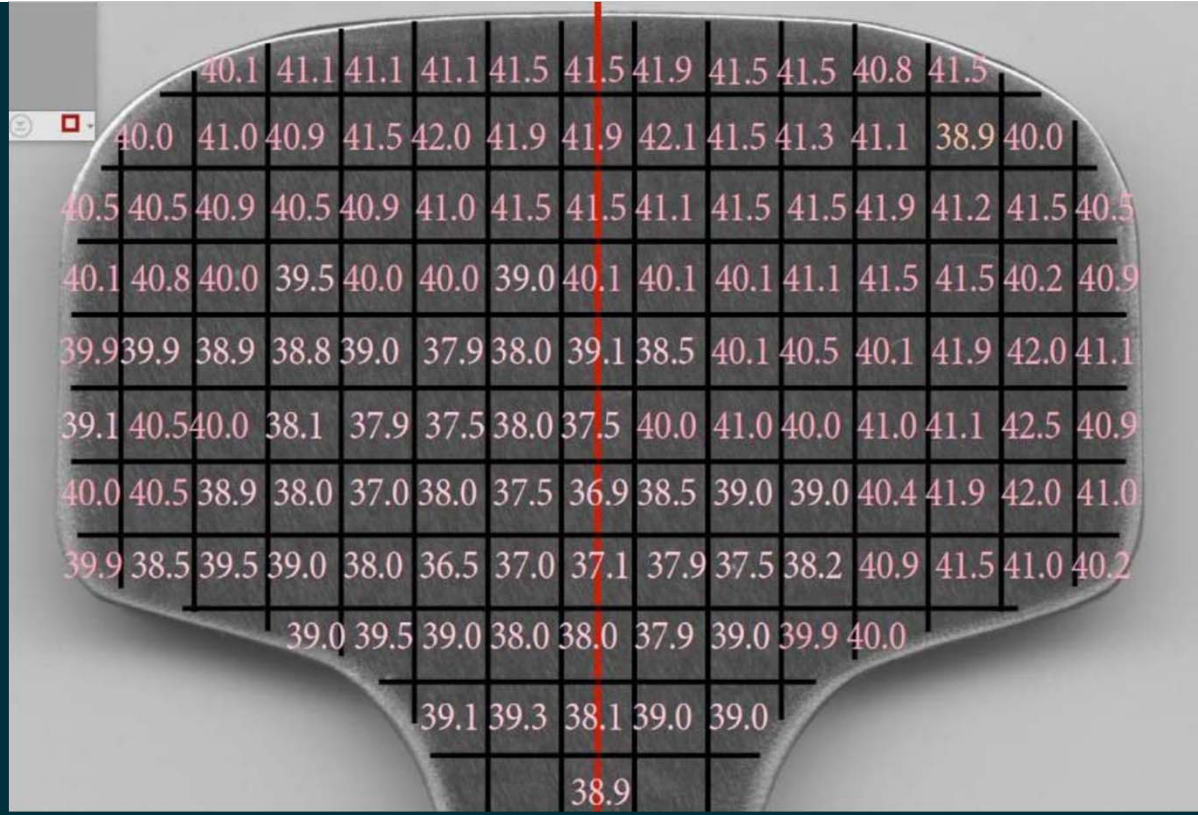
22 APRIL 2021

ICRI Presentation:

Defect Growth Characterization in Modern Rails



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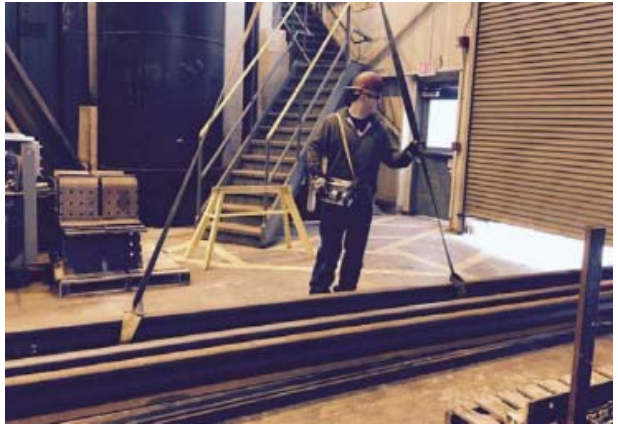
IWM

LABORATORY TESTING INC.

INTRODUCTION

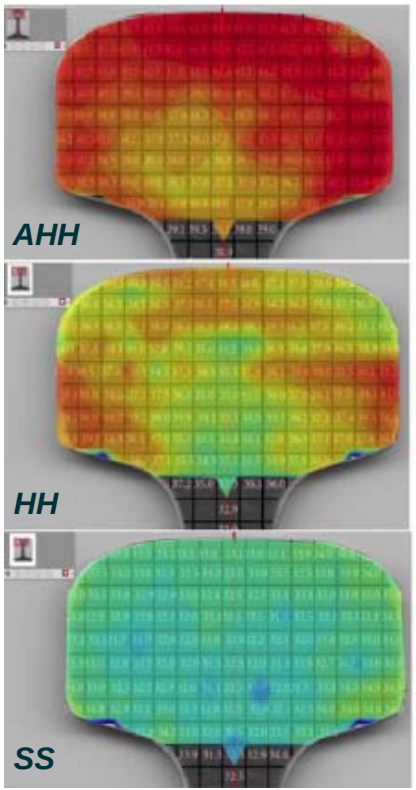
Rail Type	Designation	Manufacturer	Weight	Heat Treatment	Wear
Modern	**AHH** Advanced Head Hardened	ArcelorMittal	136 RE	Head hardened; fast cooled	New
Modern	**HH** Head Hardened	ArcelorMittal	136 RE	Head hardened	New
Modern	**SS** Standard rail	ArcelorMittal	136 RE	Control-cooled	New
Legacy	**CF&I77**	Colorado Fuel & Iron, 1977	136 RE	Control-cooled	Never used
Legacy	**HAY84**	Hayange Steel (currently Tata Steel)	136 RE	Vacuum heat treated and degassed	Never used

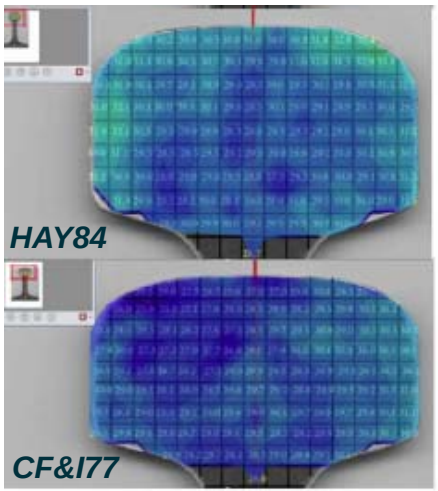


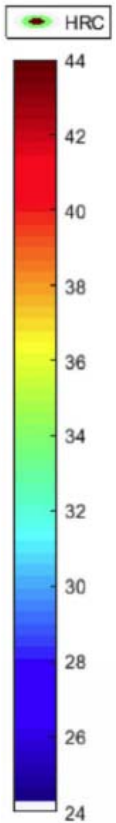
AM rails at ATLSS Labs Lehigh University

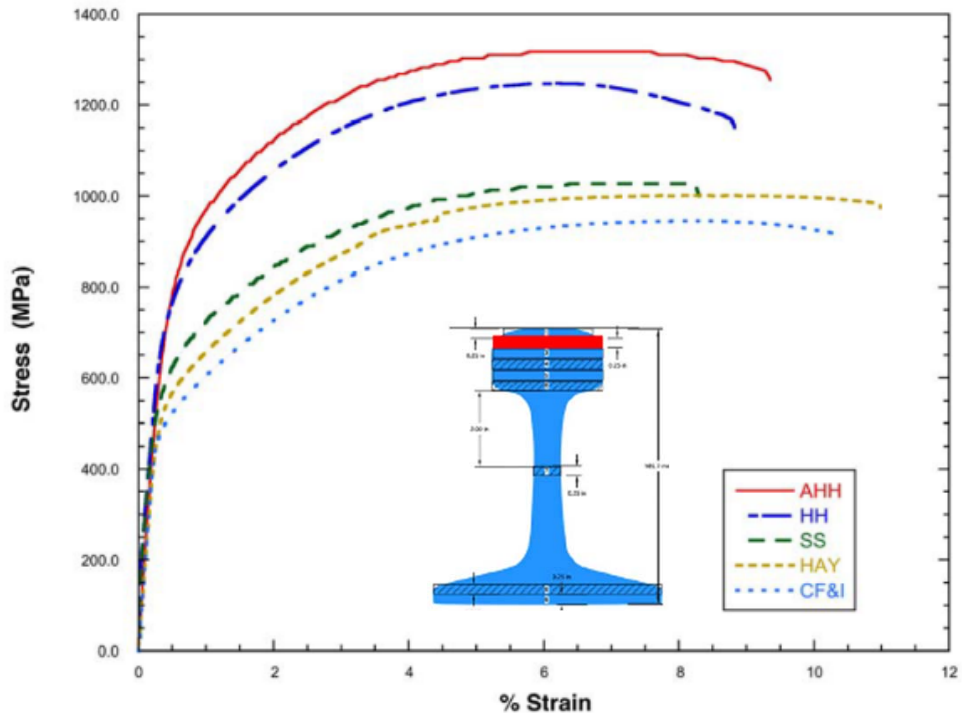
- Current inspection interval based on *LEGACY* rails: 40 MGT
- Modern rails – pearlitic, head-hardened
- *What is the effect of head-hardening on the rails steel properties?*

BASIC PROPERTIES

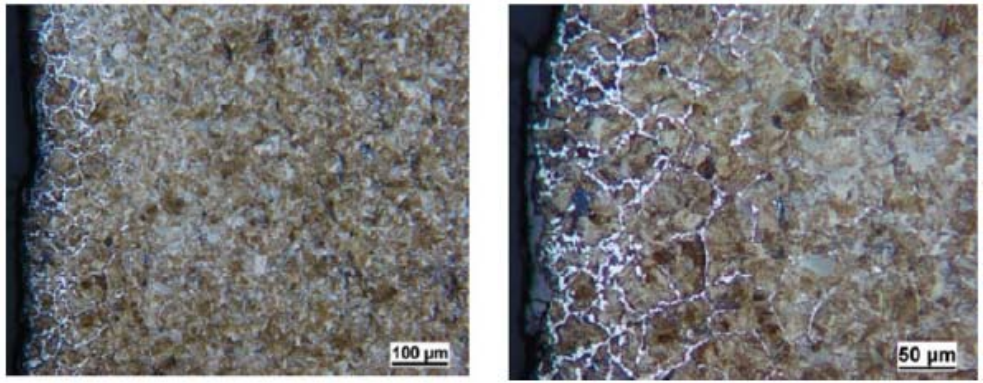




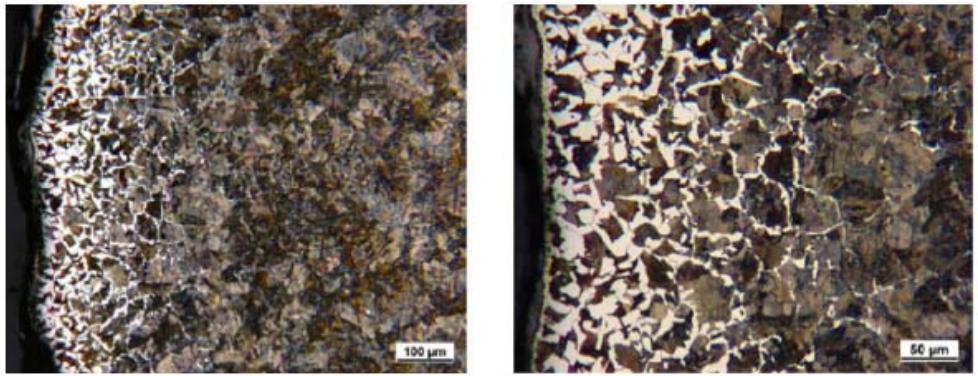




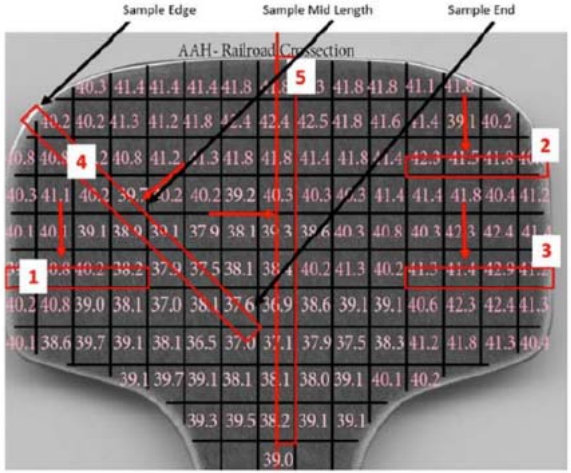
MICROSTRUCTURAL OBSERVATIONS



LOM Sample 4 from **AHH** rail at the outer edge of sample

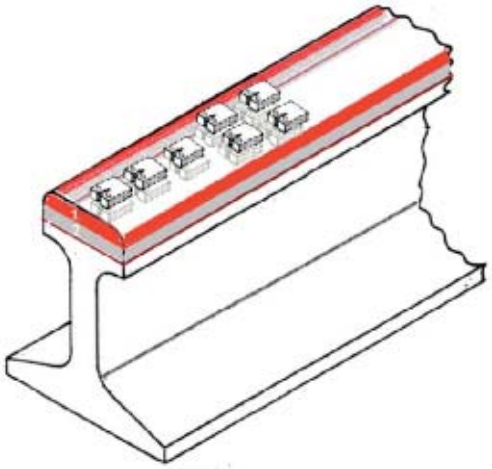


LOM Sample 4 from **HAY84** rail at the outer edge of sample



- Uniform pearlitic microstructure, except near the head surface
- Decarburization – carbon depleted zones caused by high temperature processing – not a significant effect

FRACTURE TOUGHNESS

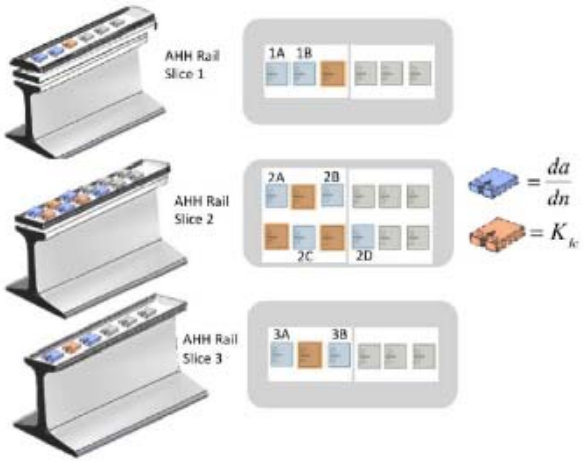


CT specimens cut from horizontal slices in the rail head

Depth in mm	AHH	HH	SS & HAY84	CF&I77
6.5	40.0	37.1	36.1	44.3
19.5	34.7	36.0	32.8	37.0
32.0	38.8	42.1	36.2	42.6

- Relatively small toughness variation across all rails
- Variation within each rail head similar to variation across all rails

CRACK GROWTH RATE



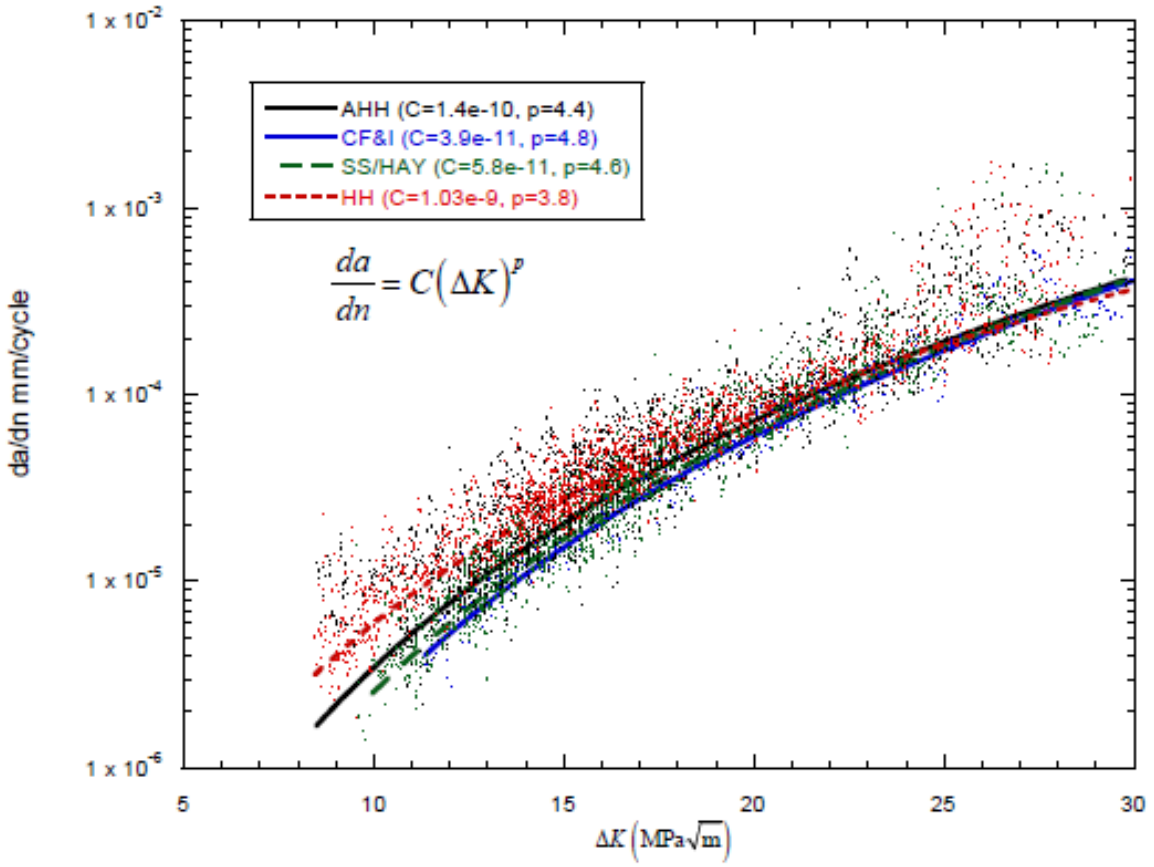
Legacy rails (Jeong et al.)

$$\frac{da}{dN} = C\frac{\Delta K^p}{(1-R)^q} \qquad \begin{aligned} C &= 10^{-11} \\ p &= 4 \\ q &= 1.63 \end{aligned}$$

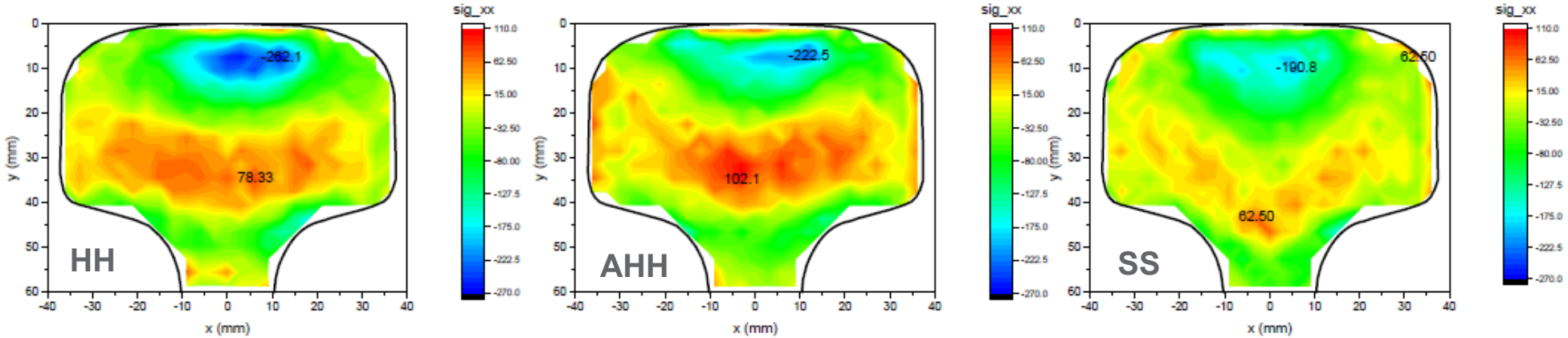
AHH – current study

$$\frac{da}{dn} = C\frac{(\Delta K)^p}{K_c - \Delta K}$$

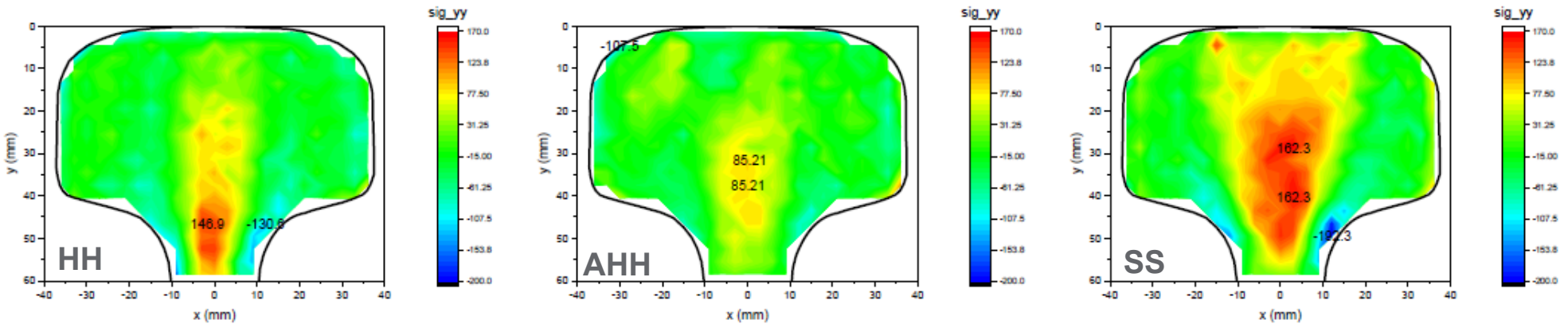
$$C = 3.69 \times 10^{-7},\ p = 2.52,\ K_c = 29.4.$$



RESIDUAL STRESS

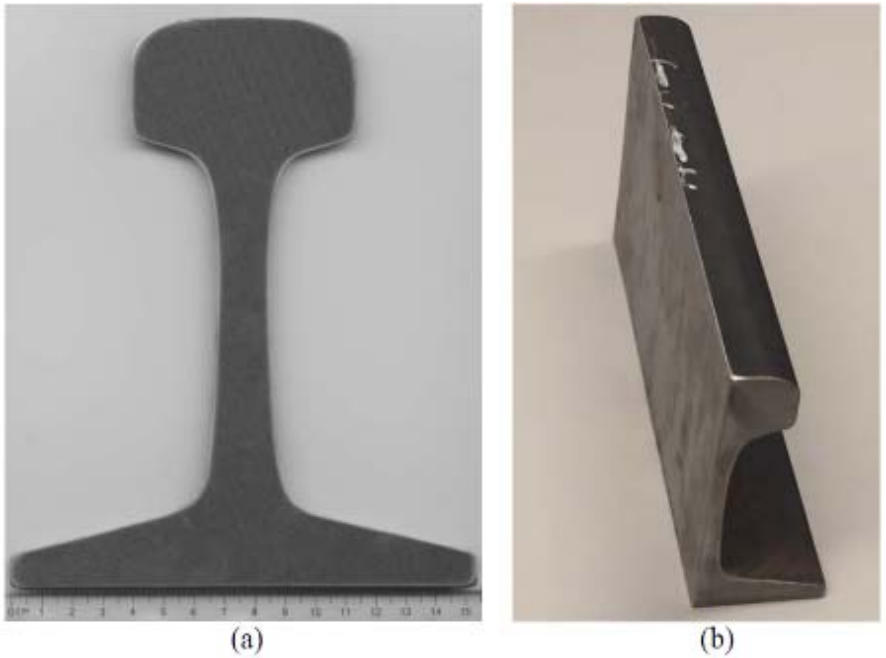


Lateral residual stress component σ_{xx} in rails

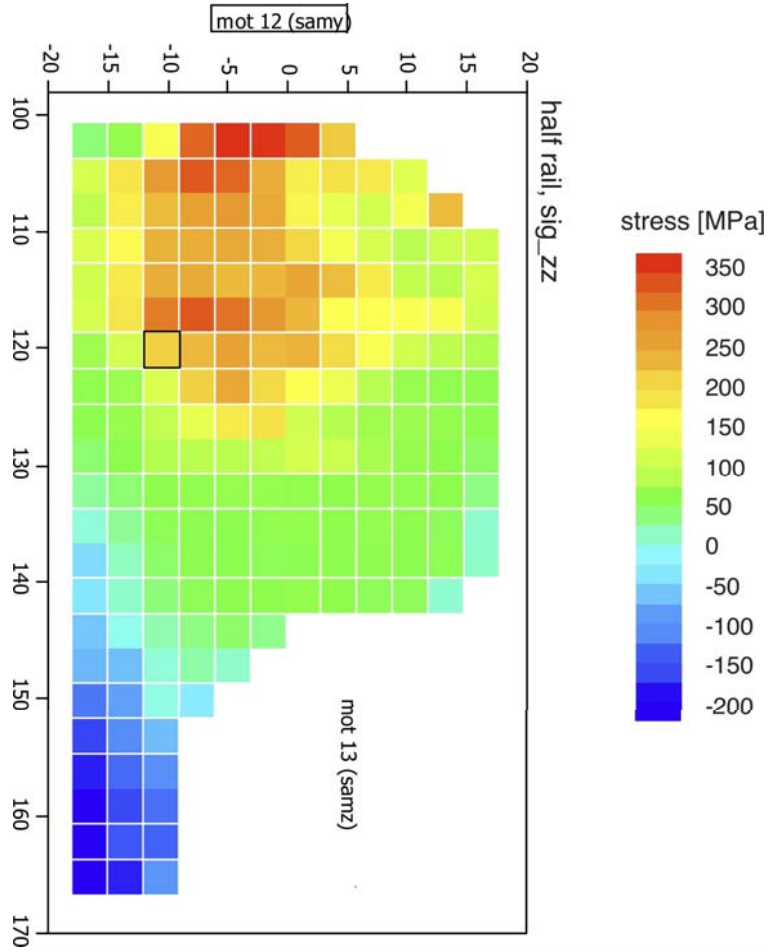


Transverse residual stress component σ_{yy} in rails

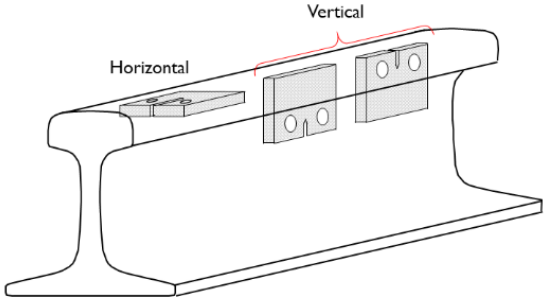
LONGITUDINAL RESIDUAL STRESS (AHH)



Specimens for residual stress measurement (a) planar, (b) half rail 300mm long

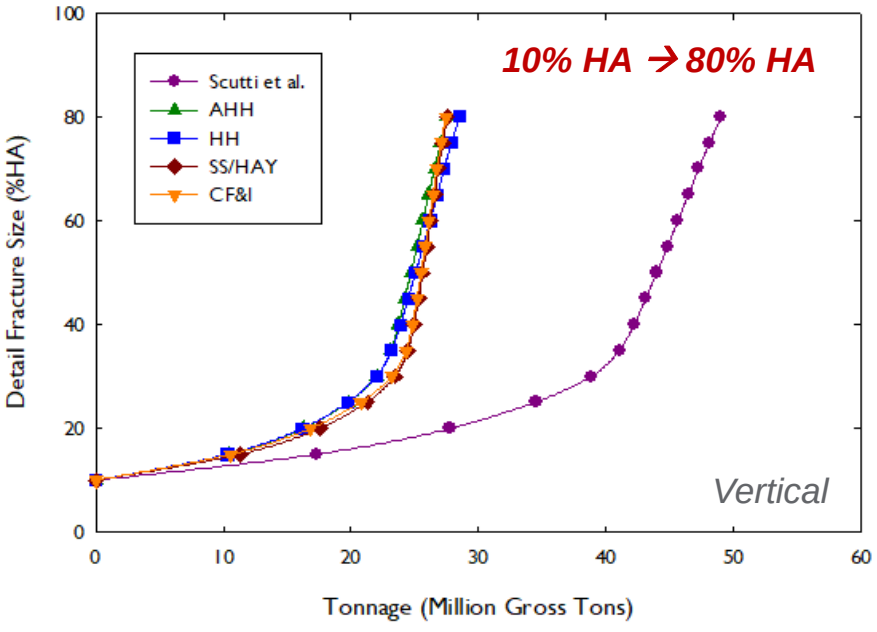


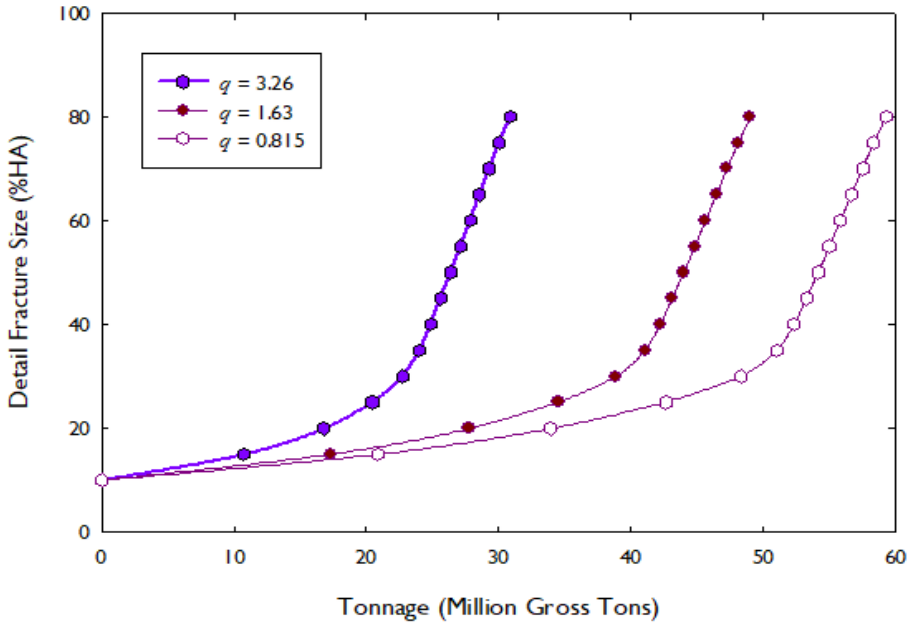
CRACK GROWTH ANALYSIS



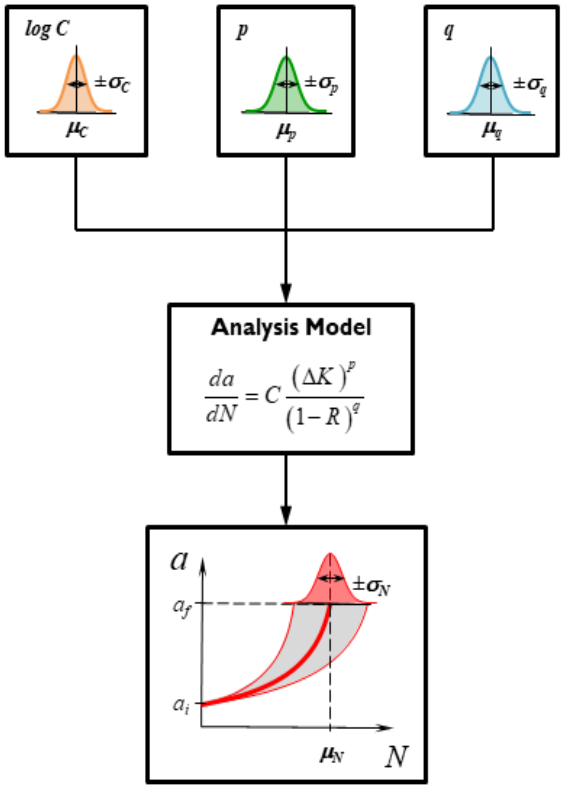
Rail Steel	*Slow Crack Growth Life (MGT)*
AHH	27.5
HH	28.5
SS/HAY	27.5
CF&I	27.4
Scutti *et al.*	49.0

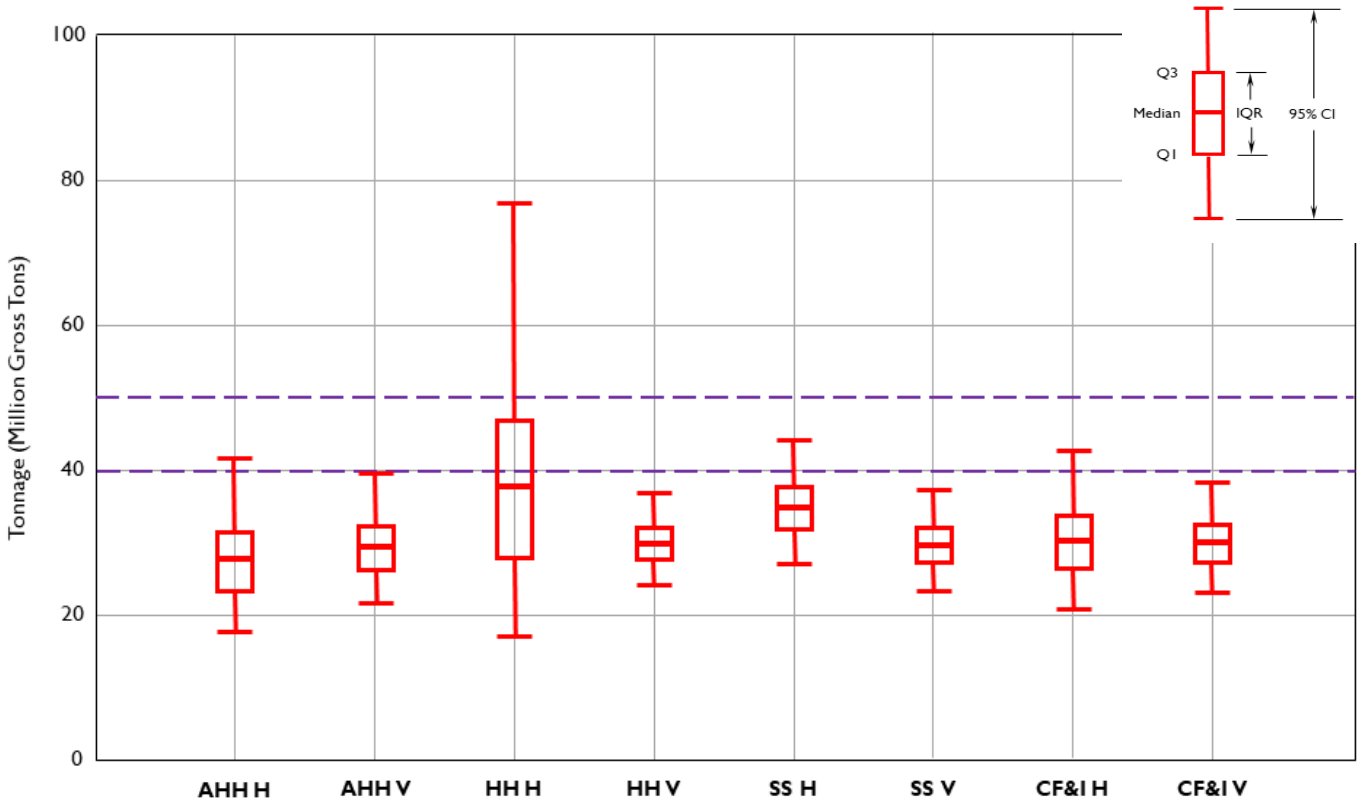
All rails analyzed with the same residual stress



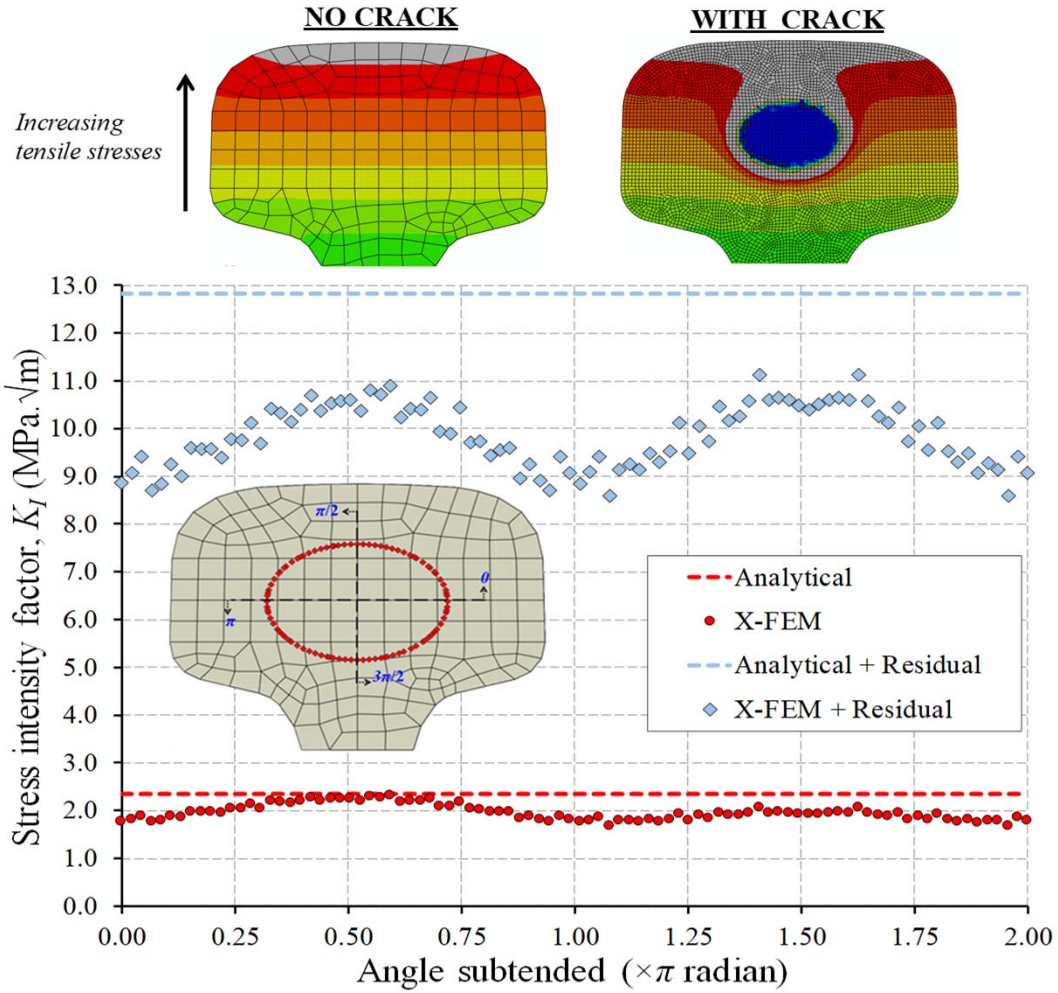


PROBABILISTIC CRACK GROWTH ANALYSIS



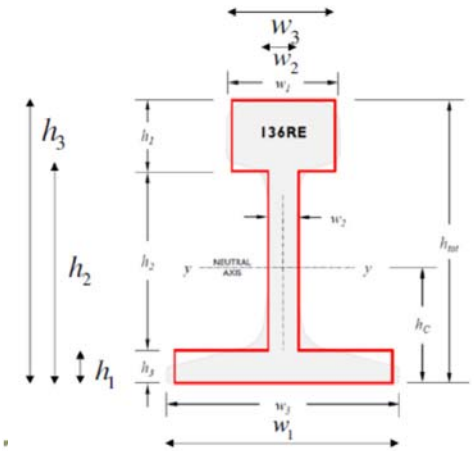


DETAILED ANALYSIS OF THE SIF



- Analytical model is conservative (as intended)
- Detailed simulation to assess the consequence of initial assumptions
- Improving the accuracy would produce longer life predictions

ROLLER STRAIGHTENING – WIP



Dimensional

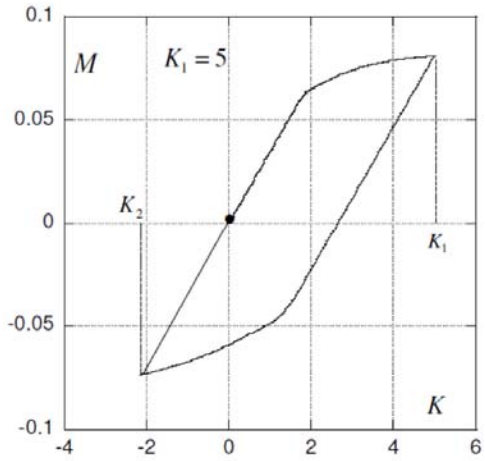
$\bar{w}_1 = 5.626$ *inches*, $\bar{h}_3 = 7.312$ *inches*

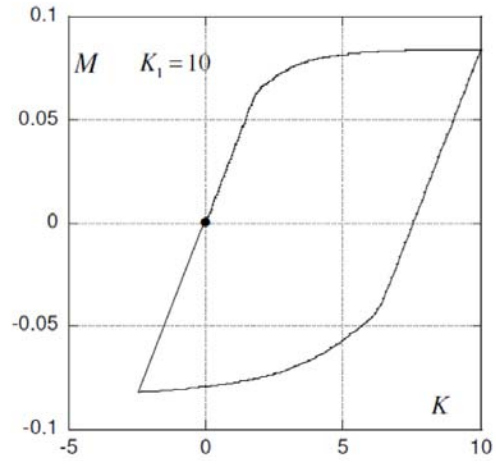
Dimensionless geometry

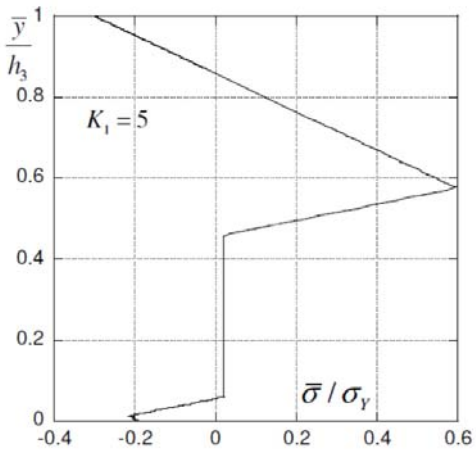
$w_1 = 1,\ w_2 = 0.139,\ w_3 = 0.474$

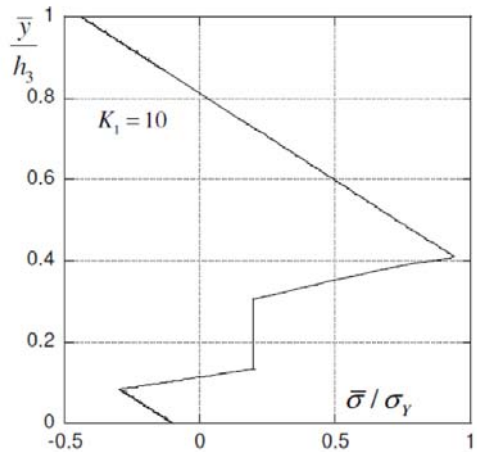
$h_1 = 0.118,\ h_2 = 0.751,\ h_3 = 1$

These refer to the larger font symbols









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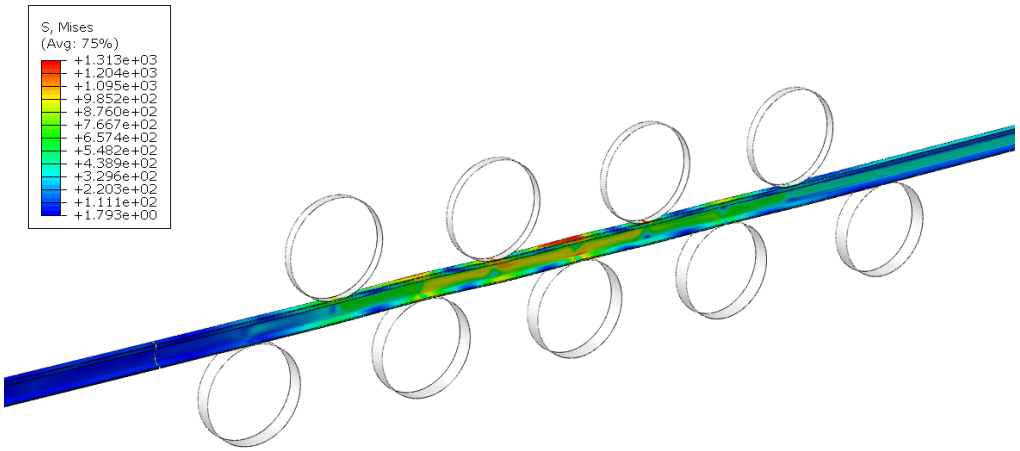
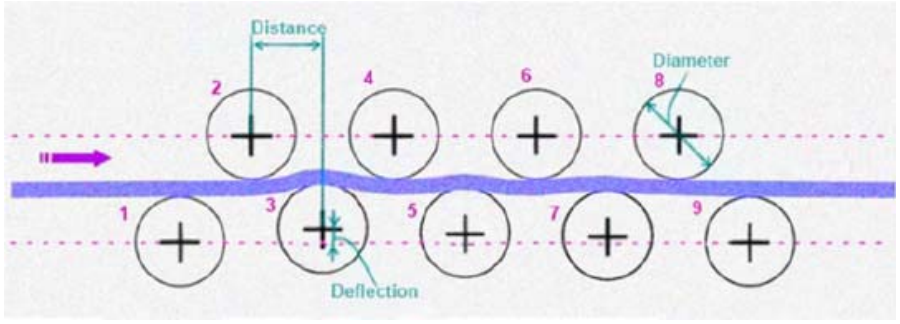
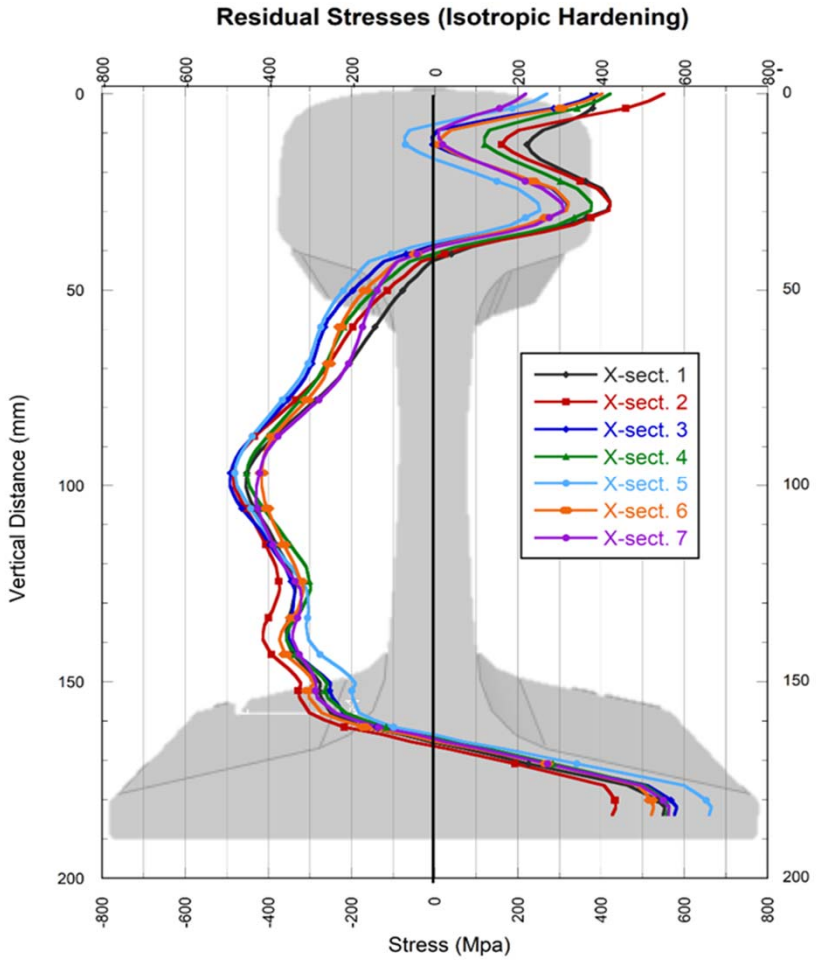
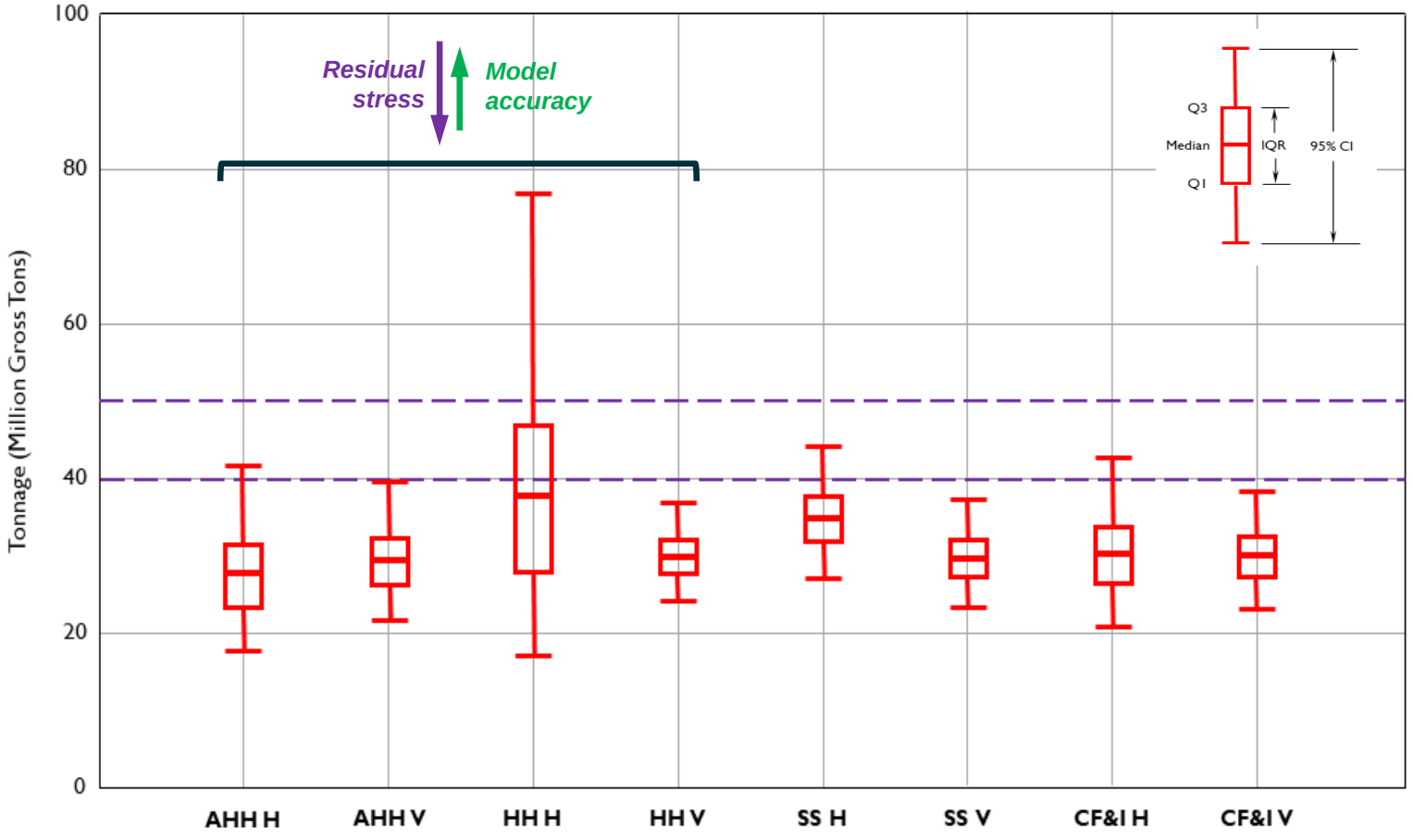






RESIDUAL STRESS AND MODEL ACCURACY



SUMMARY – WIP

- Head hardening does not significantly reduce fracture toughness of the rail steel
- Results suggest 30MGT inspection interval likely more appropriate than currently recommended 40MGT (for all rails!)
- Roller straightening is most significant driver of the residual stress: increasing steel strength increases residual stresses
- Theoretically, it is possible to get favourable stress distribution by adjusting the roller straightening process – WIP
- Reducing the level of conservatism in the analytical DF model could offset the effect of faster crack growth due to increased residual stresses – WIP