

SAE Spring FD&E Meeting 2022

Evolution and Redistribution of Residual Stress in Welded Plates During Fatigue Loading

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SAE Fatigue, Design, & Evaluation Committee

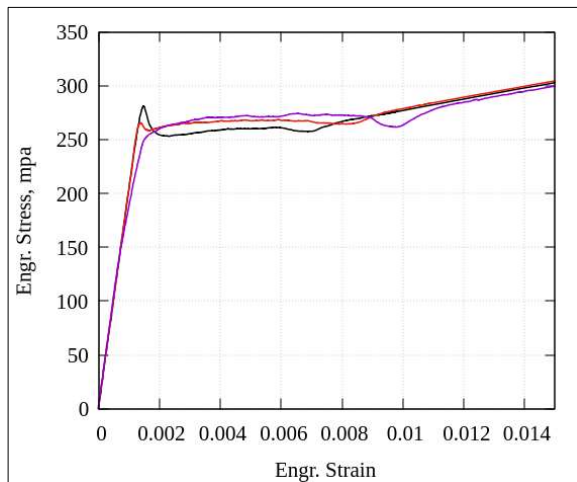
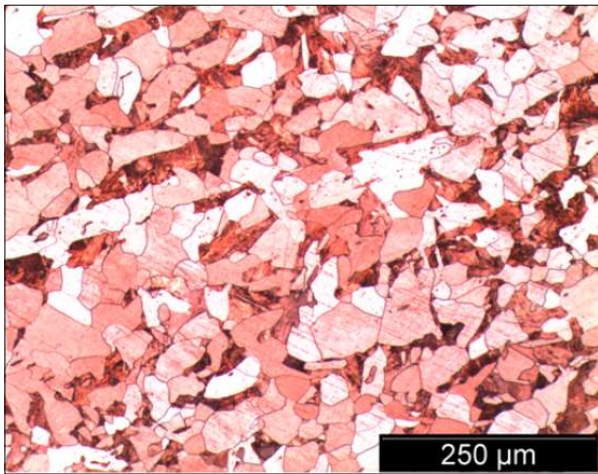
Total Life Prediction Project Overview – multi year project

- Several “T-Bar” style samples have been subjected to either constant or variable amplitude cyclic cantilevered loading.
- Various methods have been used to try and predict the initiation and propagation of cracks in these weldments.
- To do this accurately, we need to take into account the residual stresses due to the welding process to get good life predictions
- We can do this by modeling or by measurement

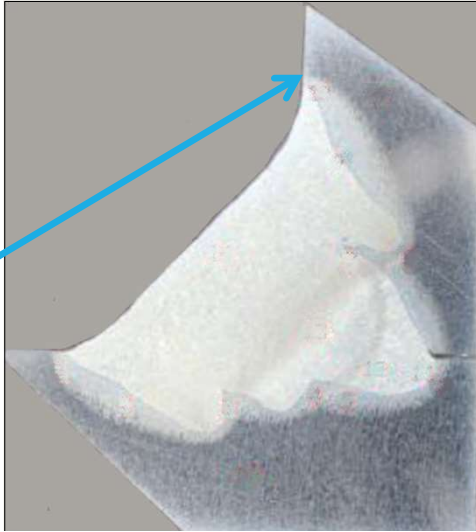


Base Metal A36 Steel

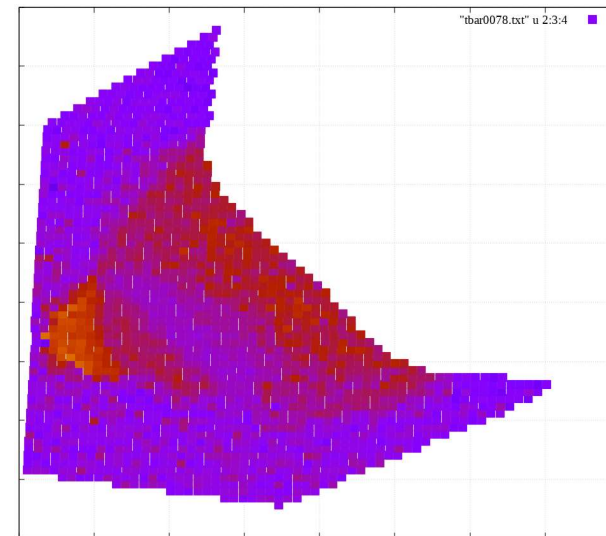
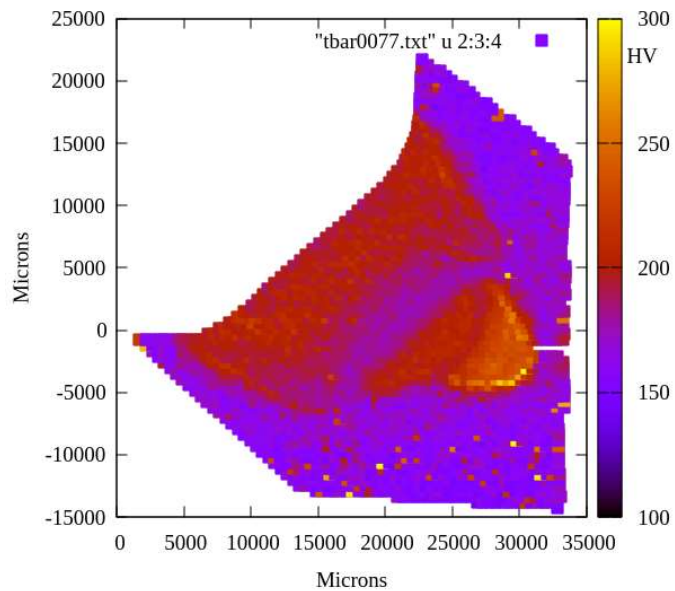
gravity welding – 6 pass sequence



Weld toe region
where cracks
typically initiate

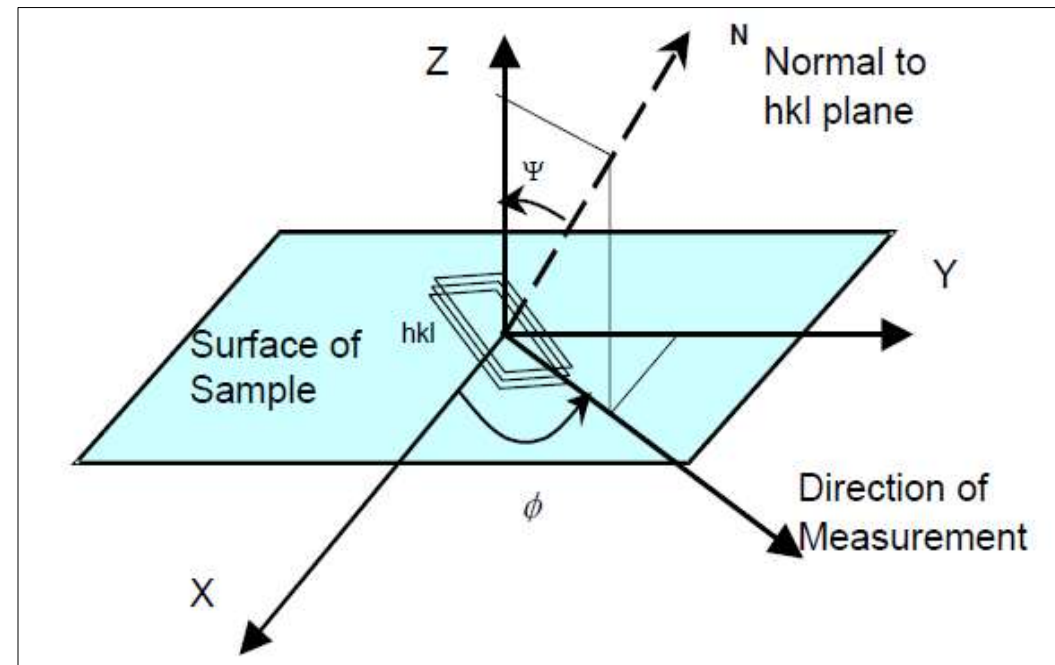
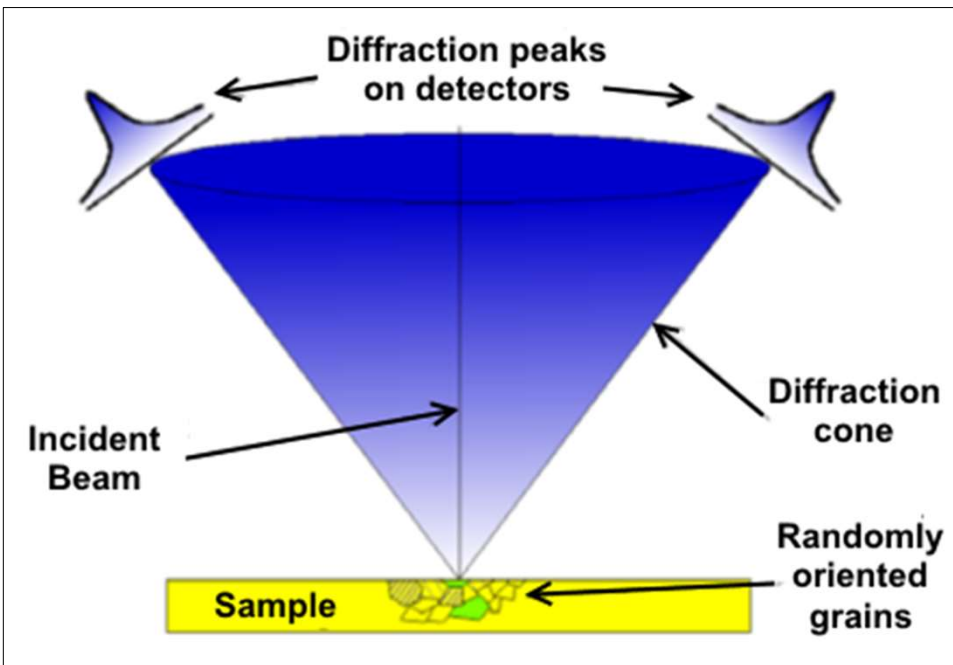


Macro etched cross
sections of T-bar
welds reveal parent
metal, HAZ, and weld
metal



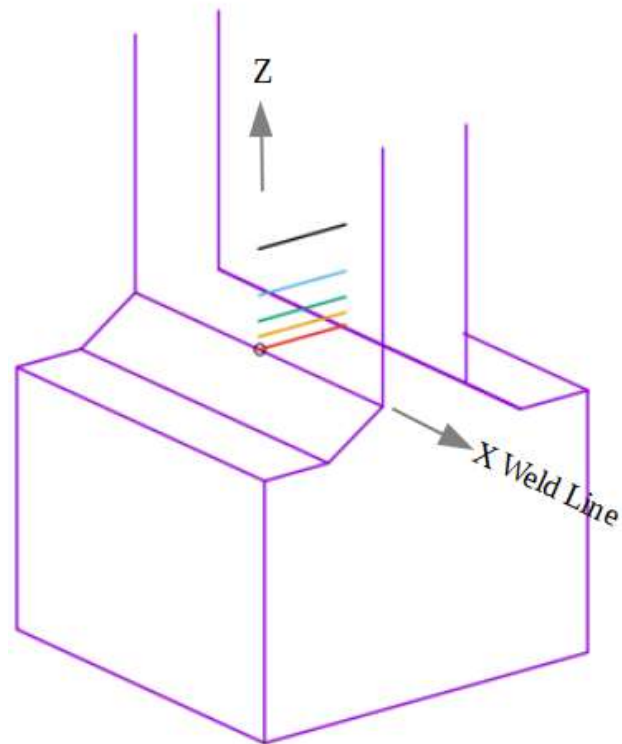
Vickers
Hardness
(Hv) Maps

XRD Method was used to measure the RS at the surface and through the cross section at various positions as a function of distance from the Weld Toe

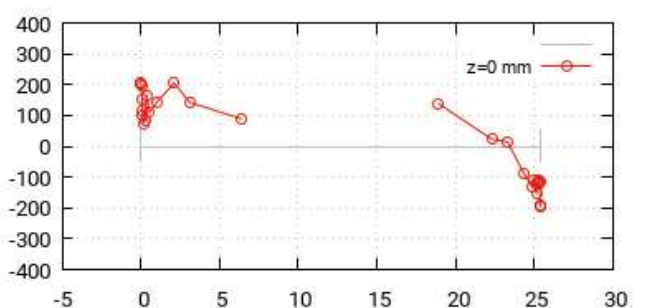
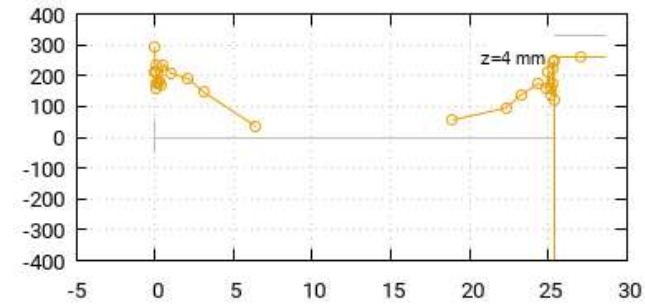
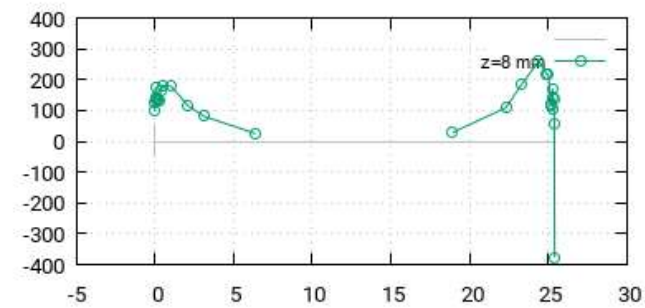
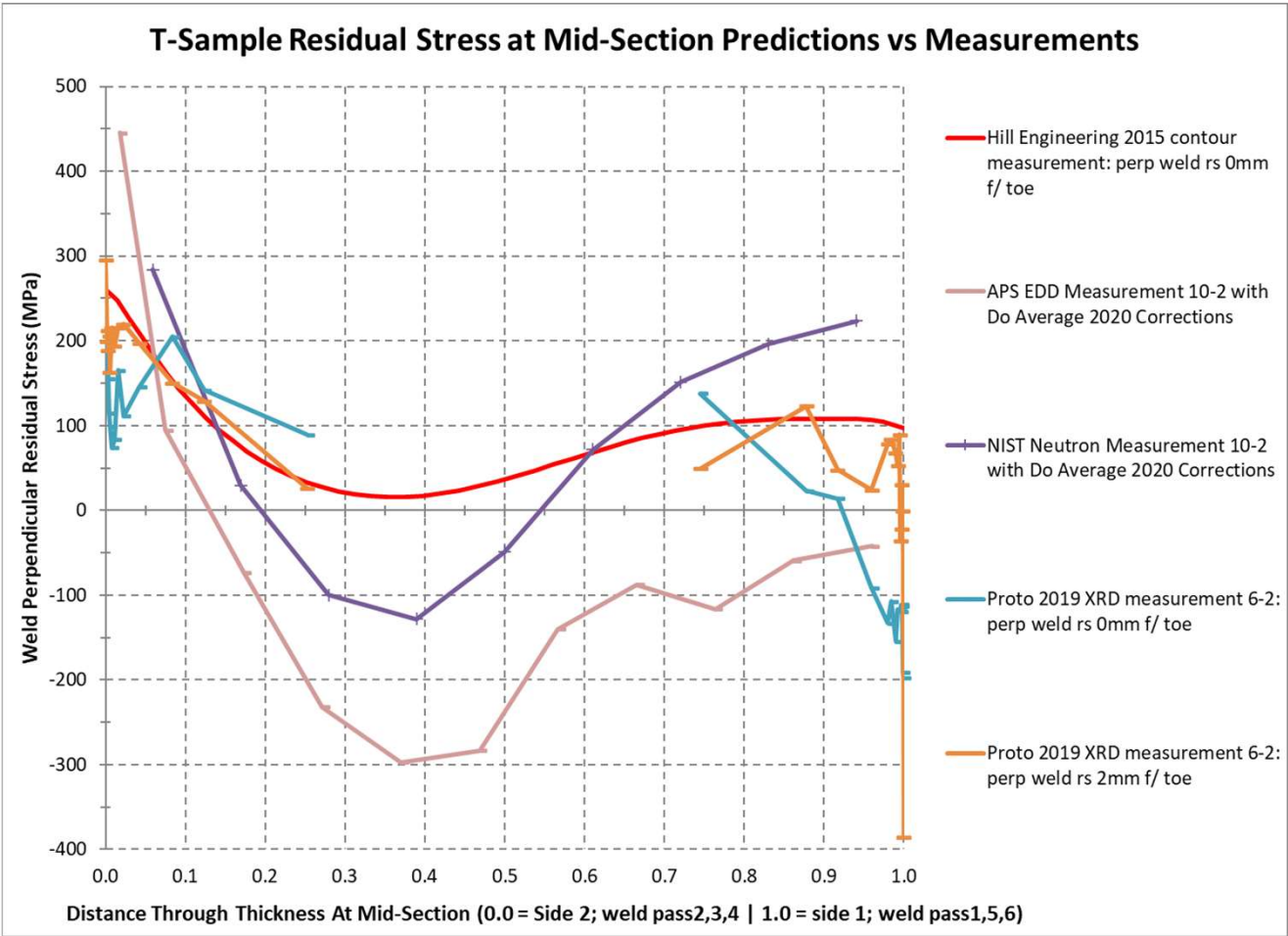




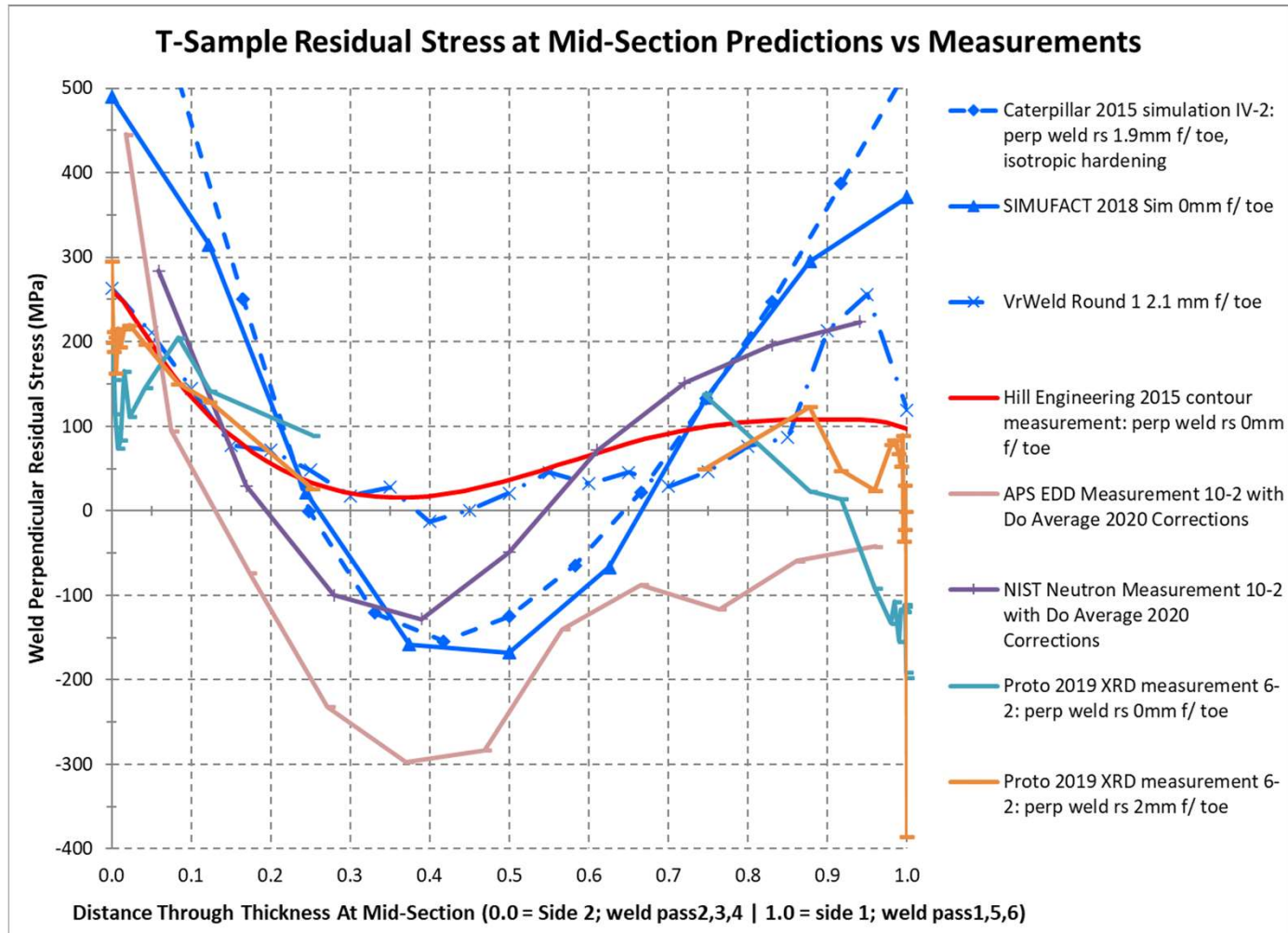
- XRD RS measurement profile locations
- initial measurements were performed in “as welded” condition.



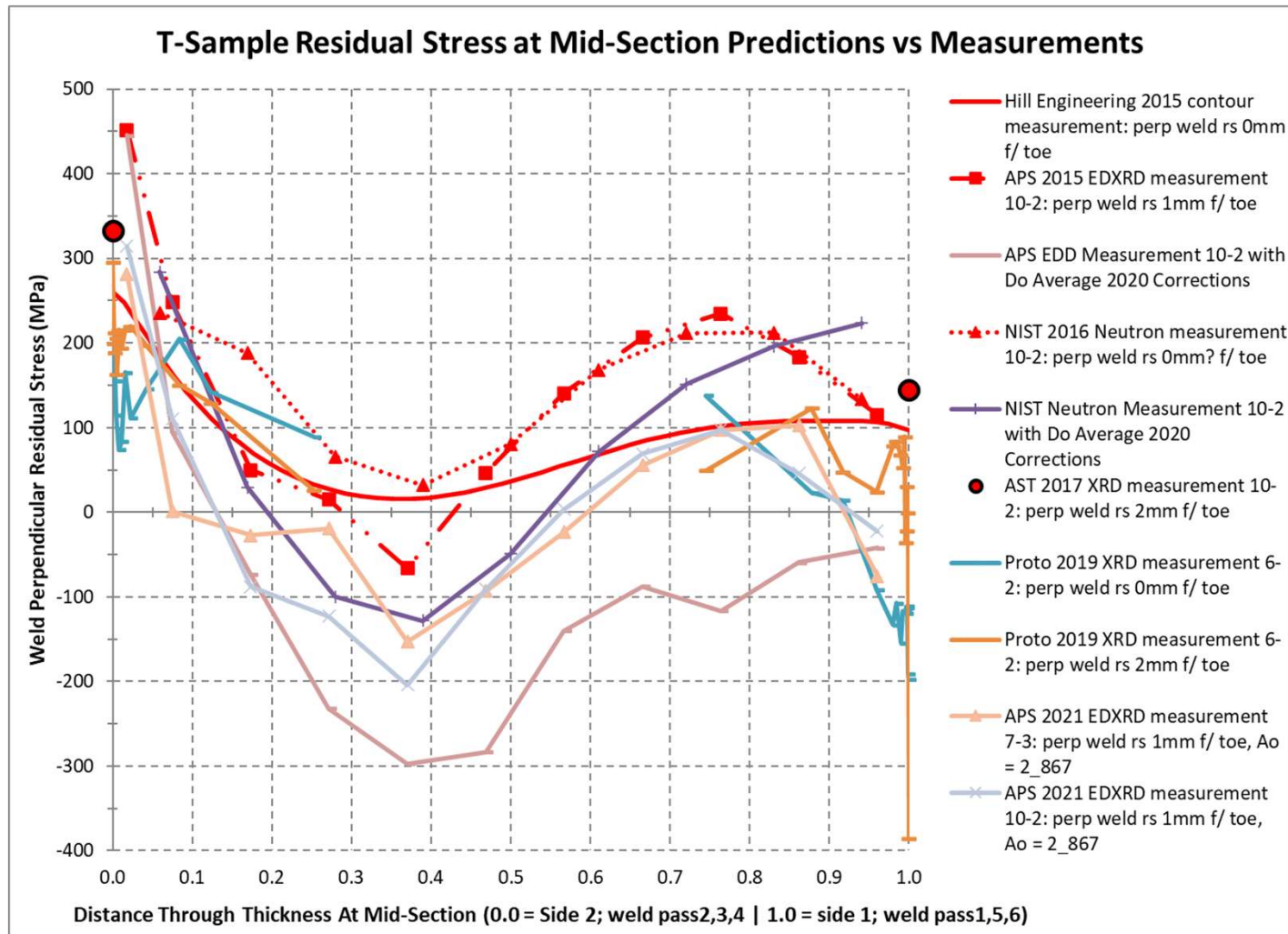
Option A: Residual Stress Profile as Welded



Option B : Residual Stress Profile

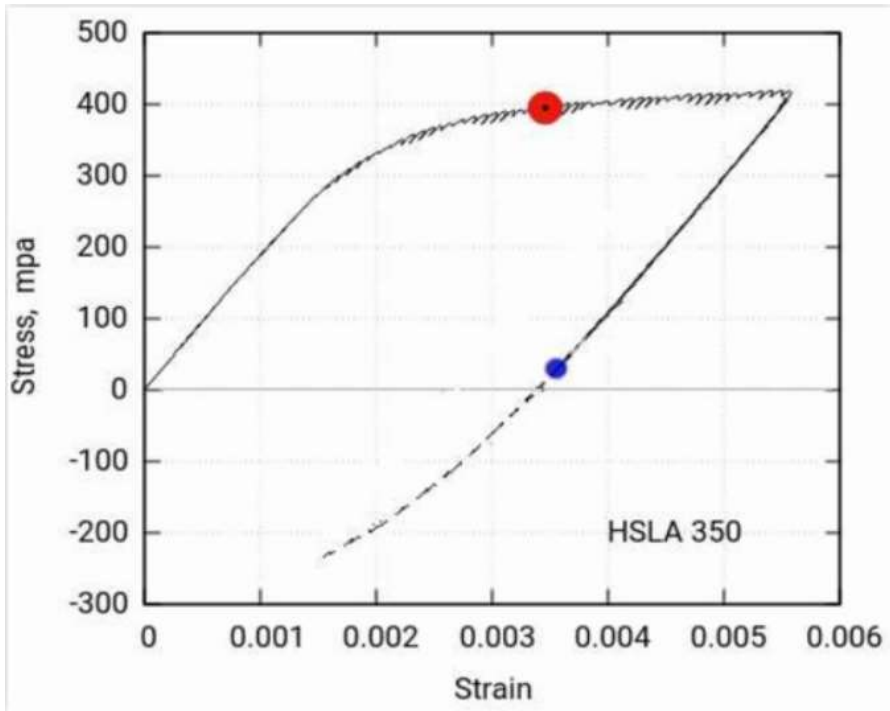


Option C : Residual Stress Profile

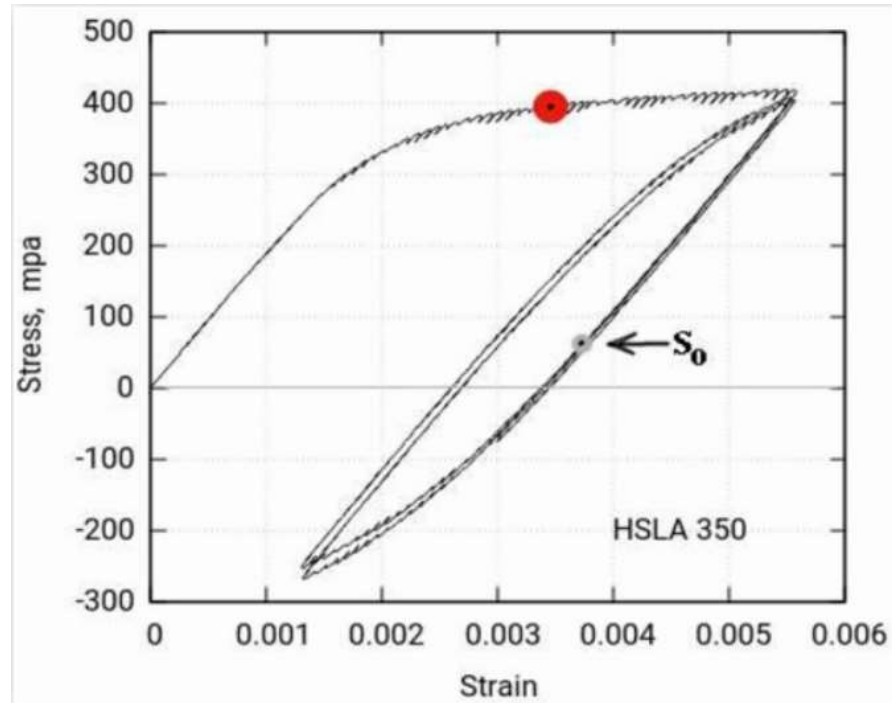


- Cracks typically initiate on the 0 side (sometime both)
- Problem for accurate predictions: What happens to the surface and subsurface RS when the T-bar is cycled in fatigue with hot-spot plasticity?
- Will RS relax?
- If so, by how much?

What is Cyclic Mean Stress Relaxation ?

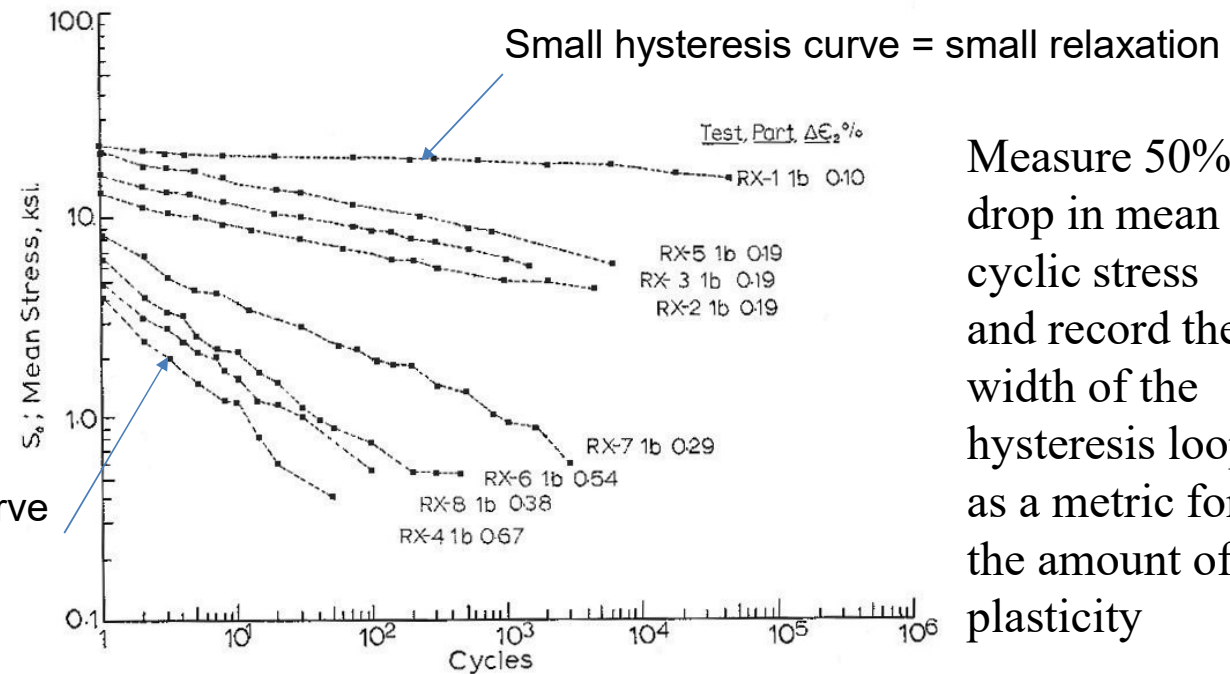
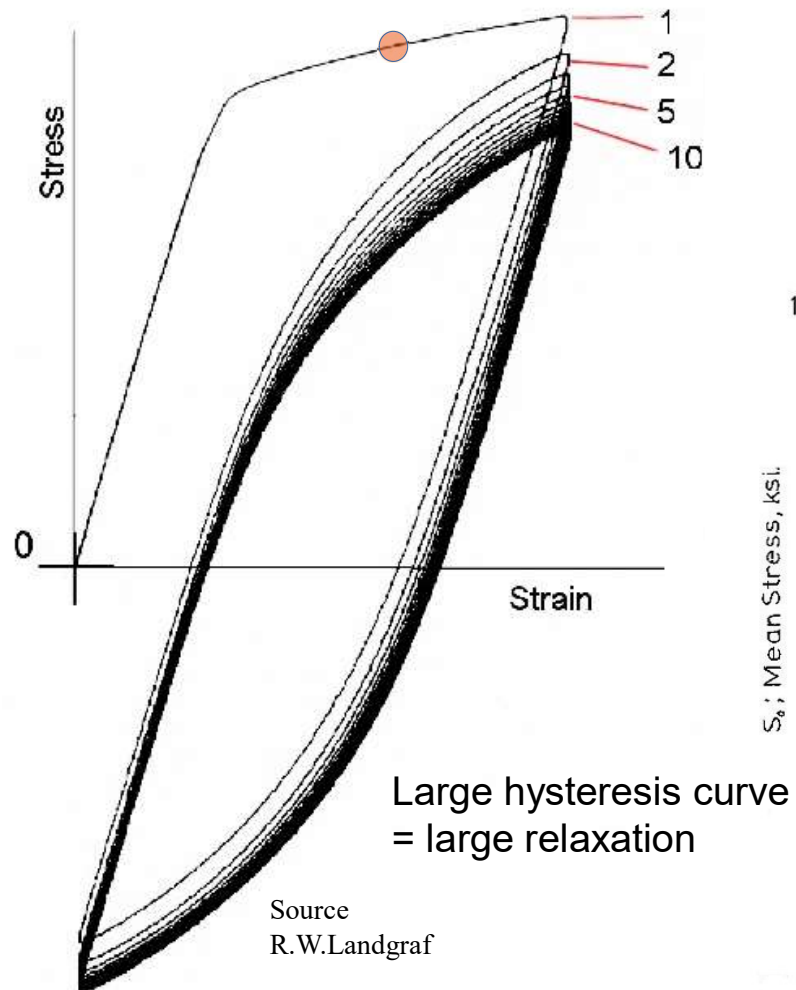


Red dot = RS near yield strength
Blue dot = RS after load and unload in tension – behavior material dependent

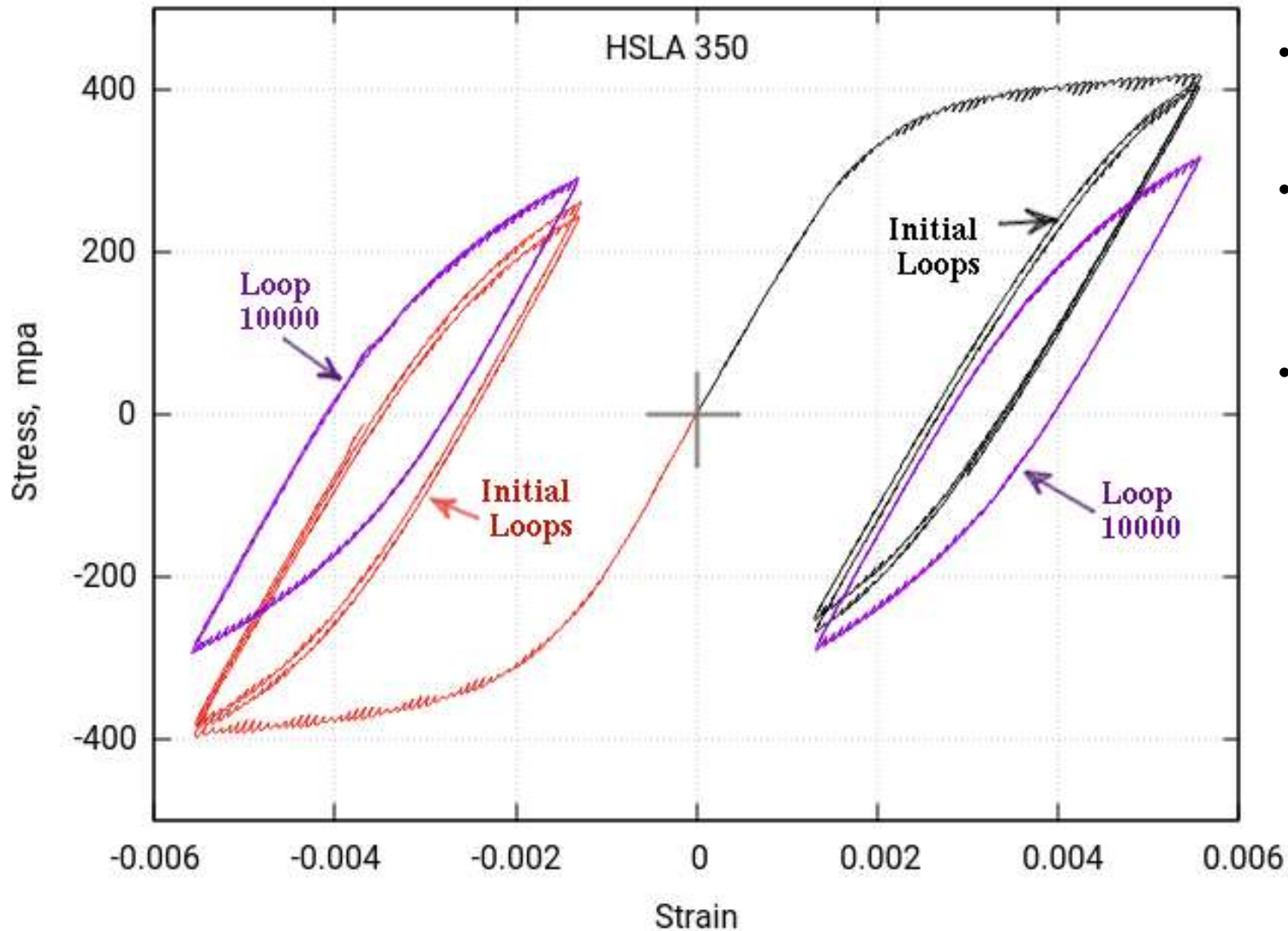


R = -1 cyclic loading hysteresis curve
 S_0 = mean cyclic stress

Cyclic Mean Stress Relaxation

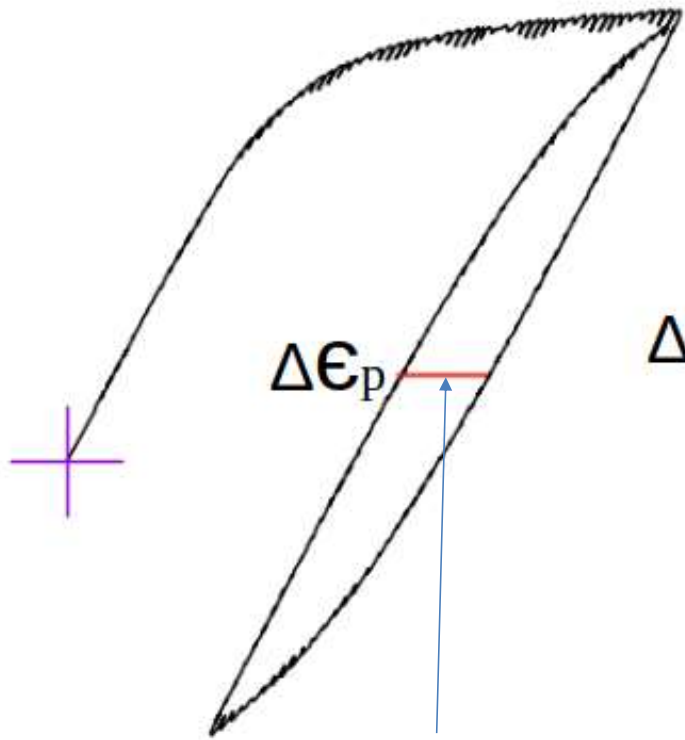


Measure 50% drop in mean cyclic stress and record the width of the hysteresis loop as a metric for the amount of plasticity

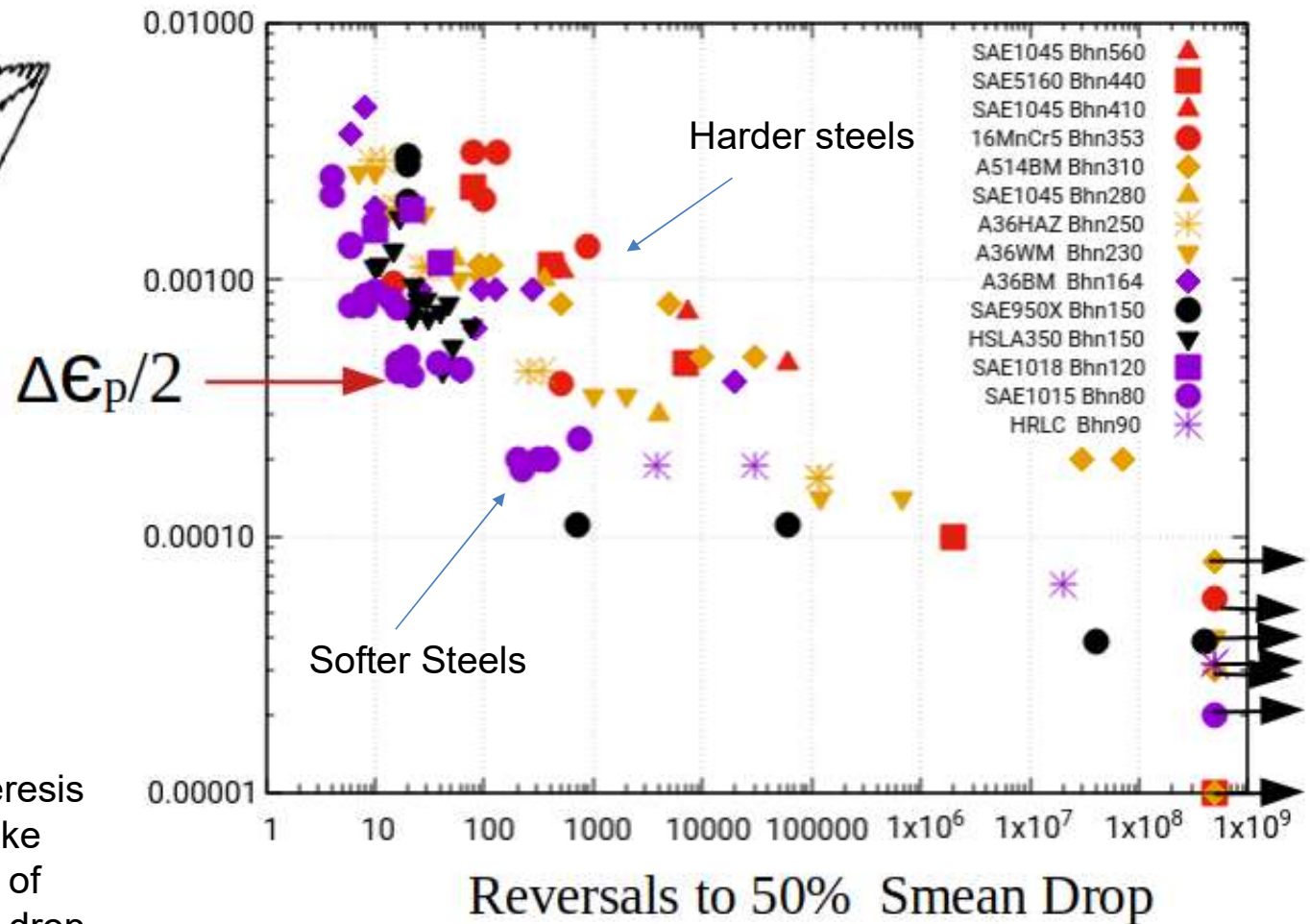


- Relaxation is similar in Tension or Compression
- Amount of relaxation is dependent upon the size of the hysteresis loops.
- In this example, after 10,000 loops the mean stress gets closer to zero

Historical data collected on cyclic relaxation in various steels



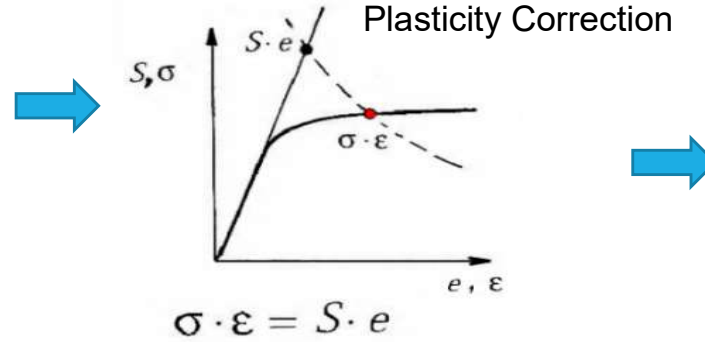
Estimate width of hysteresis loop /2 allows us to make predictions about the # of cycles needed for 50% drop in mean stress



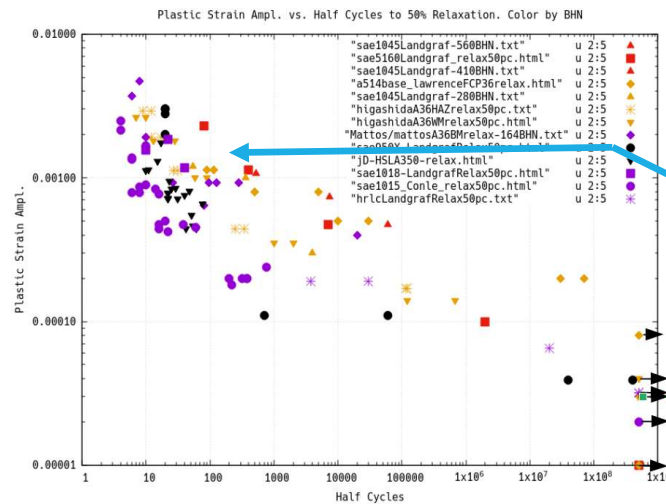
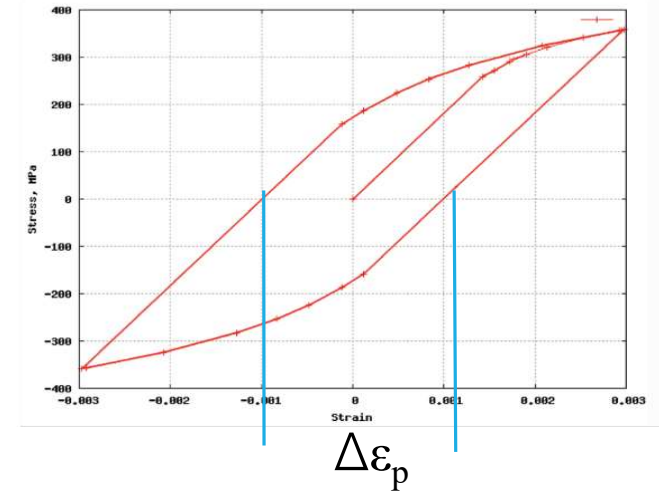
Summary of Suggested Process

- Estimate K_t based on the geometry
- Calculate S_{max} & S_{min} from loading

Specimen



Local Stress and Strain Response:

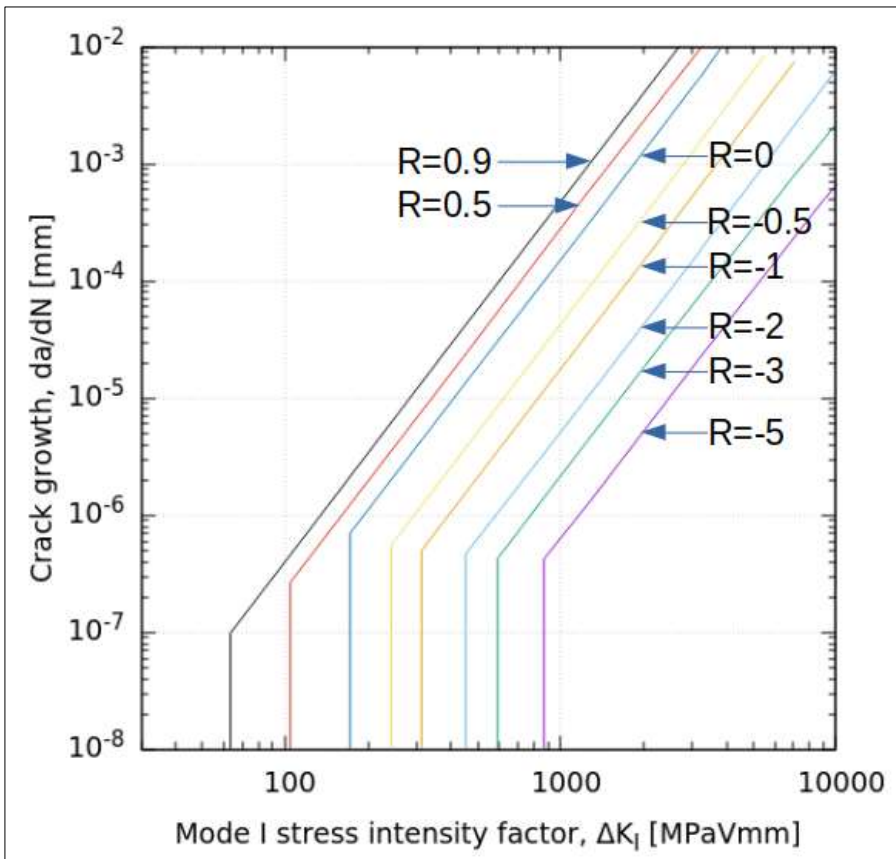


$\Delta\epsilon_p/2$

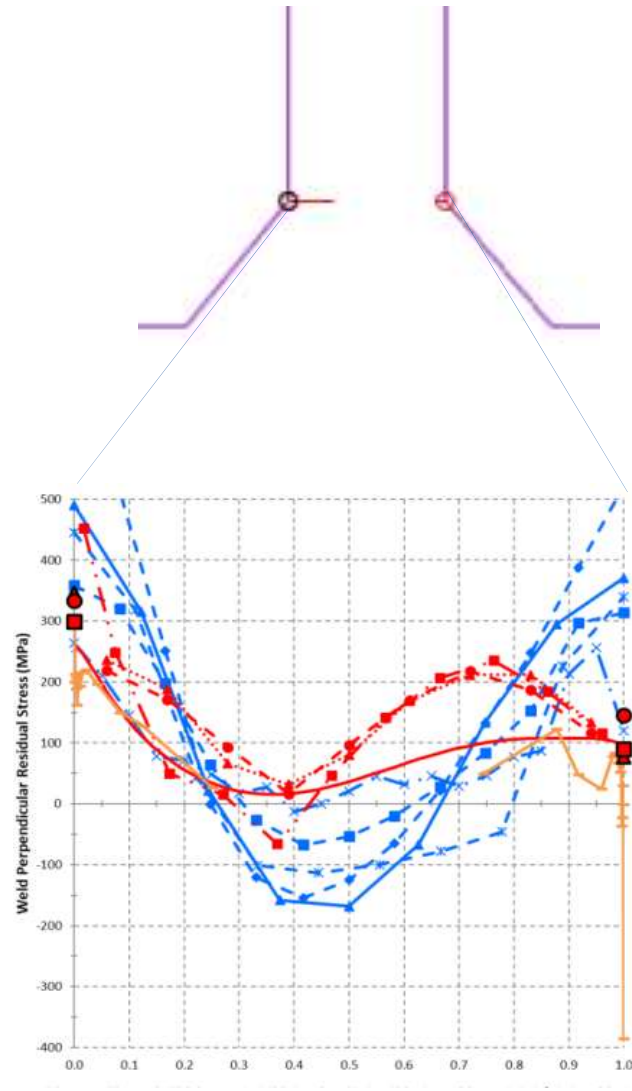
- Measure Plastic Strain Range
- Determine if relaxation is expected
- Compute expected life accordingly using 50% mean stress drop data

Why is Mean Stress of Interest? Life Prediction

Hasegawa's lines based on ASME



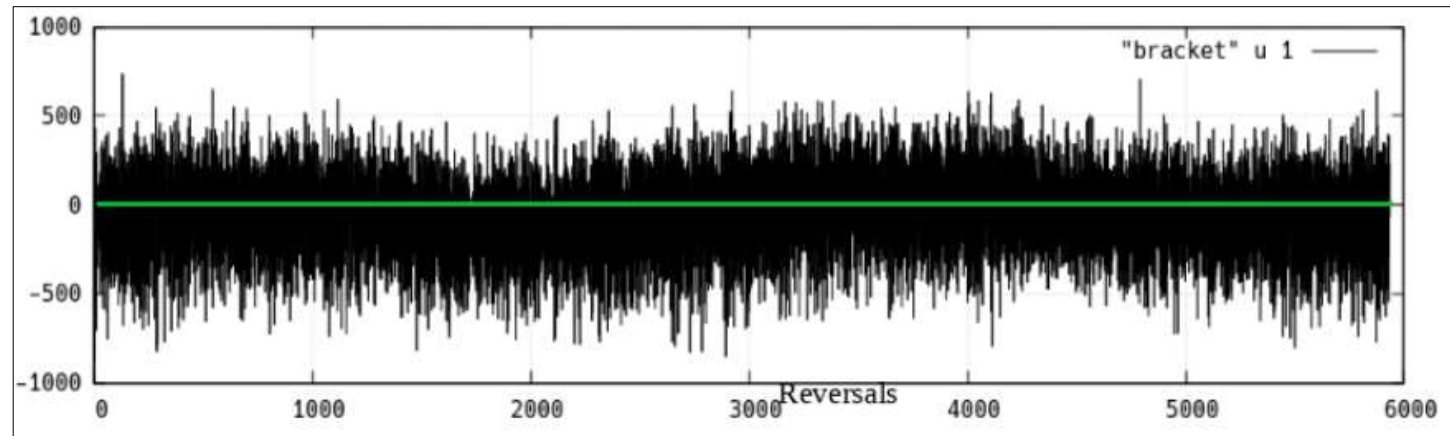
Source: Carol Liang's PhD thesis



- $R=-1$ is fully reversed loading
- Determine how quickly a crack will initiate and propagate
- If we have tensile residual stress, different da/dN lines will be activated and we will accumulate damage faster

Variable amplitude loading

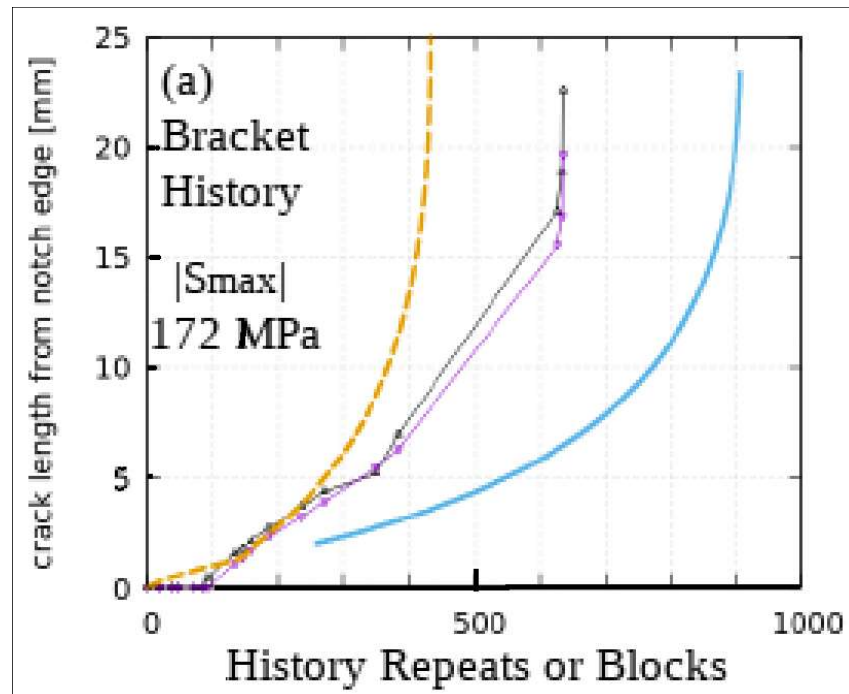
- Look for peaks
- Calculate plastic strain amplitude from hysteresis loops
- Decide if the RS will relax or not



Crack Length vs. # of Blocks

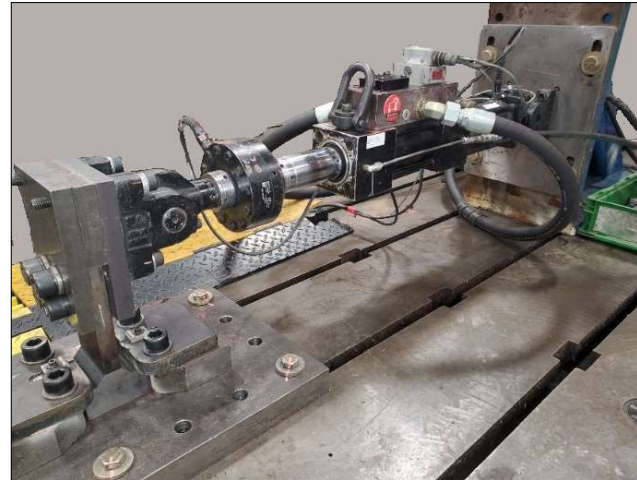
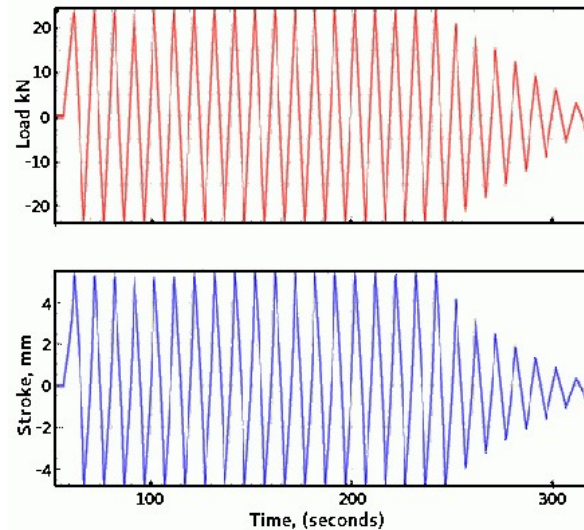
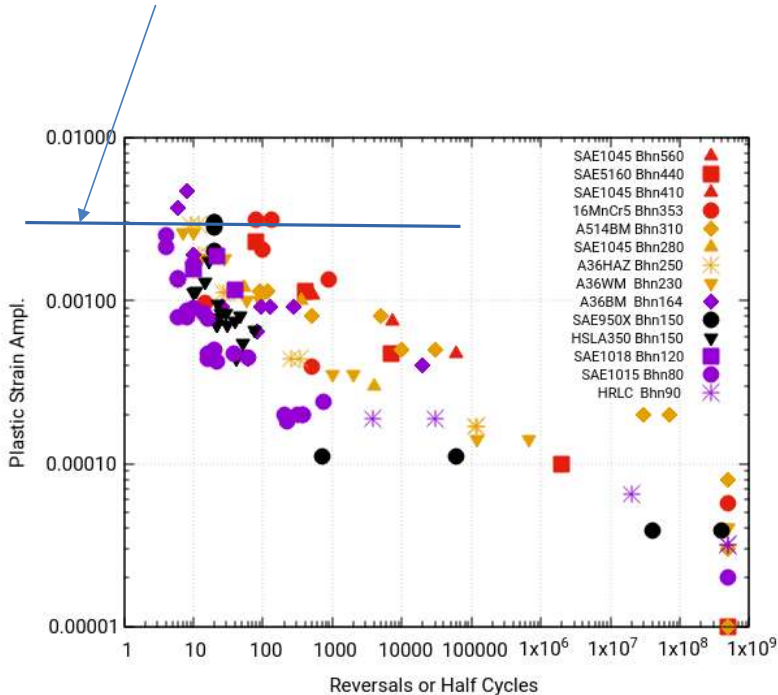
- Fine tuning predictions with RS should help better match to experimental data

(examples shown for a different sample)

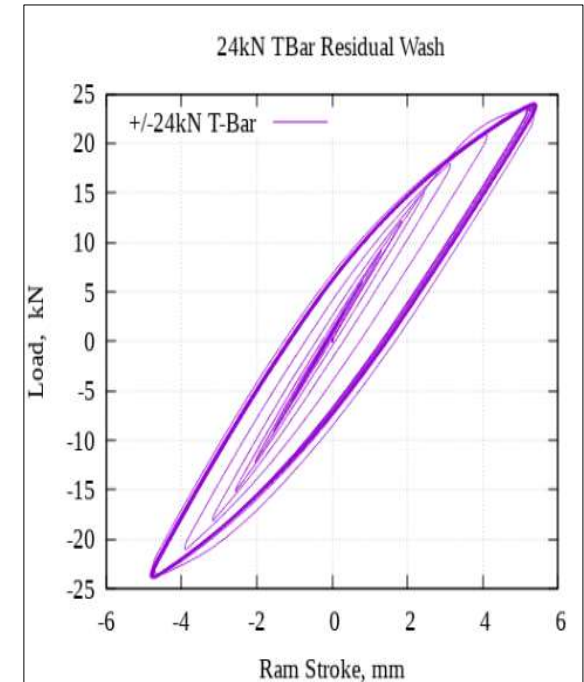


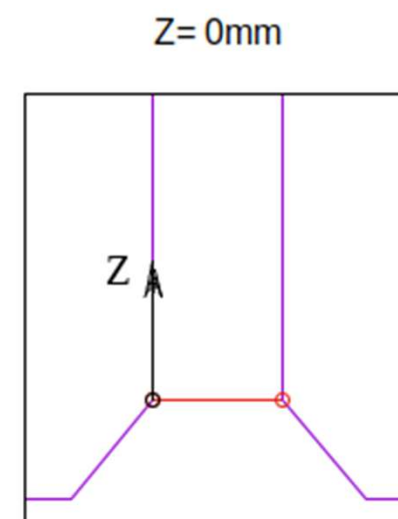
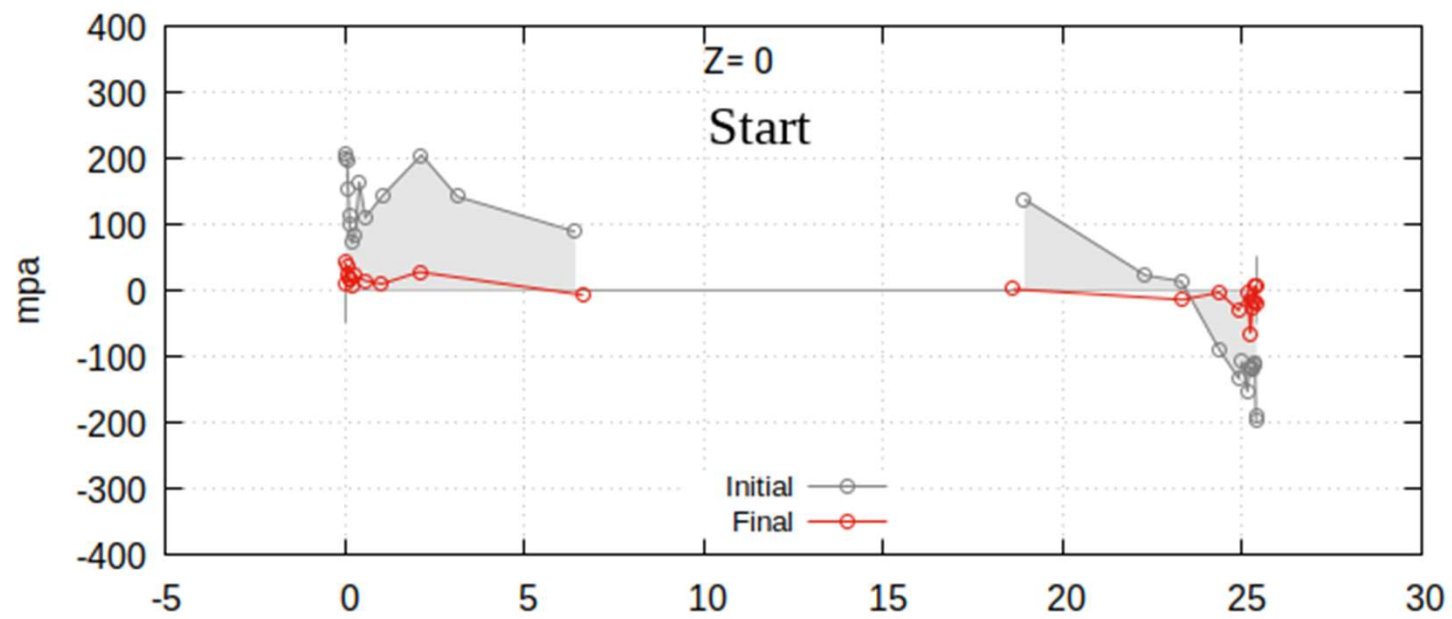
Test

- Check to see how much RS relaxation occurred for the chosen test level vs. expected So relaxation
- Chosen hot-spot load level

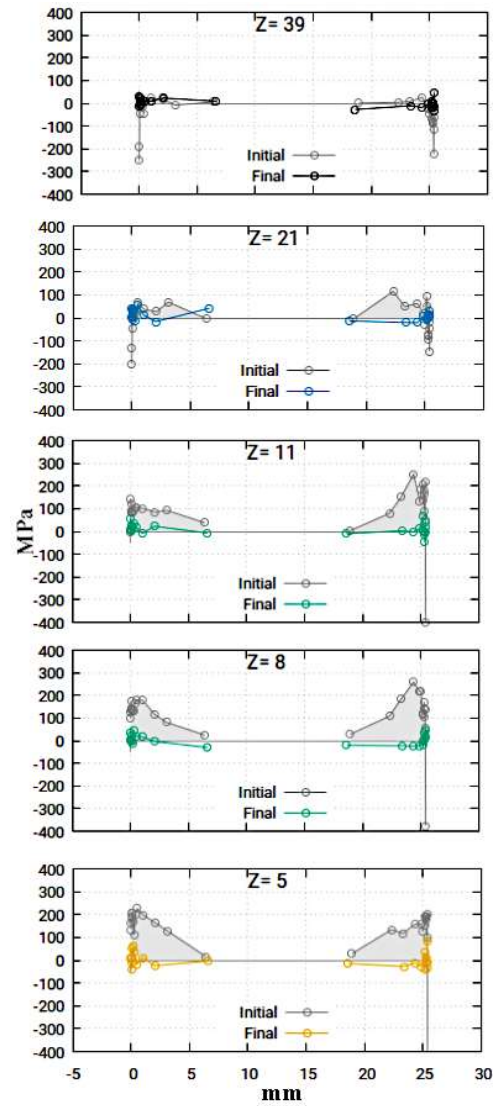
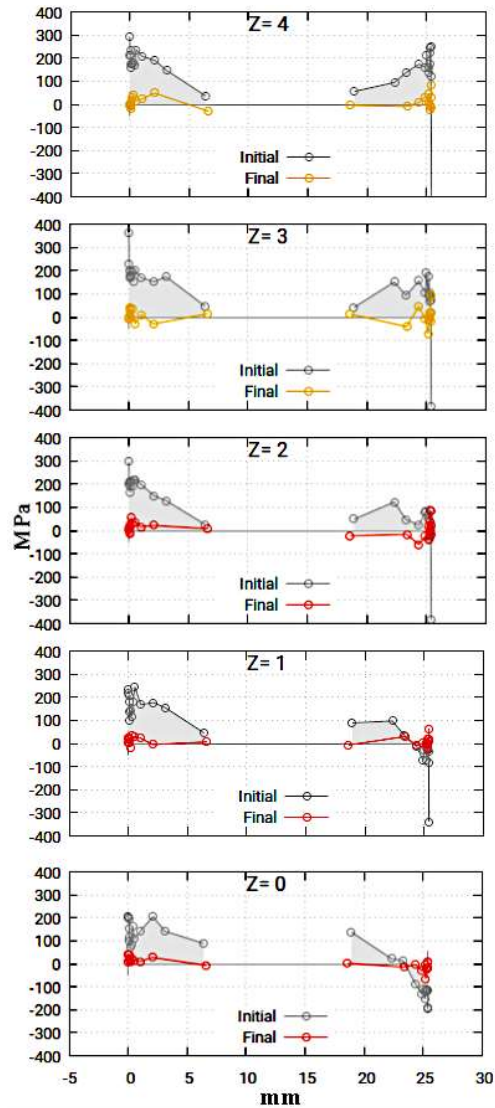


- Load 20 cycles then taper
- Stopping on big hysteresis loop creates a RS
- Taper brings RS back to that from welding only rather than from the deformation sequence

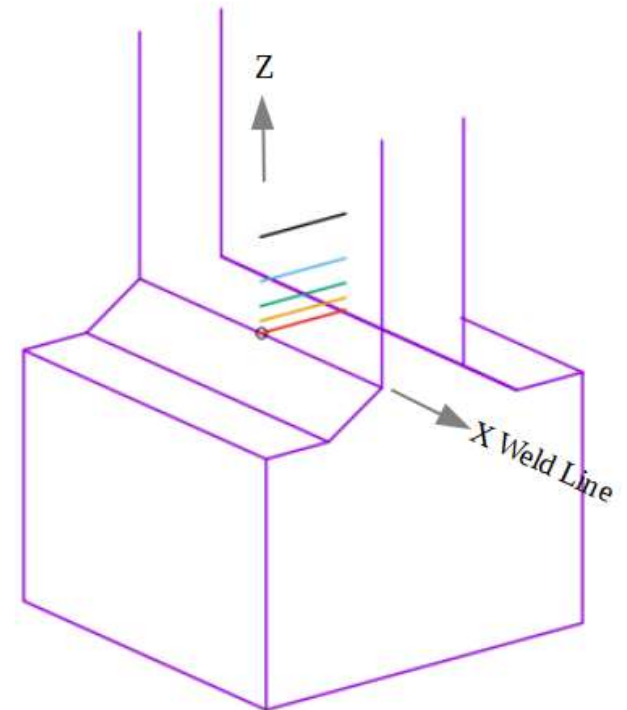




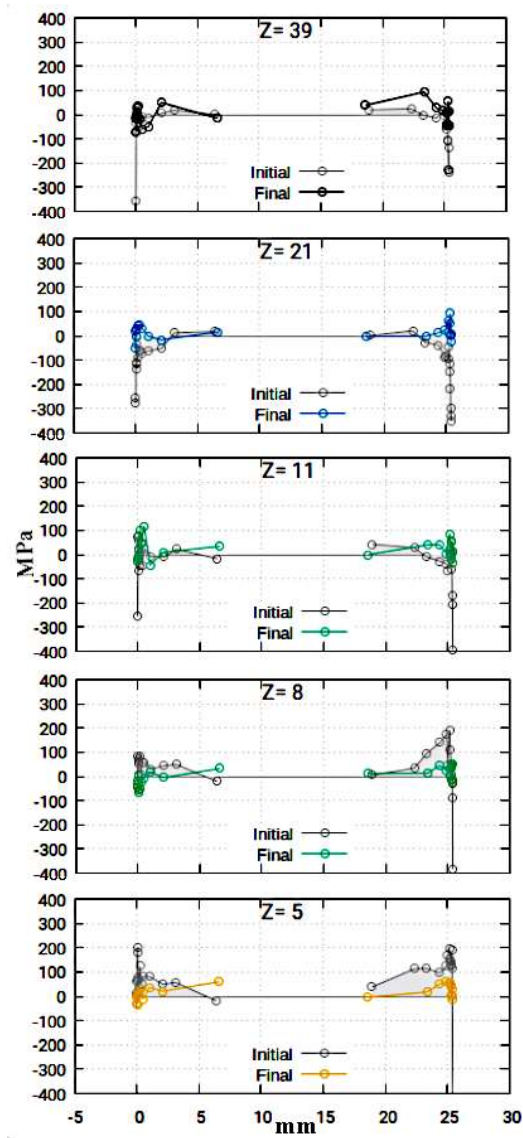
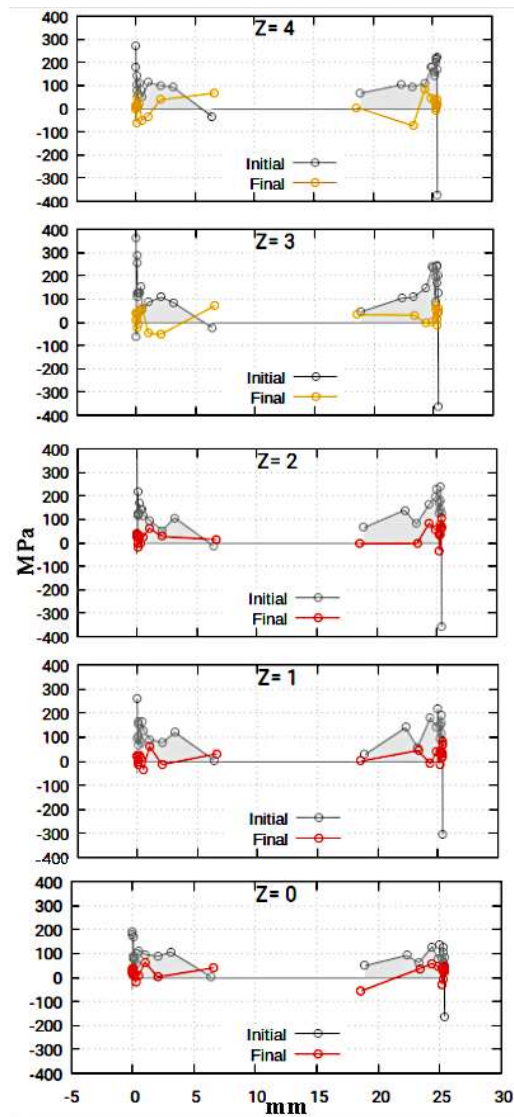
Results



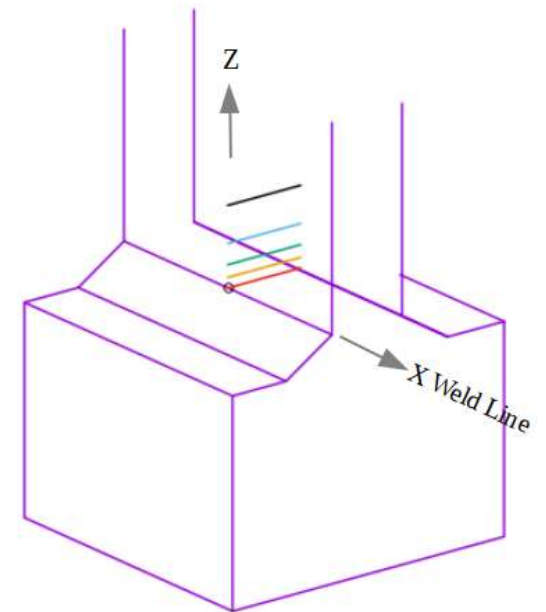
Z Direction Residuals



Results



X Direction Residuals

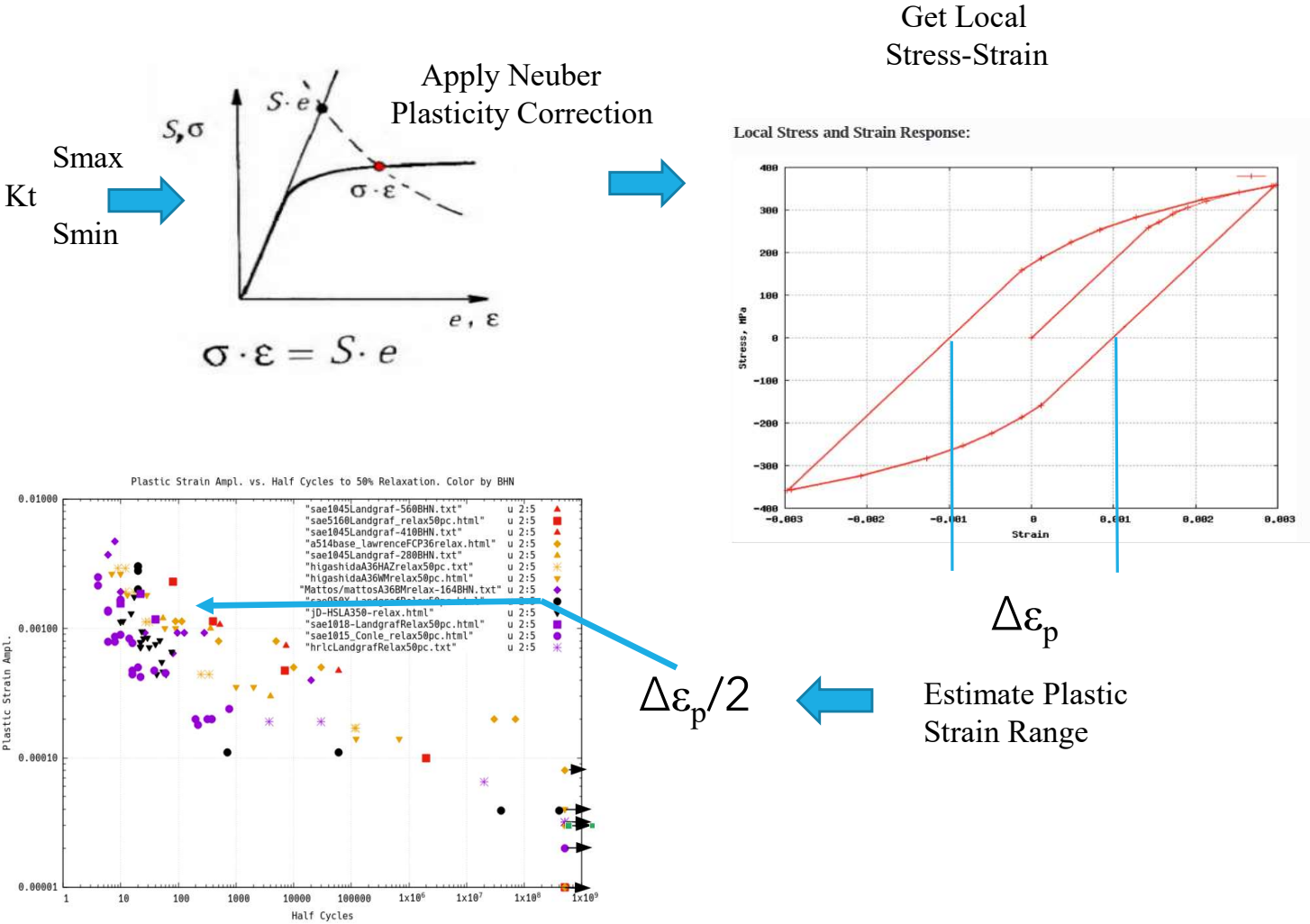


Suggested Process for crack initiation or propagation simulations



Determine if
relaxation is
expected.

Compute life
accordingly.



Future Work



Perform additional RS measurements for “in between” load levels where RS will not be completely wiped out

Fine tune and further compare inter-method comparisons (probably will be another paper on this in more detail)

Use “as-welded” and “relaxed” RS to fine tune crack initiation and propagation predictions

Speaker information



Thank you

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Speaker information



Thank you

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