# A Collection of Aluminum Cyclic Mean Stress Relaxation Data

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Fatigue Design and Evaluation
Committee, Aug. 20 2022

Stress-strain sequence from an un-notched axial loaded sample.

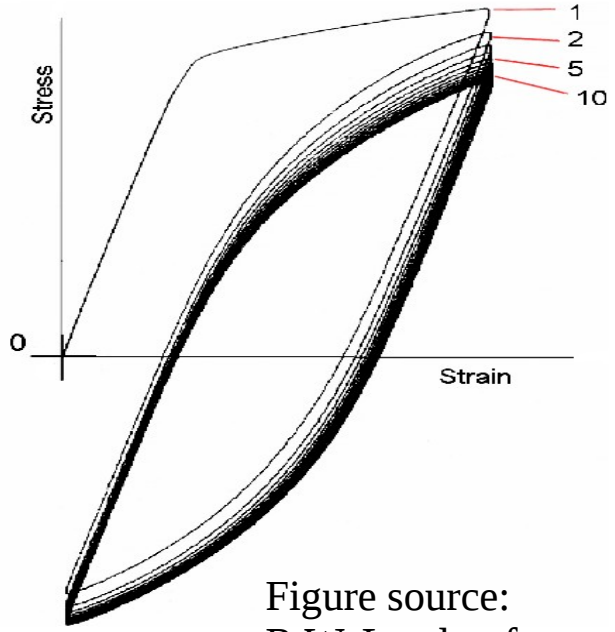
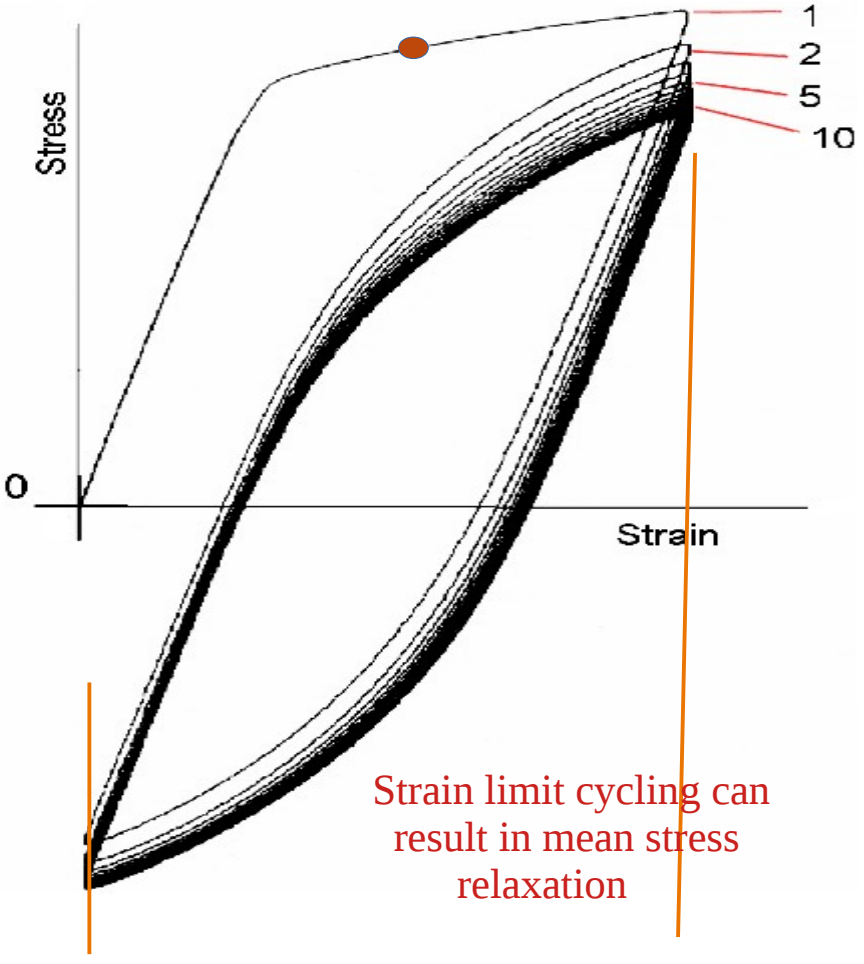



Figure source:
R.W. Landgraf

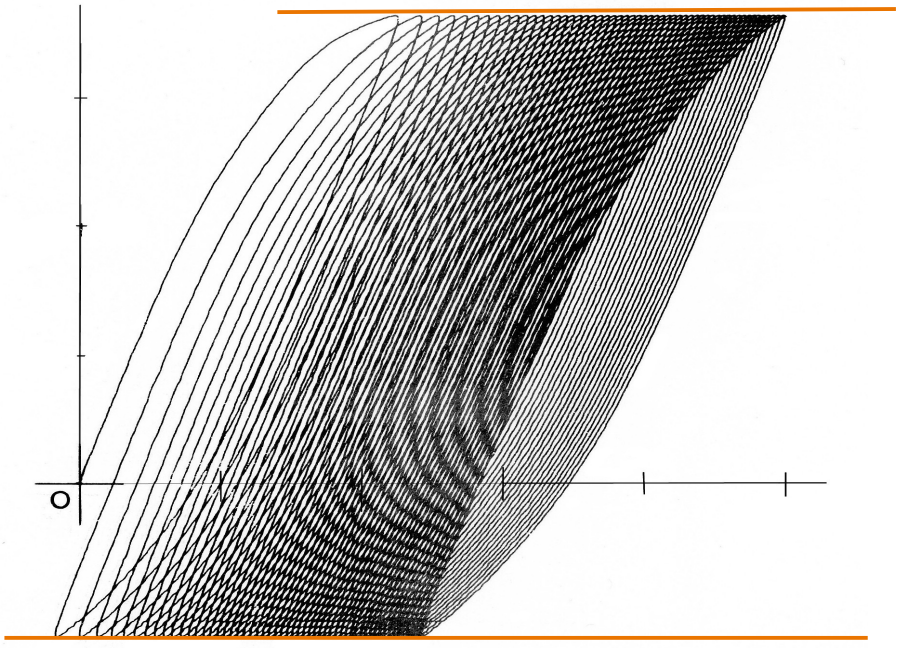
An animation of cyclic mean stress relaxation:
http://fde.uwaterloo.ca/Fde/Notches.new/Weld+Residuals/VideoA/animation.gif ( 9Mb )

The present web page is similar to the one created for cyclic mean stress relaxation in steels: https://fde.uwaterloo.ca/Fde/Articles/fde2019RelaxPres4Web.pdf

# Cyclic Mean Stress Relaxation



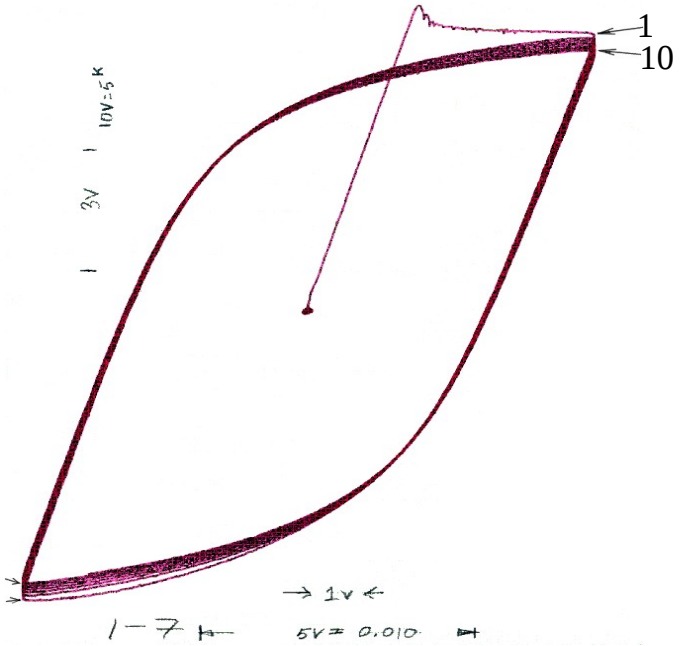

Strain limit cycling can result in mean stress relaxation



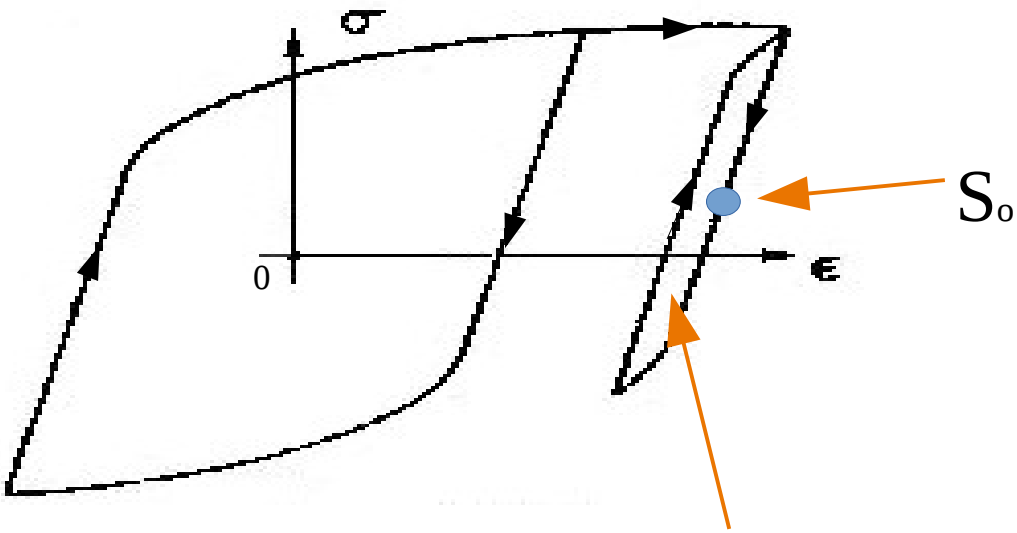

Stress limit cycling

When cycling with a mean stress the mean strain of loops will move. Termed Cyclic Creep or Ratcheting

A steady state sequence without relaxation.

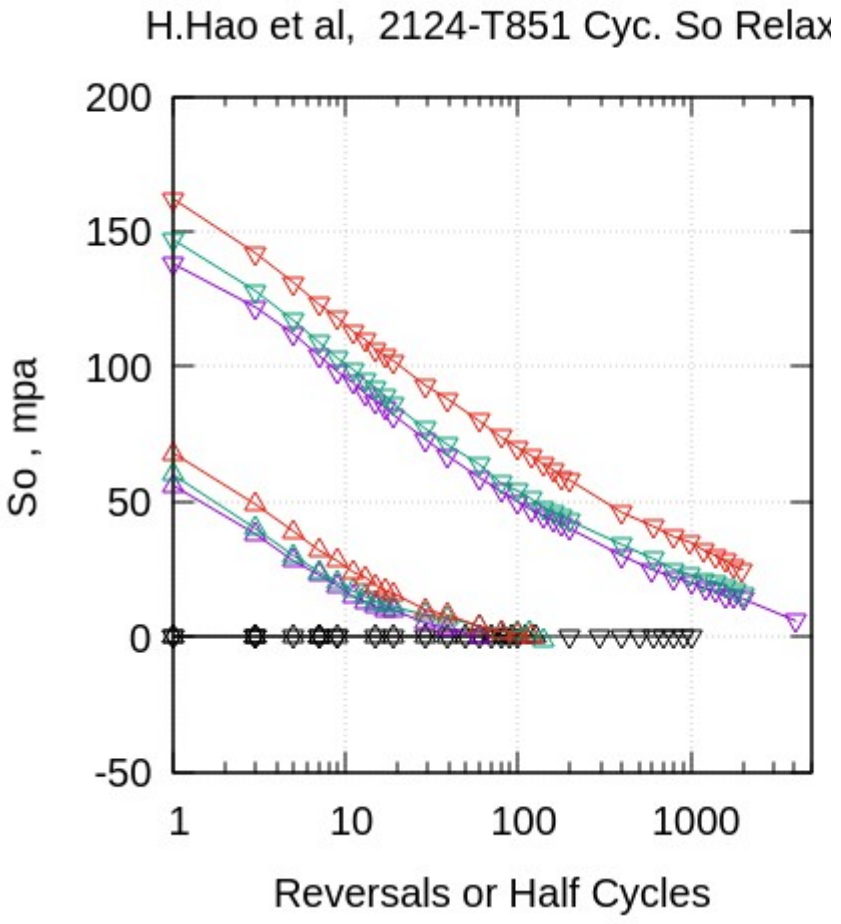



When extended to greater strains and run at smaller amplitudes a means stress So can be induced into the hysteresis loops

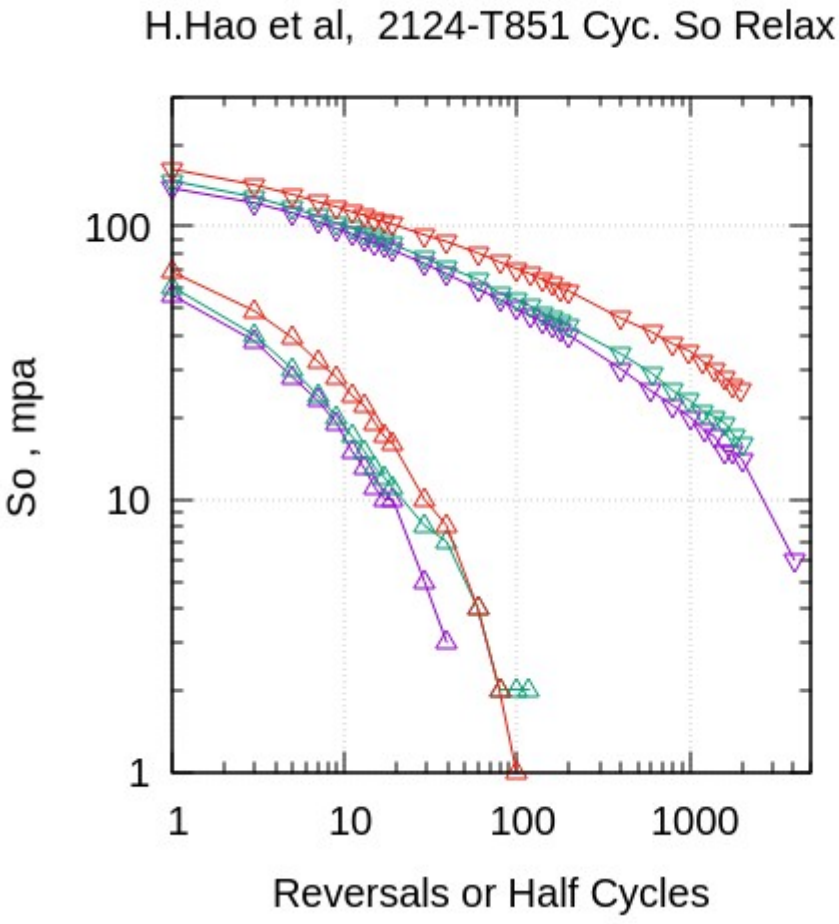



If the subsequent loops have sufficient plasticity (they are open) the mean stress will move towards zero as cycling continues.

Linear Y axis



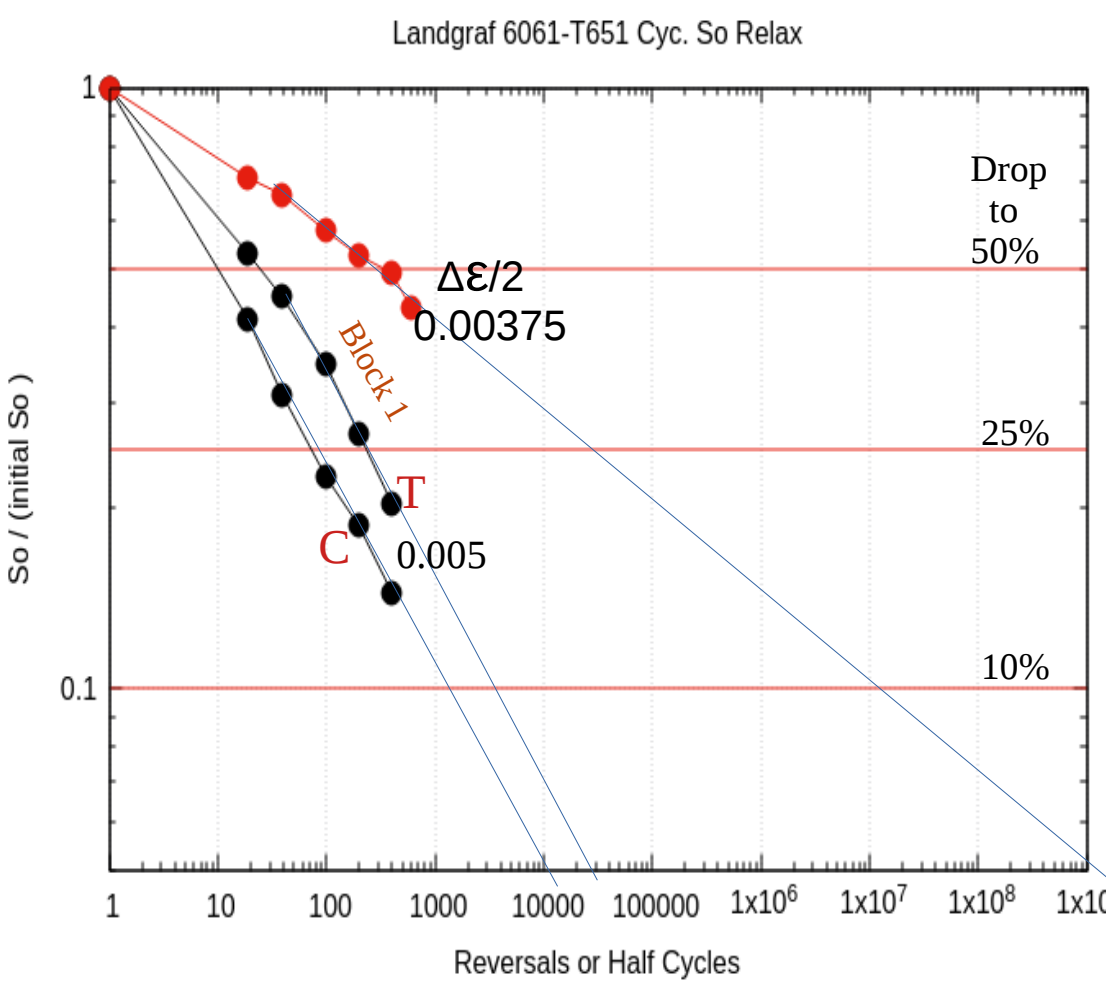

Log Log plot

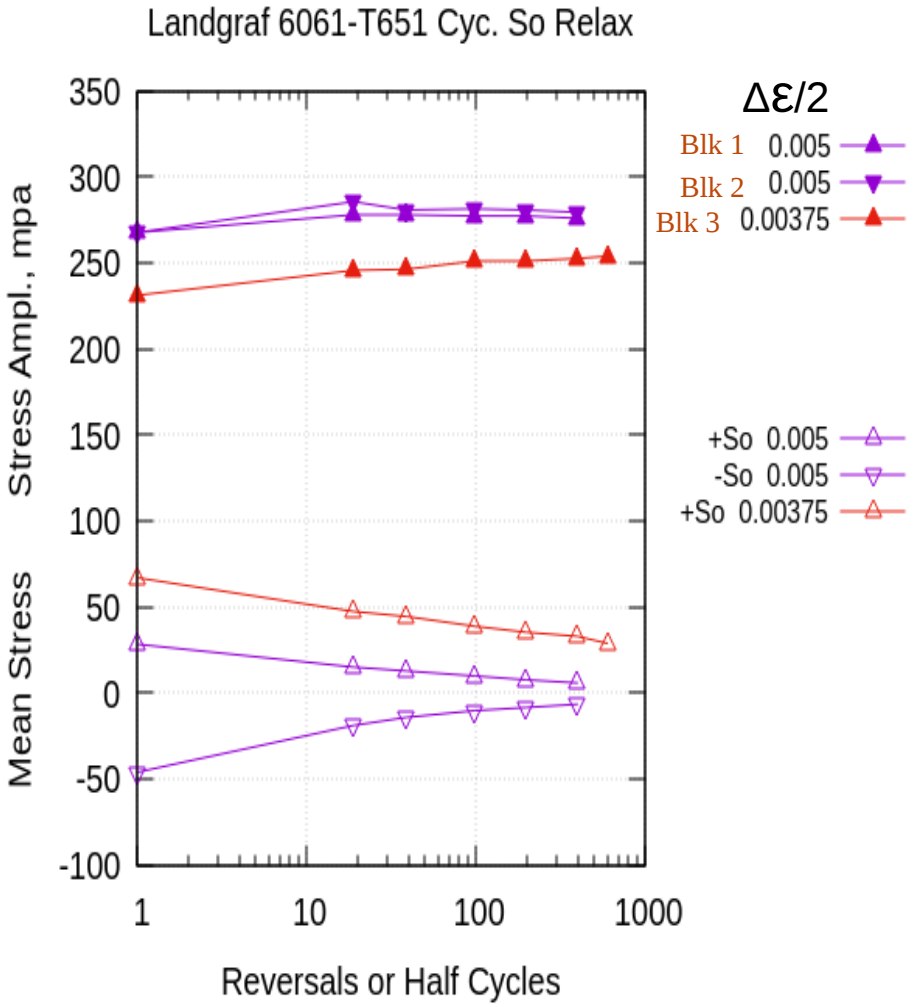


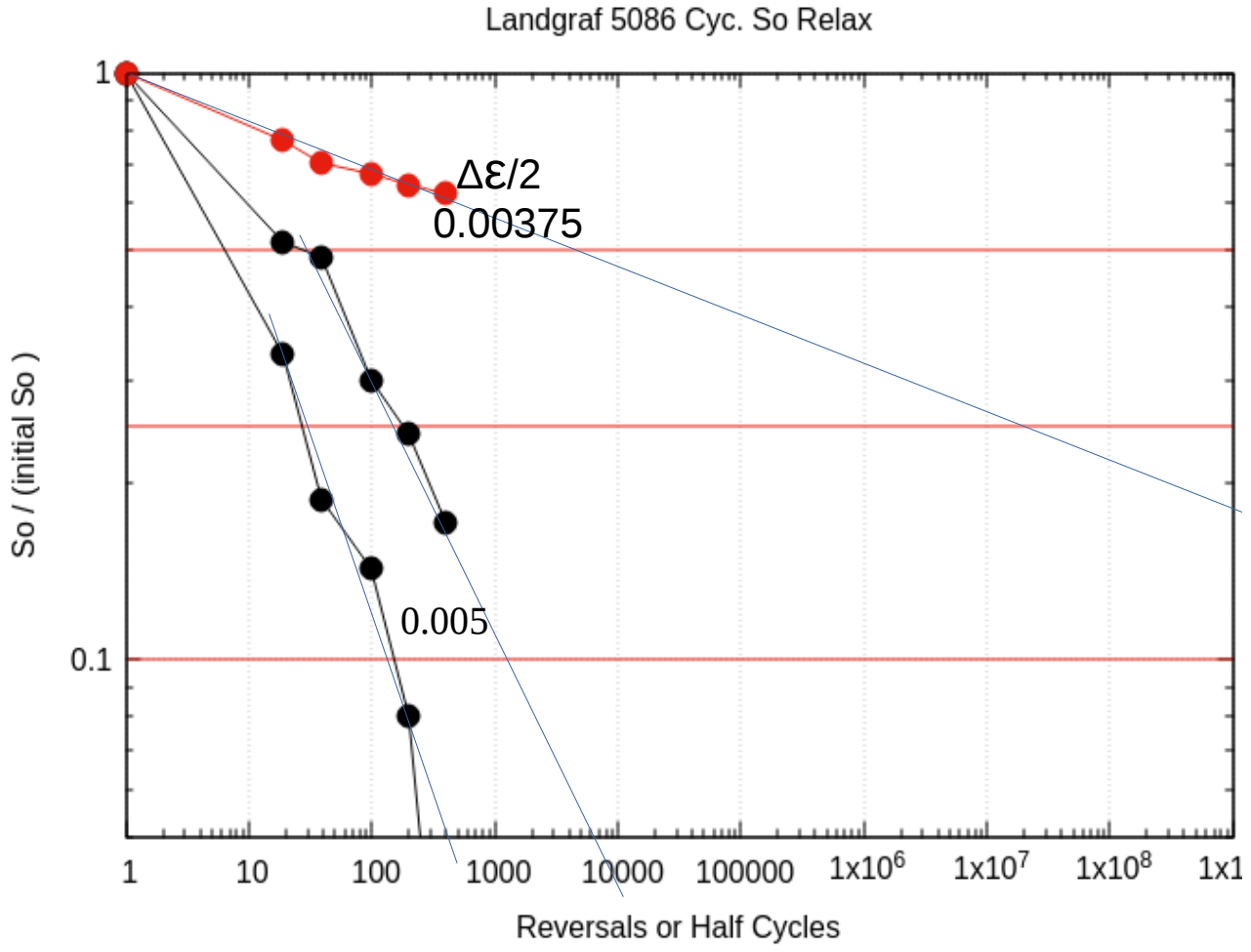

Most of the time relaxation is a straight line on a Log-Log plot, but not always.

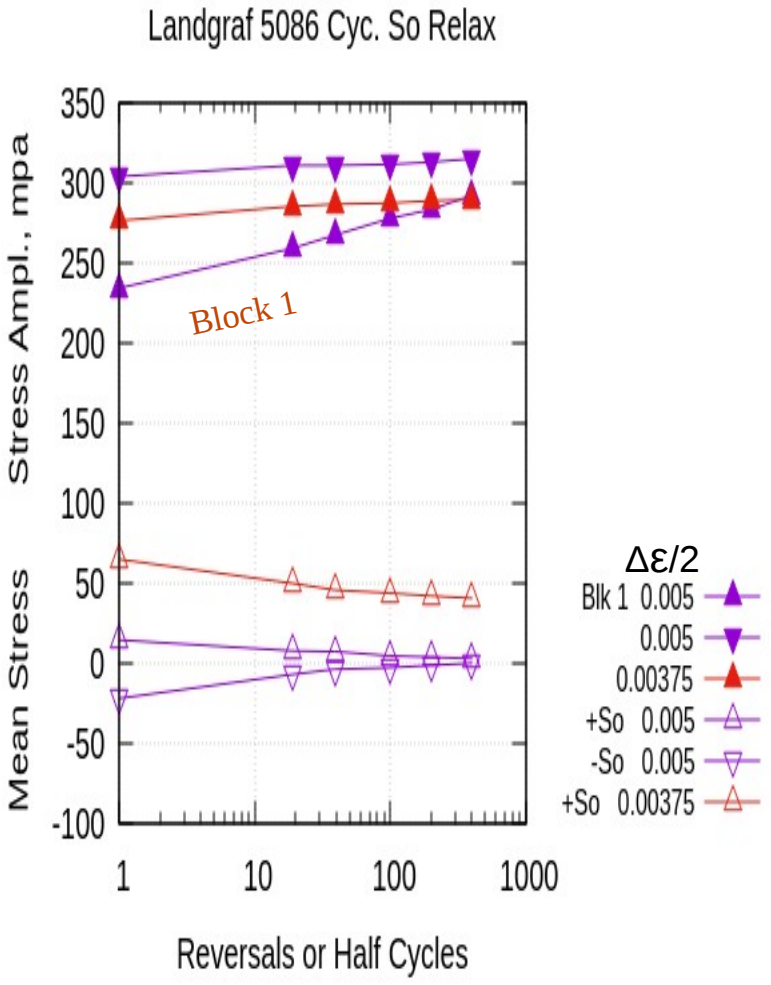
| εmin/εmax | Δε/2 |
|---|---|
| -1 | 0.006 |
| -0.06 | 0.006 |
| 0.06 | 0.006 |
| 0.5 | 0.006 |
| -1 | 0.015 |
| -0.06 | 0.015 |
| 0.06 | 0.015 |
| 0.5 | 0.015 |

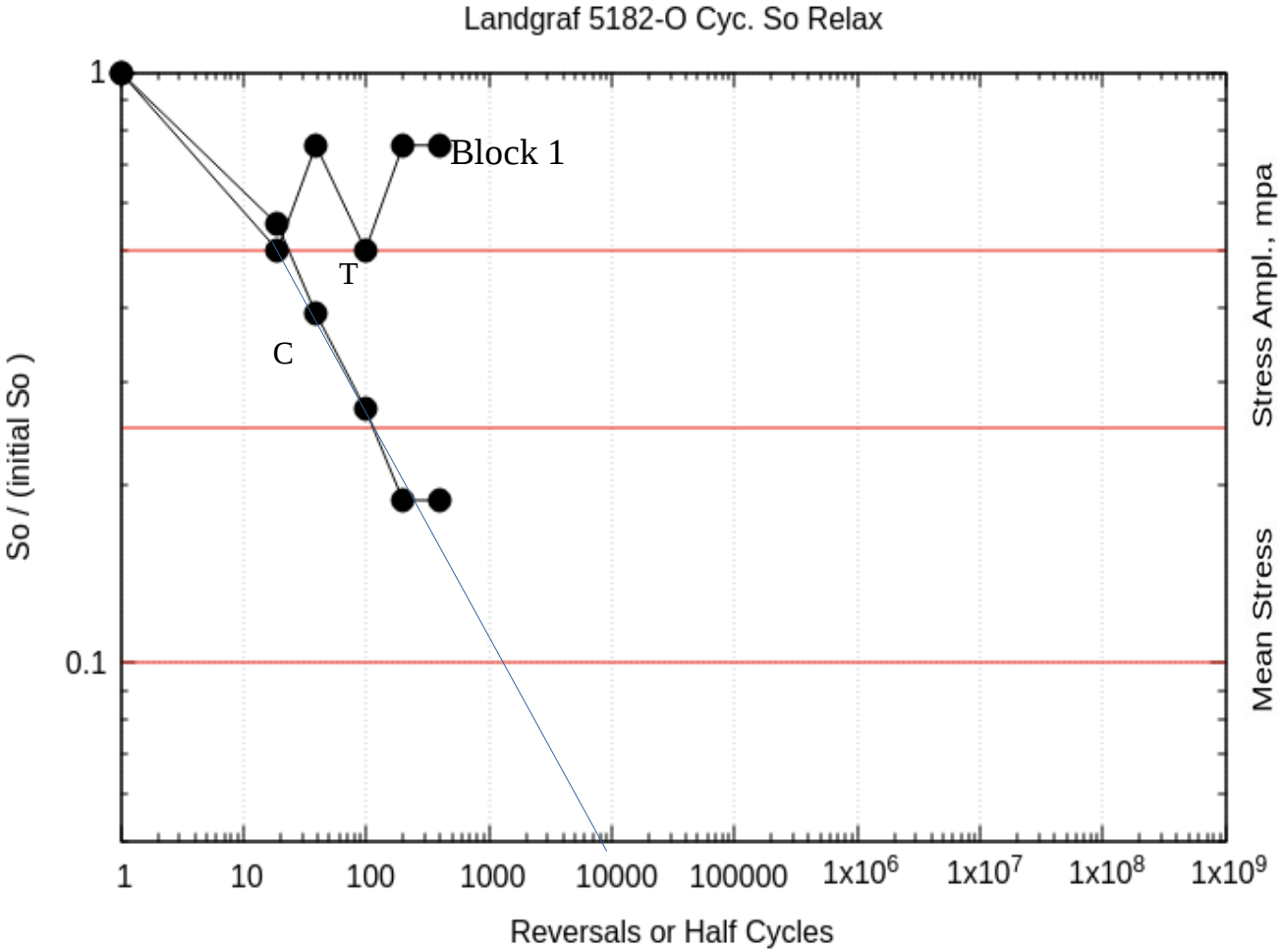
The curvature on the log log plot may be due to cyclic hardening or softening. This 6061 does neither, but is stable.

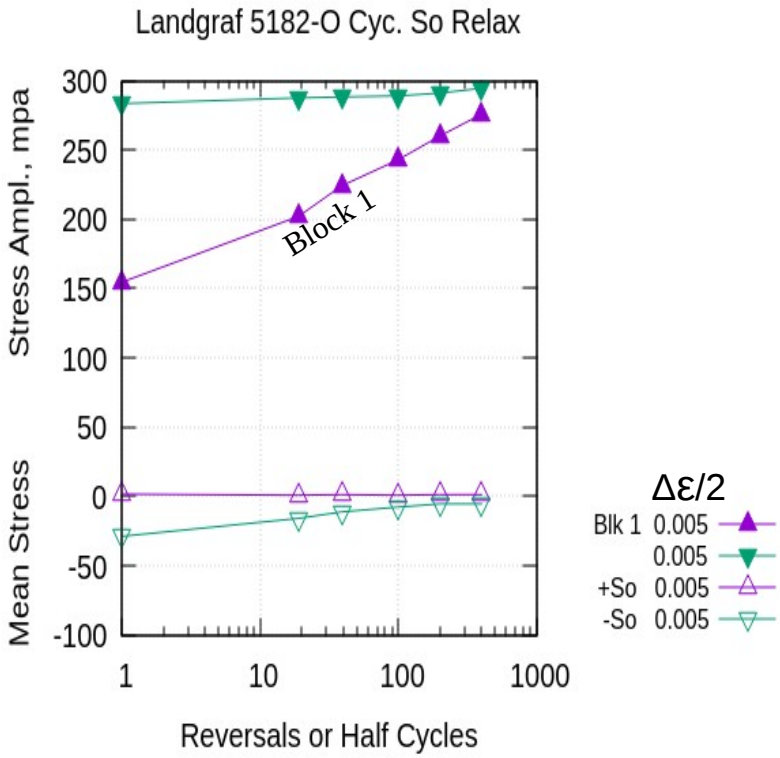


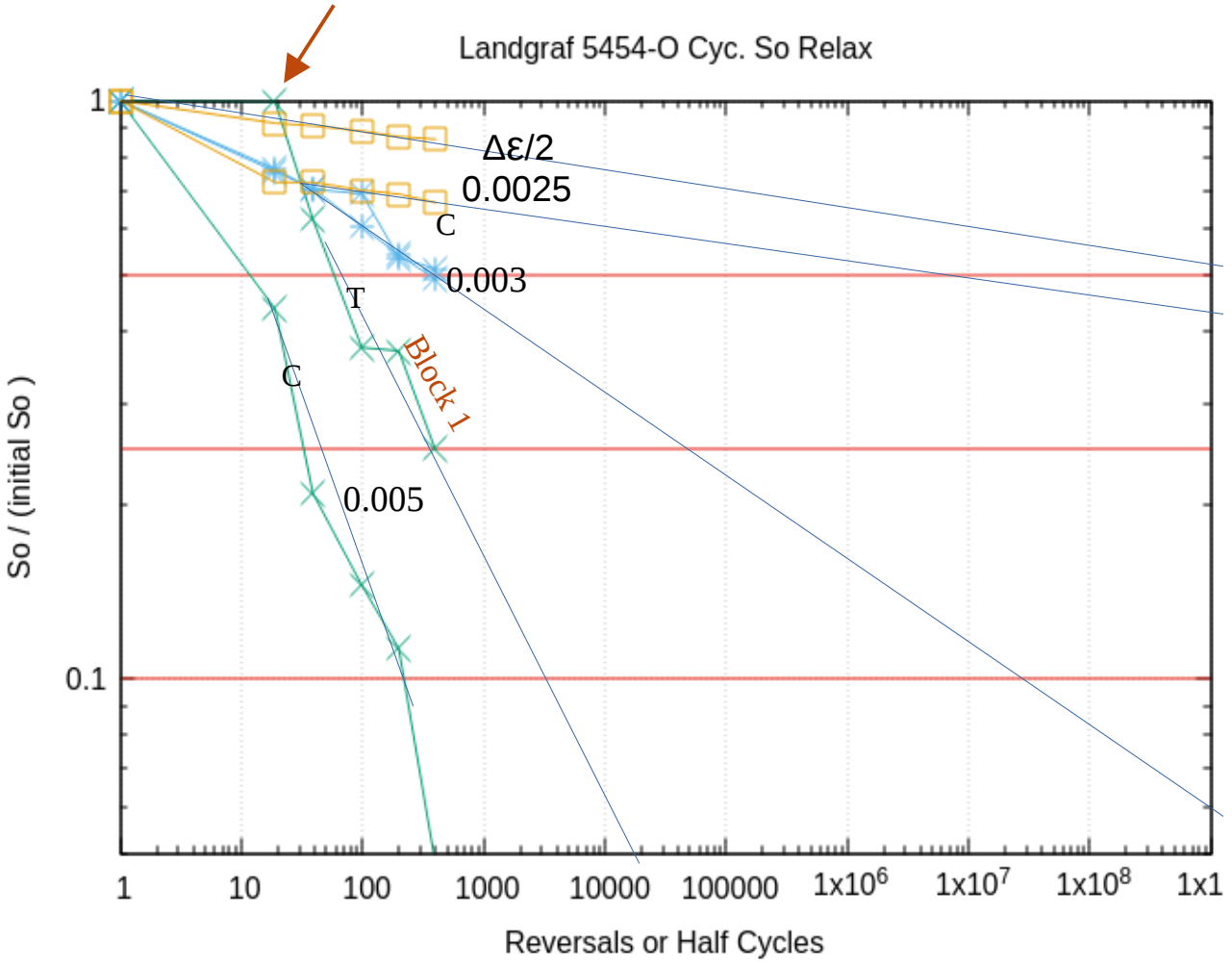



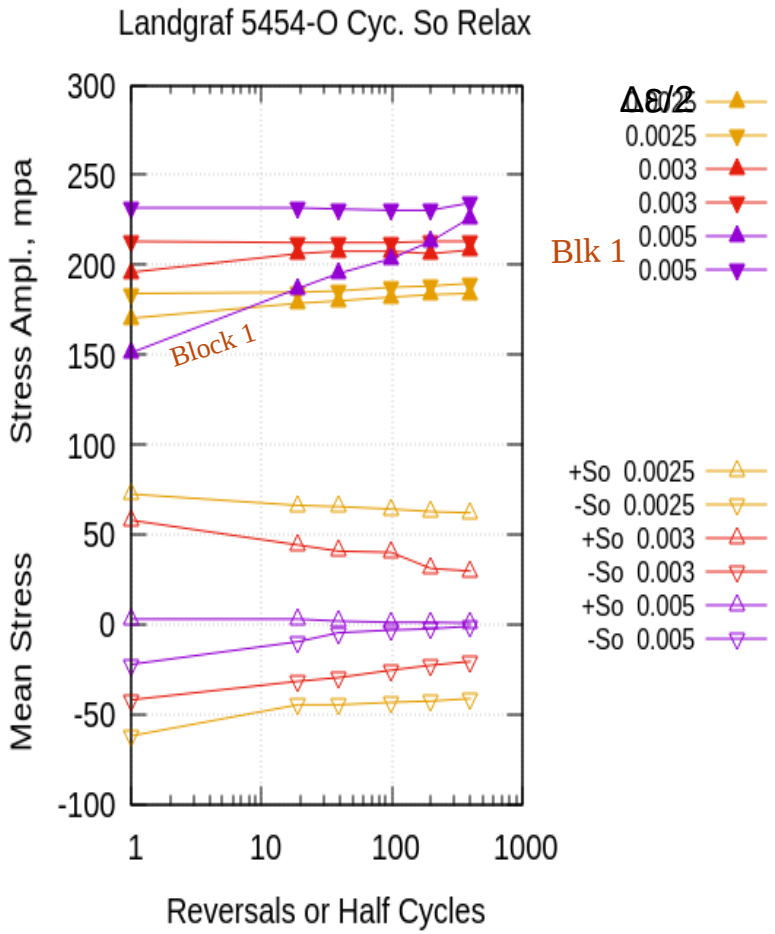

Landgraf 5086 Cyc. So Relax
So / (initial So )
1
0.1
Δε/2
0.00375
0.005
1
10
100
1000
10000
100000
1x10^6
1x10^7
1x10^8
1x1
Reversals or Half Cycles

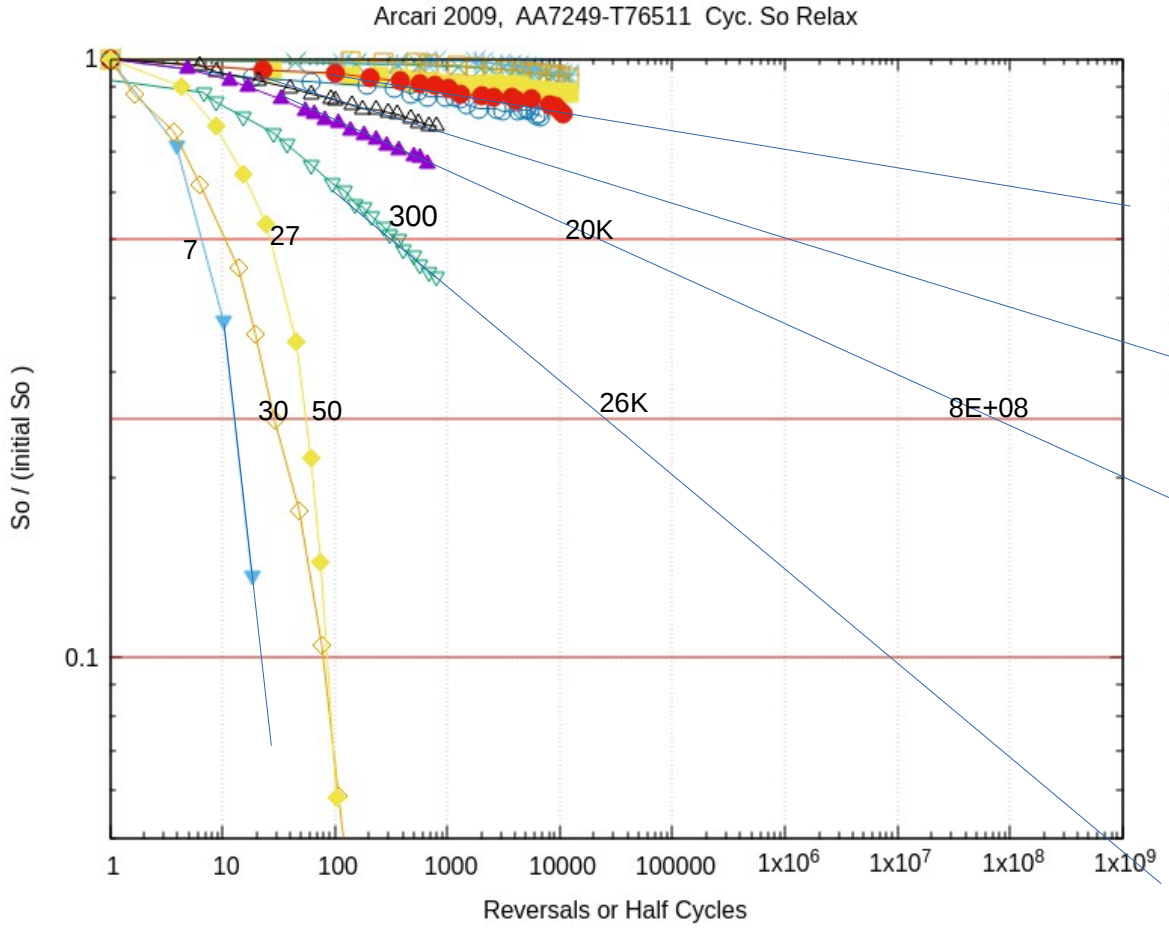

Landgraf 5086 Cyc. So Relax
Stress Ampl., mpa
Mean Stress
350
300
250
200
150
100
50
0
-50
-100
Block 1
1
10
100
1000
Reversals or Half Cycles
Δε/2
Blk 1 0.005
0.005
0.00375
+So 0.005
-So 0.005
+So 0.00375


Landgraf 5182-O Cyc. So Relax
So / (initial So )
1
0.1
Block 1
T
C
1
10
100
1000
10000
100000
1x10^6
1x10^7
1x10^8
1x10^9
Reversals or Half Cycles


Landgraf 5182-O Cyc. So Relax
Stress Ampl., mpa
Mean Stress
300
250
200
150
100
50
0
-50
-100
Block 1
1
10
100
1000
Reversals or Half Cycles
Δε/2
Blk 1 0.005
0.005
+So 0.005
-So 0.005

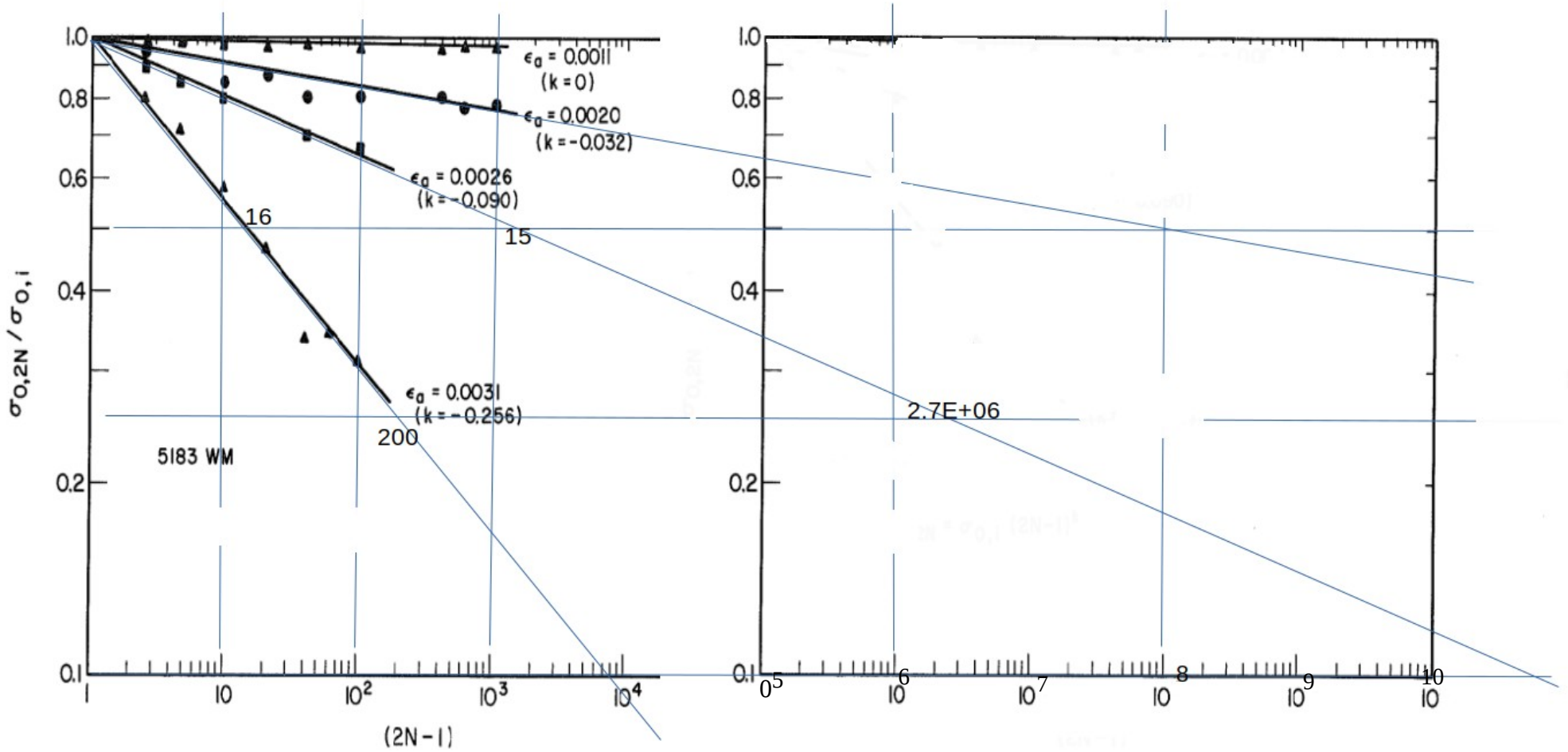

Landgraf 5454-O Cyc. So Relax
So / (initial So )
Reversals or Half Cycles
Δε/2
0.0025
0.003
0.005
C
T
Block 1
1
0.1
1
10
100
1000
10000
100000
1x10^6
1x10^7
1x10^8
1x1


Landgraf 5454-O Cyc. So Relax
Stress Ampl., mpa
Mean Stress
Reversals or Half Cycles
Block 1
Blk 1
Δε/2
0.0025
0.003
0.003
0.005
0.005
+So 0.0025
-So 0.0025
+So 0.003
-So 0.003
+So 0.005
-So 0.005
300
250
200
150
100
50
0
-50
-100
1
10
100
1000

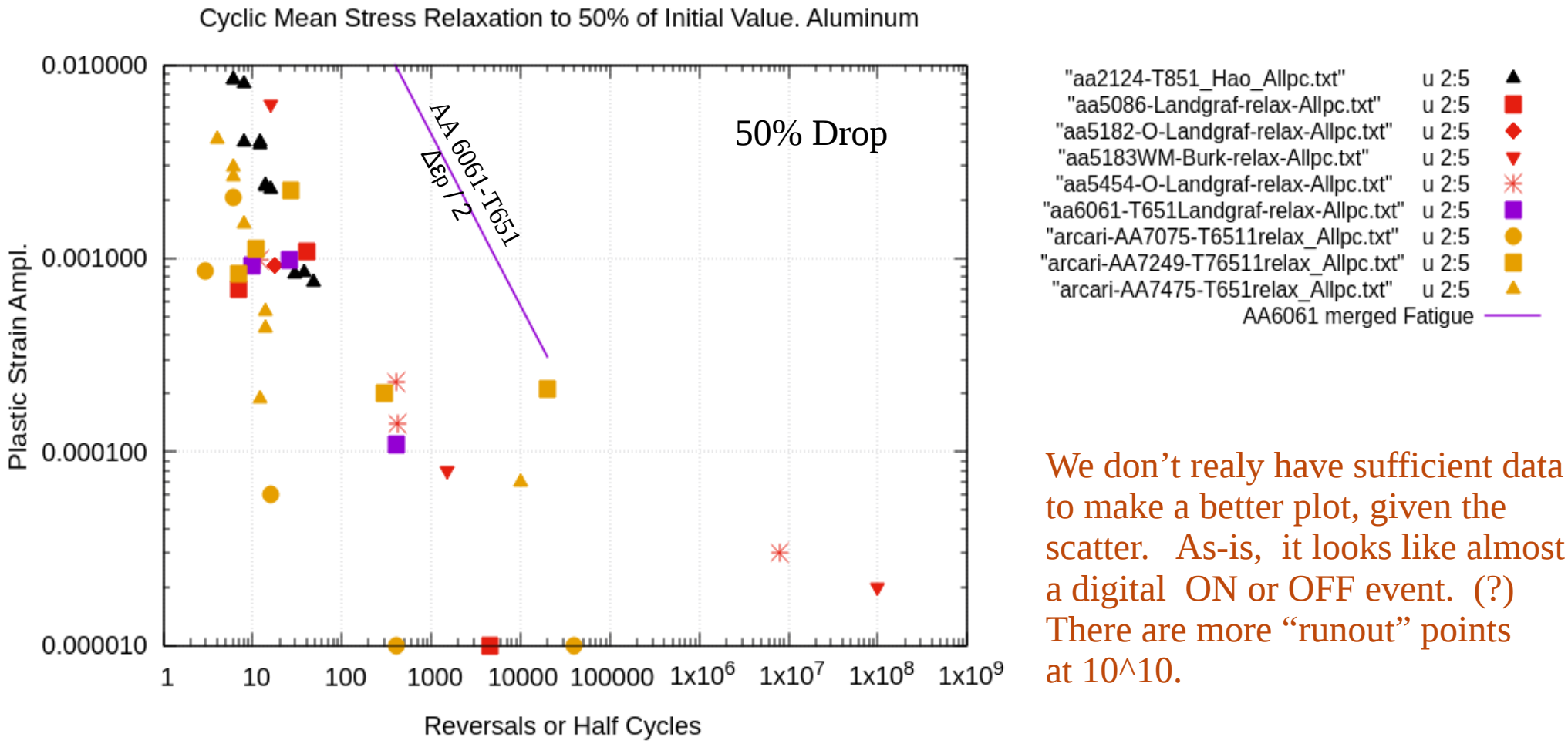



Straight line extrapolations are used to estimate intersection at 50%, 25%, 10%.
This is prone to error, obviously, and is part of the cause for scatter in the Plastic Strain vs 2N plots

J.D.Burk, AA5183 Aluminum Weld Metal ( Specimens cut from a weld )




Adapted from Burk PhD, Fig. 18, Ref.[4]




We don't realy have sufficient data to make a better plot, given the scatter. As-is, it looks like almost a digital ON or OFF event. (?) There are more "runout" points at 10^10.

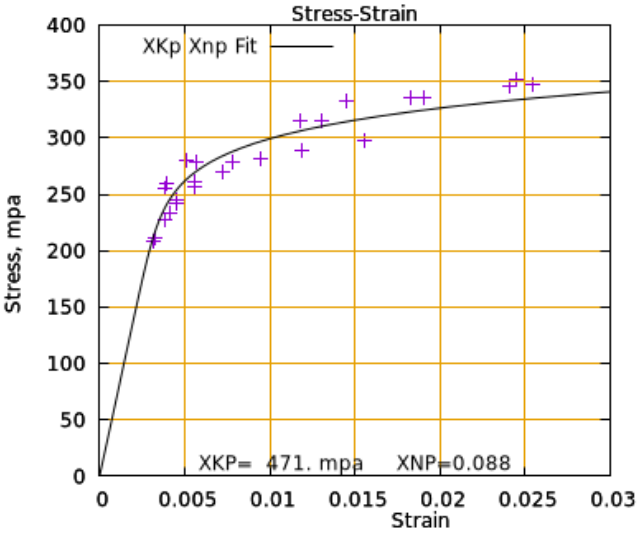
From F.D.E Database

AA6061T6xx Aluminum BHN= 0

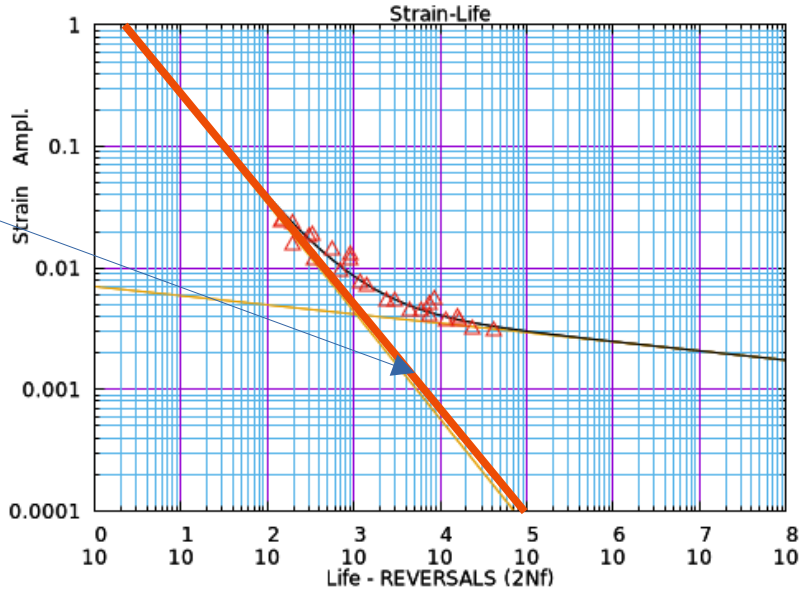
# AA 6061 Merged File: Aluminum Wrought, Data from reference:
# [1] R.F.Brodrick, G.A.Spiering, 'Low Cycle Fatigue of Aluminum Alloys',
# ASTM J.of Matls, V7 N4 Dec 1972, pp.515-526
# [2] Y.S. Chung, A.Abel, ASTM STP 942 1988.

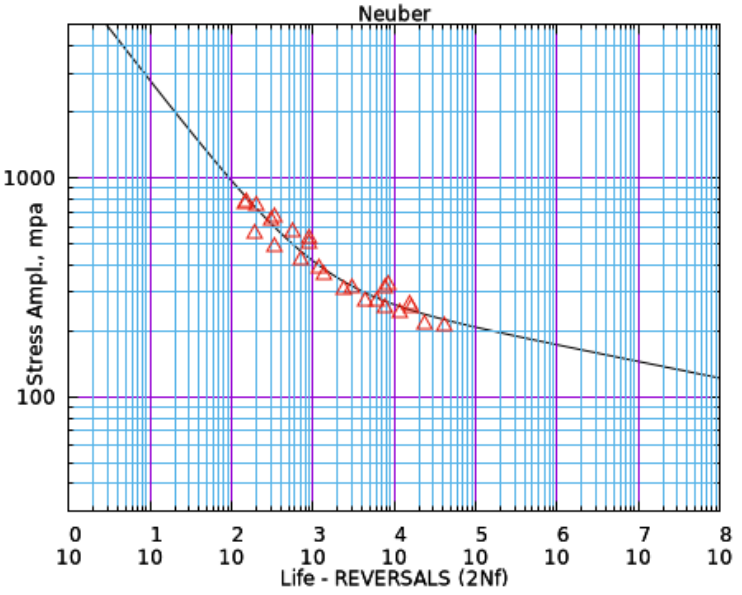
| Properties: | Monotonic | | Cyclic | |
|---|---|---|---|---|
| ELAS. MOD.= | 10100. KSI | 69637. MPA | | |
| YIELD 0.2%= | 39. KSI, | 268. MPA | | |
| ULT. STRG.= | 43. KSI, | 298. MPA | F. STRG COEF= | 71.2 KSI, 491.MPA |
| K= | 0.0 KSI, | 0. MPA | F.STRG EXP, b= | -0.0757 |
| N= | 0.0000 | | FAT DUCT COEF= | 2.0289 |
| %RED. in AREA = | 45.4 | | F.DUCT EXP, c= | -0.8874 |
| FRAC. Stress= | 69.2 KSI, | 477. MPA | Exp Cyc Yld = | 39. Ksi, 272.MPA |
| FRAC. Strain= | 0.610 | | | |
| No. data points= | 25 | | | |

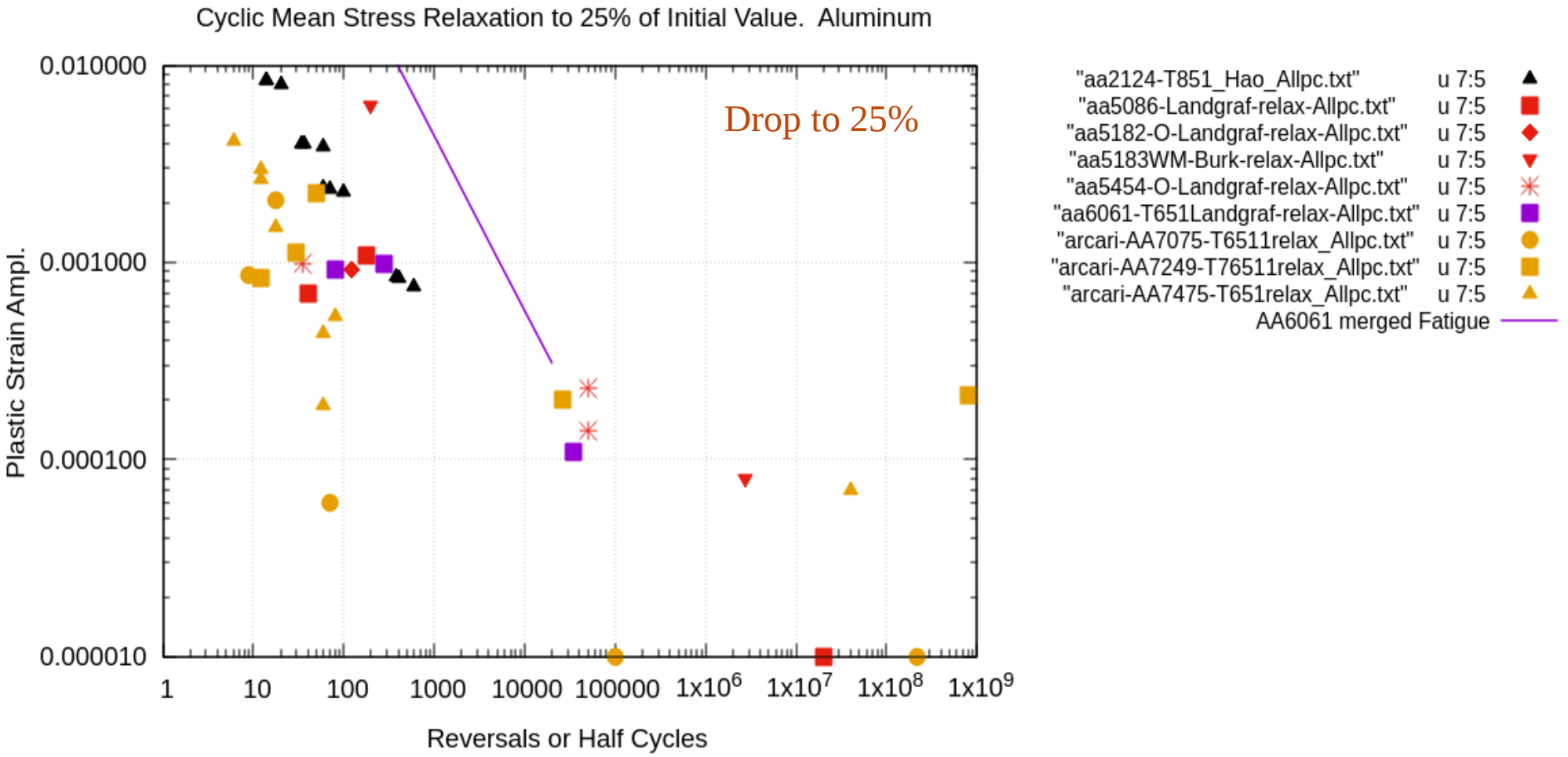
Background: http://fde.uwaterloo.ca/FatigueClass/Chap7Notches/chap7sec2-DbaseFiles.pdf

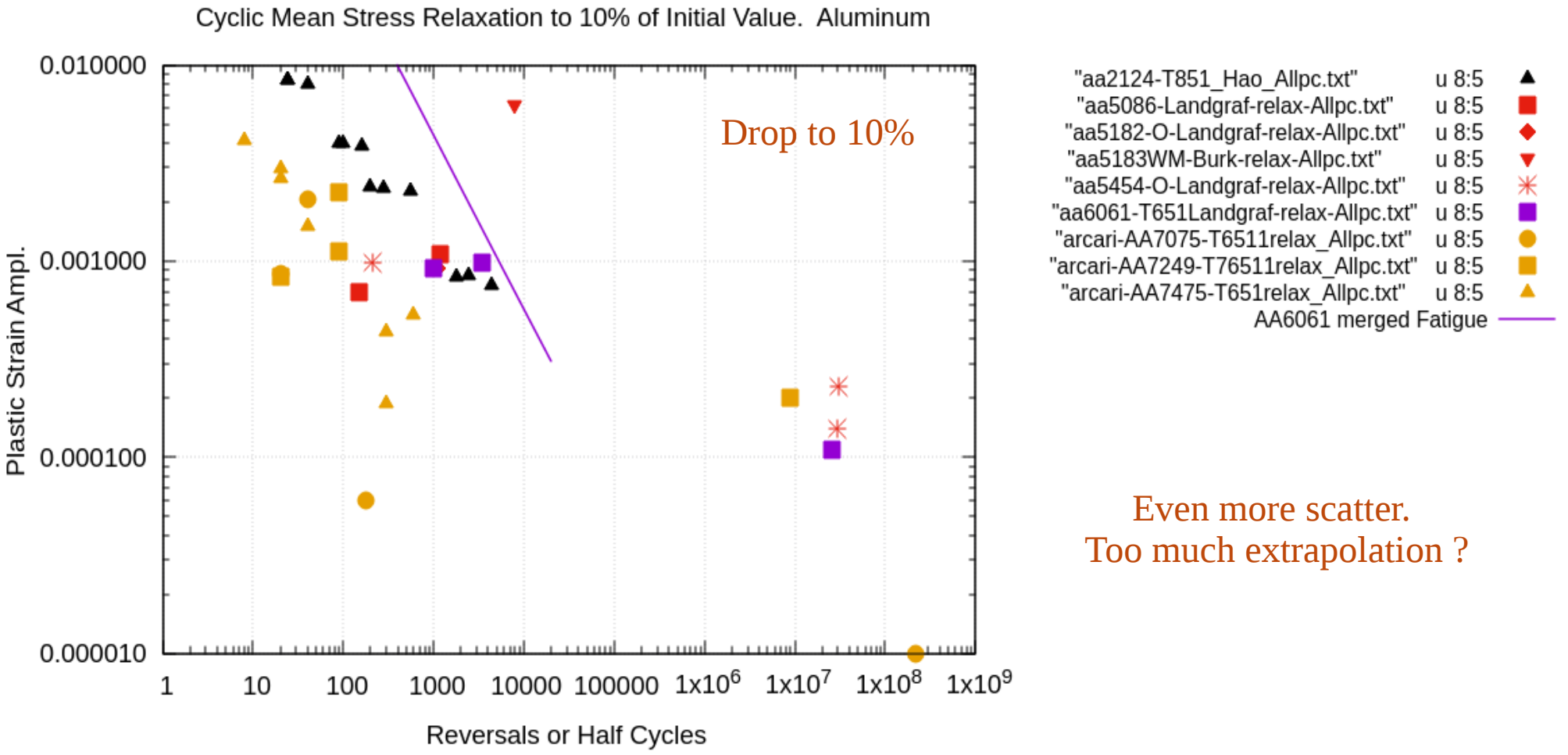



Its the same as this line




Cyclic Mean Stress Relaxation to 25% of Initial Value. Aluminum
Drop to 25%
Plastic Strain Ampl.
0.010000
0.001000
0.000100
0.000010
1
10
100
1000
10000
100000
1x10^6
1x10^7
1x10^8
1x10^9
Reversals or Half Cycles
"aa2124-T851_Hao_Allpc.txt" u 7:5
"aa5086-Landgraf-relax-Allpc.txt" u 7:5
"aa5182-O-Landgraf-relax-Allpc.txt" u 7:5
"aa5183WM-Burk-relax-Allpc.txt" u 7:5
"aa5454-O-Landgraf-relax-Allpc.txt" u 7:5
"aa6061-T651Landgraf-relax-Allpc.txt" u 7:5
"arcari-AA7075-T6511relax_Allpc.txt" u 7:5
"arcari-AA7249-T76511relax_Allpc.txt" u 7:5
"arcari-AA7475-T651relax_Allpc.txt" u 7:5
AA6061 merged Fatigue




Even more scatter.
Too much extrapolation ?

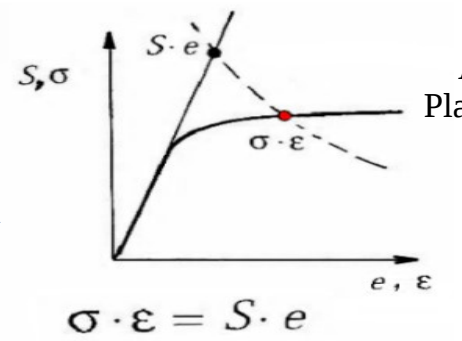
# Summary of Suggested Process:


Get:

Smax

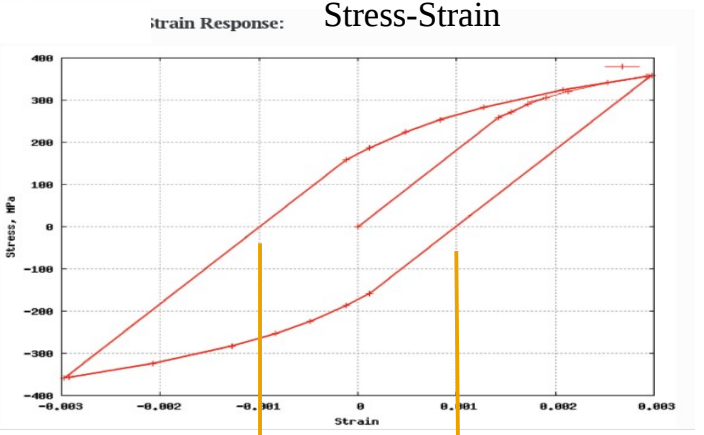
Kt

Smin




Apply Neuber Plasticity Correction

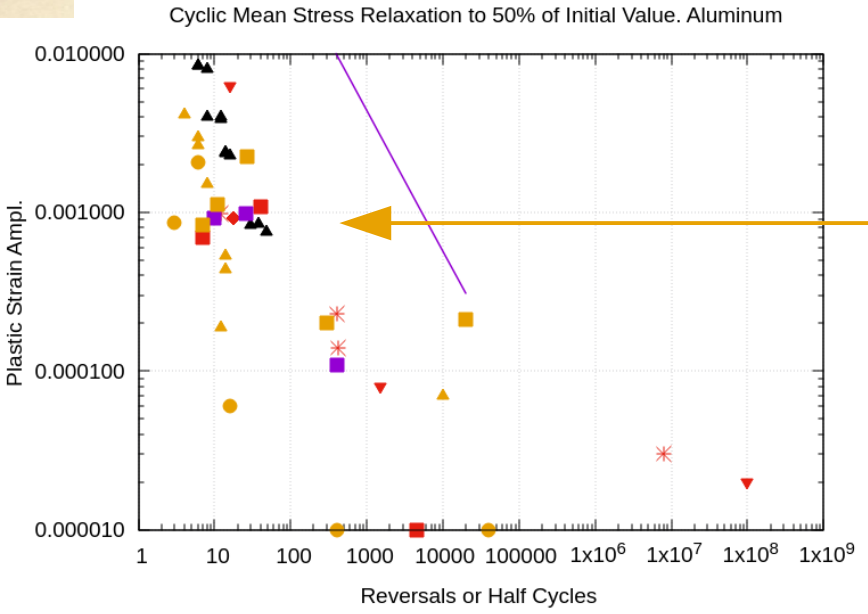
Get Local Stress-Strain




$\Delta\epsilon_p$

$\Delta\epsilon_p/2$

Estimate Plastic Strain Amplitude




Determine if relaxation is expected.

Compute life accordingly.

Refrences


[1] A similar web page for cyclic mean stress relaxation for steels is available at
https://fde.uwaterloo.ca/Fde/Articles/fde2019RelaxPres4Web.pdf

[2] Web based “Calculators” for estimating stress-strain loops and plastic strain amplitudes are available at:
https://fde.uwaterloo.ca/Fde/Materials/Alum/alum.html (!! No warranties ) e.g.:
https://fde.uwaterloo.ca/Fde/Materials/Alum/AA2xxx/AA2014/aa2014-T6merged_nonOS_fc.html

[3] Other tools for estimating Plastic Strain Ampl.:
https://fde.uwaterloo.ca/Fde/Materials/Alum/AA7xxx/merged7075T6xx_Nsim.html (“Mag factor” is like Kt)
https://fde.uwaterloo.ca/Fde/Materials/Alum/AA7xxx/merged7075T6xx_sim.html ( Hot spot strain input)

[4] J.D.Burk, F.V.Lawrence, jr., "The Effect of Residual Stresses on Weld Fatigue Life",
U.of Illinois, Urbana, Jan. 1978 Dept. Metallurgical Engr., Fracture Control Report FCP No. 29

[5] R.W. Landgraf, Prof., Virginia Tech., Personal Communication.

[6] A.Arcari, "Enhanced strain-based fatigue methodology for high strength aluminum alloys",
PhD thesis, Engr. Mech., Virginia Polytechnic, Jan 29, 2010

[7] Hong Hao, Duyi Ye, Yingzhen Chen, Feng Mi, Jianzhong Liu, "A study on the mean stress relaxation behavior of 2124-T851 aluminum alloy during low-cycle fatigue at different strain ratios".
Materials and Design 67 (2015) 272–279, # Some data also from
Hong Hao, Duyi Ye, Chuanyong Chen, "Strain ratio effects on low-cycle fatigue behavior and deformation microstructure of 2124-T851 aluminum alloy", Materials Science + Engineering A 605 (2014) 151–159