Summary of Fatigue Life Analysis of A36 T-Joint Tests Machined and Welded Completed Todate

SAE FD&E Semi-Annual Meeting

Tom Cordes, Dan Lingenfelser, Andrew Halfpenny and Mike Landgraf

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Society of Automotive Engineering Fatigue Design and Evaluation Committee (SAE FD&E) A36 T-Joint Effort Participants/Contributors

- SAE FD&E Committee Administrative/Leadership: Chad Kerestes (Chairman)-CAT, Casey Gales (Chairman)-JD, James Patterson (Vice Chairman)-Hendrickson
- Machined & Welded T-Joint Component Fatigue Tests: Ryan Blodig, Eric Norton, Mike Lister, and others-JD; Tom Cordes, Dan Lingenfelser-nCode
- T-Joint Component Finite Element Analysis: Hayley Brown-CAT, Peter Huffman-JD, Matt Campbell-Kansas State
- Generate Strain-life & Crack Growth Data: Phil Dindinger - Element Materials Technology
- Residual Stress Distribution Measurements: Perry Mason, Doug Hornbach and Paul Prevey - Lambda Technologies; Adrian DeWald-Hill Engineering
- Striation (Marker Band) Measurements: N. Jayaraman, Doug Hornbach and Paul Prevey - Lambda Technologies; Stephen Horstemeyer, Nima Shamsaei,-Mississippi State
- Welded T-joint Component Fabrication & Test Direction/Support: Eric Johnson-JD.
- Providing the Steel for the Preceding Contributions: Mary Wickham-CAT
- Funding for Some of the Preceding Contributions: Steve Haeg-MTS and Brian Dabell-nCode
- T-Joint Component Fatigue Life Predictions and Correlation to Test Data: Al Conle-University of Windsor; Semyon Mikheevskiy, Sergey Bogdanov and Grzegorz Glinka-University of Waterloo, Tom Cordes-nCode
- Residual Stress Subcommittee: Casey Gales (Subcommittee Chairman), Eric Norton, Vipul Shinde, Rakesh Goyal-JD; David Griffith, Justin Mach, Chad Kerestes, Lingyun Pan, William Ulrich, Hayley Brown, Narendra Singh, Randy Peck, Timothy Vik-CAT; Matthew Campbell-Kansas State; Steve Haeg-MTS, John Goldack-Carleton University, Stephanie Swanson-Hendrickson
- Welded T-joint Component (2nd Round of Welded Components) Fabrication and Test Direction/Support: Eric Norton, Brandon Evans, and Casey Gales-JD.
- And any other participants and contributors: who may have been inadvertently overlooked in the preceding list.

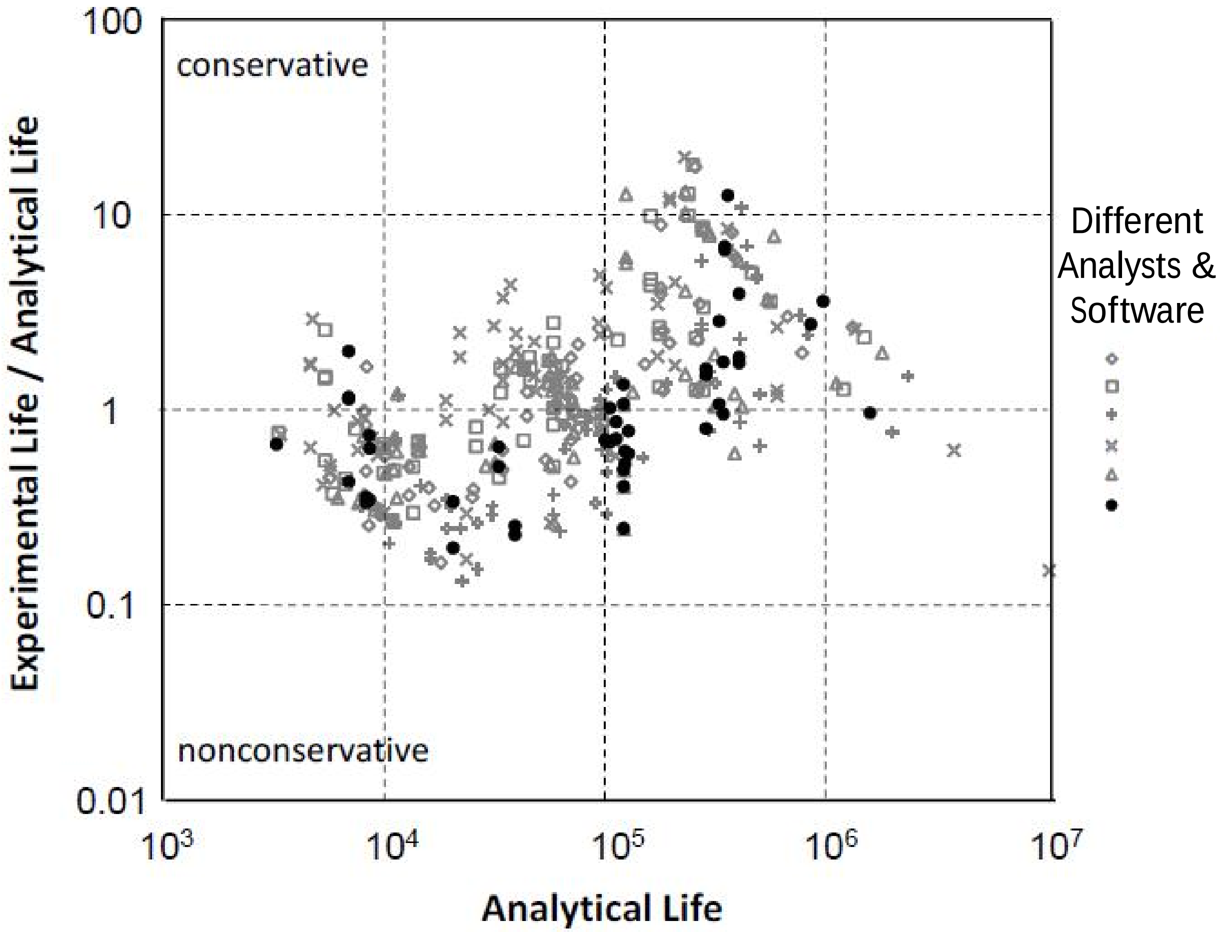
"By participating in organized efforts the committee provides a forum within which members can work together in a synergistic manner to advance the state of the art in structural durability."	"Through the years, members have found that the more they participate in the Committee activities, the more they grow in the area(s) of their particular involvement."
From: Multiaxial Fatigue of an Induction Hardened Shaft (AE28) - Editors: Tom Cordes and Kevin Lease	

- Background on total life project
- Test results to date
- Whole Life & Strain-Life Crack Initiation prediction process
- Comparison of predictions to test results

Total Fatigue Life: Crack Initiation and Crack Propagation…Background

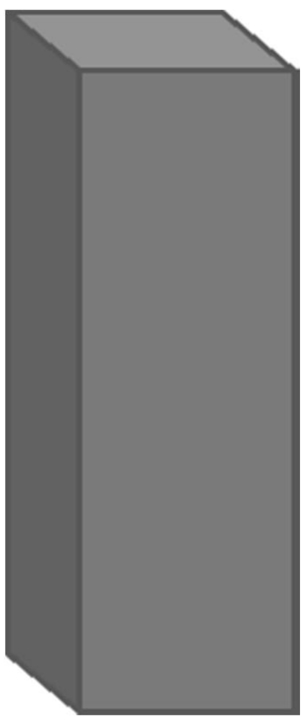
Previous SAE FD&E Analysis to Test Correlation Effort Results

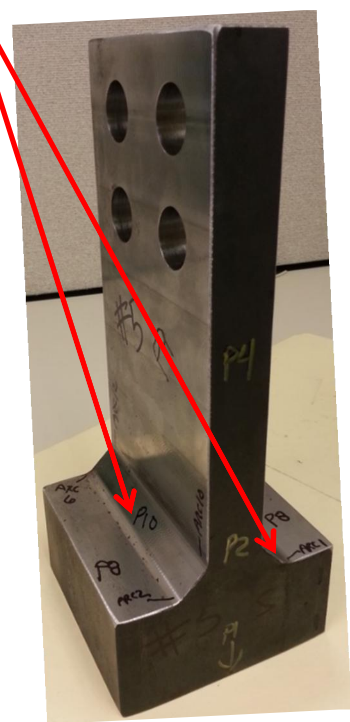
A brief summary of the fatigue theories and strategies employed by the various software packages used to compute fatigue lives is given below. A common feature of all of the analysis is that they used what may be termed the strain-life method. Commonality ends there. They all used different notch rules and fatigue damage models.

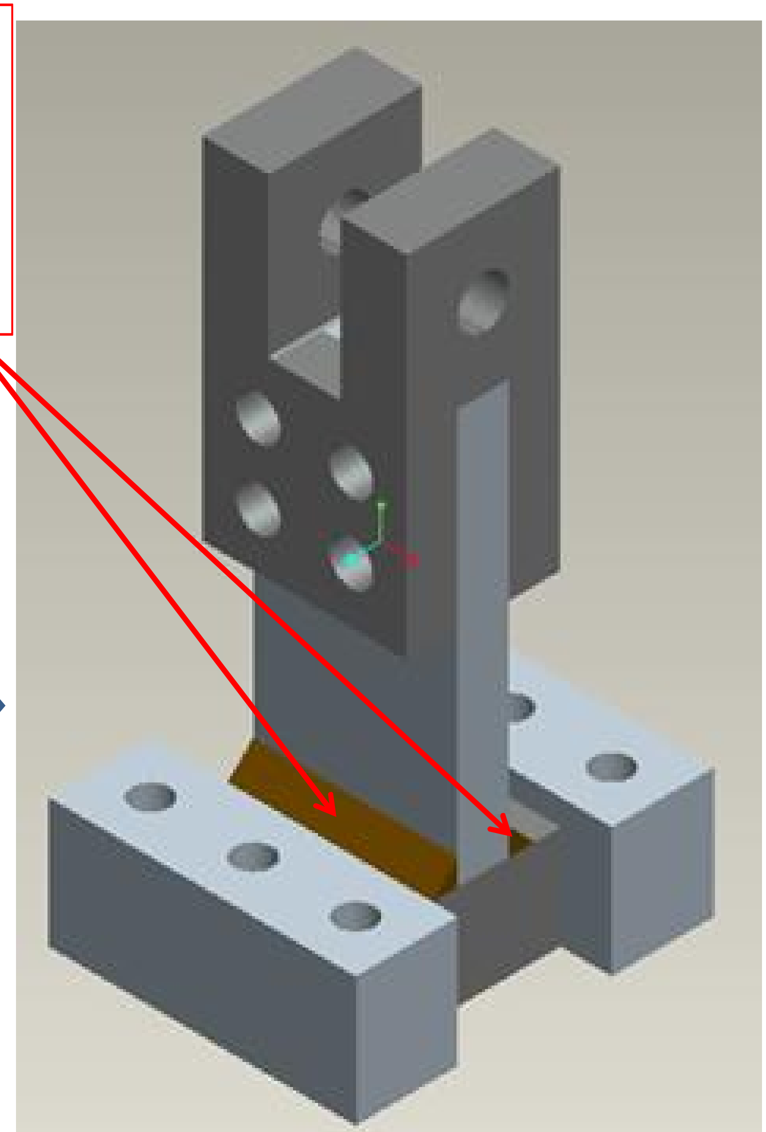


Machined
Specimen Configuration and Test Fixture/FEM Boundary Conditions

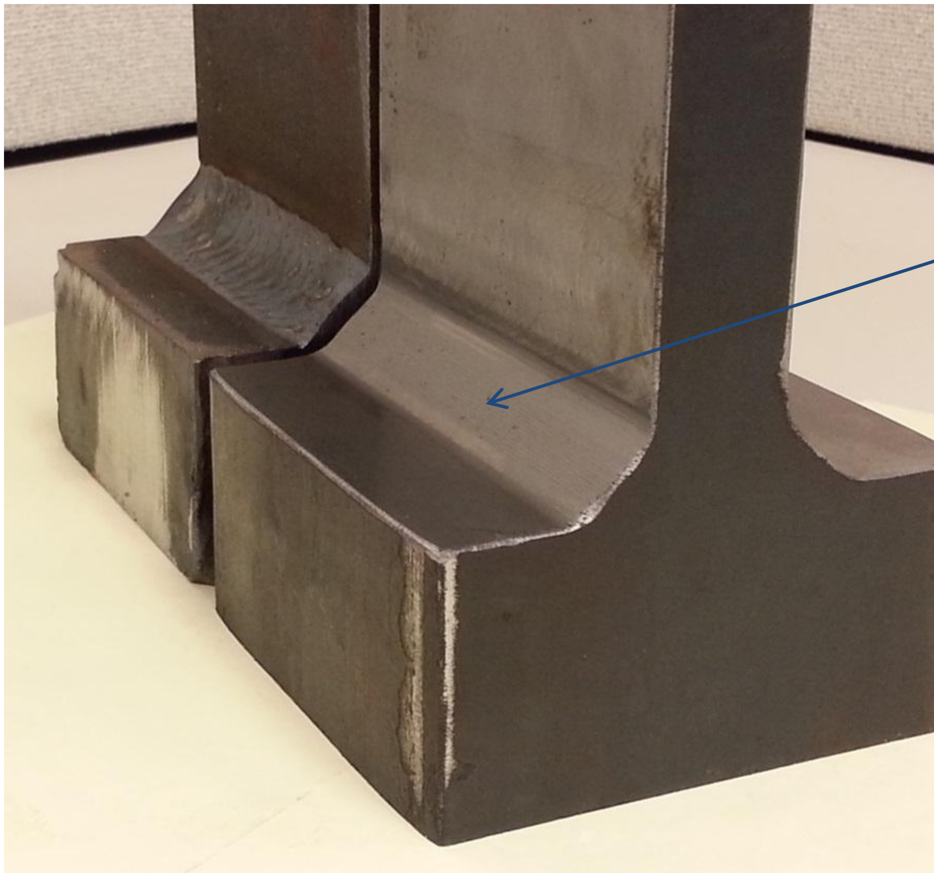
Eliminate the weld entirely – machine the entire specimen from the 101.6 mm x 101.6 mm bar. Duplicate, by machining, the weld profile and weld toe radius as closely as possible so the sample is consistently made from the same material. Comparing the test /analysis from these samples relative to the test/analysis results from the welded samples, will confirm (or not) assumptions like "can we use the base material properties when analyzing welded structures", etc.



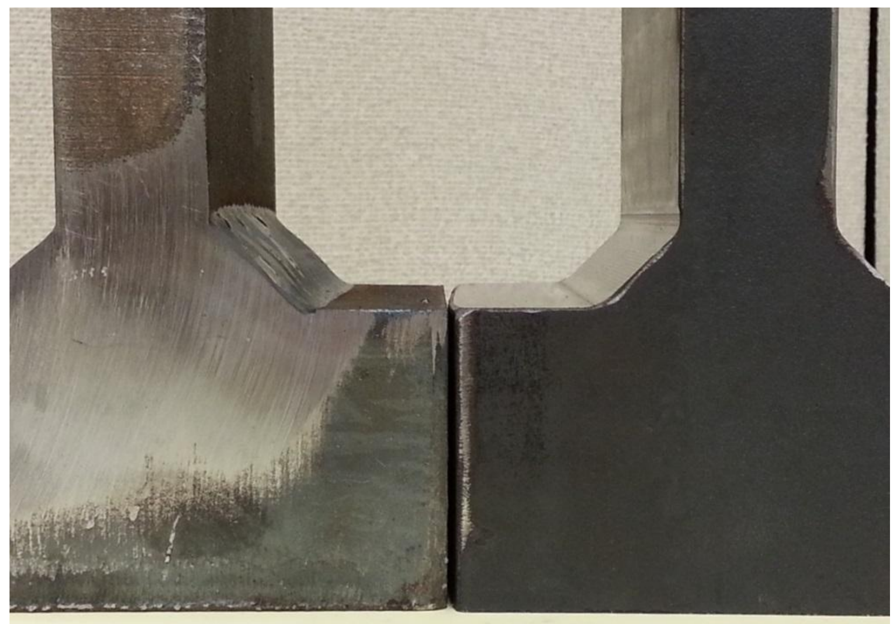




Welded and Machined Specimens

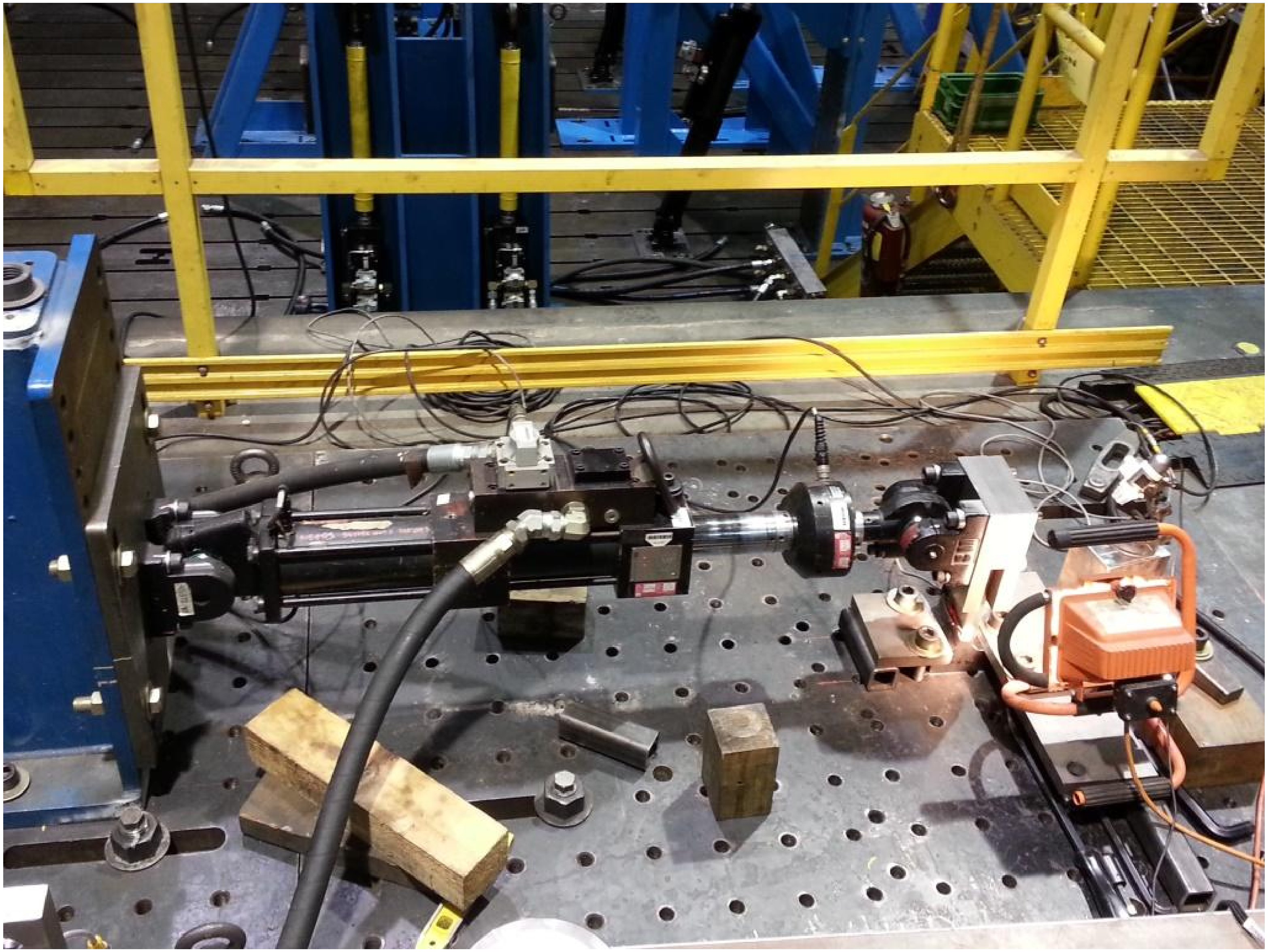


Machined T-Bar Replicates
Welded Specimen Geometry



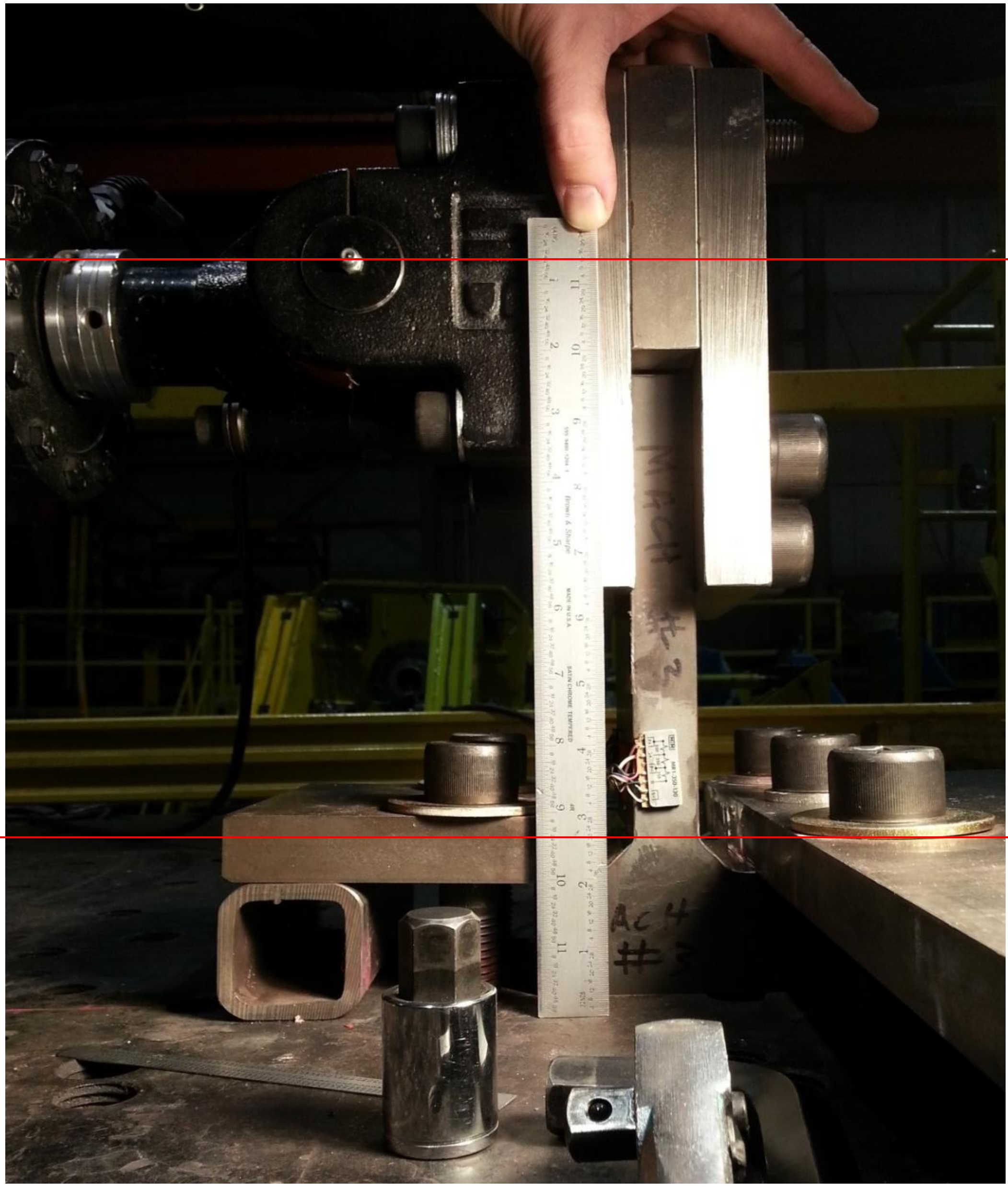
Total Fatigue Life: Crack Initiation and Crack Propagation…Info

<u>Specimen in Test Fixture</u>



Total Fatigue Life: Crack Initiation and Crack Propagation…Info

Specimen in Test Fixture/ for FEM Boundary Conditions



222.25mm
From Applied
Load Line to
Radius

Total Fatigue Life: Crack Initiation and Crack Propagation….Test

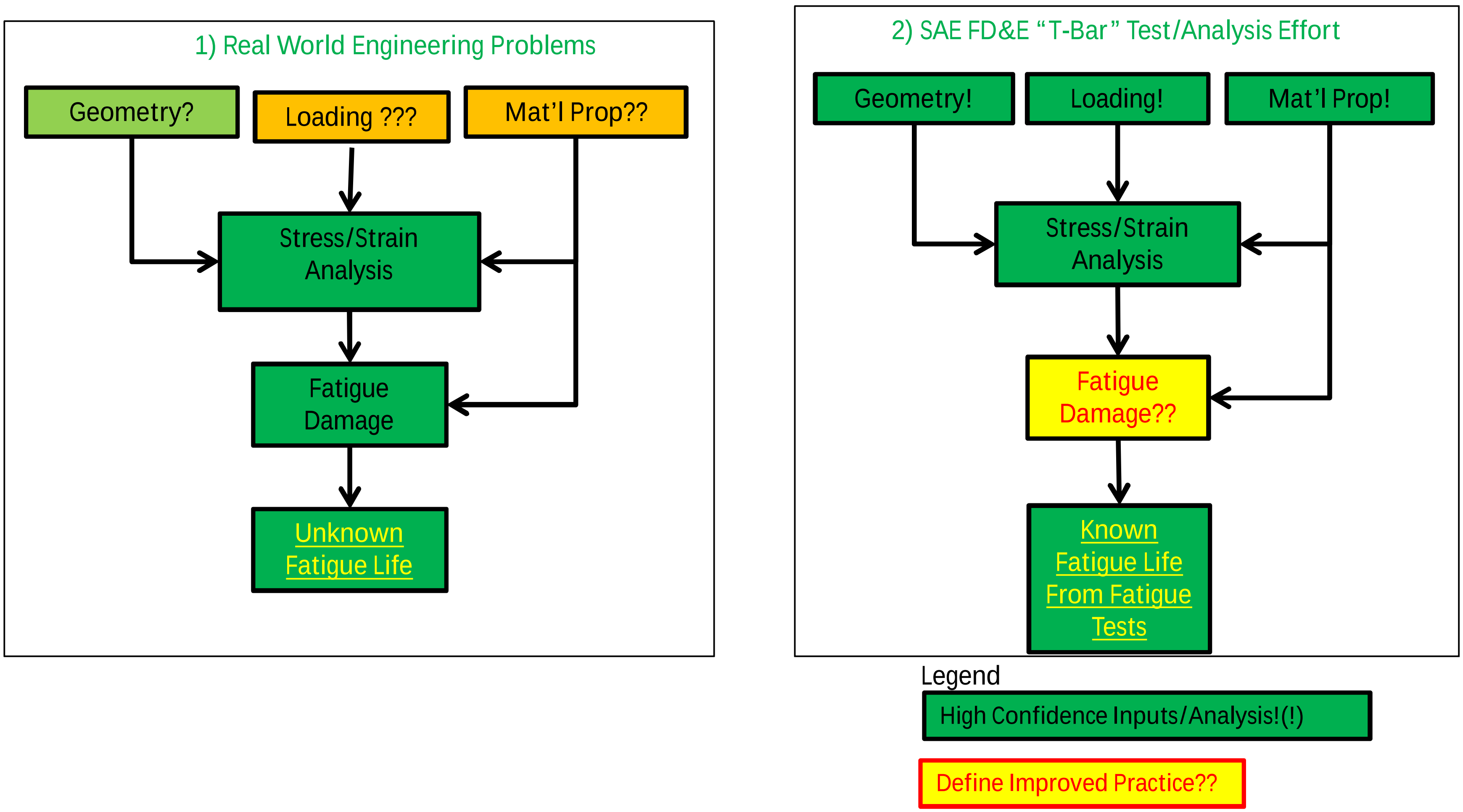
29 A36 T-Joint Test Results to Date

Machined Specimens (12)			
Max Ld kN	Max Stress Mpa	R Ratio Dimensionless	Experimental Test Life Cycles
24	870.44	0.3	218,671
24	870.44	0.3	200,464
24	870.44	0.1	58,481
24	870.44	0.1	70,011
18	652.83	0.1	411,745
18	652.83	0.1	424,431
10.8	391.70	-1.0	214,765
10.8	391.70	-1.0	271,951
24	870.44	*Block Ld: 0.1/.5	326,135
24	870.44	*Block Ld: 0.1/.5	301,938
24	870.44	**Var Amplitude	224,672
24	870.44	**Var Amplitude	232,696

Note: *5,000 24Kn R=0.1 Cycles followed by 40,000 24Kn R=0.5 Cycles
**C1xSAE Transmission+ C2xBracket+C3xSuspension PV File

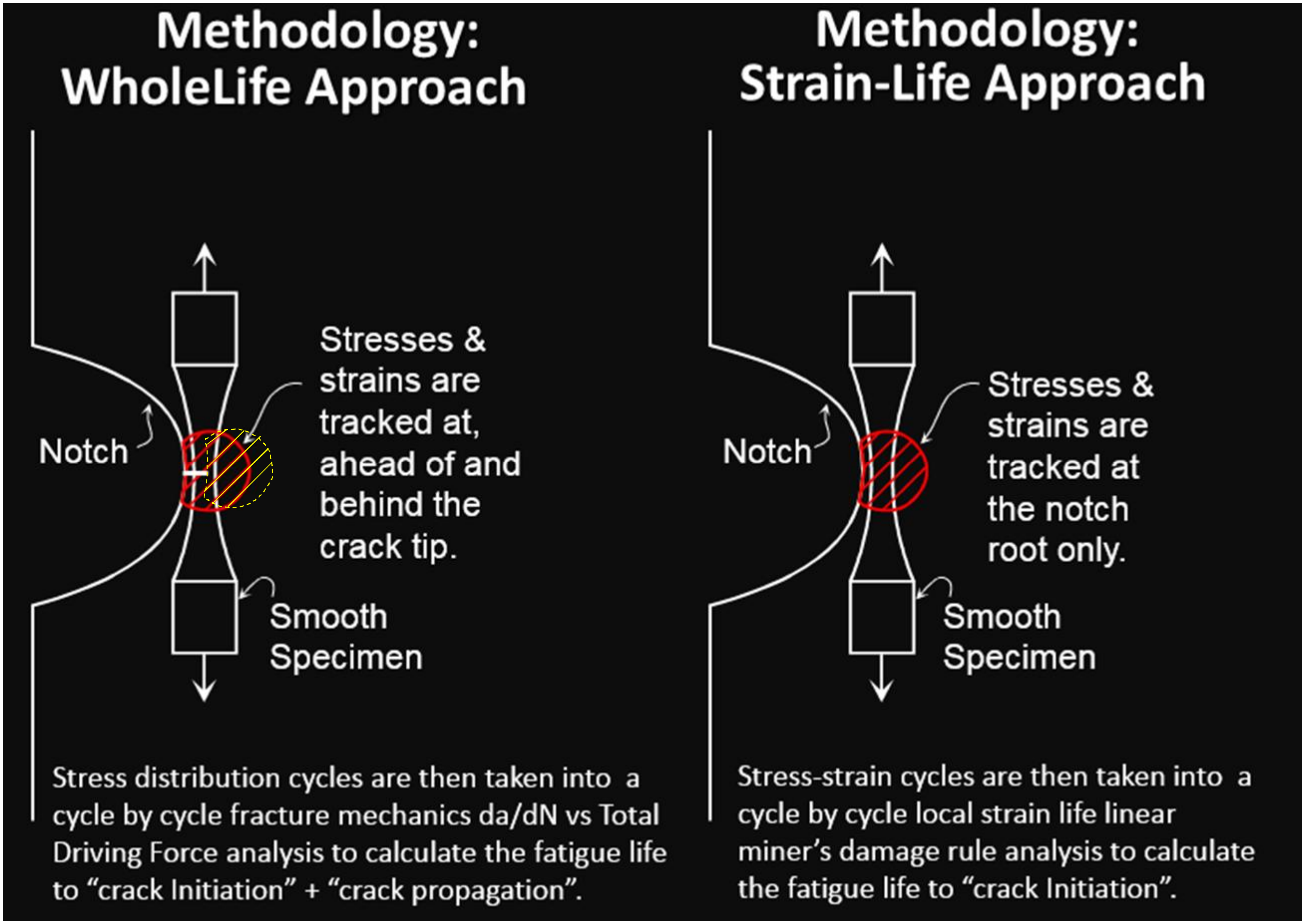
Welded Specimens (17)			
Max Ld kN	Max Stress Mpa	R Ratio Dimensionless	Experimental Test Life Cycles
24	902.62	0.1	36,895
24	902.62	0.1	48,160
24	902.62	0.1	62,047
14	526.53	0.1	325,579
14	526.53	0.1	375,813
14	526.53	0.1	494,456
24	902.62	0.3	105,522
14	526.53	0.3	922,658
24	902.62	0.5	262,628
24	902.62	0.5	349,002
24	902.62	0.5	503,441
20	752.18	0.5	592,250
17	639.36	0.5	4,901,846
24	902.62	*Block Ld: 0.1/.5	138,421
24	902.62	*Block Ld: 0.1/.5	174,069
24	902.62	**Var Amplitude	168,504
24	902.62	**Var Amplitude	168,504

Total Fatigue Life: Crack Initiation and Crack Propagation

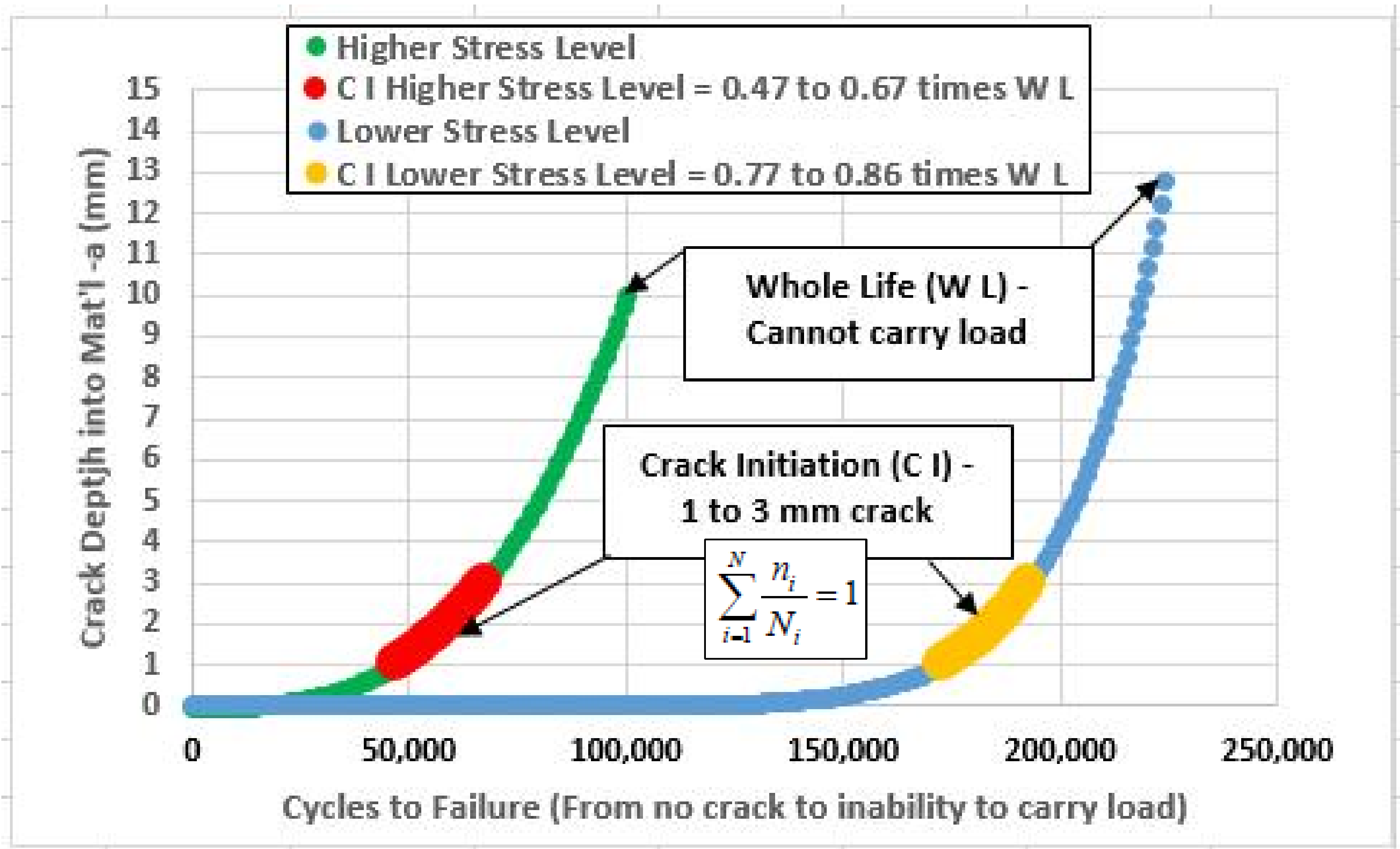


This effort is using "very well defined/controlled analysis inputs" to address an engineering problem to validate (or not) a potential "Total Fatigue Life Prediction Improved Practice"

Total Fatigue Life: Crack Initiation and Crack Propagation…Analysis



Total Fatigue Life: Crack Initiation and Crack Propagation…Analysis

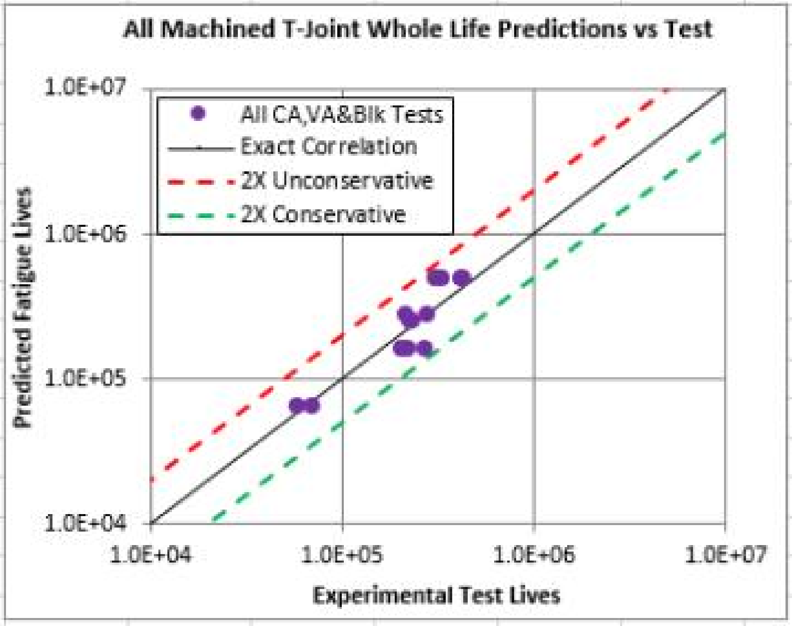


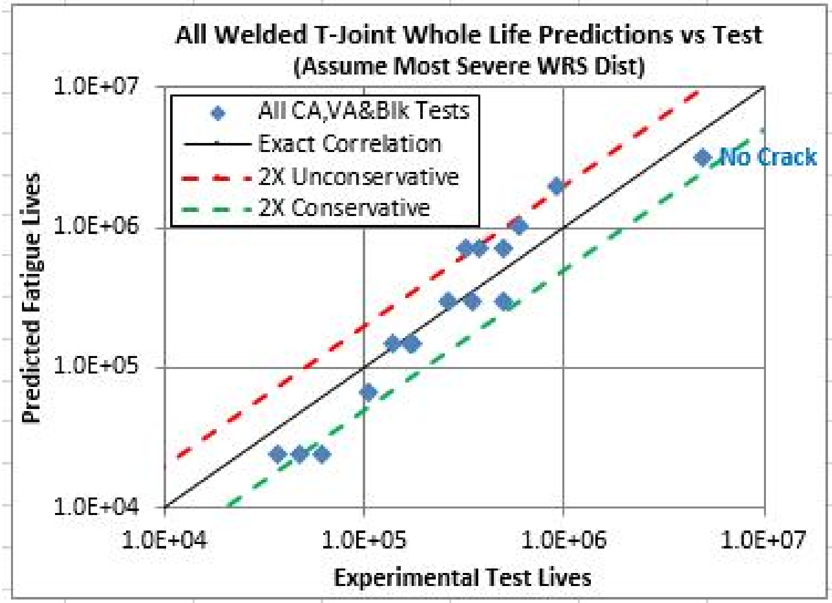
Note that crack initiation (CI) life predictions are not made to a "definitive" crack size. The predicted CI crack size is usually assumed to be an (observable) crack of between 1 to 3 mm. When CI predictions for tests are expressed as percentages of the test Whole Lives (WL) to failure, there is variation in the percentages. That scatter is the result of testing to different load/stress levels (as shown), R ratio differences, different cycle distributions/order in variable amplitude histories, etc.

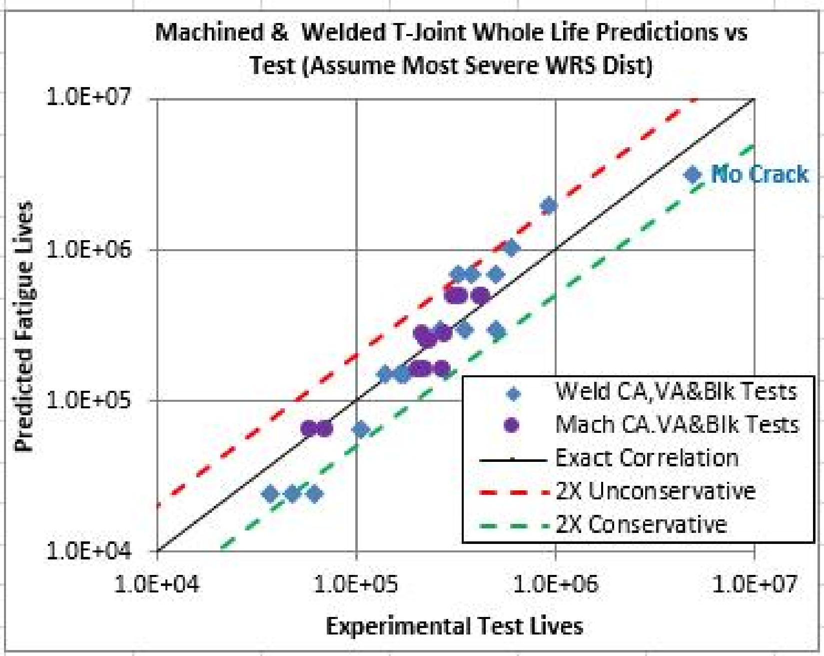
Whole Life Prediction Activities

- Developed "Whole Life" script
  - Python script
  - Runs as "user defined" glyph in nCode GlyphWorks environment
  - User defined method using production data I/O and results viewing
  - Provides flexibility in outputting/viewing intermediate results
- Developed in collaboration with Greg Glinka
  - Highly aligned with methods in his publications
- The following predictions based on this script

Total Fatigue Life: Crack Initiation and Crack Propagation Analysis … Whole Life







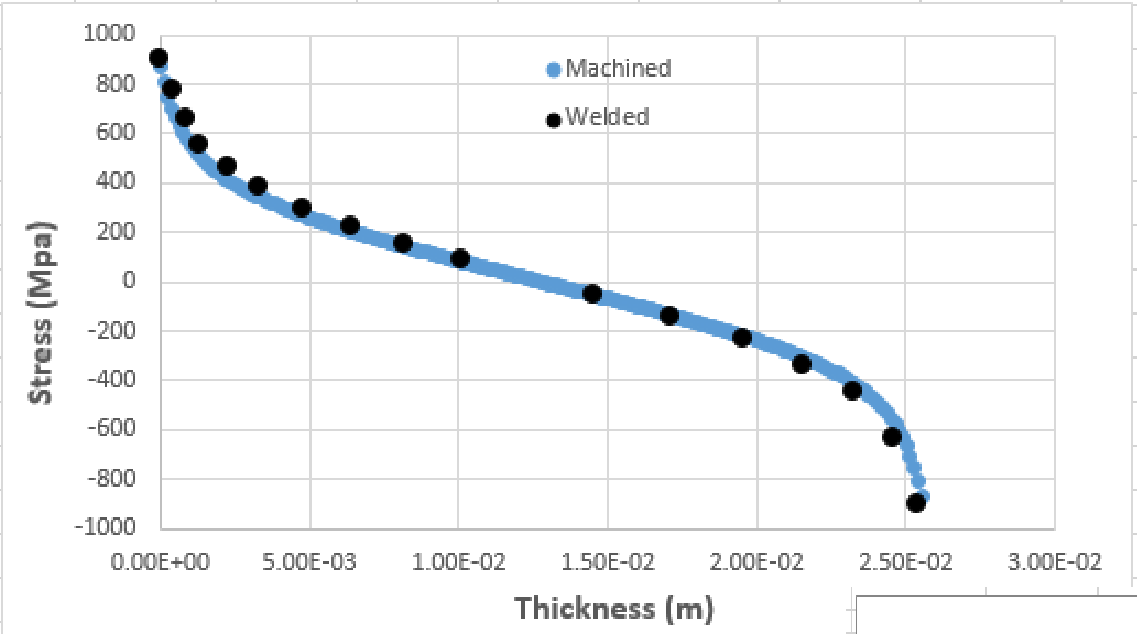
Whole Life Fatigue Life Predictions to *"Failure"*

1)The fatigue life predictions of the welded samples appear to be consistent with the fatigue life predictions of the machined samples.

2)All the predicted fatigue lives fall within scatter bands of approximately +/- 2 times the test lives to failure.

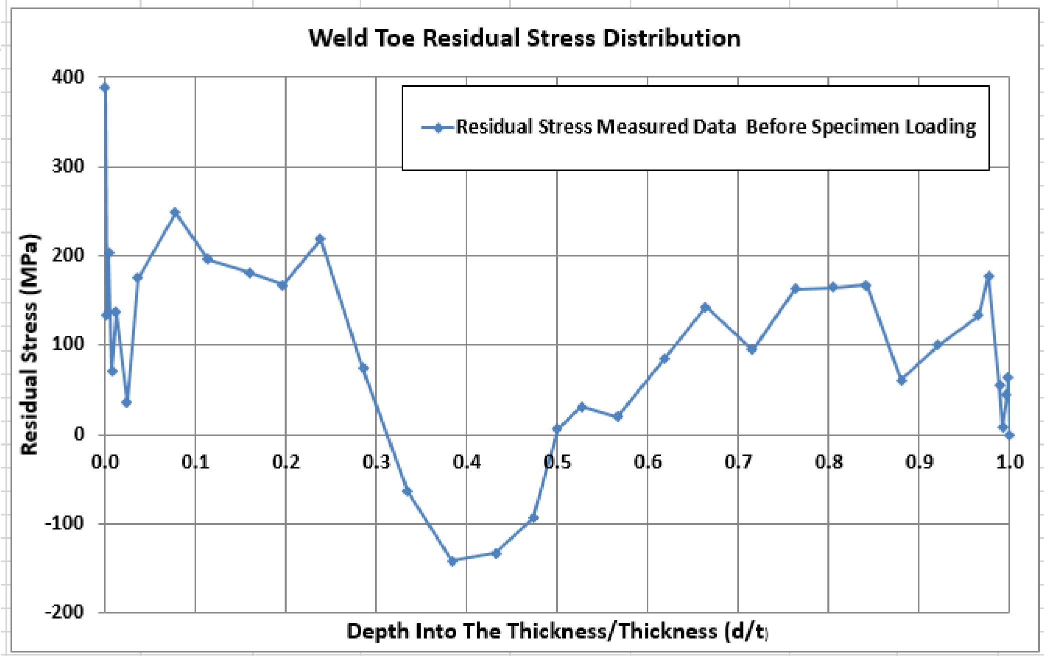
Total Fatigue Life: Crack Initiation and Crack Propagation Analysis … Whole Life

Comparison - Welded to Machined FEM Stress Distributions

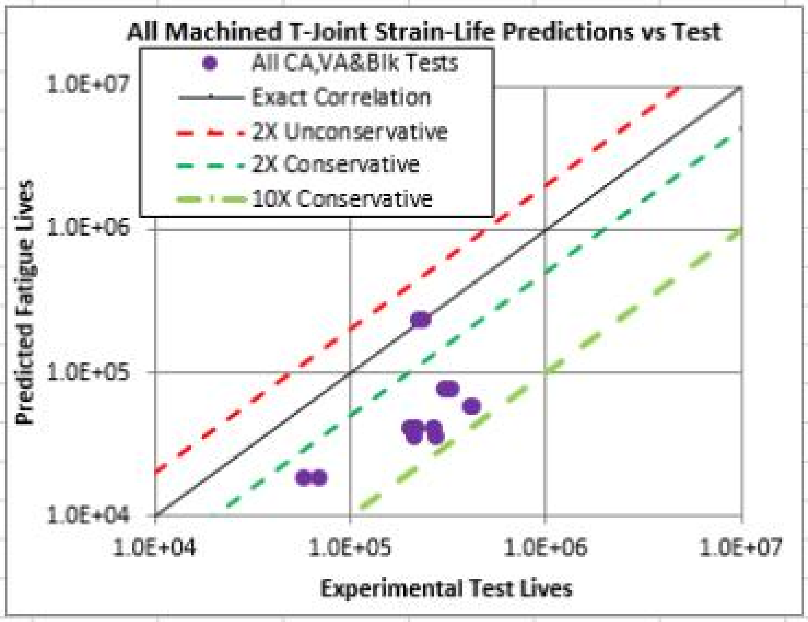


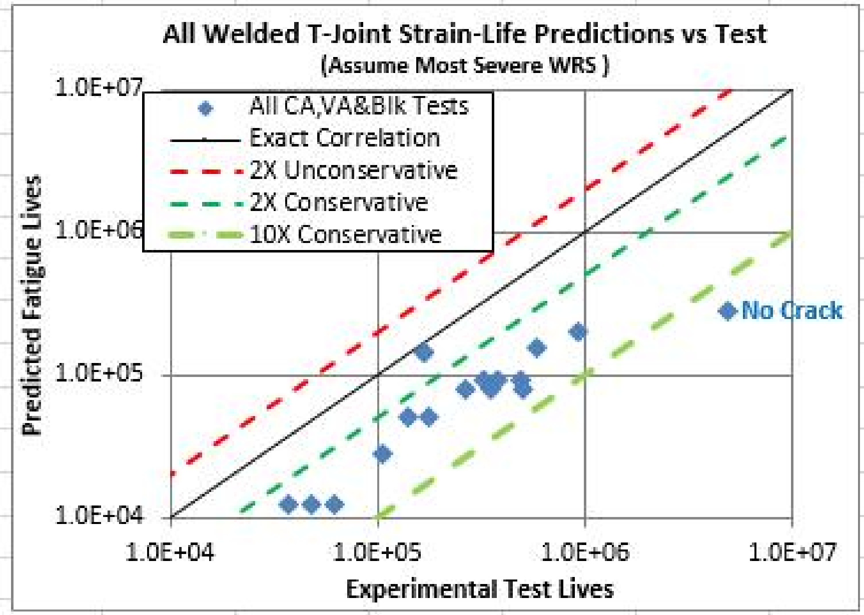
The welded analysis was exactly the same as the machined analysis except the FEM stress distribution input was changed (slightly) from the machined distribution to the welded distribution as shown in the figure on the left.....

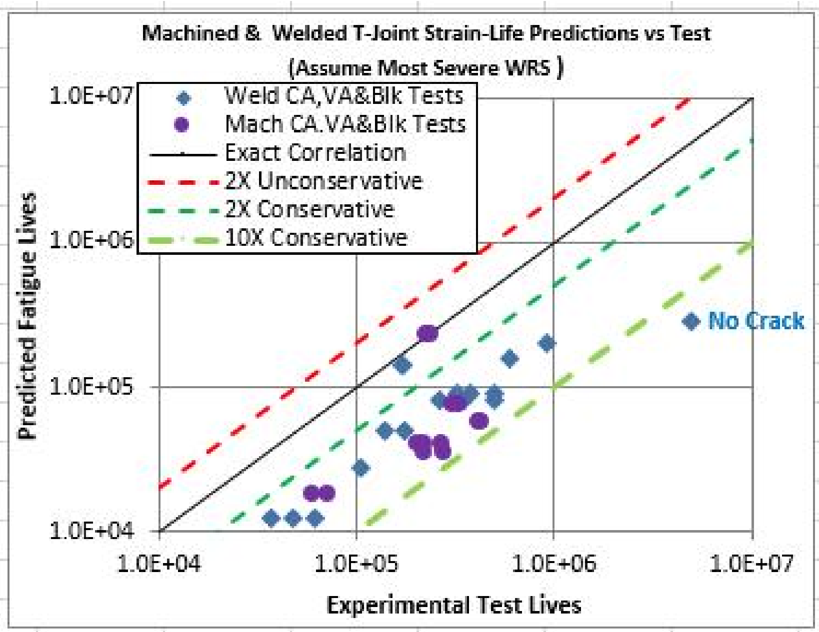
And the welding residual stress distribution (shown in the figure on the right) was included in the analysis. No residual stress distribution was input in the machined analysis.



Total Fatigue Life: Crack Initiation and Crack Propagation Analysis ... Strain-Life





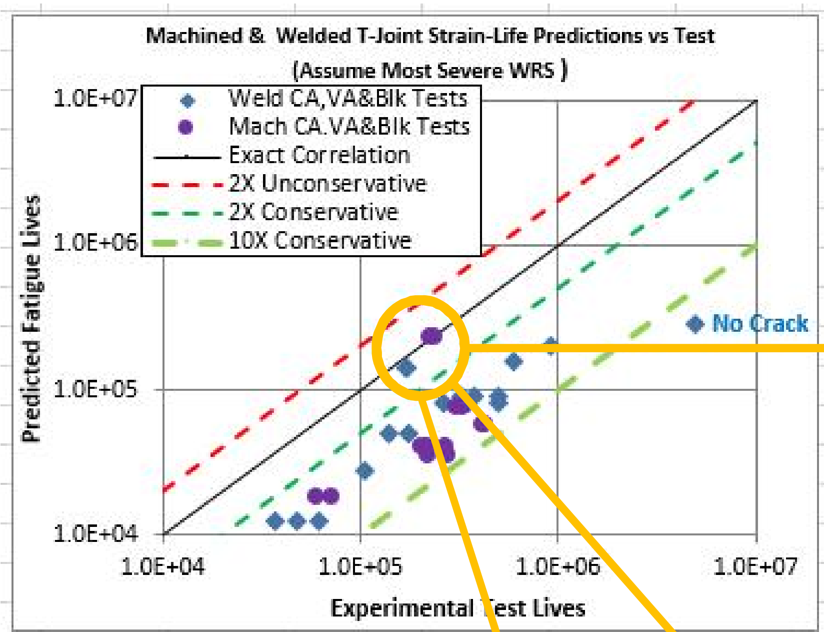


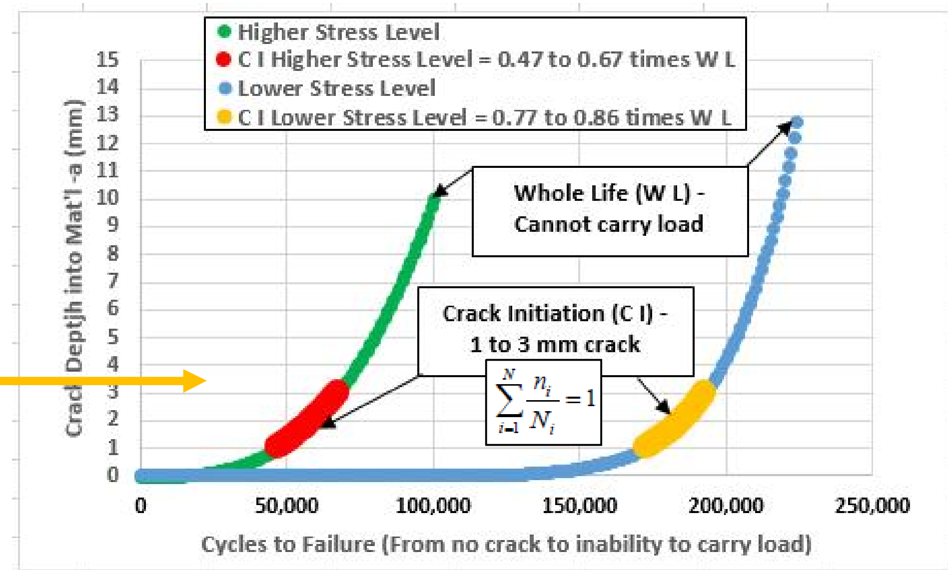
Strain-Life Fatigue Life Predictions to *"Crack Initiation"*

1)The fatigue life predictions of the welded samples appear to be consistent with the fatigue life predictions of the machined samples.

2)All the predicted fatigue lives fall within scatter bands of approximately -2/-10 times the test lives to failure just considering CA. (1/-10 times including VA)

Total Fatigue Life: Crack Initiation and Crack Propagation Analysis … Strain-Life





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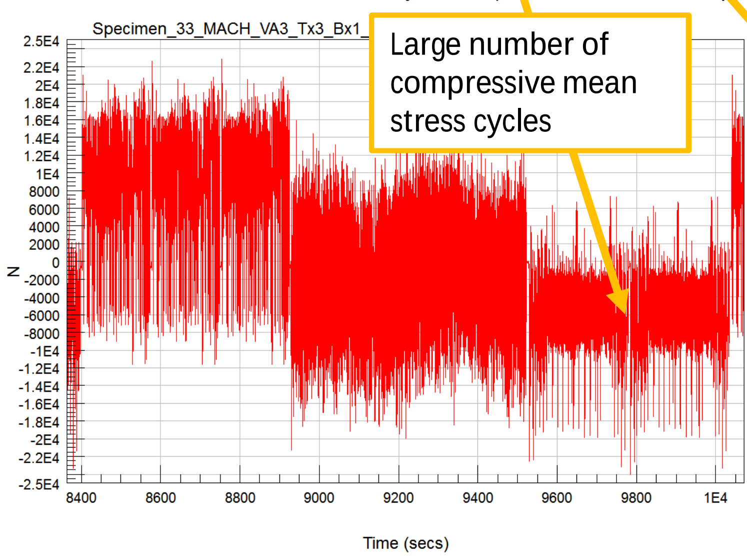
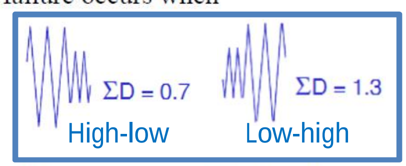
24 kN Max / 24 kN Min, VA, Time History Profile (Trans x3, Brkt x1, Susp x2)



1. "High-low" fatigue tests where testing occurs sequentially at two stress levels (σ_1, σ_2) where $\sigma_1 > \sigma_2$ generally shows that failure occurs when

$$\sum_{i=1}^{2} \frac{n_i}{N_i} = c$$

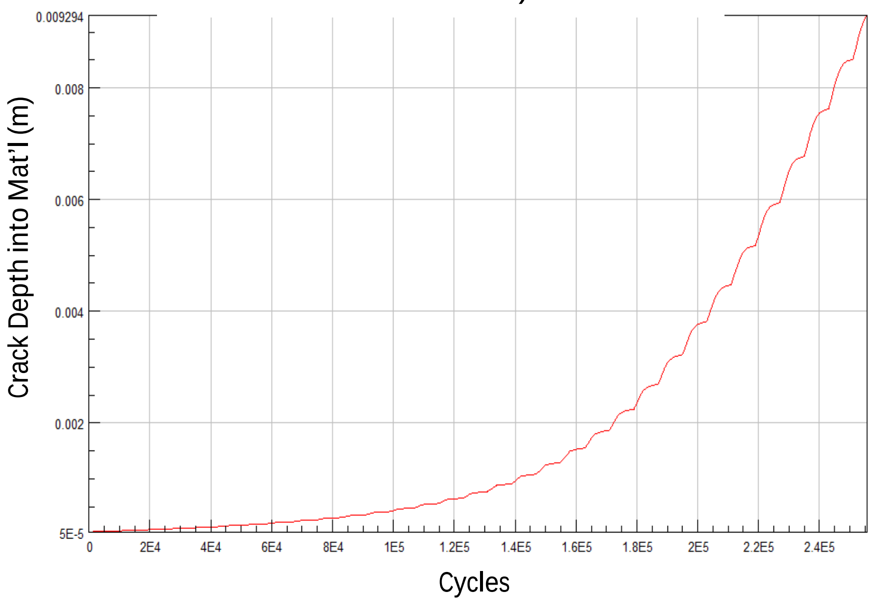


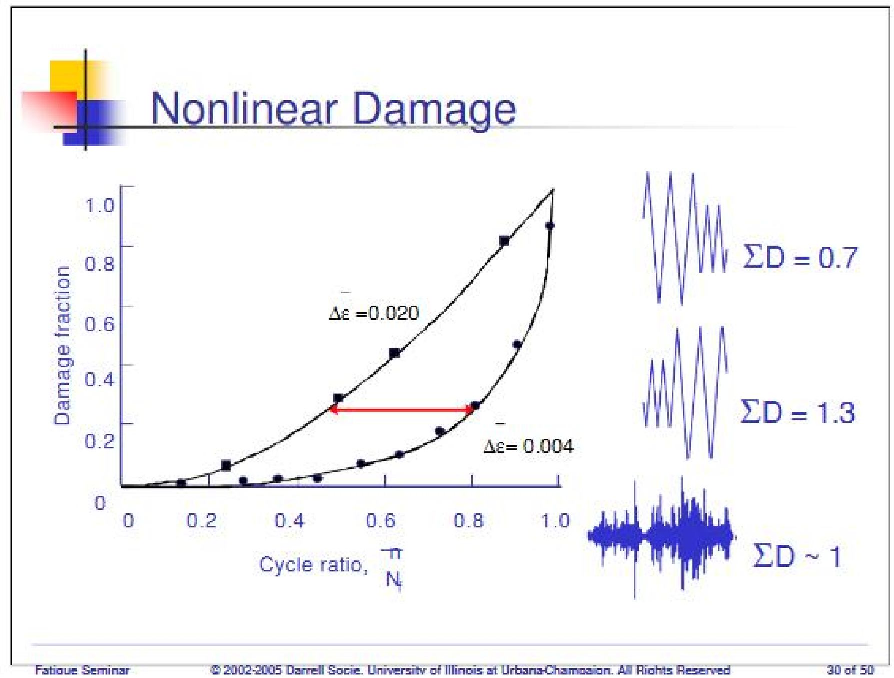
where c normally is < 1, i.e the Palmgren-Miner rule is non-conservative for these tests. For "low-high" tests, c values are typically > 1.

2. For tests with random loading histories at several stress levels, correlation with the Palmgren-Miner rule is generally very good.

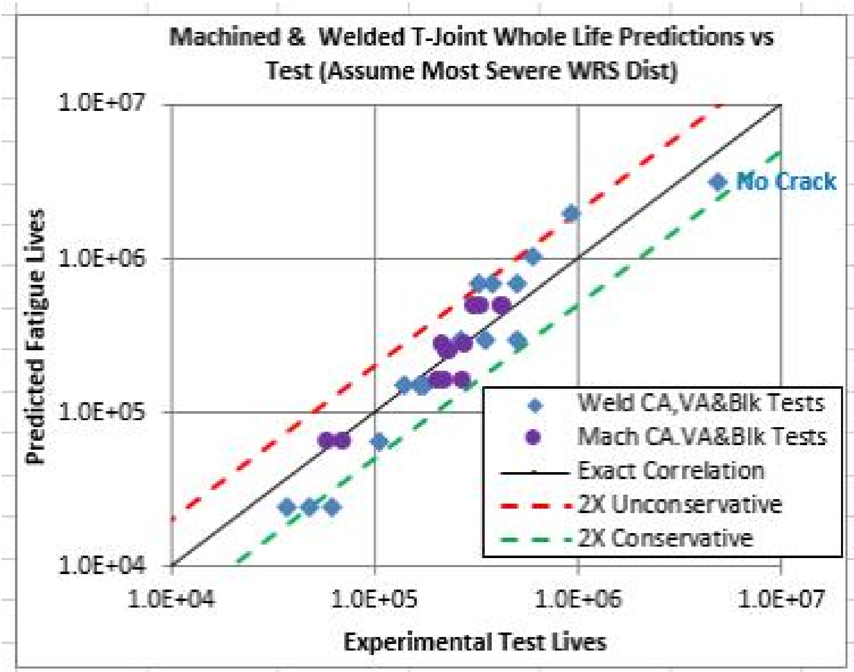
If a “Stair-Step” a vs N Curve is observed from a Whole Life Fracture Mechanics Analysis (especially for crack sizes much less then .001m)

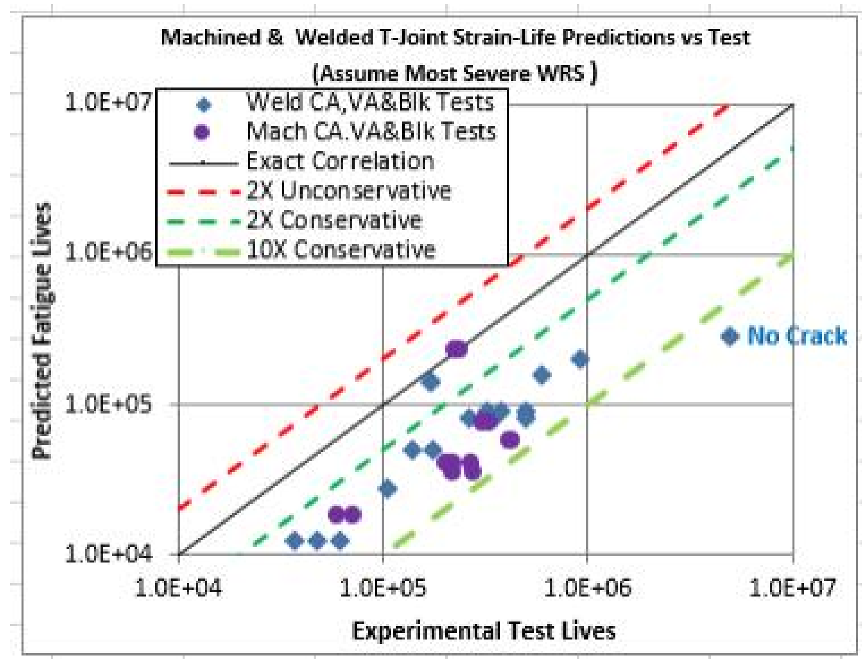
That may indicate a “Nonlinear Damage Analysis” is necessary, using the Variable Amplitude Local Strain-Life Methodology, to get consistent results





Total Fatigue Life: Crack Initiation and Crack Propagation Analysis…Summary





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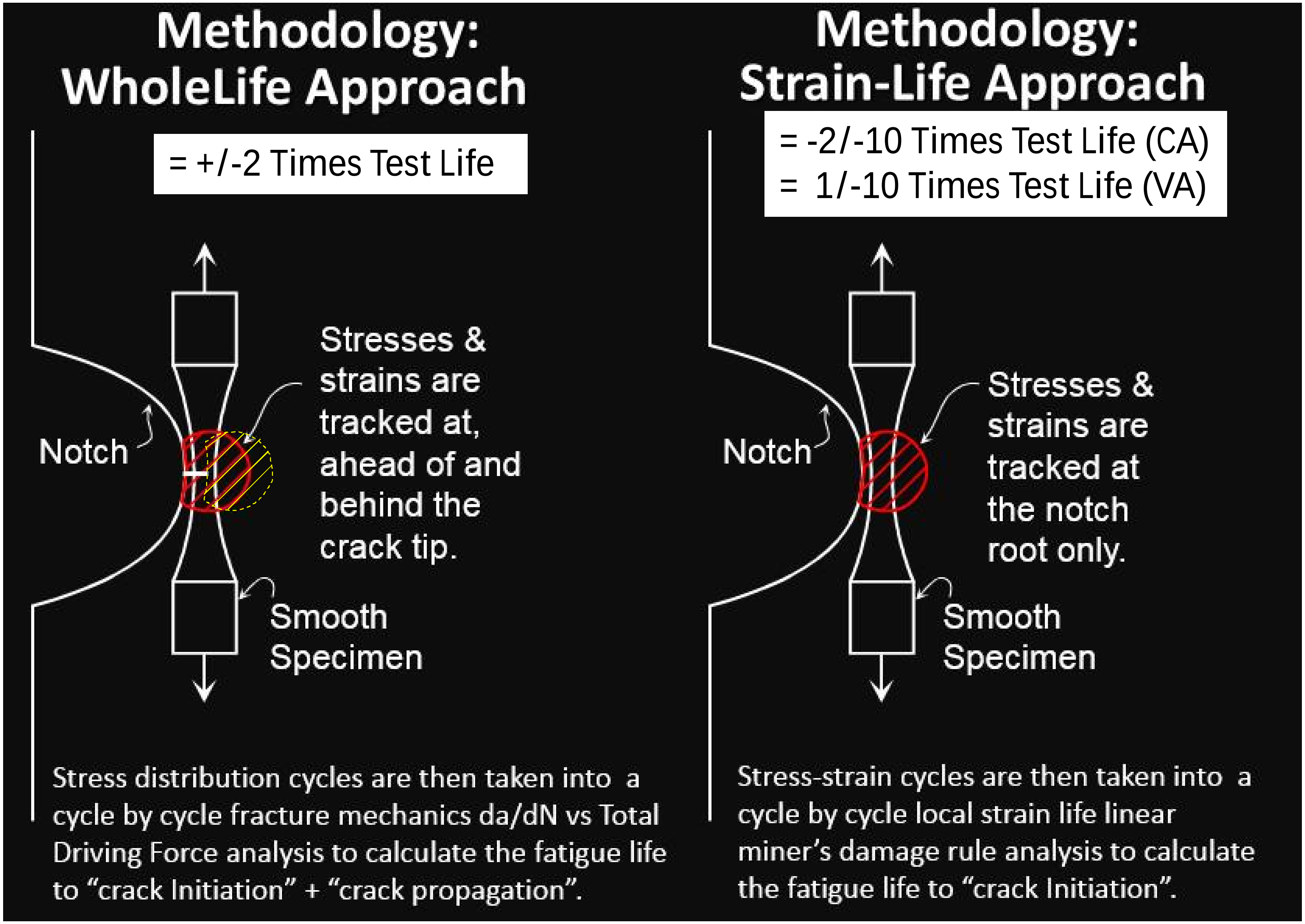
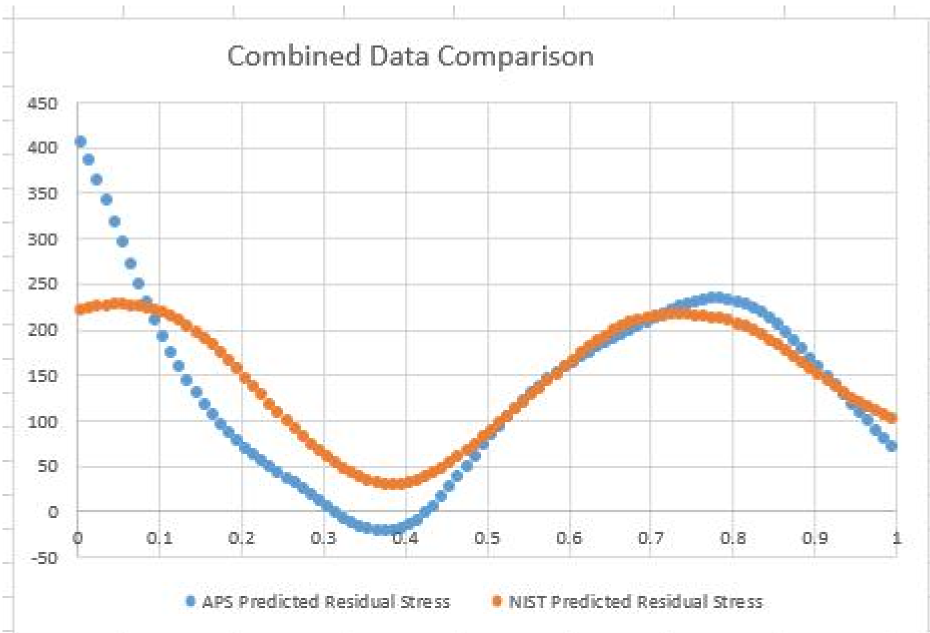
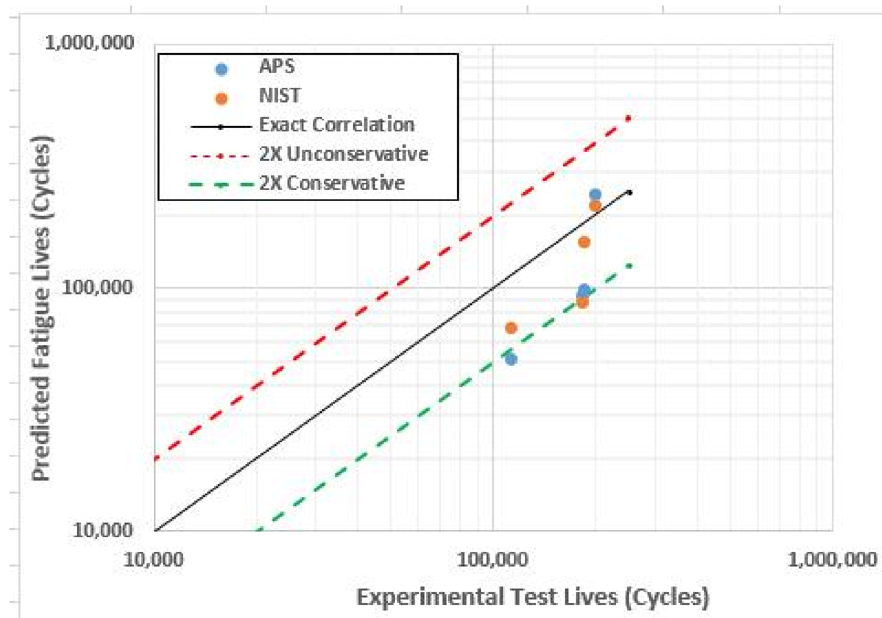
Total Fatigue Life: Crack Initiation and Crack Propagation Analysis…Summary



Total Fatigue Life: Crack Initiation and Crack Propagation Analysis… New Topic
Evaluate Residual Stress Distributions Obtained by Two Different Methods

Specimen	Designation	Load (kN)	R Ratio (σ_{min} / σ_{max})	Cycles	Notes	S=	902.62 APS		NIST	
36	RBW2_2.2	18	0.1	185,863	Side 2 in tension, Higher tensile residual stress	676.965	99,388	-0.47	153,306	-0.18
37	RBW2_2.3	18	0.1	201,168	Side 1 in tension, Lower tensile residual stress	676.965	241,514	0.20	218,823	0.09
38	RBW2_3.2	24	0.3	112,464	Side 2 in tension, Higher tensile residual stress	902.62	50,944	-0.55	69,155	-0.39
39	RBW2_3.3	24	0.3	183,223	Side 1 in tension, Lower tensile residual stress	902.62	93,117	-0.49	87,529	-0.52





NIST residual stress distribution *may* give *slightly* better correlation to test data