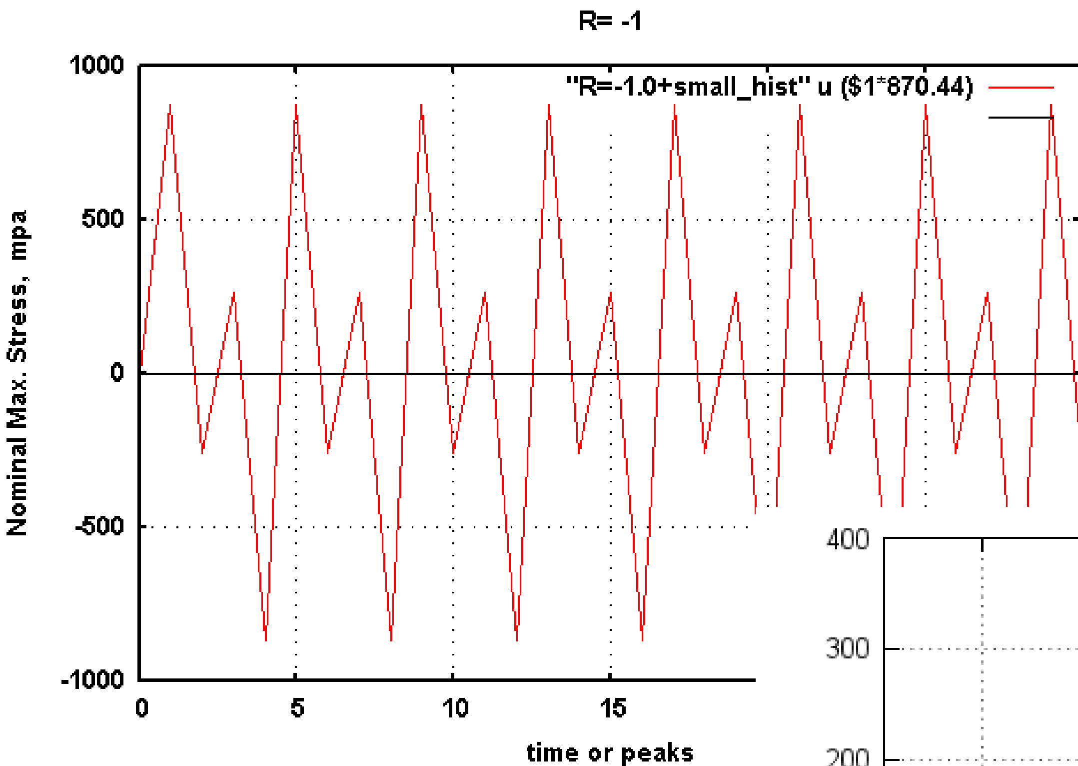
24kN test at R= 0.3



Nominal stress history and simulated local hysteresis loops using Kt= 1.784

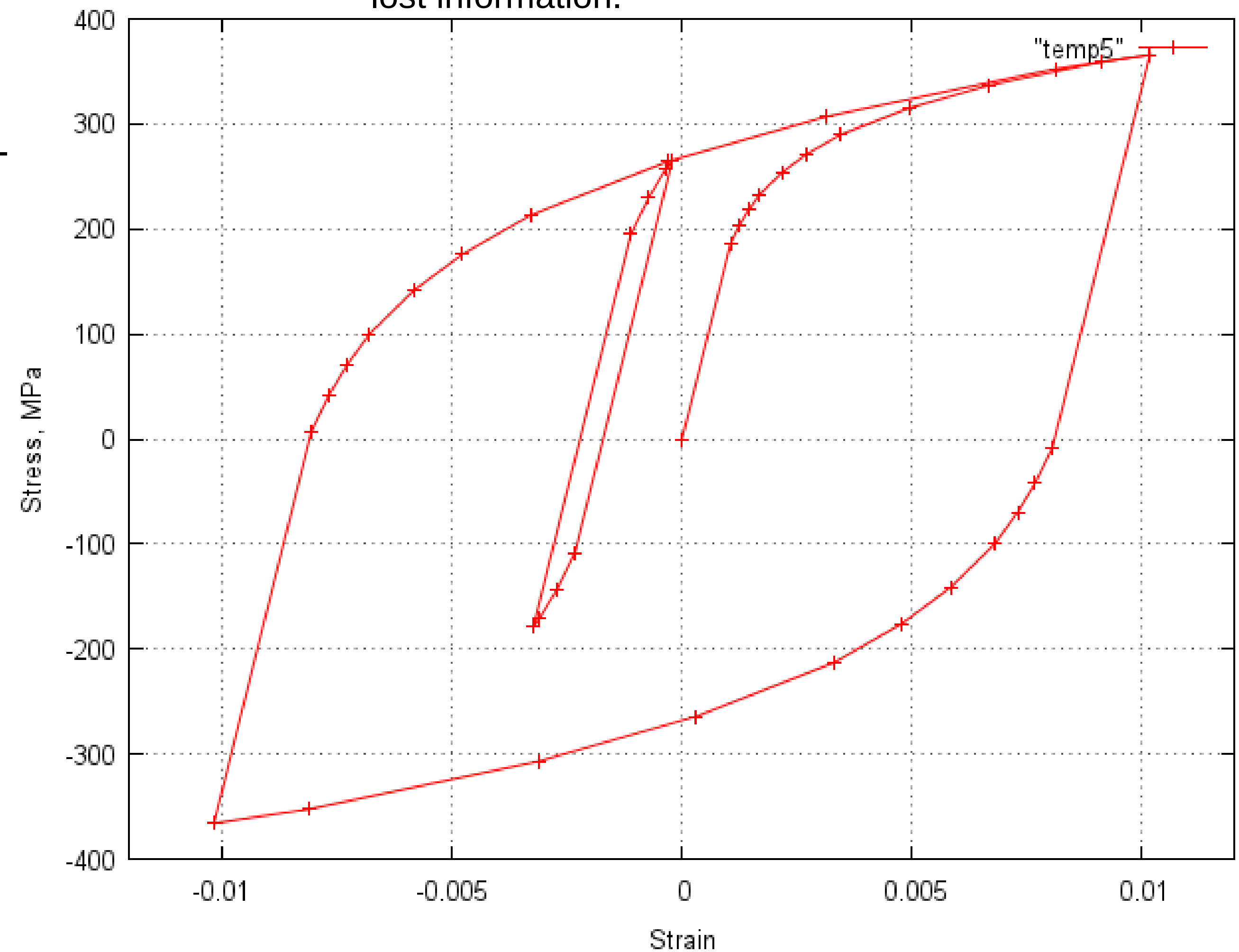


Again the initially induce mean stress in the cyclic loop may or may not wash out with cycling

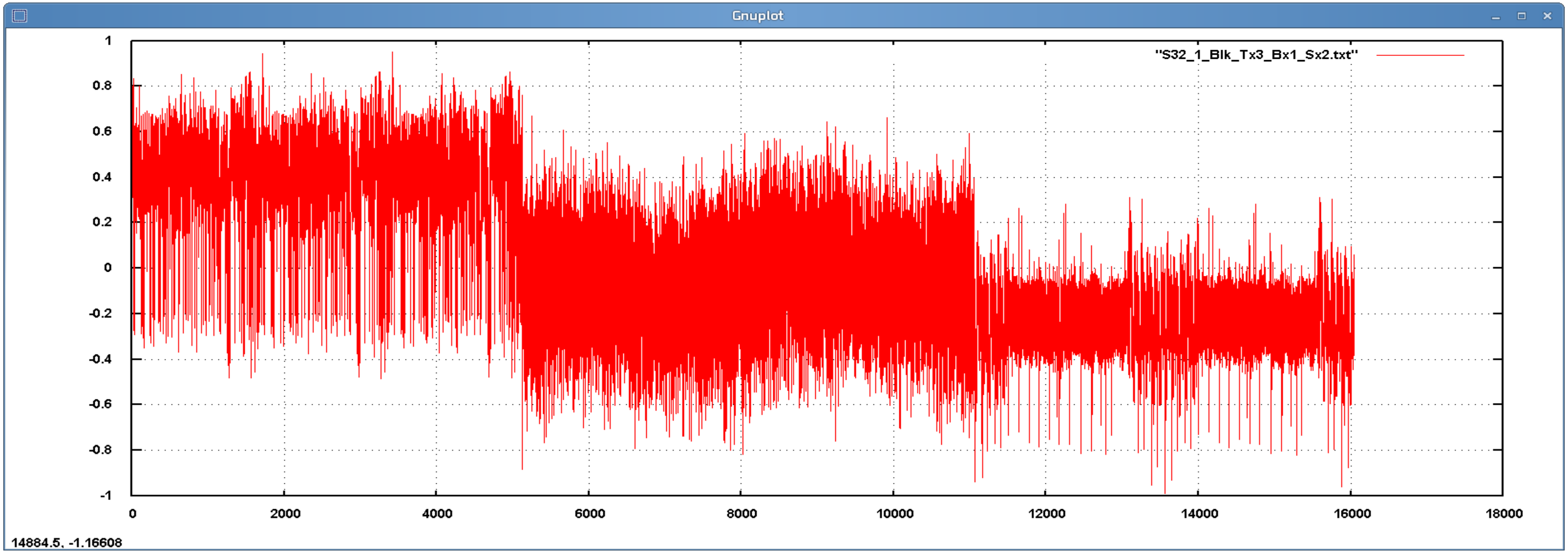


Simulation only: 24kN R= -1.0 with small cycle inserted in history in each unloading half-cycle

Local loops are determined by Rainflow cycle counting the Nominal history. Loops are then positioned within the largest overall loop.
This is due to a flaw in Rainflow counting: Range and mean are correct but position within other loops is lost information.

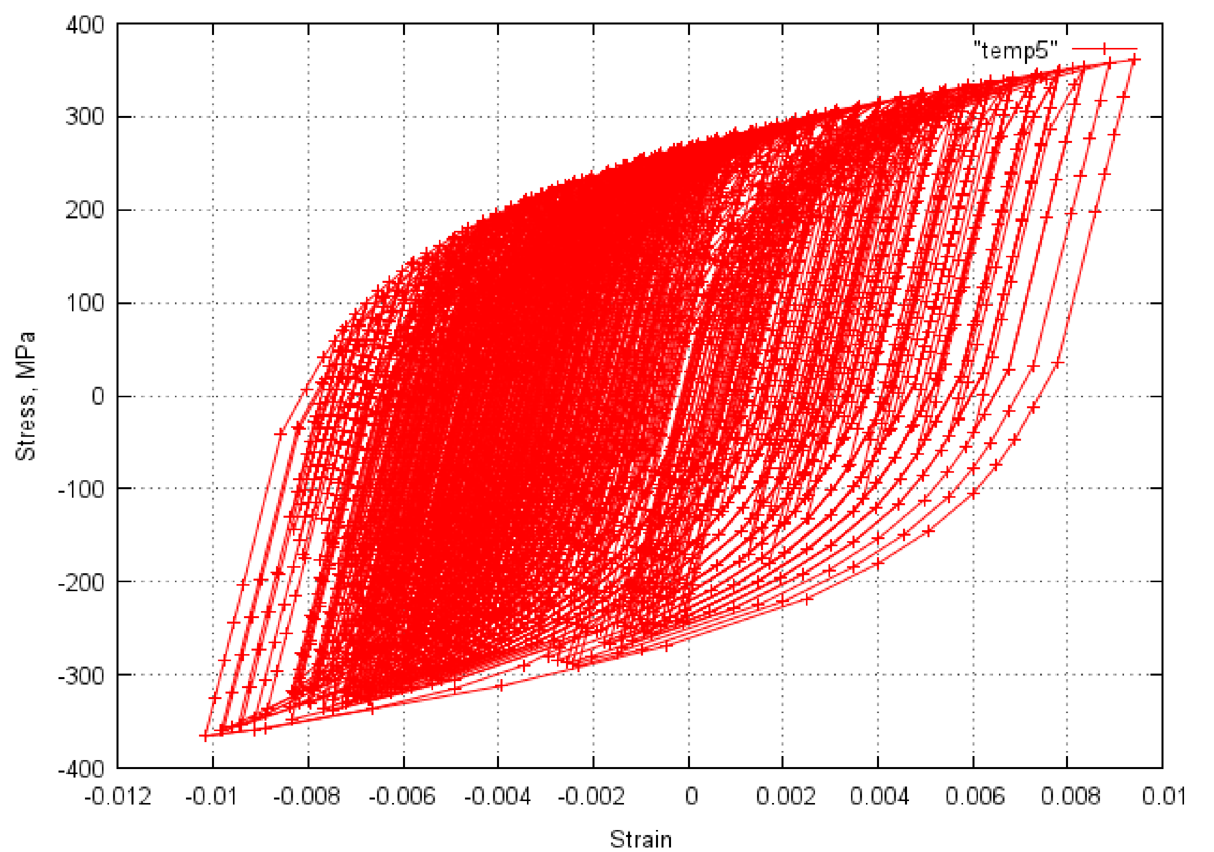


Most crack initiation simulation software programs make a similar assumption. It is conservative.

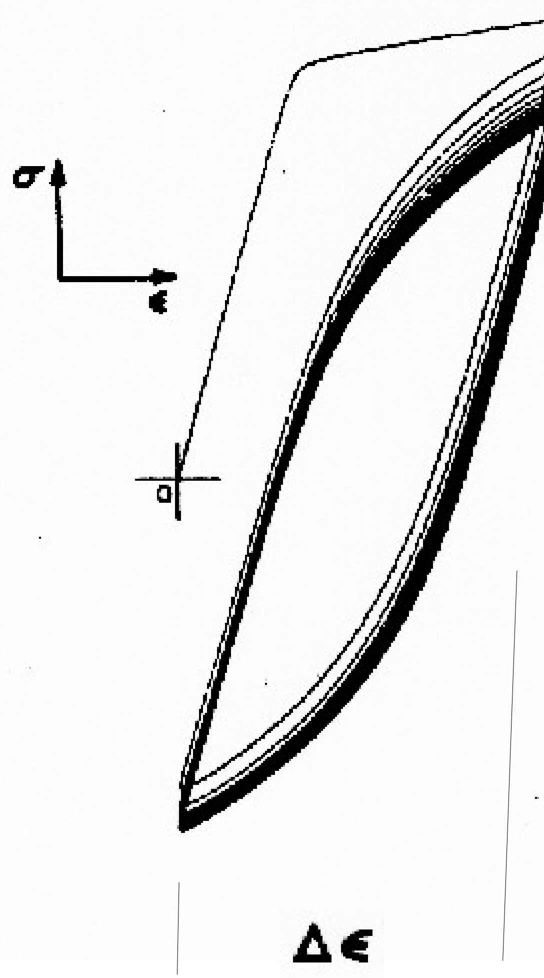


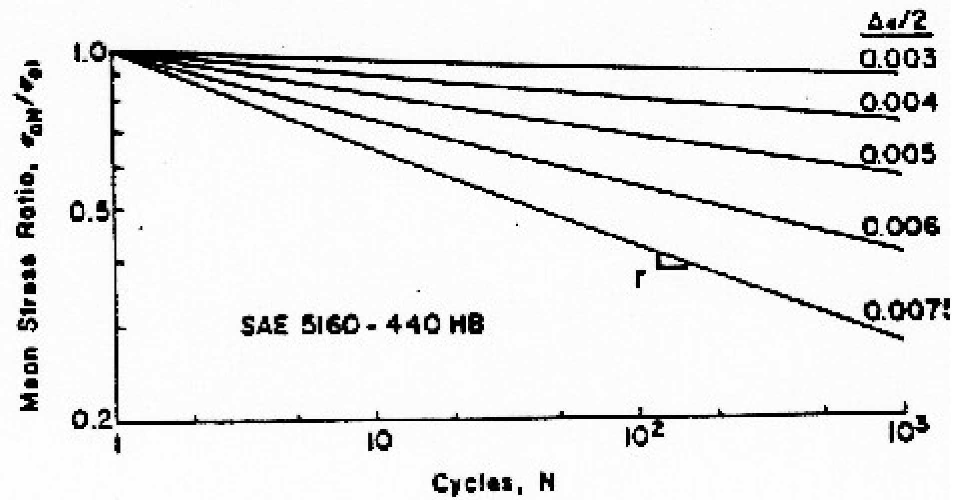
Nominal and local behavior for the 24kN Variable Amplitude test. Note that in the local simulation all small loops are attached to the tensile half cycle of the largest loop.

Also note that the overall plasticity of the local loop is very large.



Cyclic Stress Relaxation





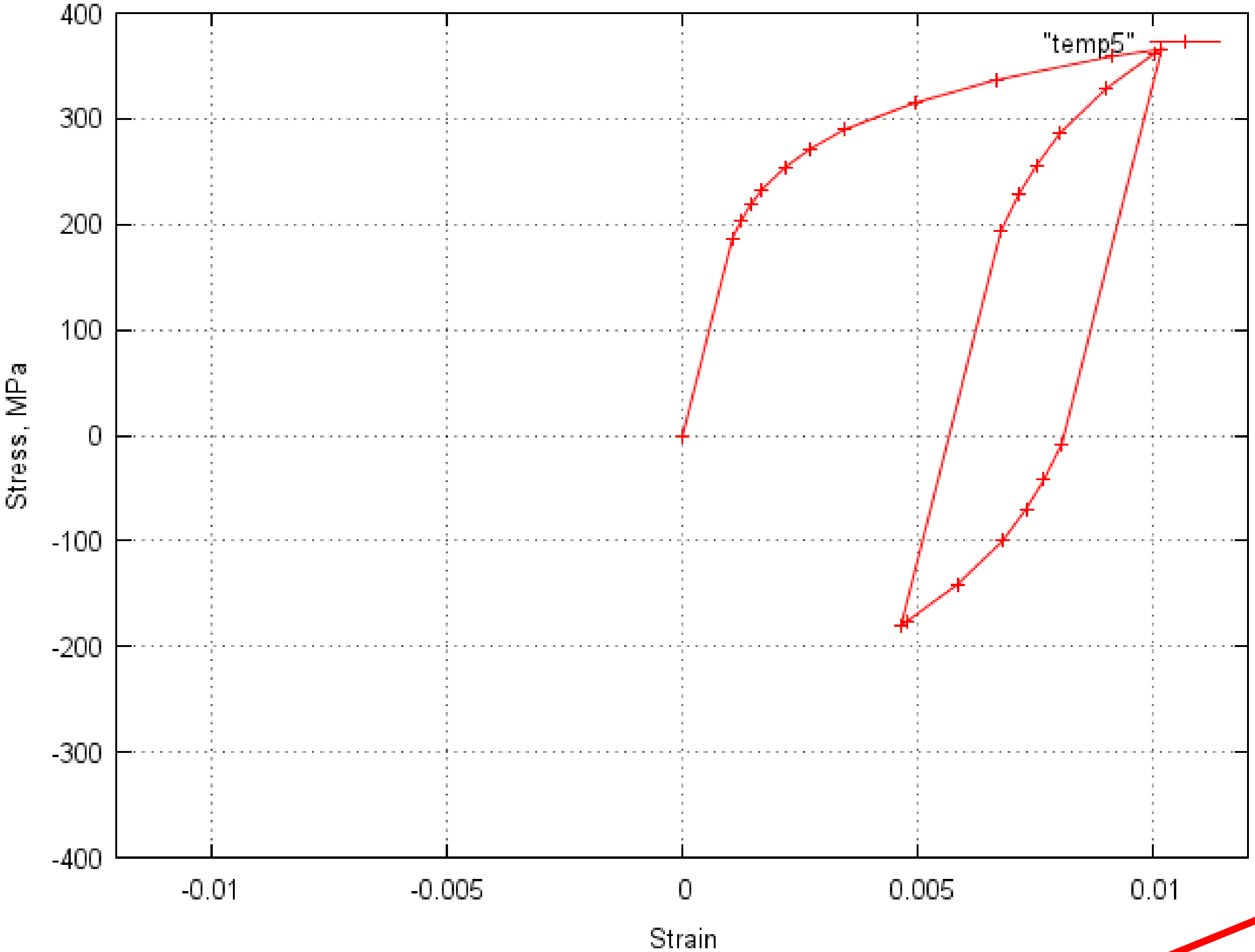
$$\sigma_{oN} = \sigma_{o1}(N)^{r}$$

- σ_{o1} — Mean stress, 1st cycle
- σ_{oN} — Mean stress, Nth cycle

$r = f(HB, \Delta\epsilon)$

Ref.:   R.W. Landgraf

Constant Amplitude Life Simulations:



R= 0.1 (24kN test)

Kt = 1.784 gives

Smax = 870.4 nominal elastic
Smin = 87.0

Note the Strain Range of loop is about 0.5%
(Used in next slide)

Prediction if mean stress does NOT relax

Initiation Predictions for various damage parameters:

StrainLife_Reps	SWaT_Life_Reps	StressLife_Reps	Morrow_Reps	Goodman_Reps
46743.2	24218.0	46743.2	12378.3	4589.0

Prediction if mean stress relaxes

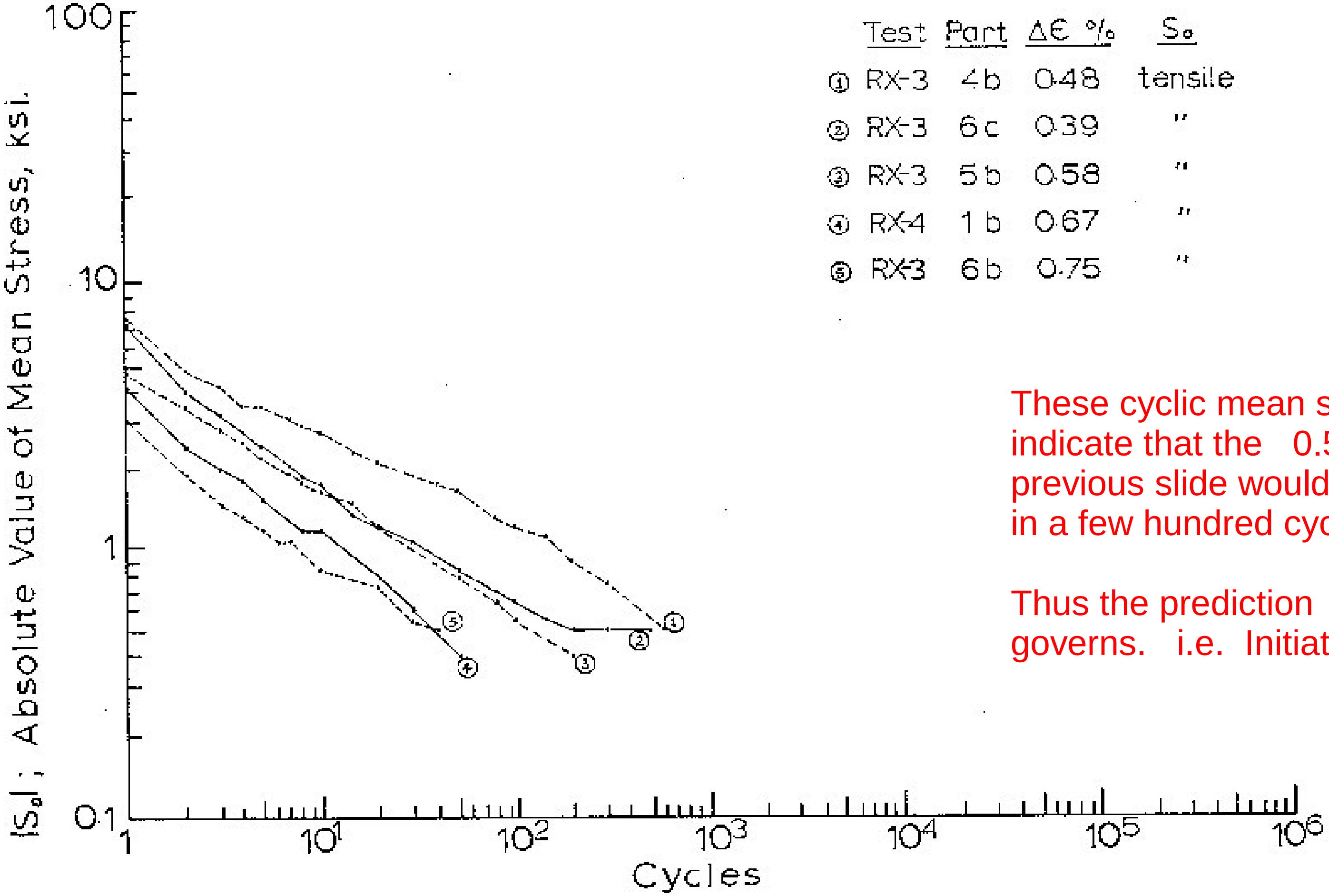


Fig.7 Absolute Value of Mean Stress vs. Cycles for several Intermediate Secondary Strain Ranges.

These cyclic mean stress relaxation plots indicate that the 0.5% strain range test in previous slide would lose its mean stress in a few hundred cycles.

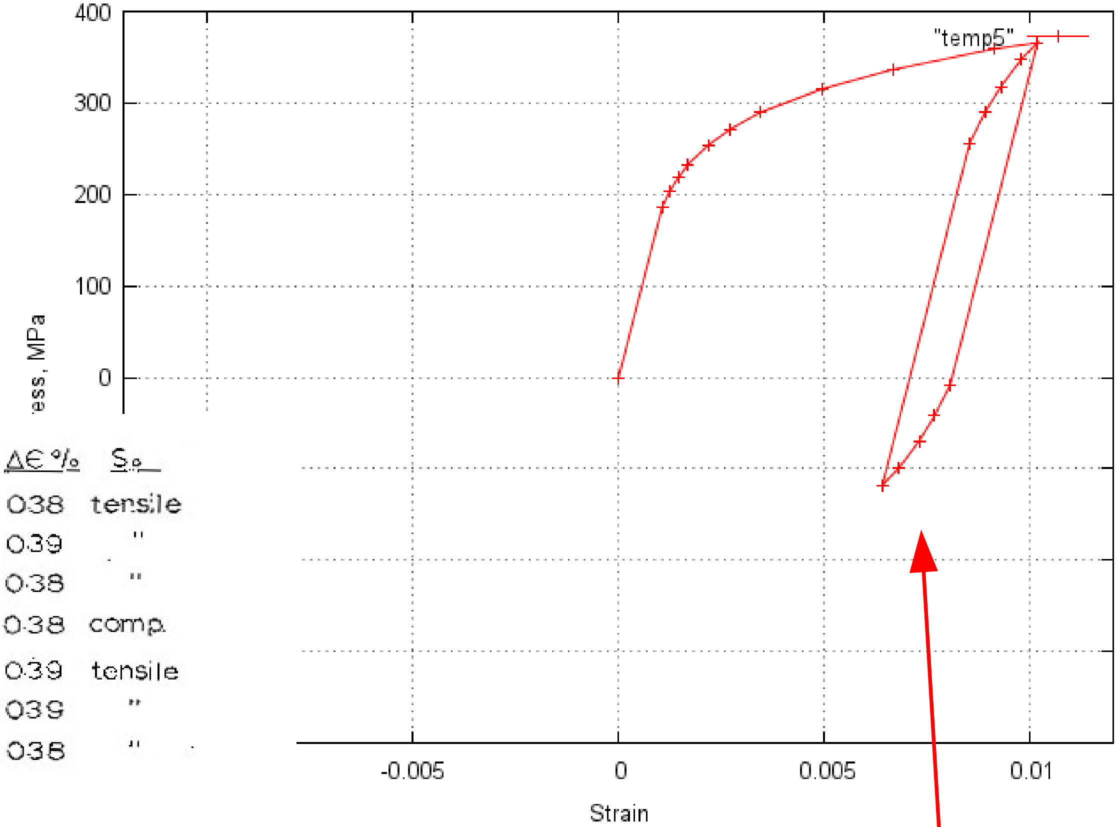
Thus the prediction without mean stress governs. i.e. Initiation Life = 46743 cycles

More Cyclic Mean Stress Relaxation information for low carbon steel is available here:

http://fde.uwaterloo.ca/Fde/Articles/Relax/conleSo.html

R= 0.3   (24kN test)

Kt = 1.784 gives
Smax = 870.4 nominal elastic
Smin = 261



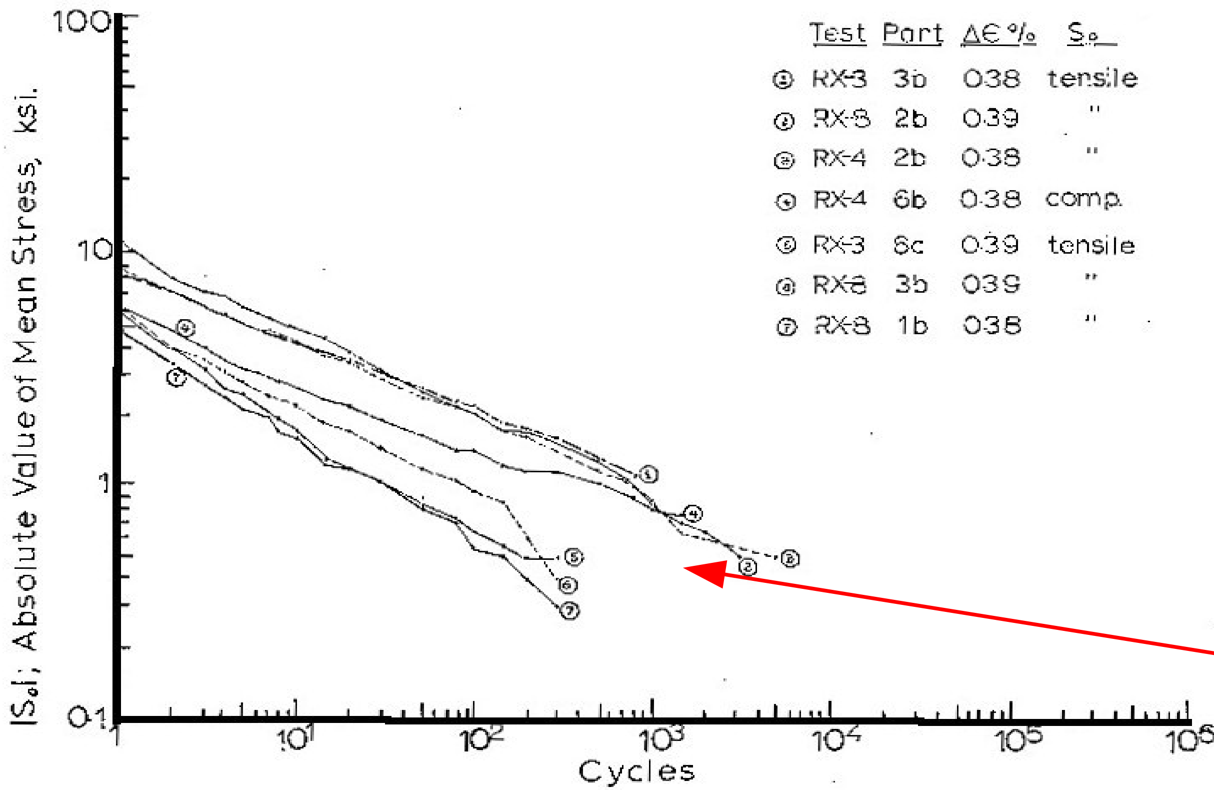


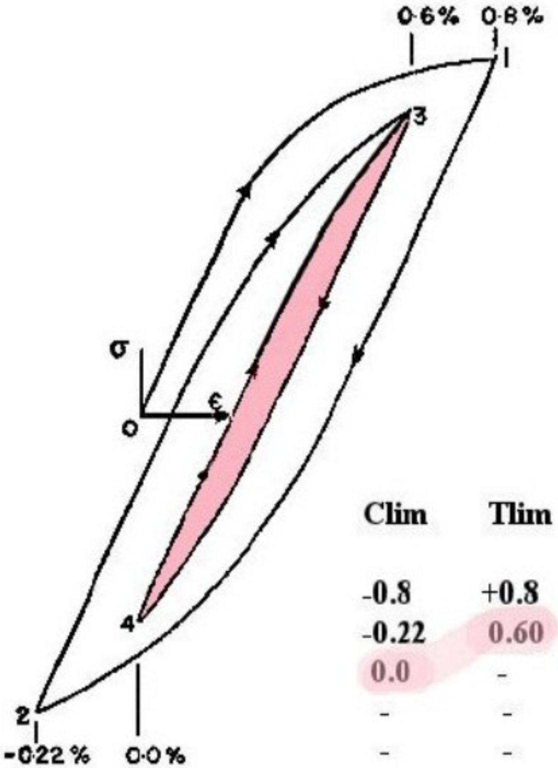
Fig.6 Absolute Value of Mean Stress vs. Cycles at Secondary Strain Range $\Delta\epsilon_s \cong 0.4$ %

Similarly: The local loop's strain range of 0.38%
is expected to wash out the mean stress in about 1000 cycles.

Thus use the no mean stress prediction.

StrainLife_Reps	SWaT_Life_Reps	StressLife_Reps	Morrow_Reps	Goodman_Reps
167399.8	57674.3	167399.6	27832.1	6709.1

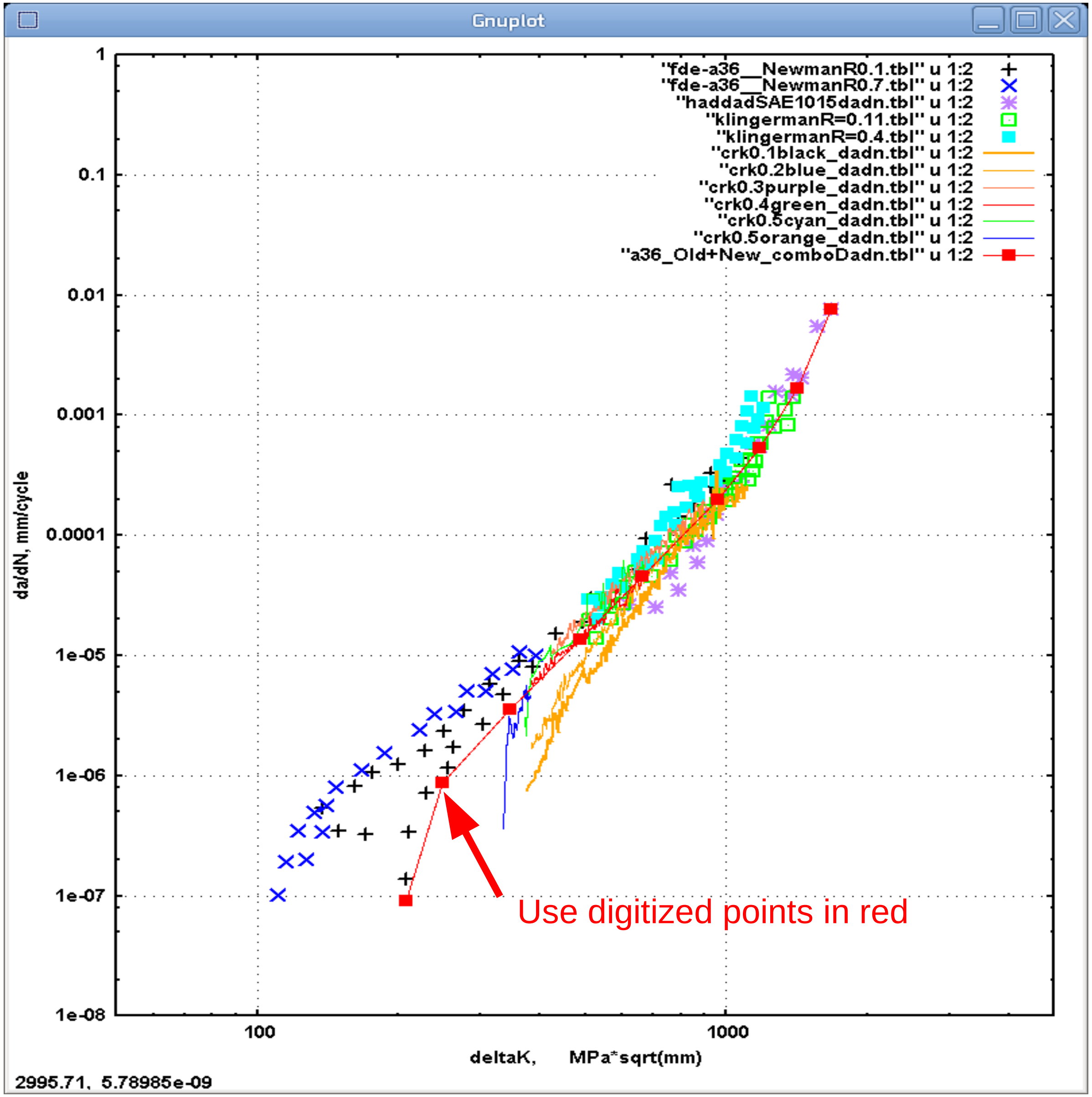
Crack Propagation: Use BS7910- 2005 Cycle by cycle simulation with Material Memory Effect compensation but No mean stress corrections



Clim	Tlim
-0.8	+0.8
-0.22	0.60
0.0	-
-	-
-	-

When a limit is hit, the latest entry in both Tlim and Clim define the closed hysteresis loop.

Both limits are removed and the loop is "counted"

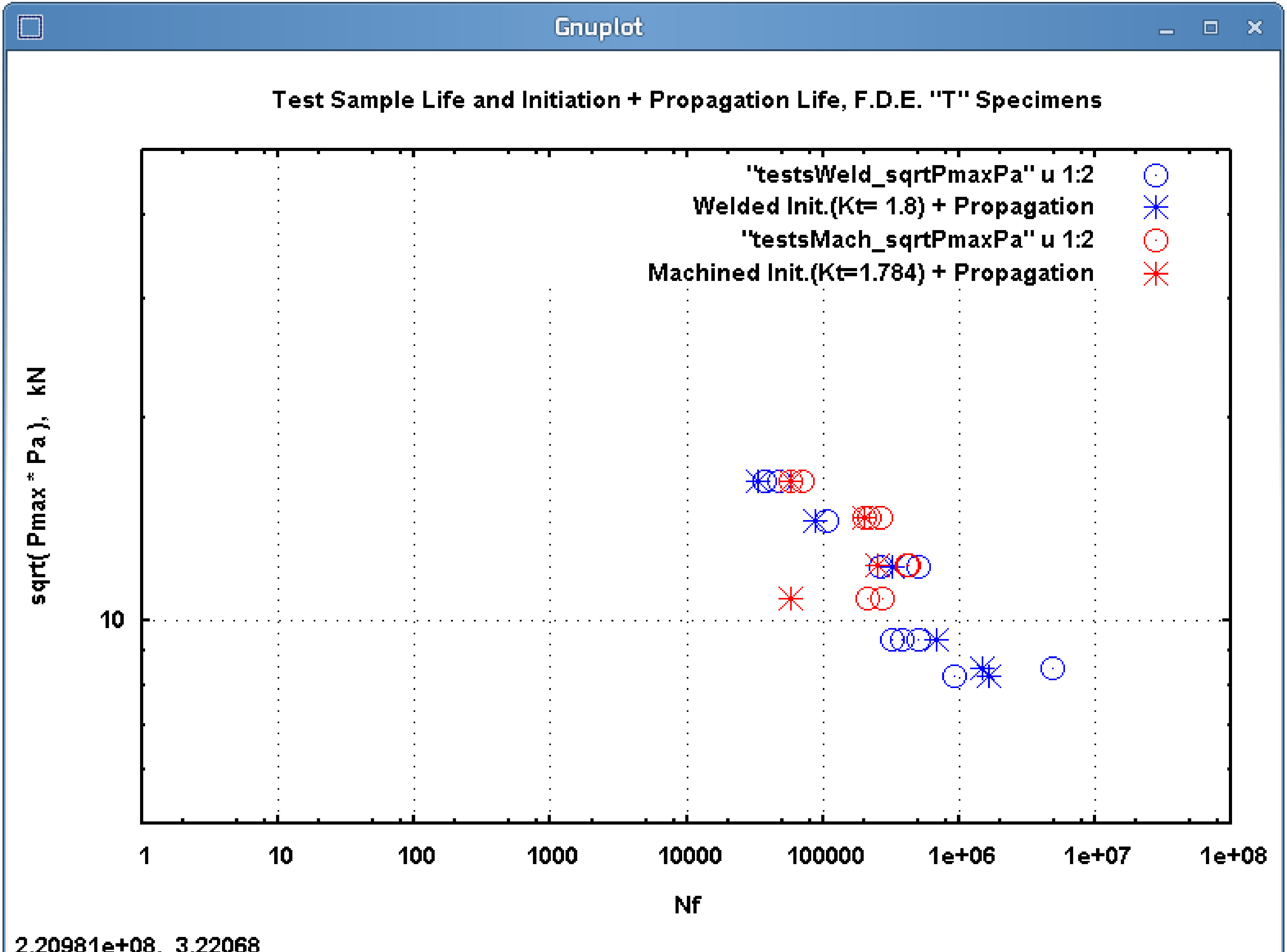


For more information on software:

http://fde.uwaterloo.ca/Fde/Crackgrowth/fdeSpringPres2013_published.pdf

Table for Constant Amplitude Results (Machined T bar Specimens)

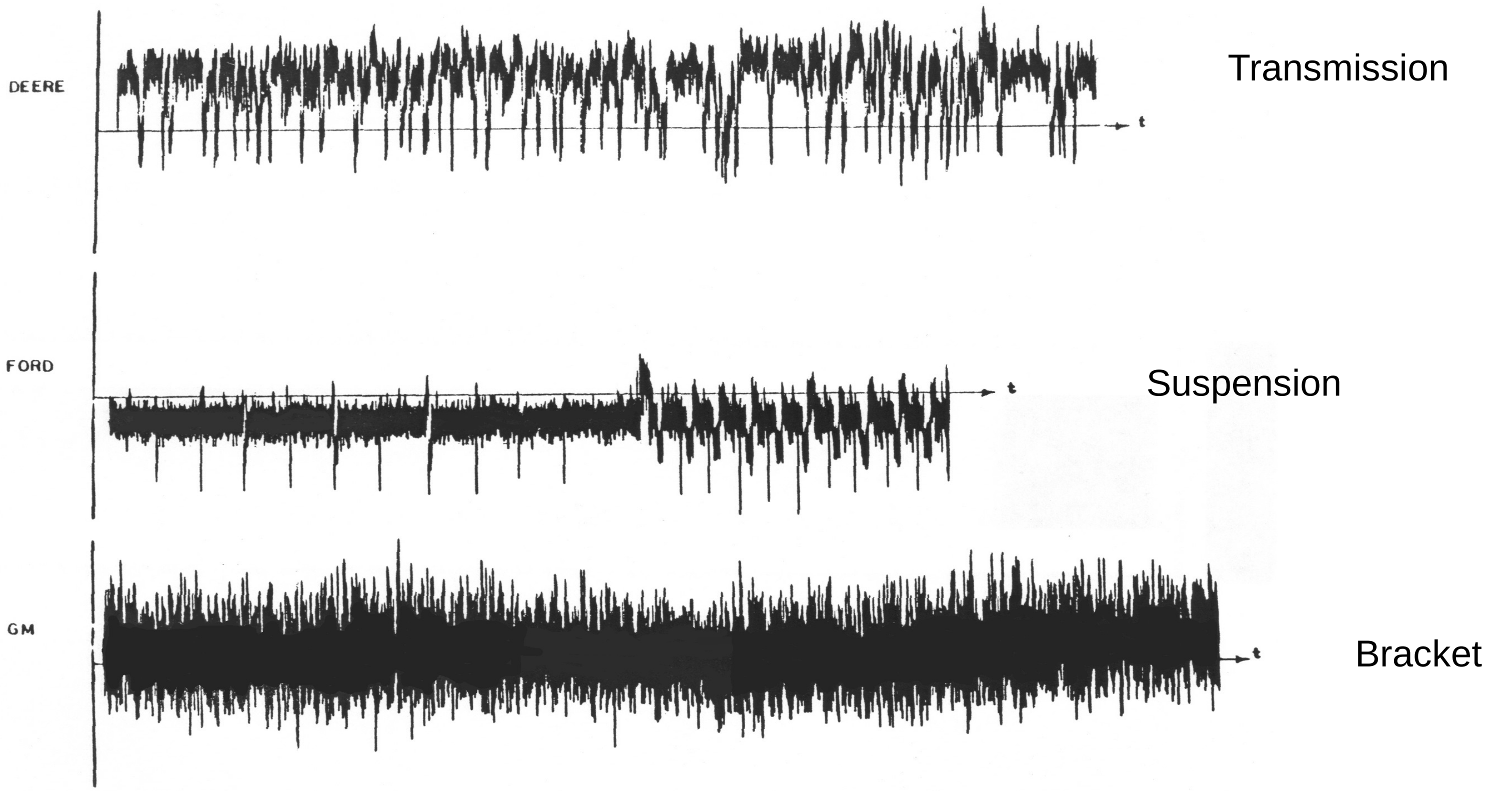
		24kN R=0.3	24kN R=0.1	10.8kN R=1	18kN R=0.1
Bending Stress (without Kt)	max	488.0	488.0	219.6	366.0
	min	146.4	48.8	-219.6	36.6
Nominal stress with Kt=1.784	Smax	870.4	870.4	391.8	652.9
	Smin	261.1	87.0	- 391.8	65.3
Initiation Life					
With No Relax (SWT)		57,674	24,234	46,778	83,189
With Relax (Strain Life)		167,399	46,780	46,788	204,242
Crack Propagation a0= 0.5mm c0= 4.0					
Half Ellipse Surf. crack		1	1	2	1
followed by Full width crack a0= 0.5mm		33,300	10,300	10,692	43,960
Total Life		200,700	57,080	57,470	248,202
Test Life Mid Range		233,000	64,000	243,000	418,000



Gnuplot
Test Sample Life and Initiation + Propagation Life, F.D.E. "T" Specimens
"testsWeld_sqrtPmaxPa" u 1:2
Welded Init.(Kt= 1.8) + Propagation
"testsMach_sqrtPmaxPa" u 1:2
Machined Init.(Kt=1.784) + Propagation
sqrt(Pmax * Pa), kN
10
1
10
100
1000
10000
100000
1e+06
1e+07
1e+08
Nf
2.20981e+08, 3.22068

Part 3: Variable Amplitude Simulations: Tests used FDE Keyhole specimen histories

1. Periodic Overstrain Effect on “Strain” life data.



Introduction: A number of fatigue design codes now recognize that in variable amplitude fatigue loading, that the small cycles, normally below the fatigue limit, cause damage due to the presence of the larger cycles. See: e.g. Eurocode 9, IIW code

For example if one subjects axial samples in strain control to repeated blocks of the Suspension history the results for the complete history are shown here.

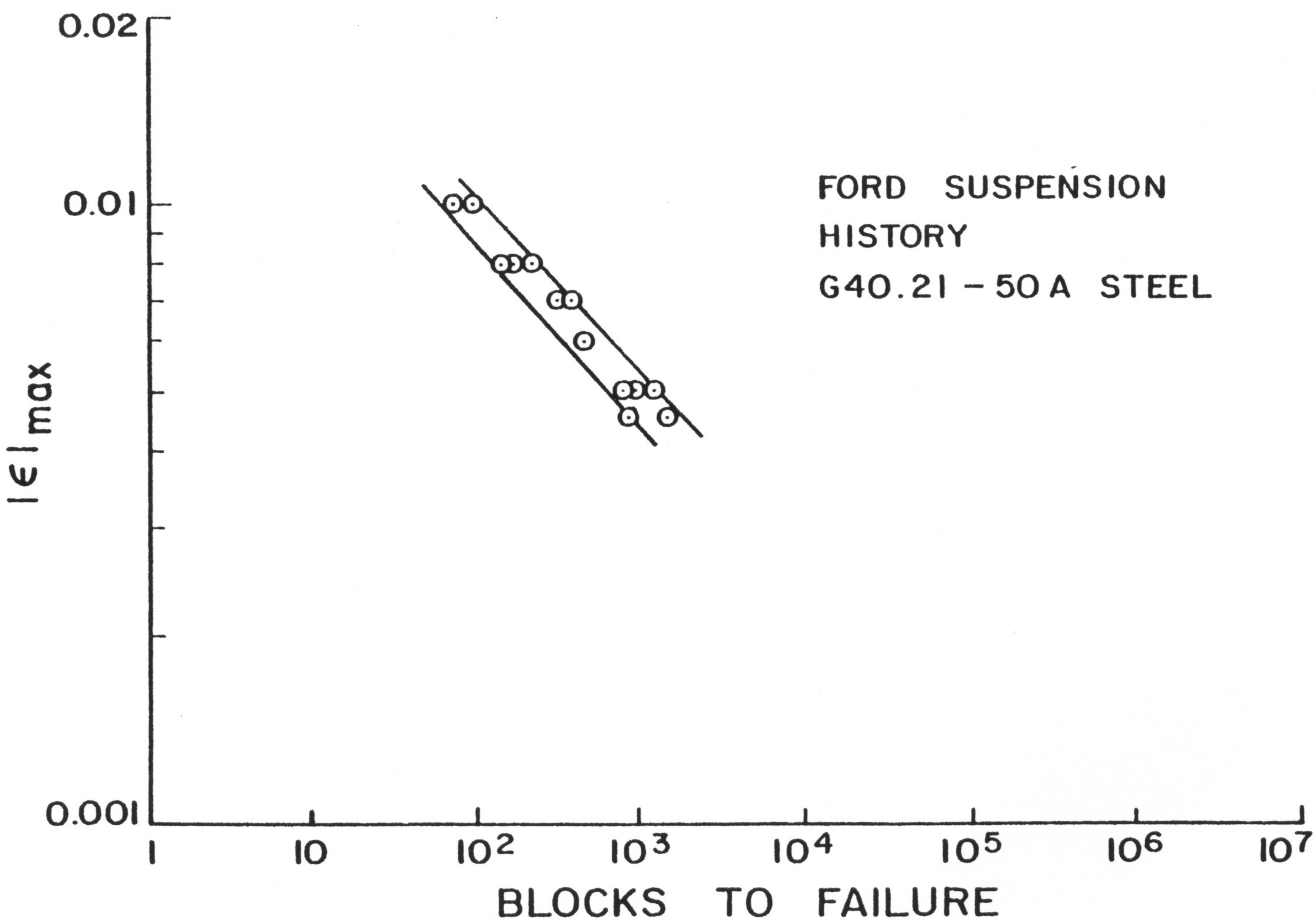


Fig. 32 Variable Amplitude Fatigue Life Results

When one then removes sets of small cycles below the fatigue limit and tests specimens with this shortened history the new blocks to failure increases. The increase must be due to the cycles removed; thus one can calculate a fatigue damage or equivalent constant amplitude life for the small cycles.

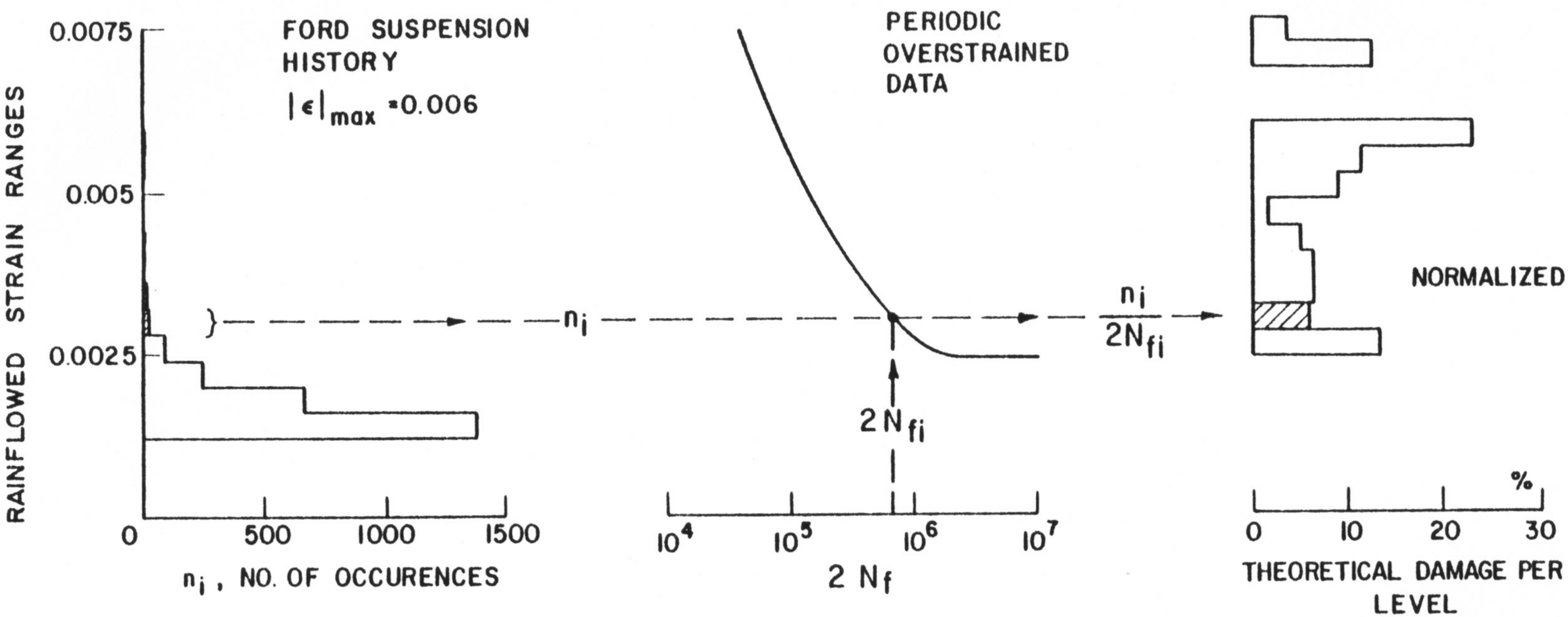


Fig. 35 Computation of Theoretical Damage Per Level Histogram: G40.21-50A Steel

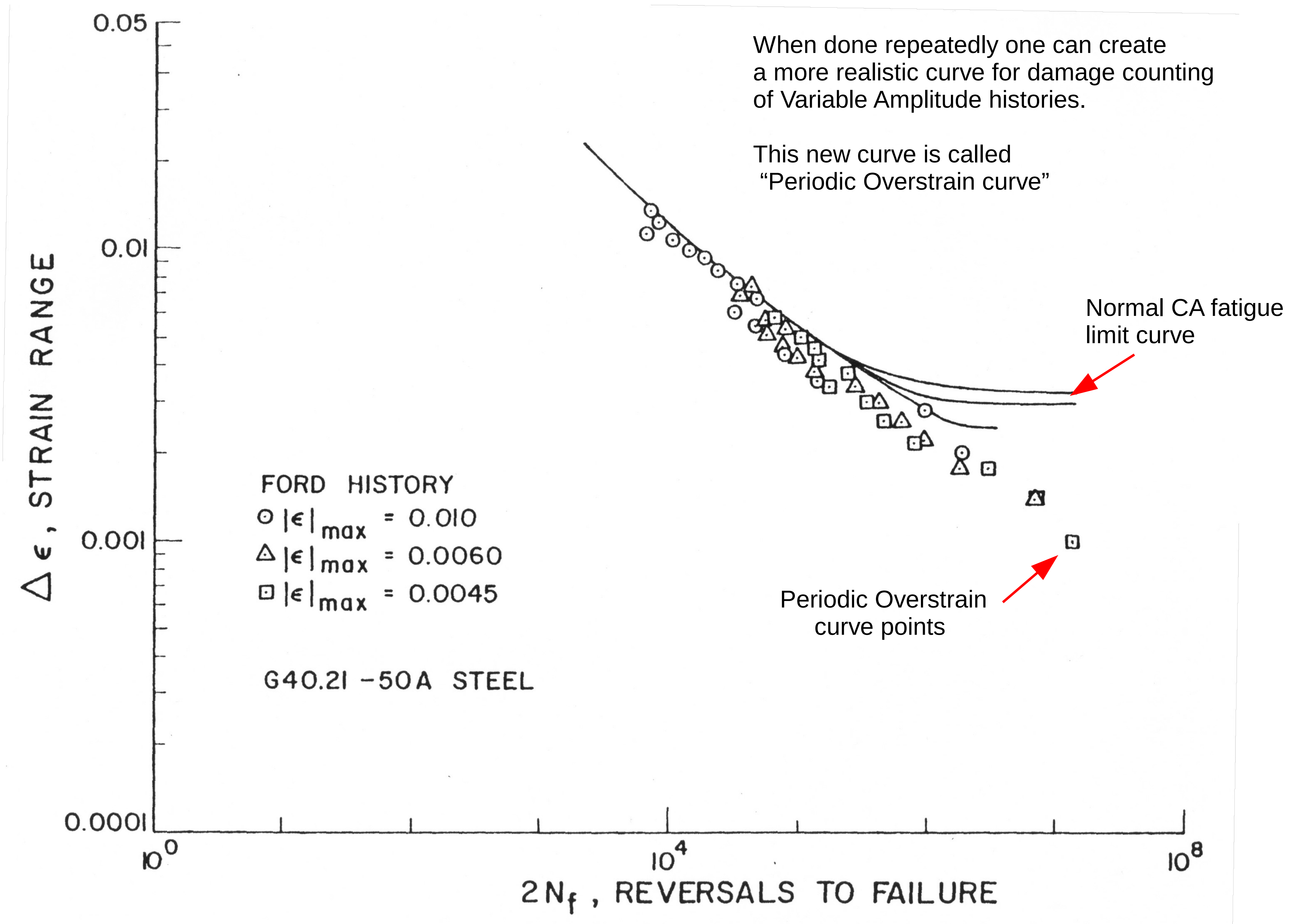


Fig. 39 Computed Strain Life Data Based on Ford Omission Tests Compared to Fig. 6 Data (Solid Lines)

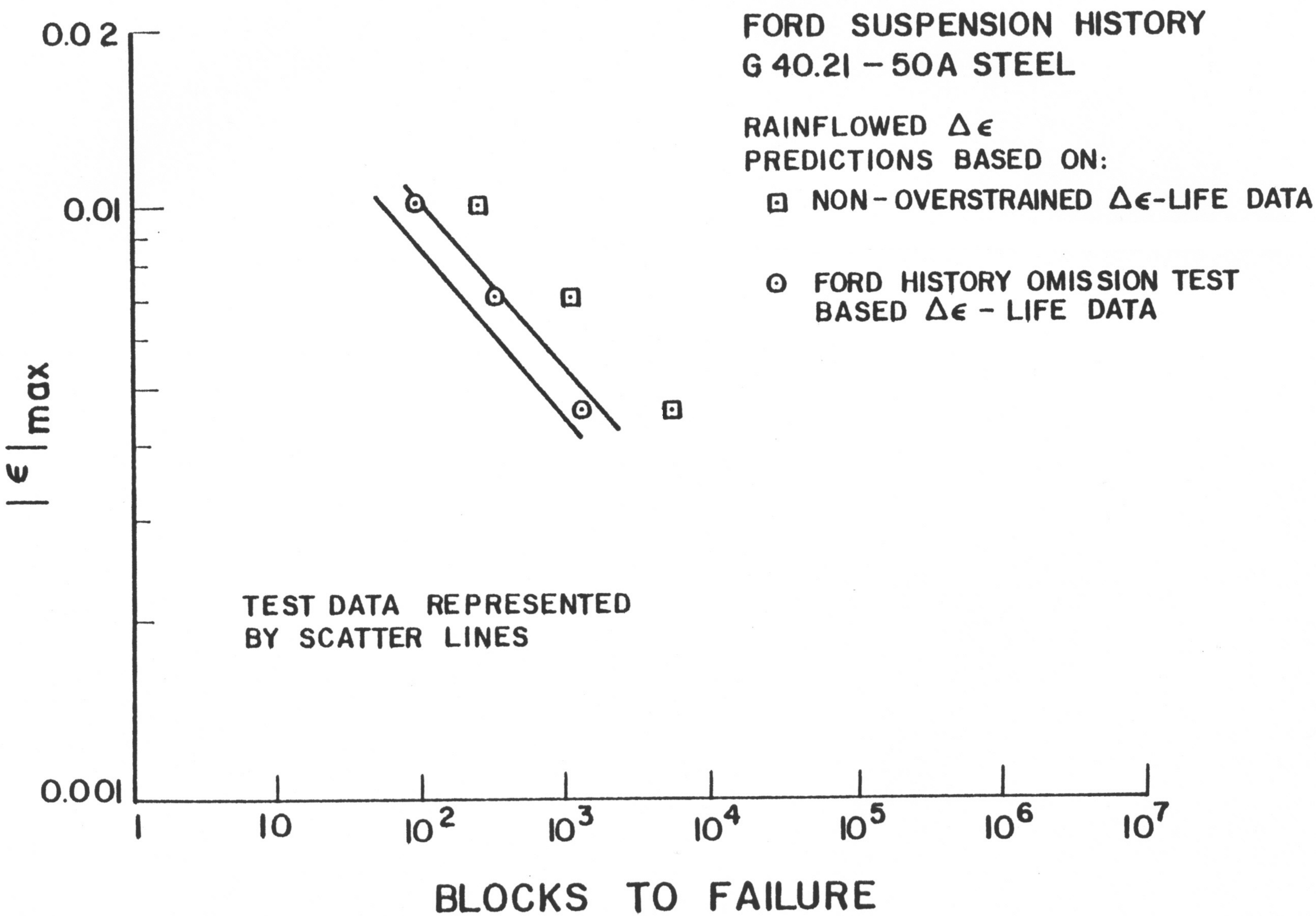
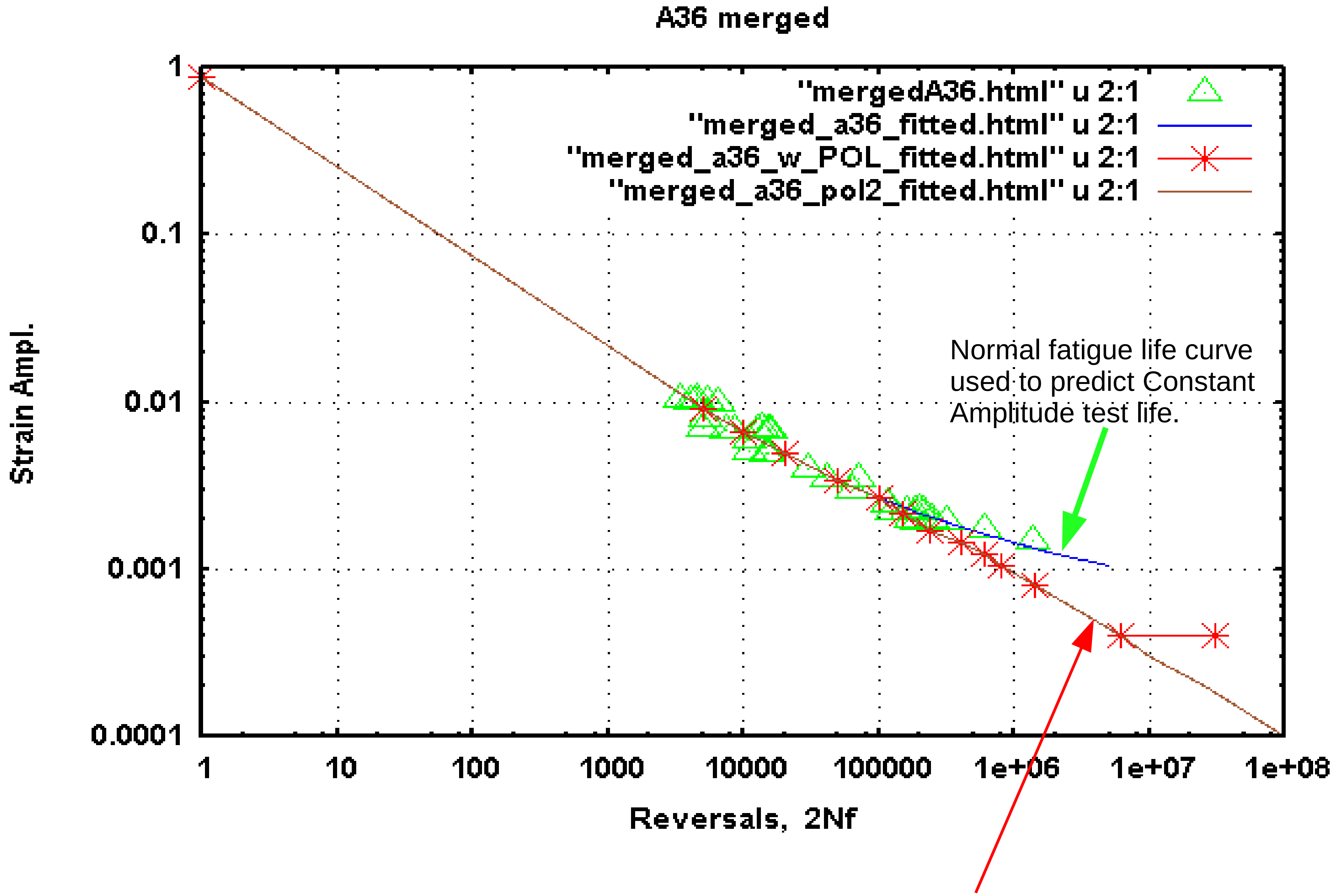
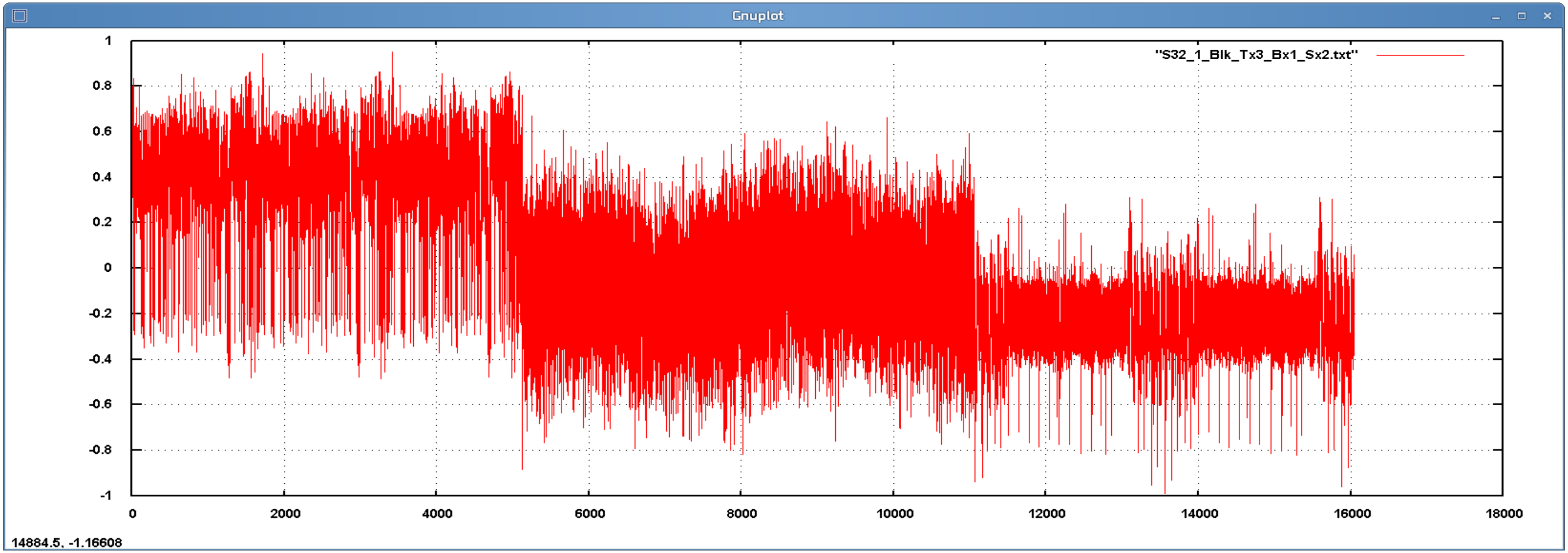


Fig. 41 Comparison of Actual and Predicted Variable Amplitude Test Lives

From experience with a number of materials it has been found that the periodic overload effect drops the Constant Amplitude fatigue limit to about 50%.



In this study the periodic overstrain curve assumed was used to predict crack initiation life for the Variable Amplitude tests.



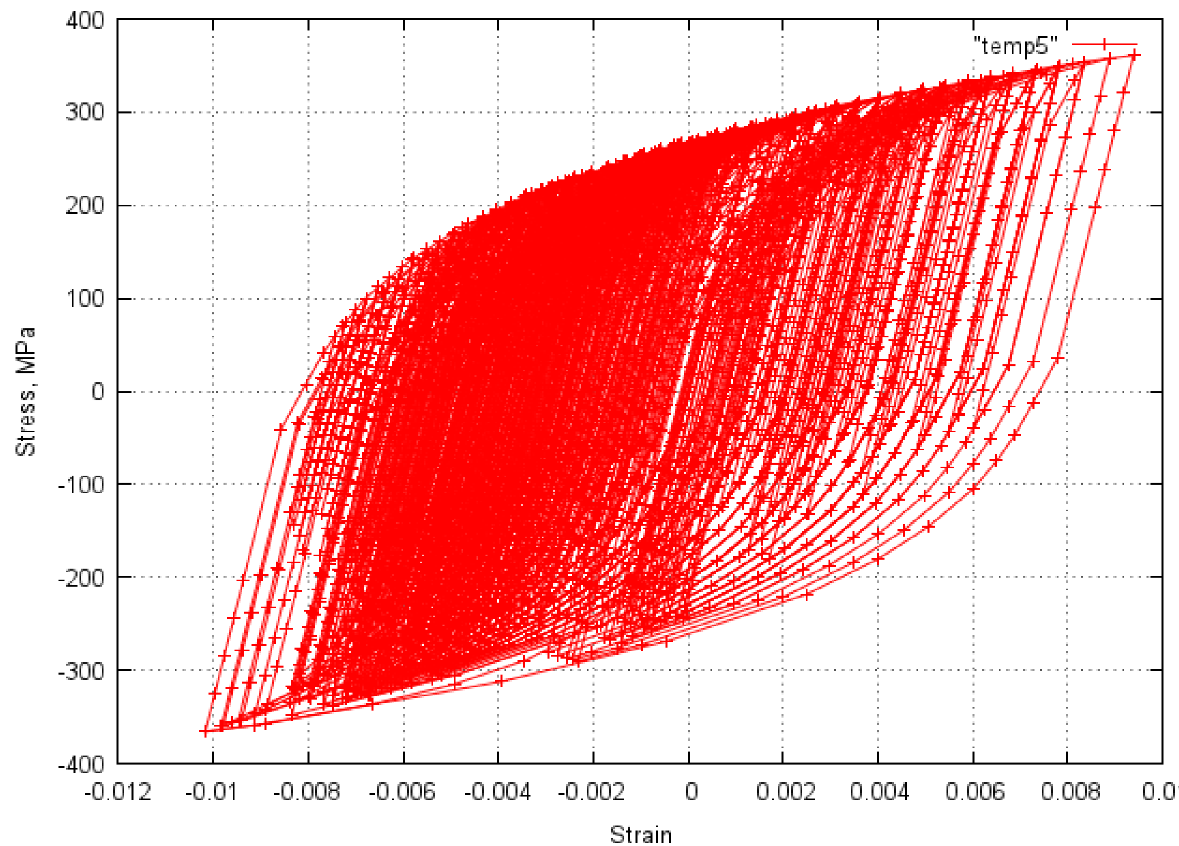
Crack Initiation and Propagation simulation results for Variable Amplitude test.

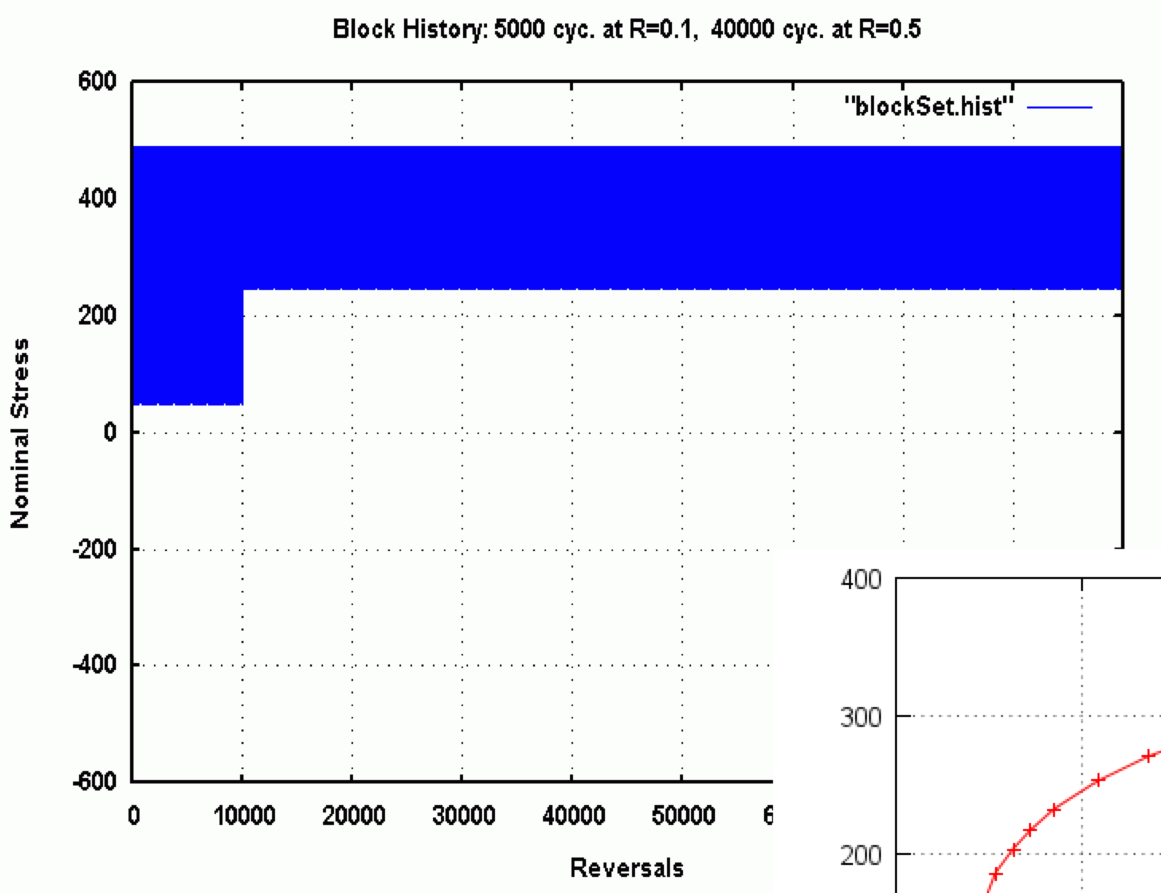
Test total life: 28.5 average

Sim.:

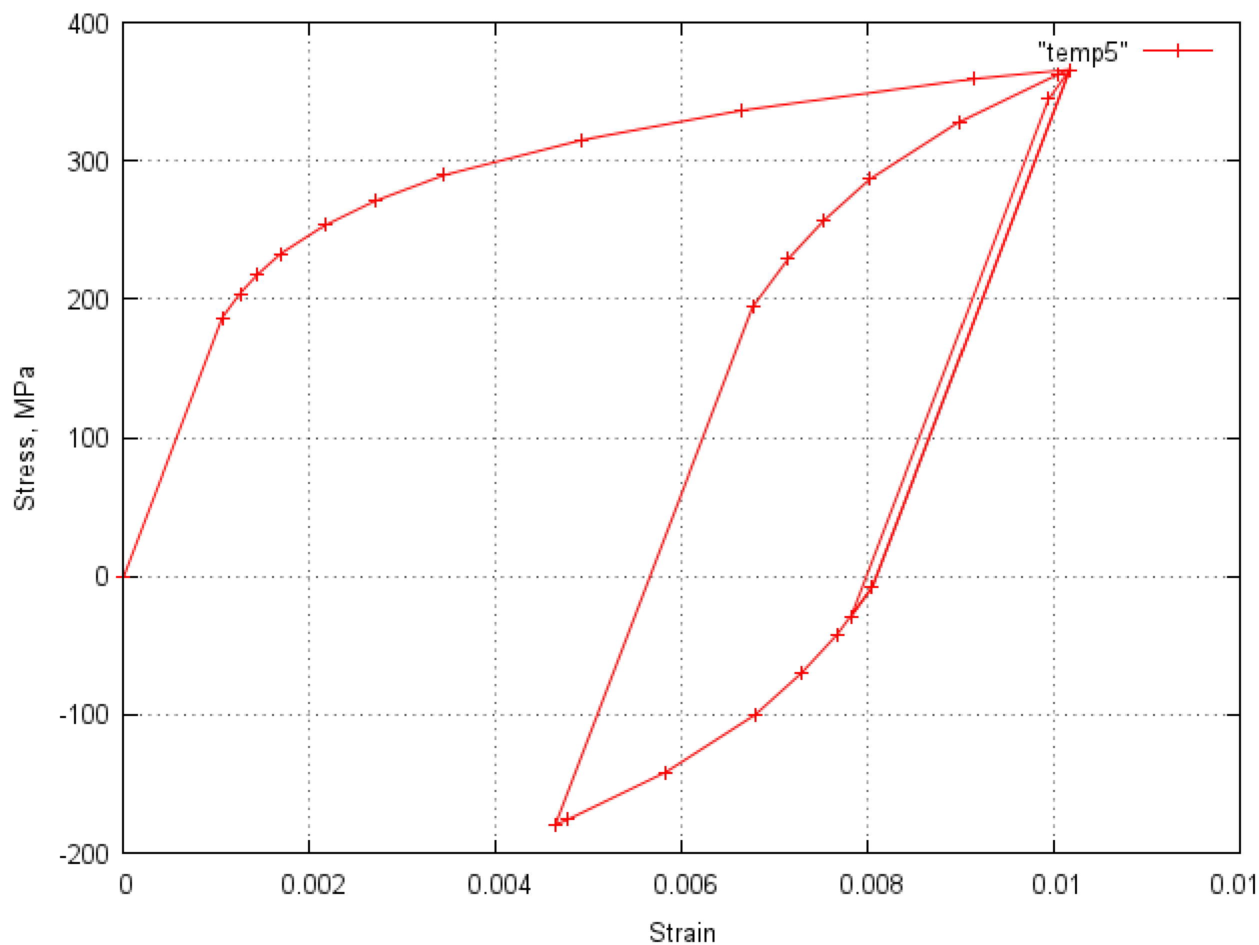
Initiation: 22.3 Blks
(using periodic o/s)

Propagation= <1 blk.





Crack Initiation and Propagation simulation results for 2 level block loading test



Test total life: 6.9 blks average

Sim.:

Initiation 7.4 blks
(not using periodic o/s curve but with cyclic relaxation)

Propagation <1 blk

References for Open Source Software used in study:

1. Crack Initiation: http://fde.uwaterloo.ca/Fde/Calcs/saefcalc2.html

2. Crack Propagation: http://fde.uwaterloo.ca/Fde/Crackgrowth/crackprop.html

https://github.com/pdprop/pdprop/tree/Master/CleanPdprop

Load History for Variable Amplitude test: http://fde.uwaterloo.ca/Fde/Loads/hindex.html
(See FD+E Total Life Project)

Cyclic Mean Stress Relaxation data for Low Carbon Steel:

http://fde.uwaterloo.ca/Fde/Articles/Relax/conleSo.html