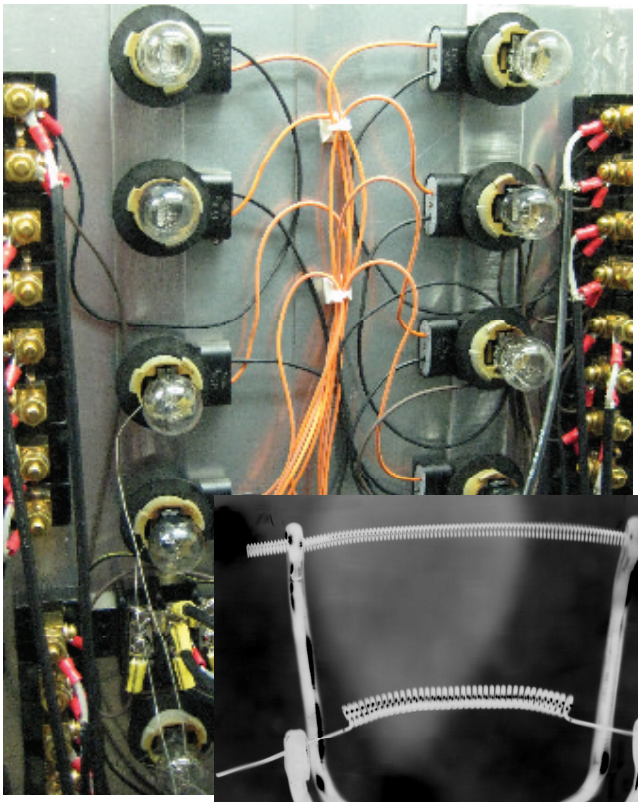
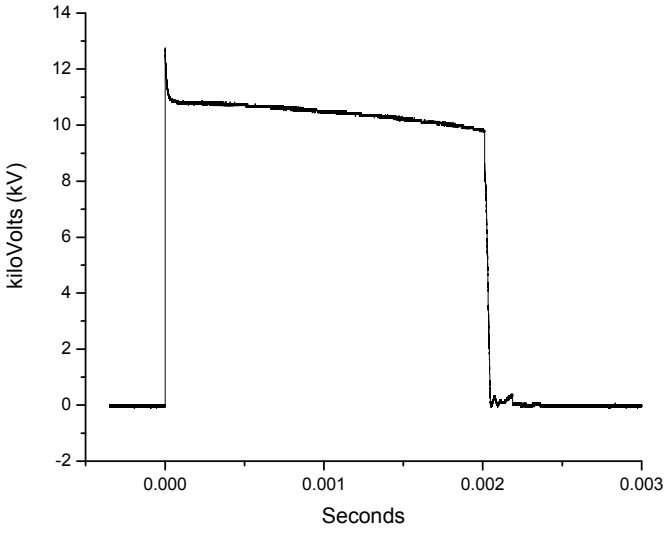
FDE Weld Challenge Review
Spring 2008 -- Caterpillar

John Bonnen
Ford Motor Co.

Need New Project Leader





Challenge Purpose

Collaboration to assess and improve industry fatigue life predictive capabilities where welds are concerned.

Look at:

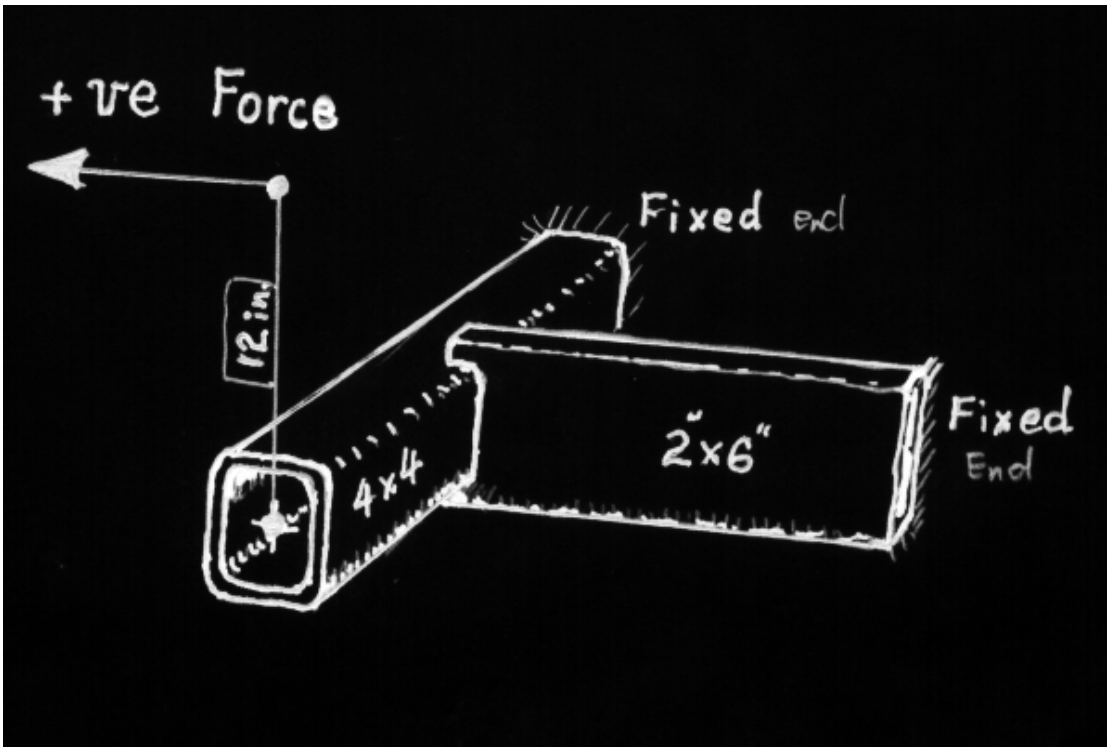
- Constant Amplitude
- Variable Amplitude
- Induced Residual Stress
- Design

T-weld

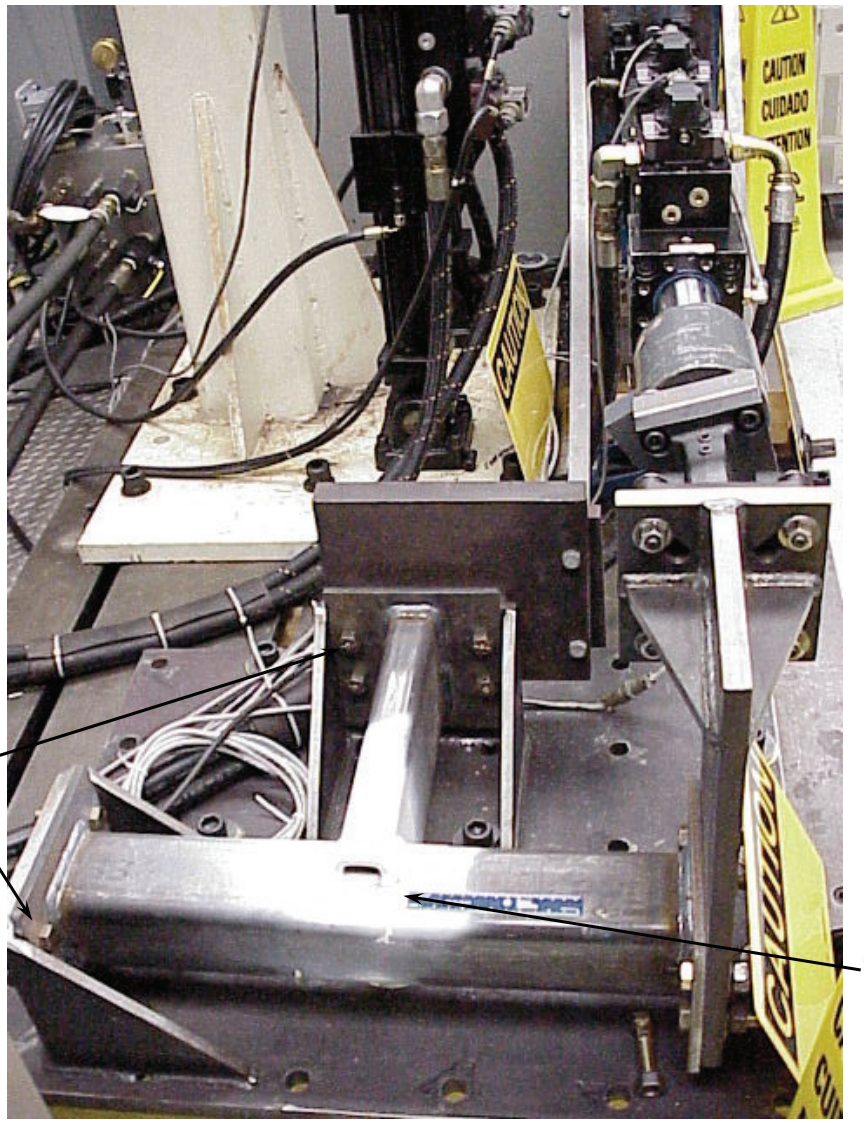
- Constant Amplitude – Challenge I
- Variable Amplitude – Challenge II
- Peened – Challenge IIIb
  - Normally
  - Ultrasonic
  - Duplex
- Other T-bar Results

Original Deere Component from which specimen design was derived

Weld challenge: specimen design with loading



Test setup
(Ford)



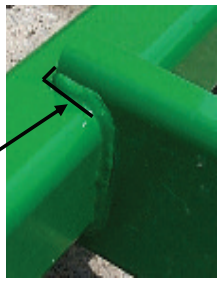
Constraint

Test Specimen

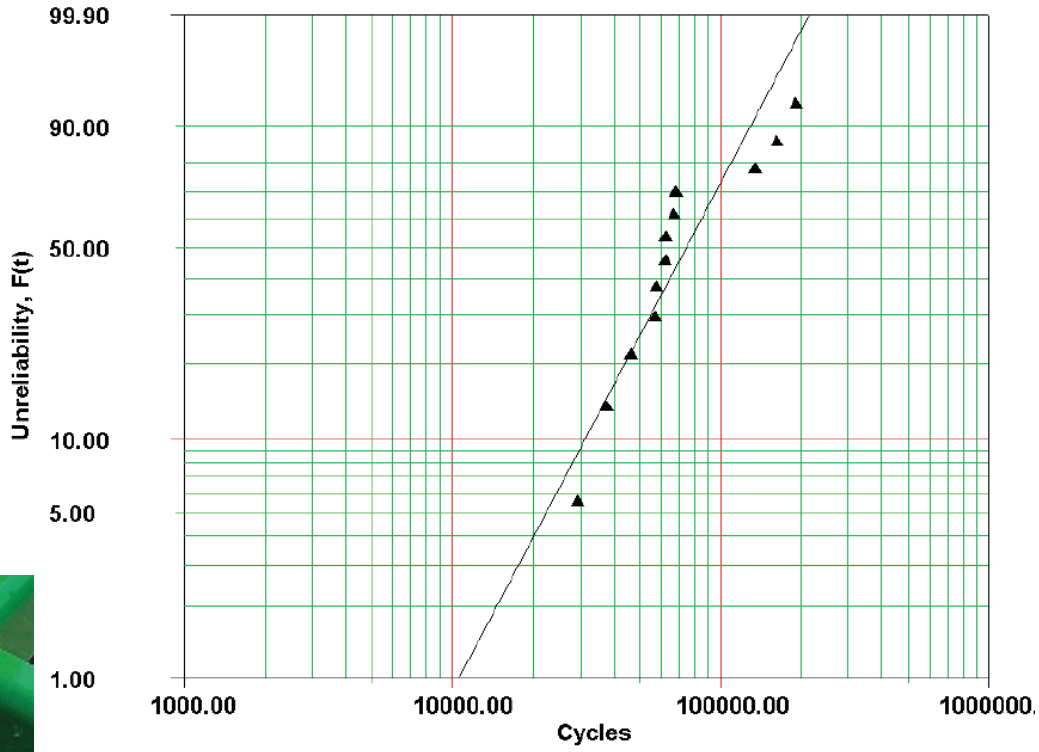
First Challenge Test Results
Constant Amplitude, R=-1, P=17792N (4000lb)
Failure Criterion: predetermined stroke limit

Lives (cycles)
29190
37340
46480
56570
57510
62080
62780
67010
68130
134950
161650
190450

Ave.=81,200
±51,680



Init. Site



$L_{d,50}$=75,000 cycles

Results

Name	Nf (R=0)	Nf (R=-1)	Comment
UIUC - C. Sanger/P. Kurath	174,000	**21,800**	**BS7608 Class W**
	267,000	**33,529**	**BS7608 Class G**
Ford – Research	200,000	**30,000**	**Hand Calculation**
DaimlerChrysler w/ nCode	580,000	**53,000**	**3D model, full penetration**
	155,000	**54,000**	**10% penetration**
	640,000	**211,000**	**50% penetration**
	2,100,000	**674,000**	**90% penetration**
DaimlerChrysler w/Femfat	9,870,000	**245,700**	**HV, fixed bdy. Condi.**
	7,300,000	**164,000**	**HV, not as fixed**
	244,000	**16,400**	**T,fixed bdy. Cond.**
	406,000	**29,200**	**T, not as fixed**
Battelle	573,000	**77,100**	**Mesh 1**
	549,000	**66,100**	**Mesh 2**
	641,000	**68,900**	**Mesh 3**
Ford + Battelle	877,000	**105,000**	**Coarse Mesh**
	750,000	**90,000**	**Fine Mesh**
International + Battelle	353,000	**51,000**	**Fixed bdy. Cond.**
	241,000	**35,000**	**Not as fixed**
U. Tulsa - V. Viswananthan	224,000		**'textbook' guess based on FEA**
	42,000		**w.surf. Rough. Corr. factor 0.65**

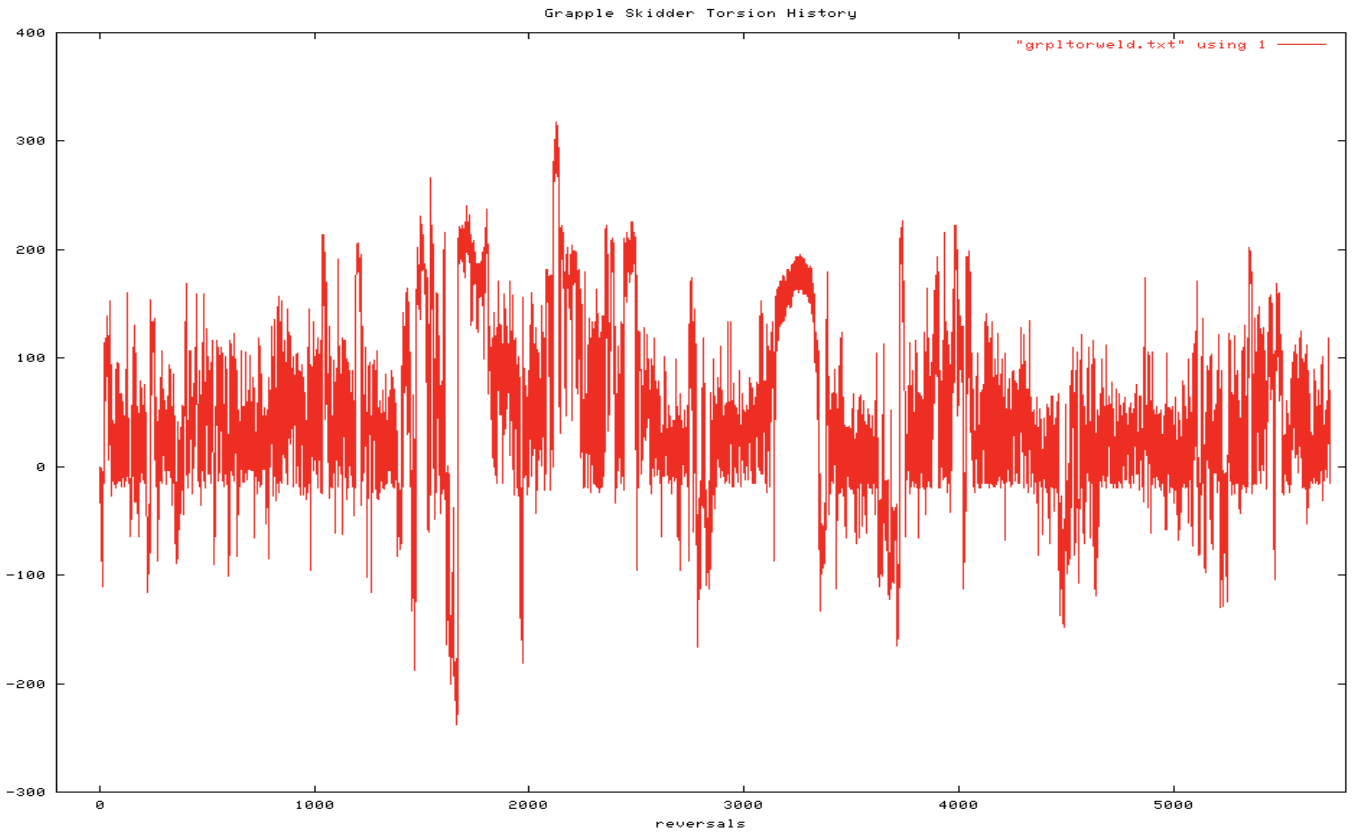
CA Prediction Results

Given the scatter in the experimental results,
all of the predictions were good.

Challenge II – Variable Amplitude

Load History Applied to Test specimens

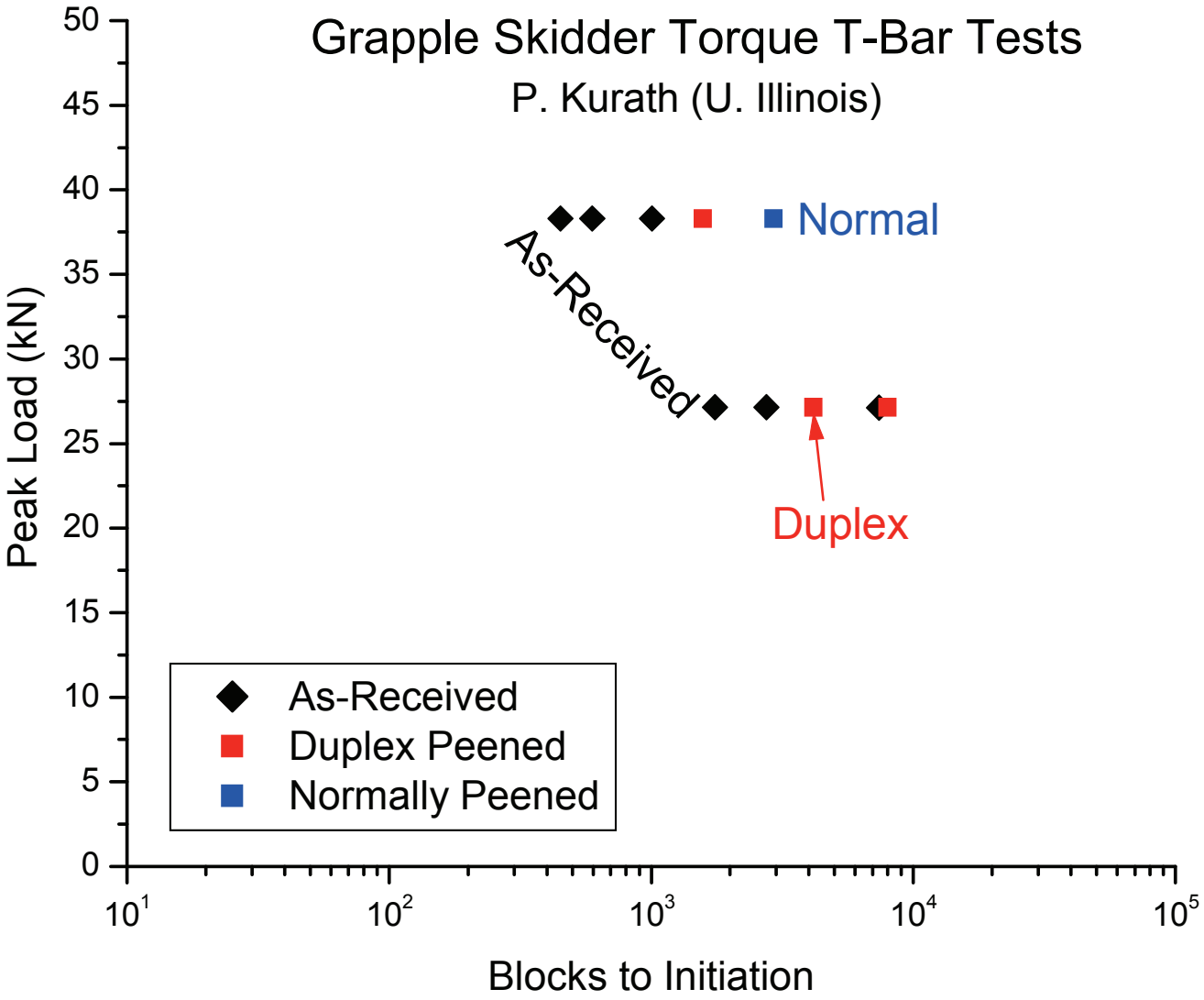
Factors:19.2x & 27.1x (Max load: 26.8kN, 37.2kN)



Results

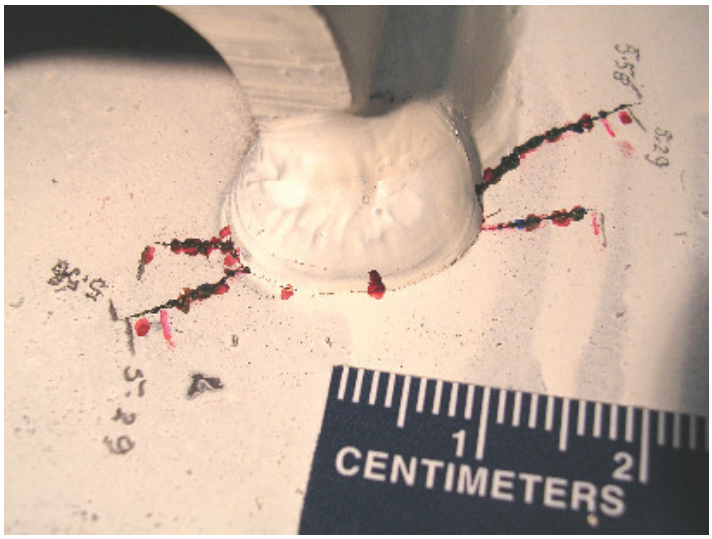
Participant	Life(blocks) for 19.2x (6106lb)	Life(blocks) for 27.1x (8608)	Comments
		Predictions	
DCX + FEMFAT	1468	344	partial penetration, corner*
Ford FLOW + Battelle	2044	364	full penetration, end*
	3273	1143	full penetration, corner*
	786	274	partial penetration, end*
	2065	721	partial penetration, corner*
Caterpillar + Battelle	1067	380	end*
	3016	1042	corner*
Navistar + Battelle	2362	824	corner*
Ford Research	2040	413	superposition+Neuber, near corner
		Test Results	
Ford Research	1750	450	partial penetration, earliest detection of crack
	8618	1850	30mm crack
U. of Illinois	3430	1005	partial penetration, earliest detection of crack,5mm crack
	10962	1505	30mm crack

*"corner" or "end" indicates the failure site predicted

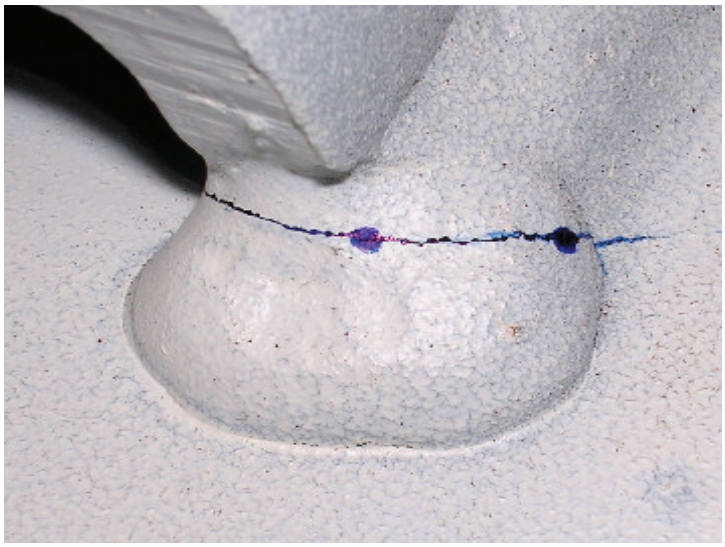

Grapple Skidder Torque T-Bar Tests
P. Kurath (U. Illinois)
Peak Load (kN)
Blocks to Initiation
Normal
As-Received
Duplex
As-Received
Duplex Peened
Normally Peened

Variable Amplitude Prediction Results

Given the scatter in the experimental results,
all of the predictions were good.



Type A -- Mostly CA As-Received
Most Init. OL
½ Grapple (Mixed)



Type B – Two Peened CA

Type C – Peened CA &
1/2 Grapple (Mixed)

Type D – 1 As –Recv'd
Init OL

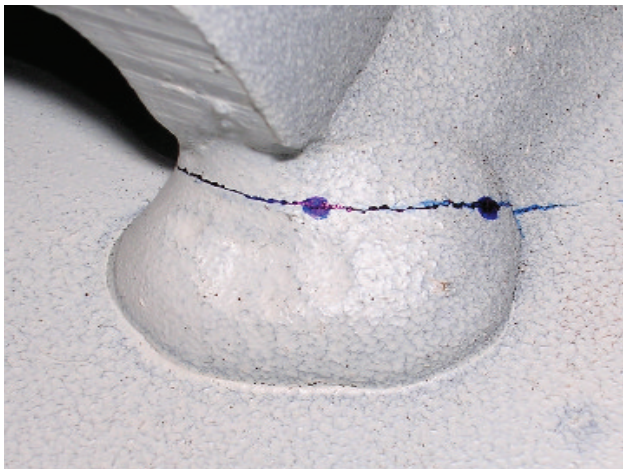
Weld Challenge III (b)

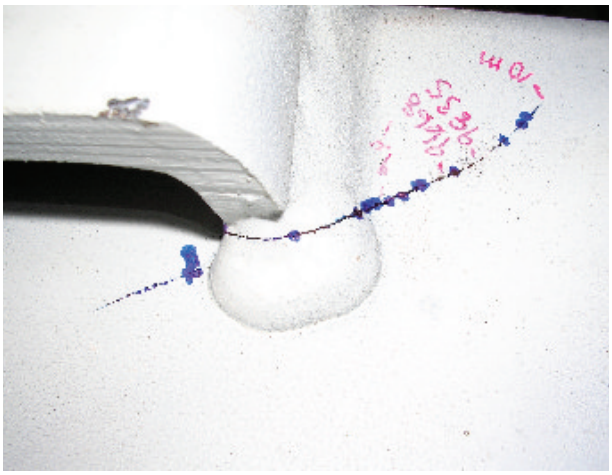
- Two T-weld peened and tested at +/- 11,120N
  - 1 with standard peening process (Ford)
  - 1 with duplex peening process (UIUC)

Institution	Life Estimate
Ford Research	300,000
International	240,000

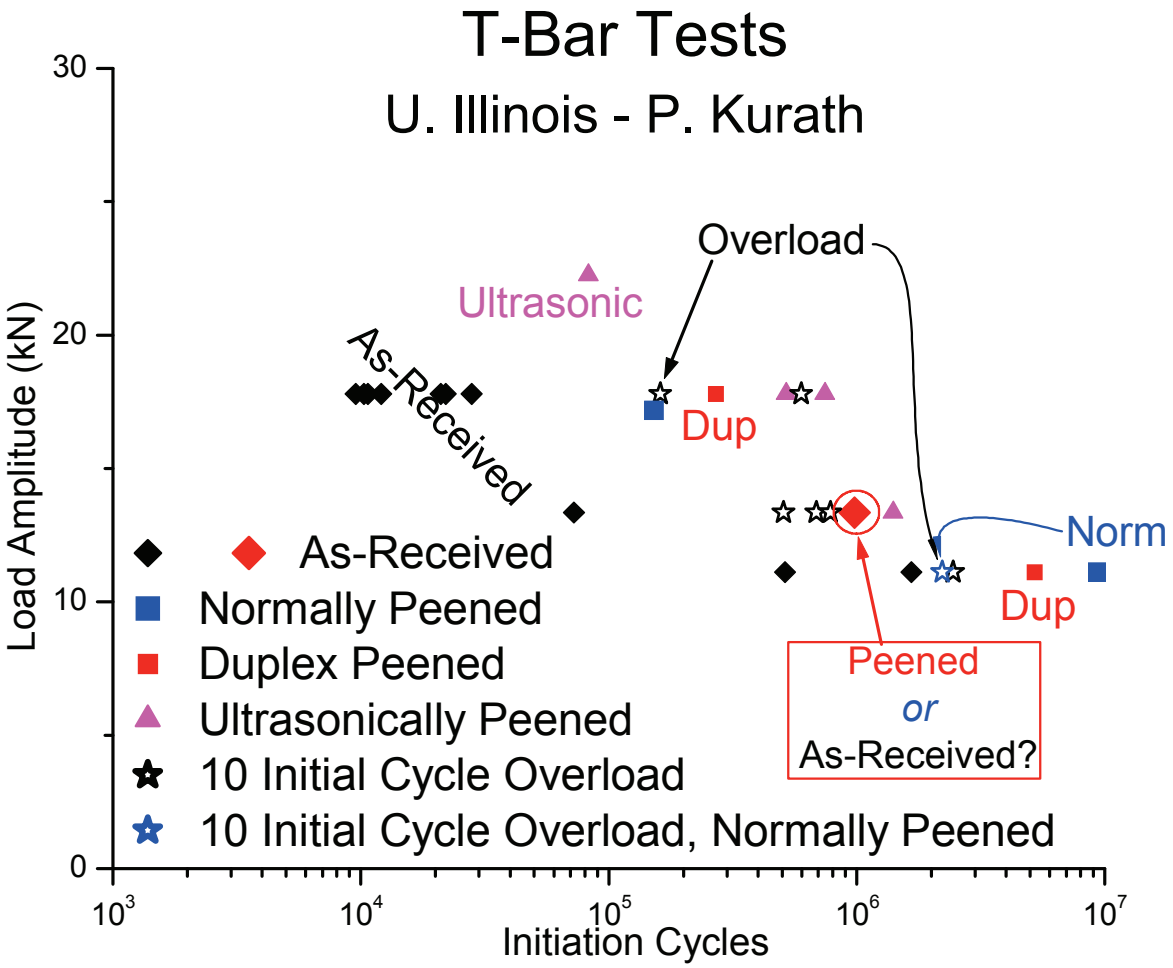
Challenge IIIb Test Results

Test ID	condition	Life
UIUC1	unpeened	1,414,570
FORD3	Single peen	9,400,000
UIUC11	Duplex peen	5,200,000





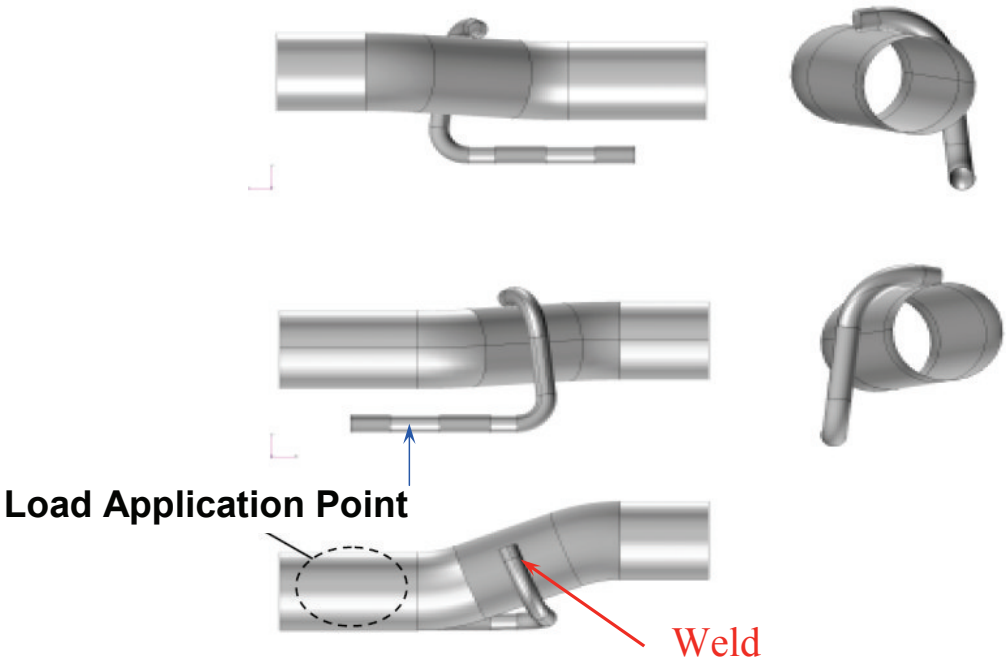
“Constant Amplitude” T-bar Results Summary



Next Steps for T-weld

- One last as-welded specimen
  - Ideas for test?
- More specimens?
  - Different surface prep.?
- Testing Volunteers
  - Kurath re-volunteer?
  - Others?

Weld Challenge 3a
Exhaust Tube and Hanger



Challenge IIIa Results

More details of these analyses at
http://www.fatigue.org/Weld/weld.html

Load(N)	Exper.Cycles to Failure
1023	72,000 ±52,000
845	390,000 ± 240,000
689	1,110,000 ± 120,000
578	3,000,000 ± 1,000,000

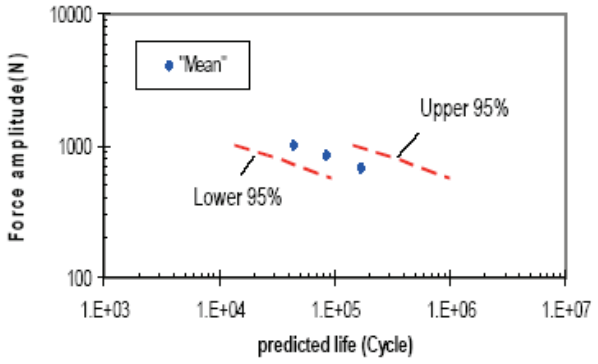
LMS

F [N]	Cycles to failure
1023	1.92E+04
845	3.94E+04
689	8.47E+04
578	1.64E+05

International

578 N	5315 cycles
689 N	3107 cycles
845 N	1665 cycles
1,023 N	929 cycles

Battelle

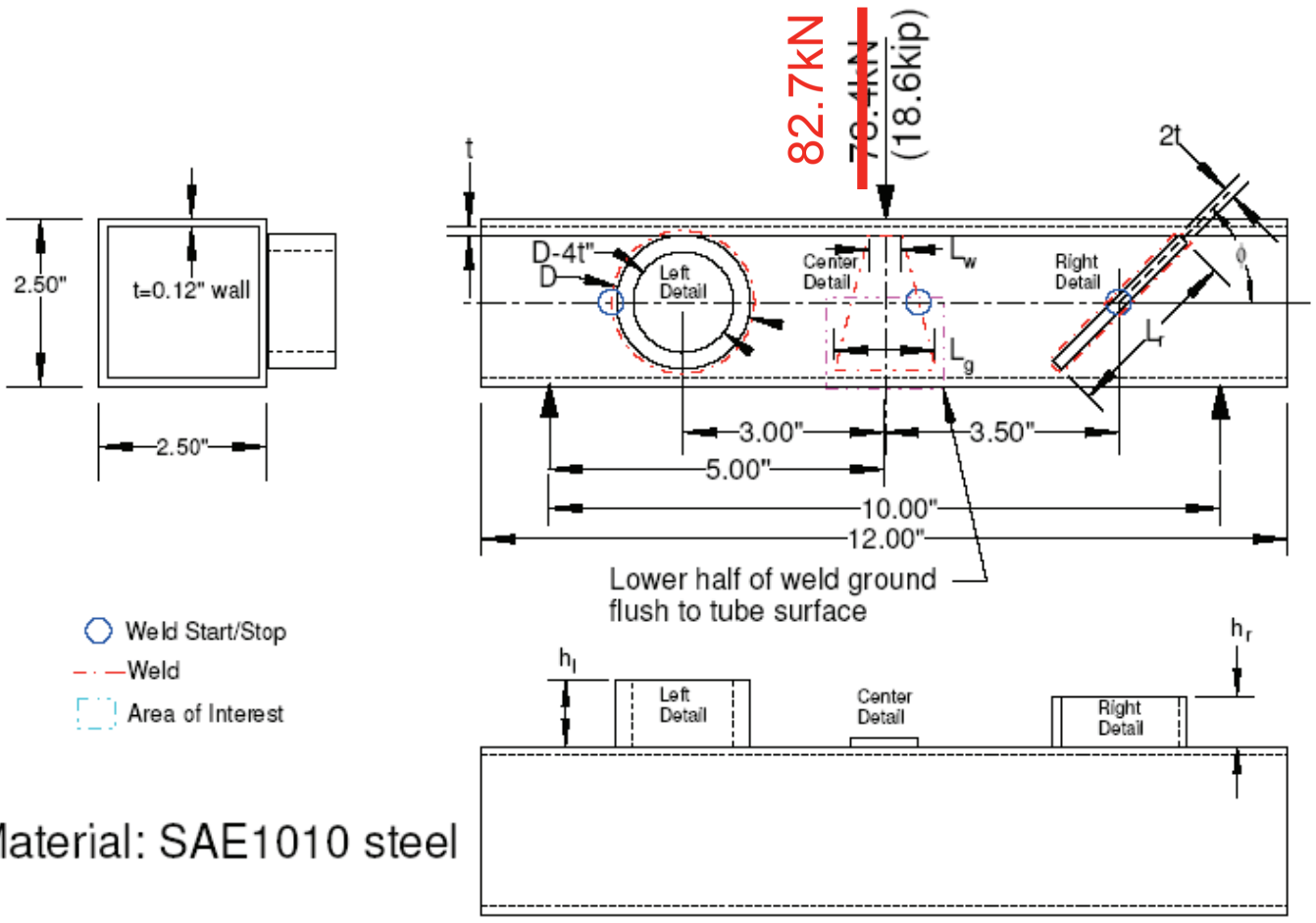


FEMFAT

	FE-mesh (shell-shell) / flared Joint		FE-mesh (shell-solid) / T-joint		FE-mesh solid Tet10	
Force amplitude	Damage	**Fatigue life**	Damage	**Fatigue life**	Damage	**Fatigue life**
578	0.30	**3300**	0.08	**11891**	0.81	**1238**
689	0.67	**1497**	0.21	**4878**	2.12	**472**
845	1.67	**599**	0.56	**1779**	5.66	**177**
1023	3.95	**253**	1.46	**684**	14.75	**68**

Tube design for weld challenge IV

0-max loading (R=0)

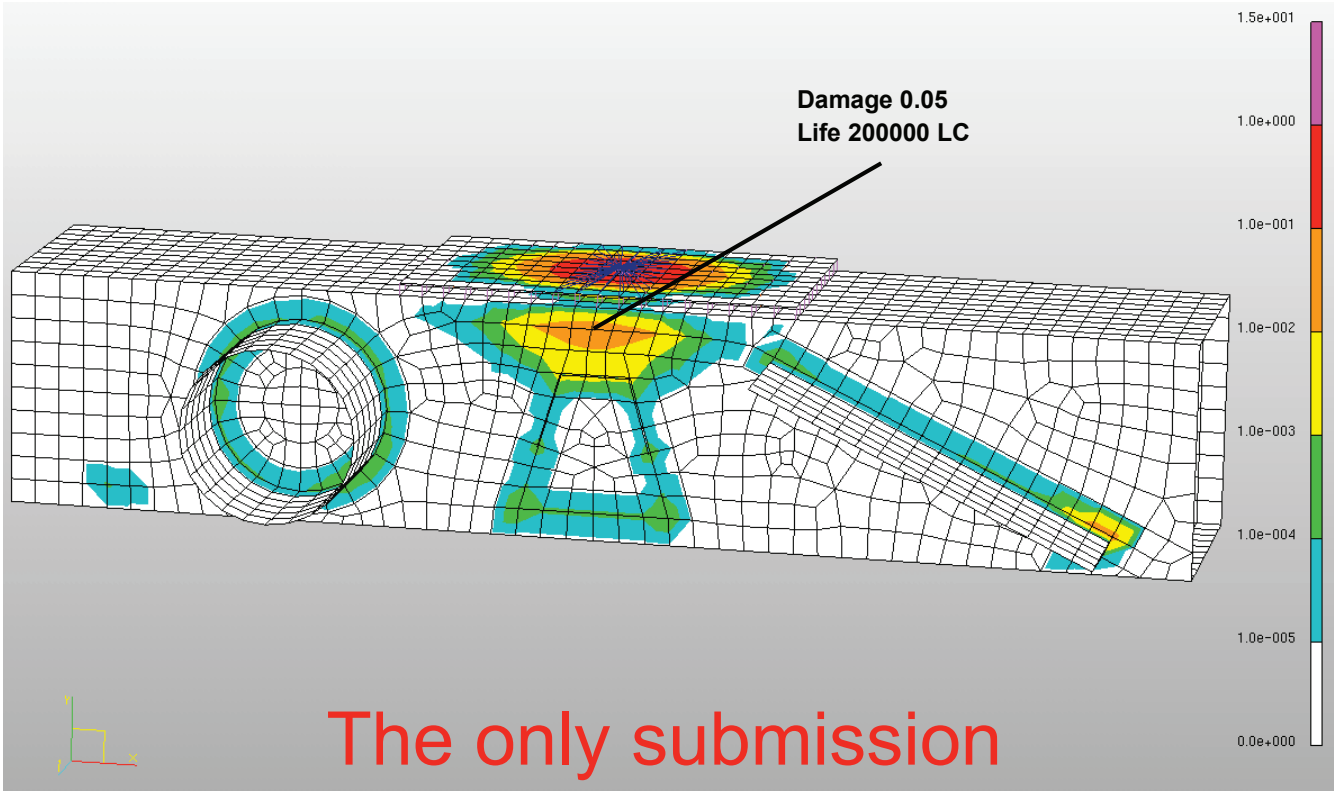


Material: SAE1010 steel

Version 1

MAGNA STEYR

FD & E – Weld Challenge IV – Results Version 1



The only submission

Many Iterations Followed …

Three principle participants

- Magna Powertrain – Klaus Hofwimmer (2d FEA)
- USM – Ali Saeedy (3d-FEA)
- Ford – Hari Agrawal/Ramamohan Potukutchi (2d FEA)

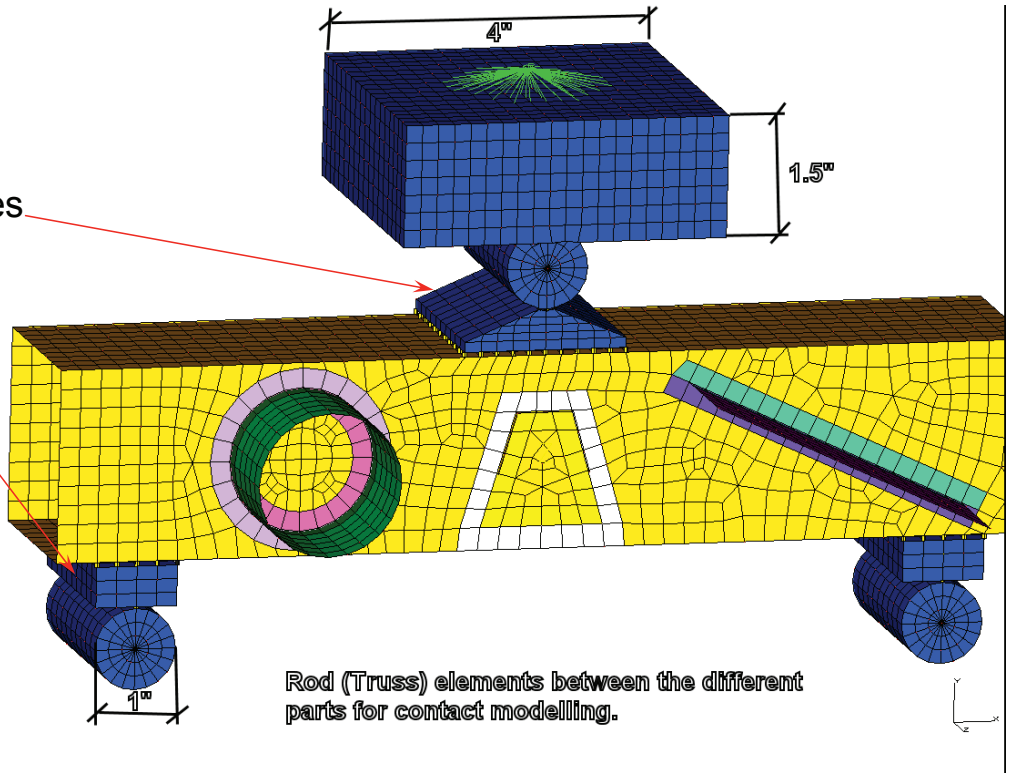
Many refinements/modifications to the challenge:

- Material properties released for original SAE1010
- Loading blocks defined, included in FEA & modified
- Material changed to ASTM A500 Grade b (HSLA) because not enough separation between weld and parent material fatigue performance.
  - Best guess A500-b material properties released

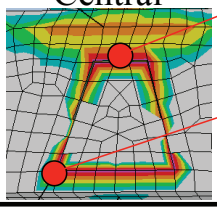
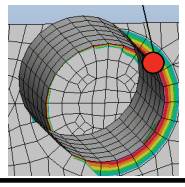
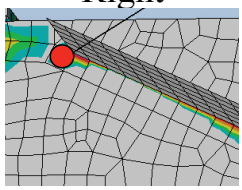
Final Models Presented Fall 2006

Magna Powertrain/Ford/USM

Load Distribution Blocks
Added to Reduce Stresses
In Parent Metal.

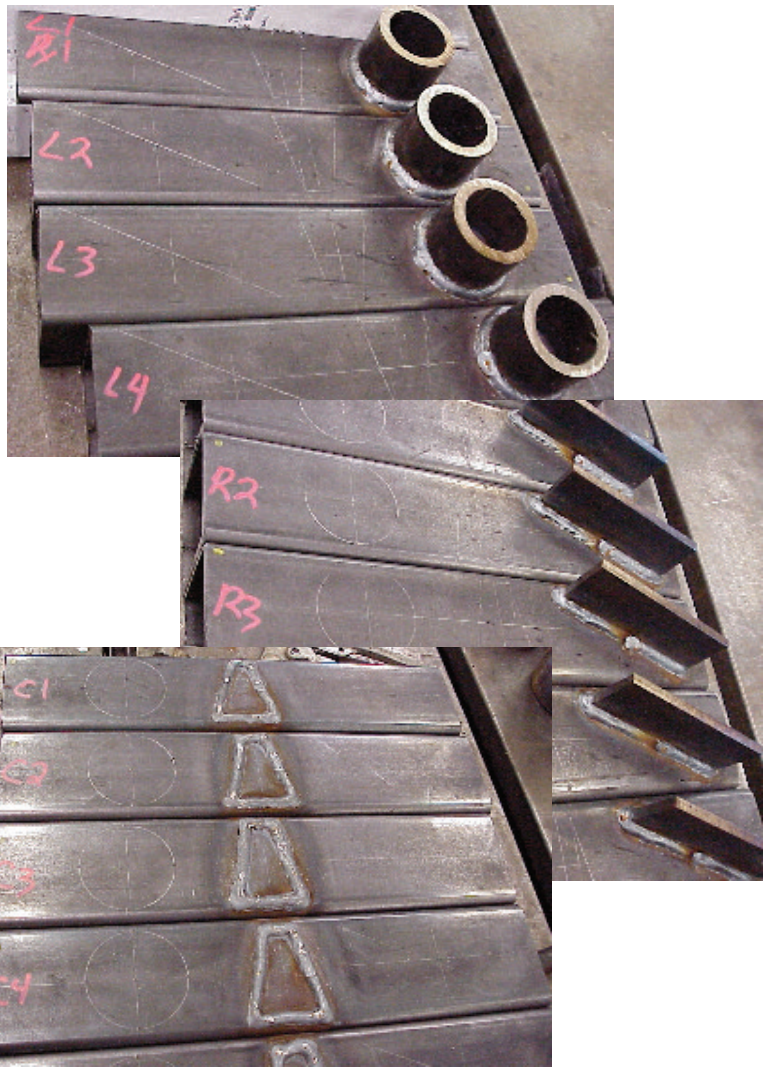


Magna Powertrain FE-Model

Attachment	Location	Model	Von Mises Stress (MPa)	Life
Parent Metal	Top Inside Tube	Ford	-427 (346)	(22500000)
		Magna	-425	1980000000
		USM	-499	13500000
Central 	Top Weld	Ford	195*	153000
	Bottom-Weld (Ground)	Magna	304	532000
		USM	287	36000
Left 	Weld @ 2 o'clock	Ford	191*	165000
		Magna	254	30200000
		USM	278	63000
Right 	Weld	Ford	116*	763000
		Magna	318	30700000
		USM	332	53000

*Structural Stress

Tube Construction



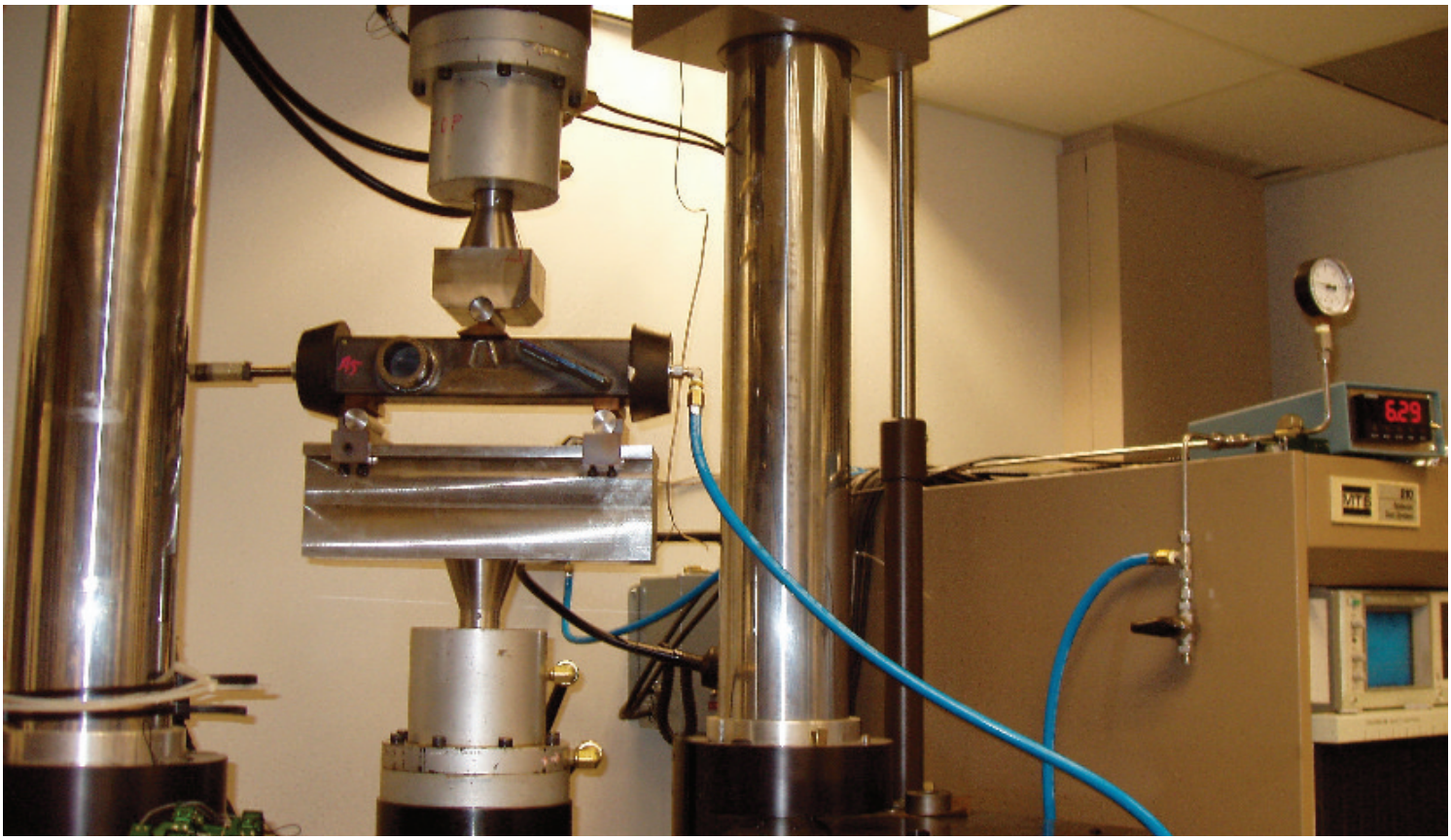
Results

- Testing performed by
  - Phil Dindinger / Stork-Technimet
  - John Bonnen / Ford

- Mixed

Ford Test Setup (John Bonnen)

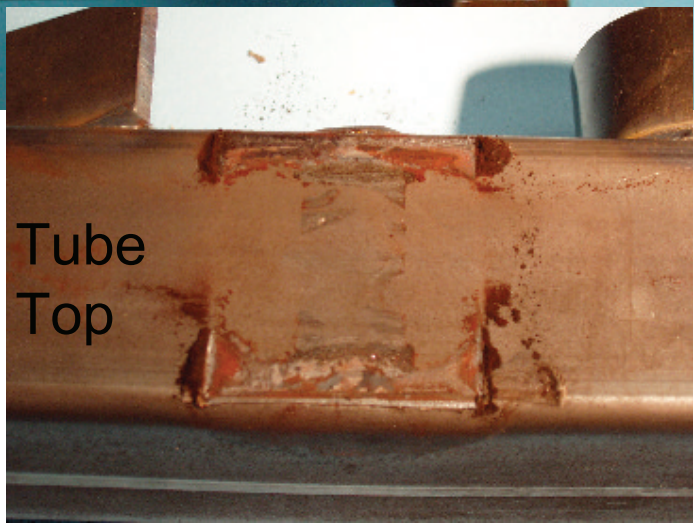
showing pressure monitor



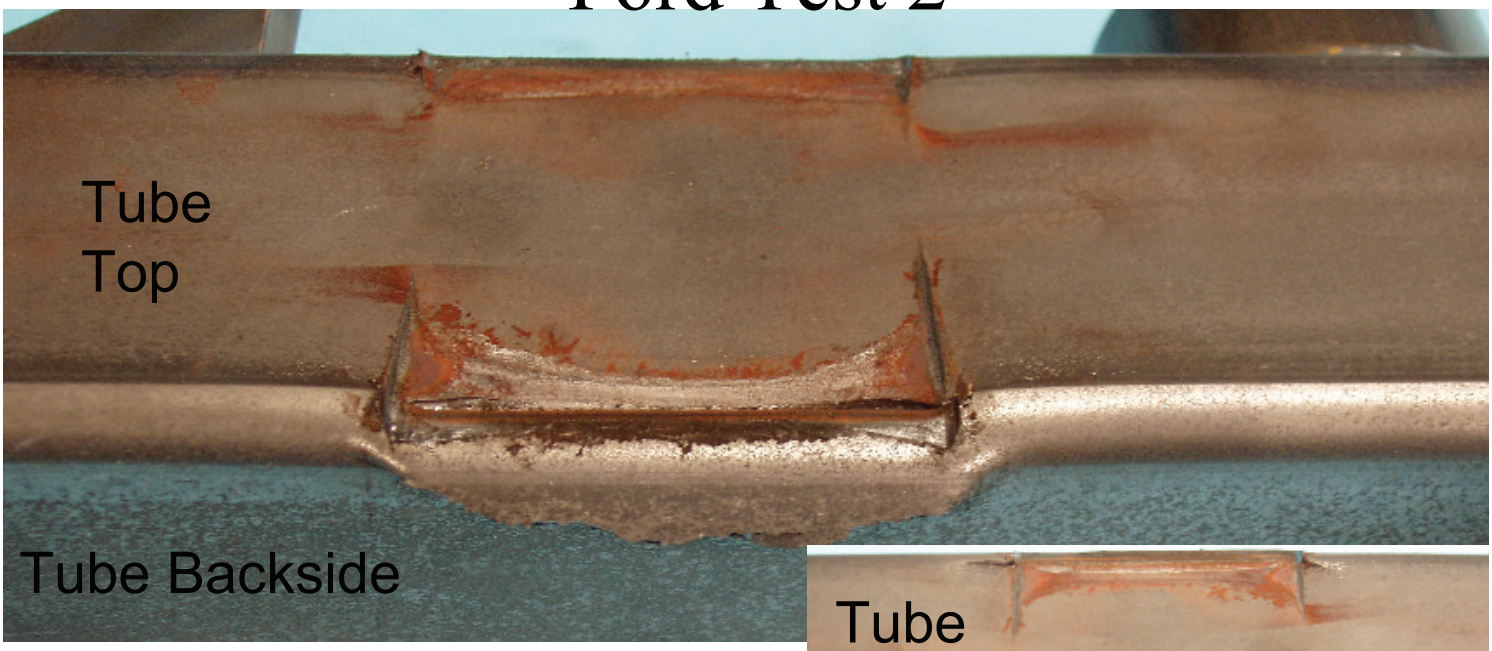
Ford Test 1

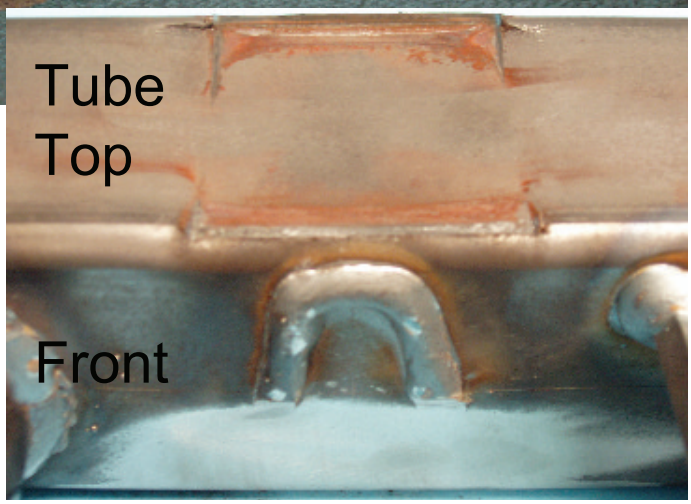
-84500N to -1800N
82700N Range
82700N Target

Life = 118690 cycles with much
tube & lower block rotation



Ford Test 2



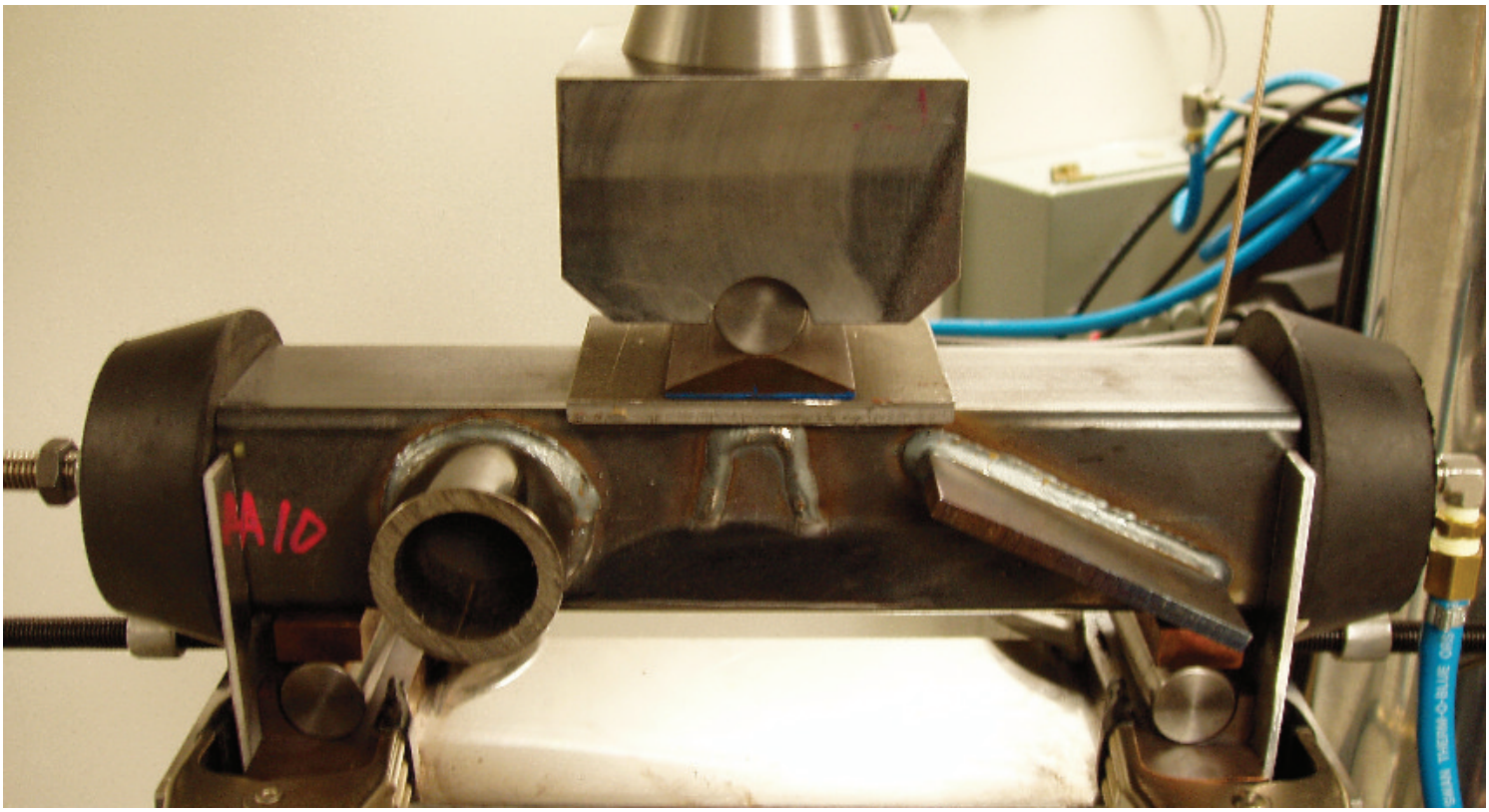


-84500N to -1800N
82700N Range
82700N Target

Life = 99900 cycles with no rotation

Ford Test Setup (John Bonnen)

Showing additional ¼” plate to reduce wall buckling



Ford Test 3

-84500N to -1800N

82700N Range

82700N Target

Life = 97,400 - 200,000 cycles

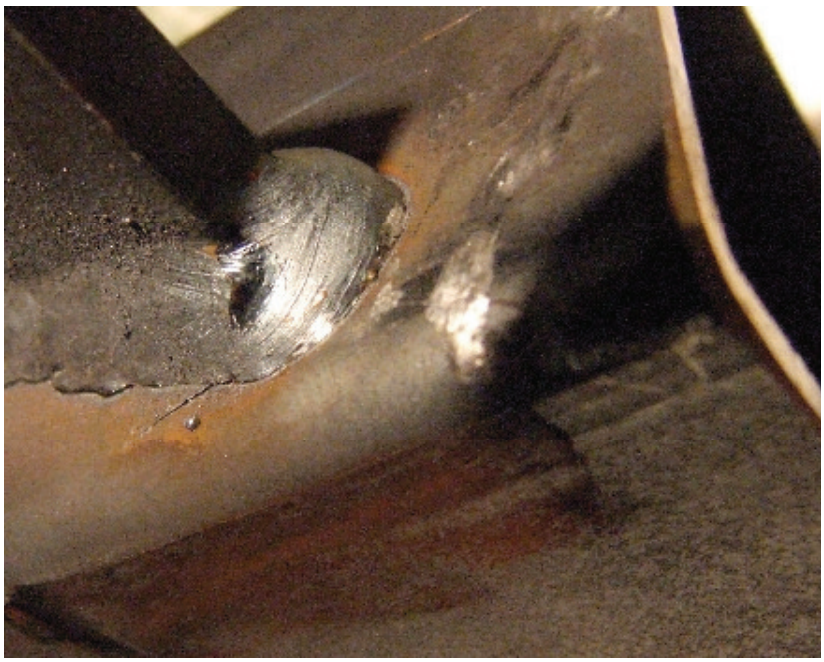
with some rotation of ¼” plate

Neglected to set limits & stop criteria

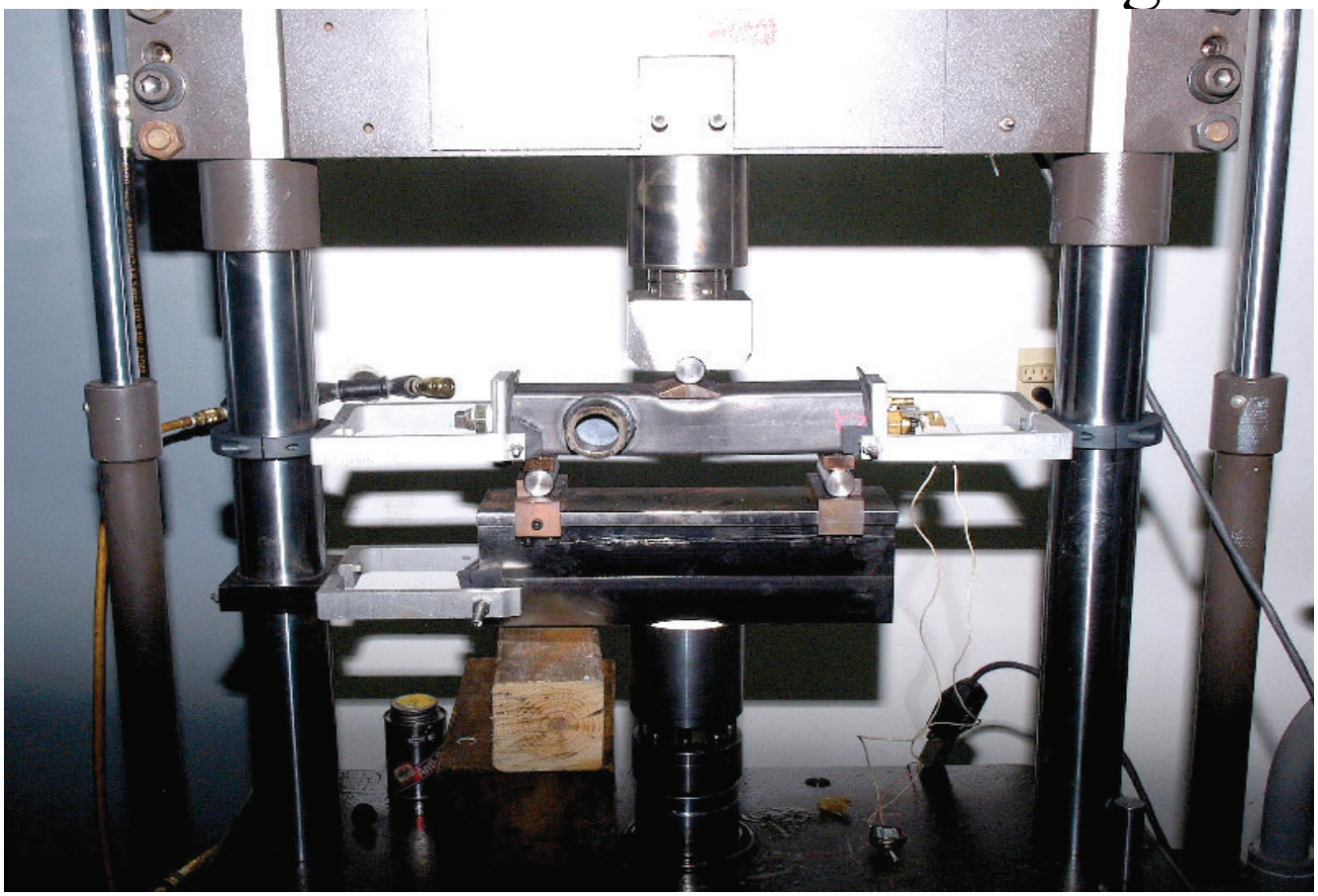
Result = ????!!!!

Ford Tube 3

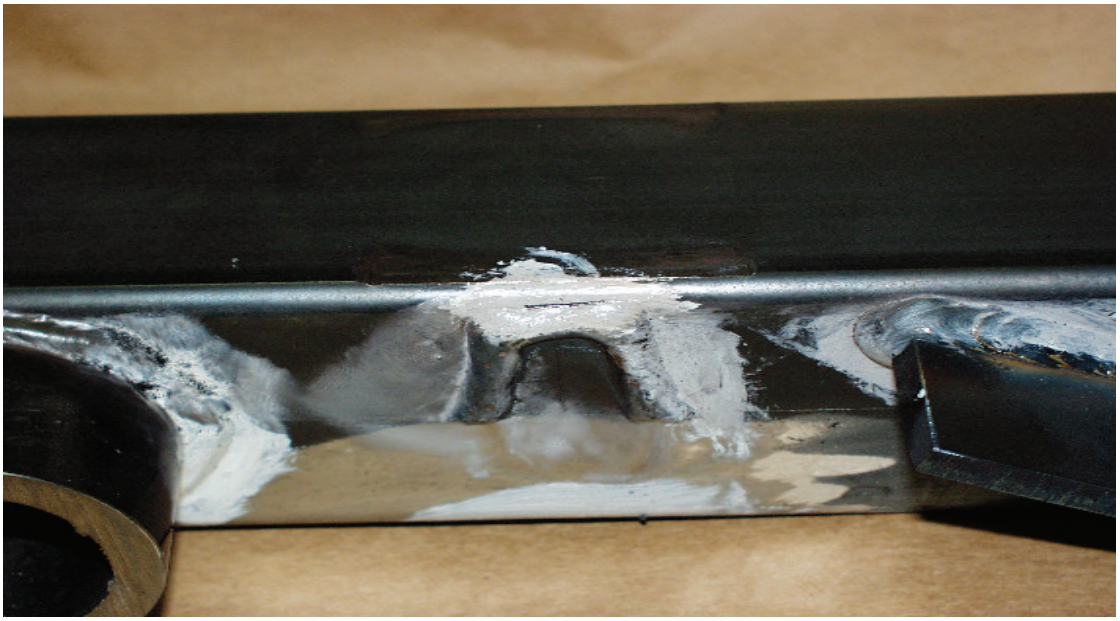
Ford Tube 3 Cracks



SAE Tube Test Set-up
Stork Technimet -- Phil Dindinger

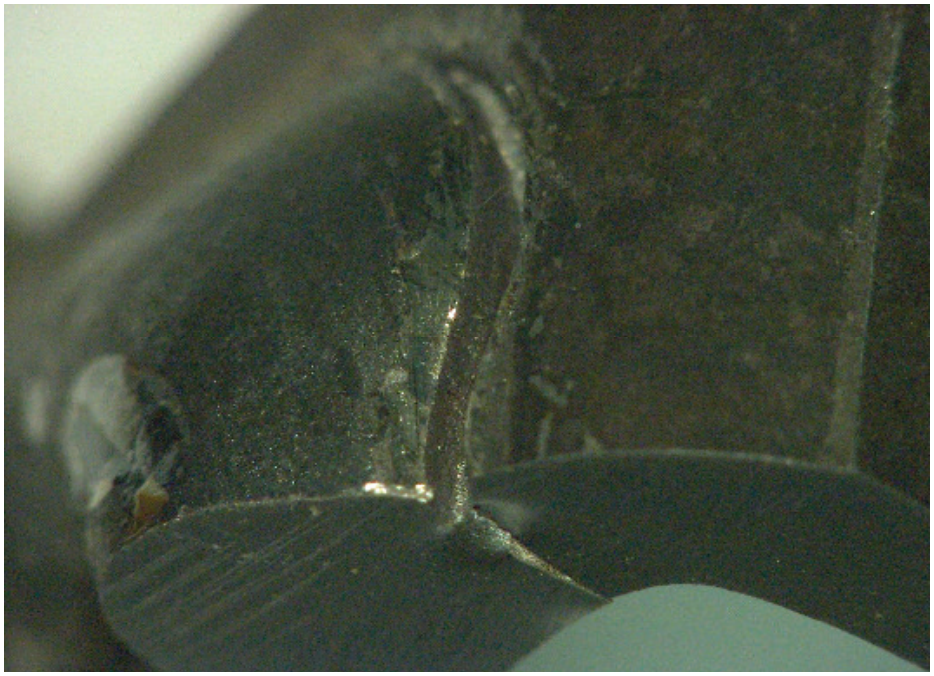


SAE Tube Weld Crack
Stork Technimet -- Phil Dindinger

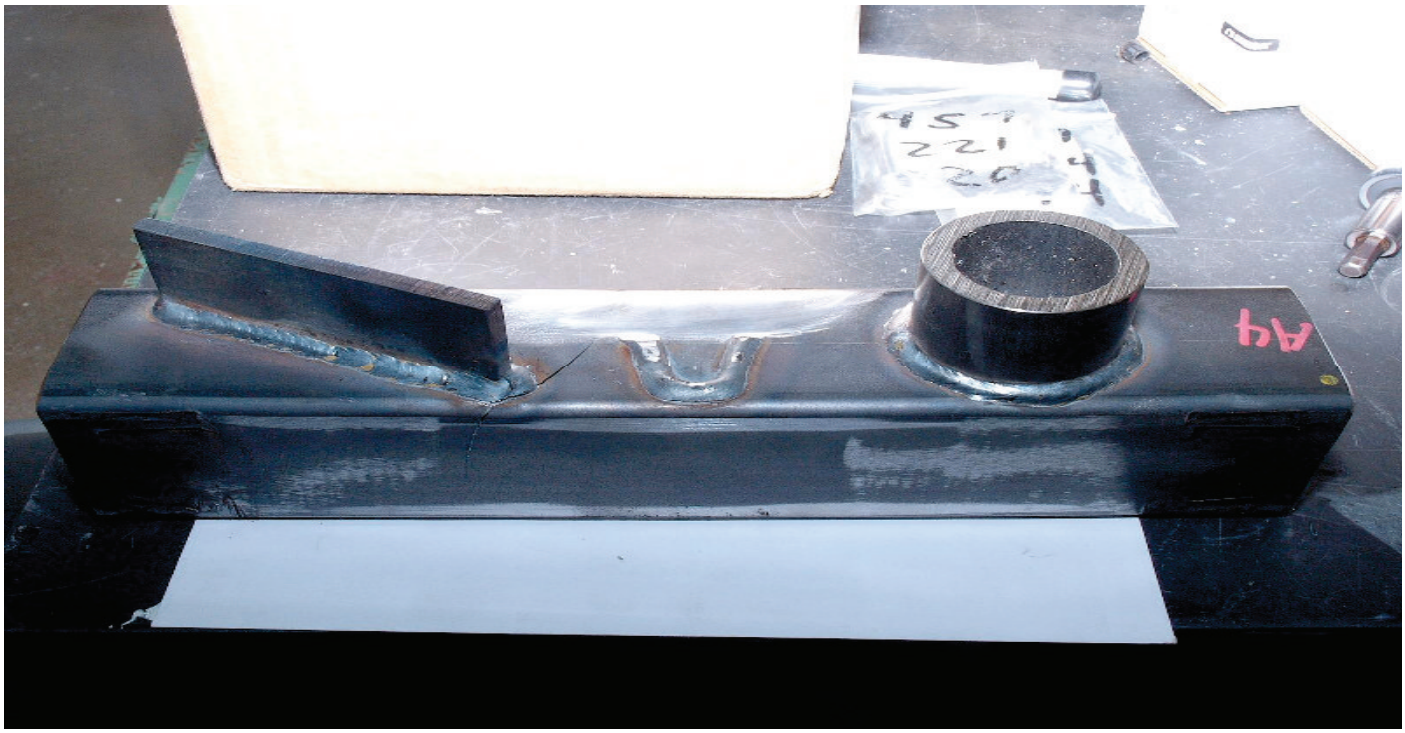


-9940 +/- 9380 lbs. Life = 69467 cycles
-85940N to -2500N (83450N range)
Target 82700N

Weld Crack
Stork Technimet -- Phil Dindinger



Sample Loaded Up-Side Down
Stork Technimet



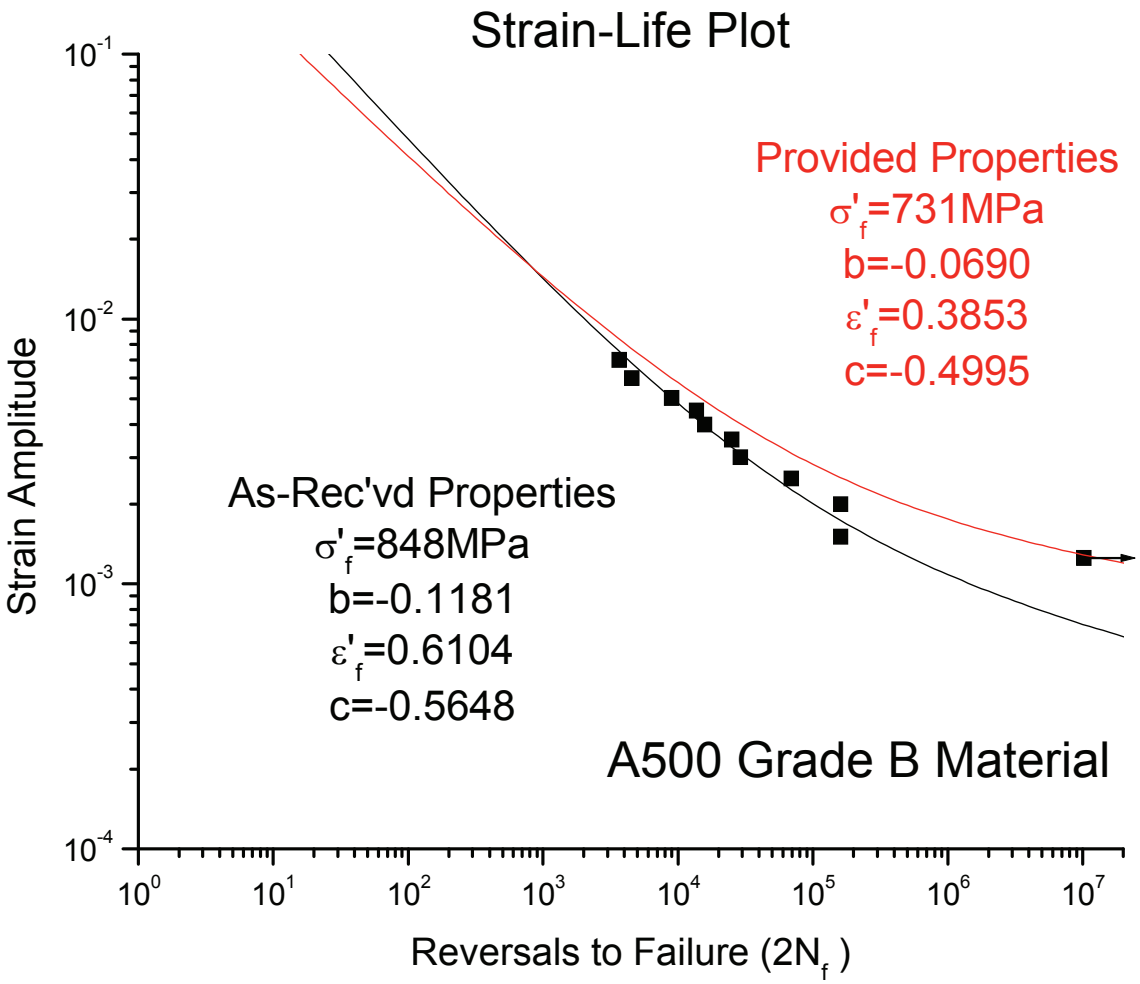
-9940 +/- 9410 Lbs Life = 172,089 cycles

83700N range Target 82700N

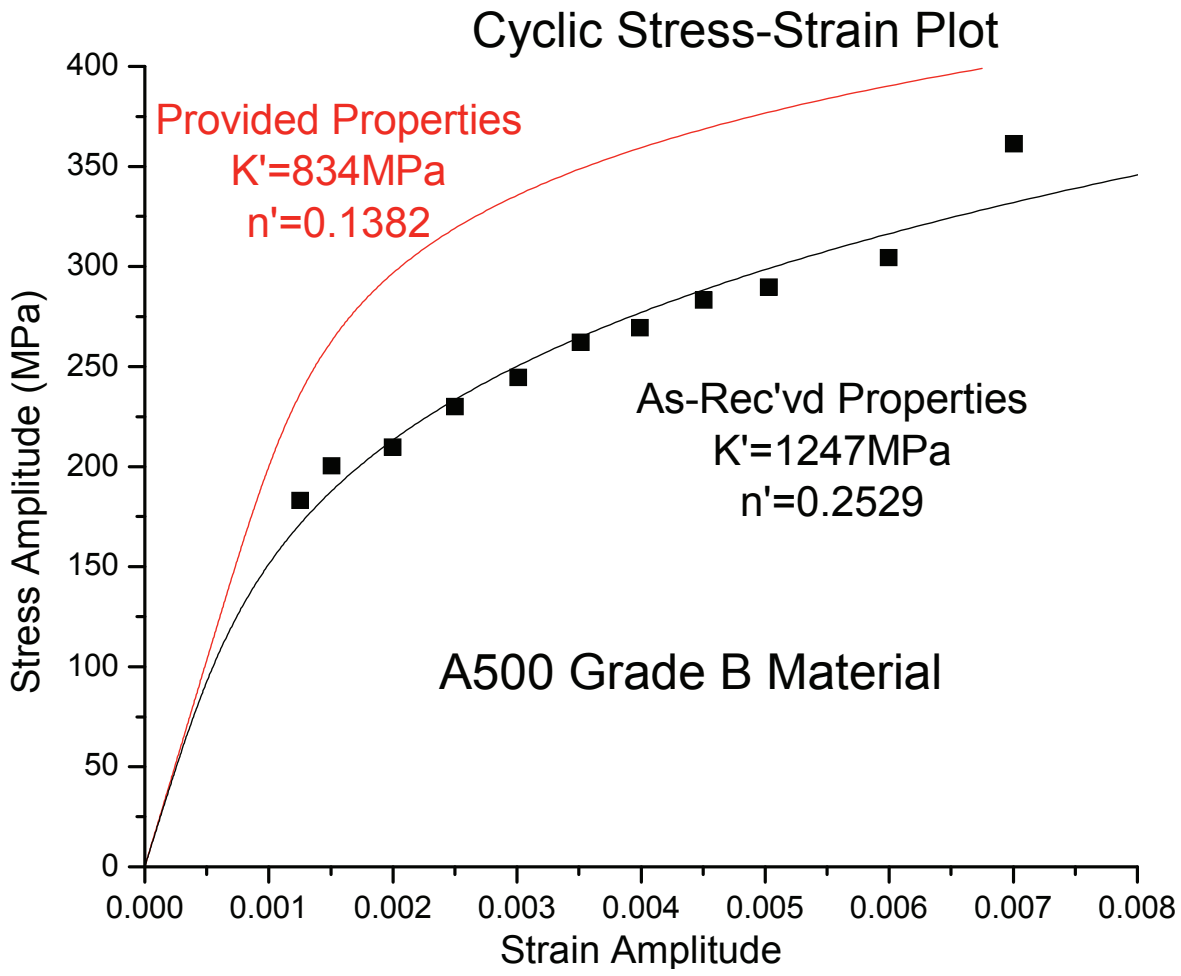
Results Summary

Specimen	Failure Life (cycles)	Failure Location
Ford 1	118,690	Rear wall, buckling
Ford 2	99,900	Rear wall, buckling
Ford 3	97,450- 200,000	? Left attachment at tube bottom?
Stork 2	69,467	Central detail, top (?buckling?)
Stork 1 invert	172,089	Left attachment at tube “top”

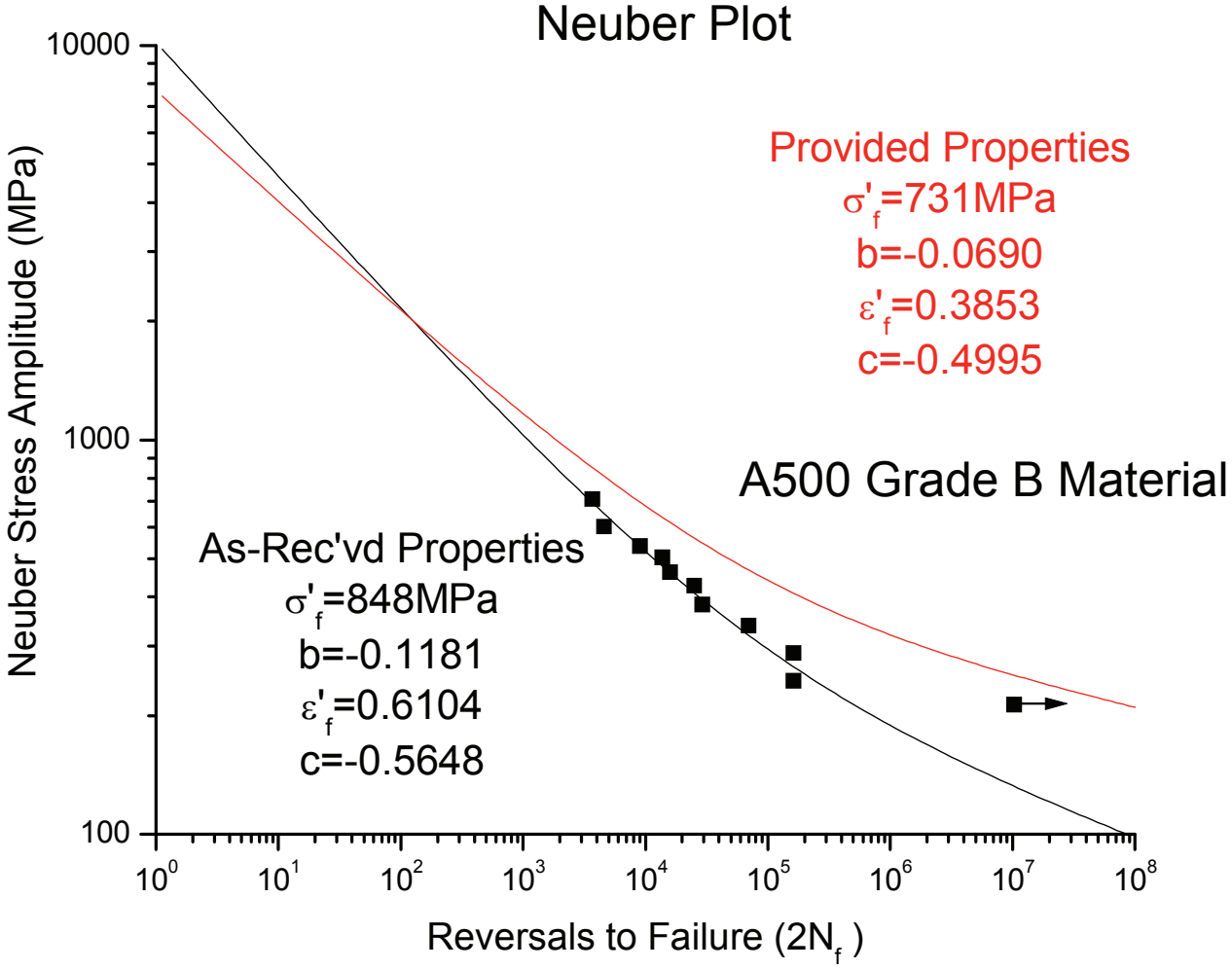
Stork Technimet Tests on Tube Material



Stork Technimet Tests on Tube Material



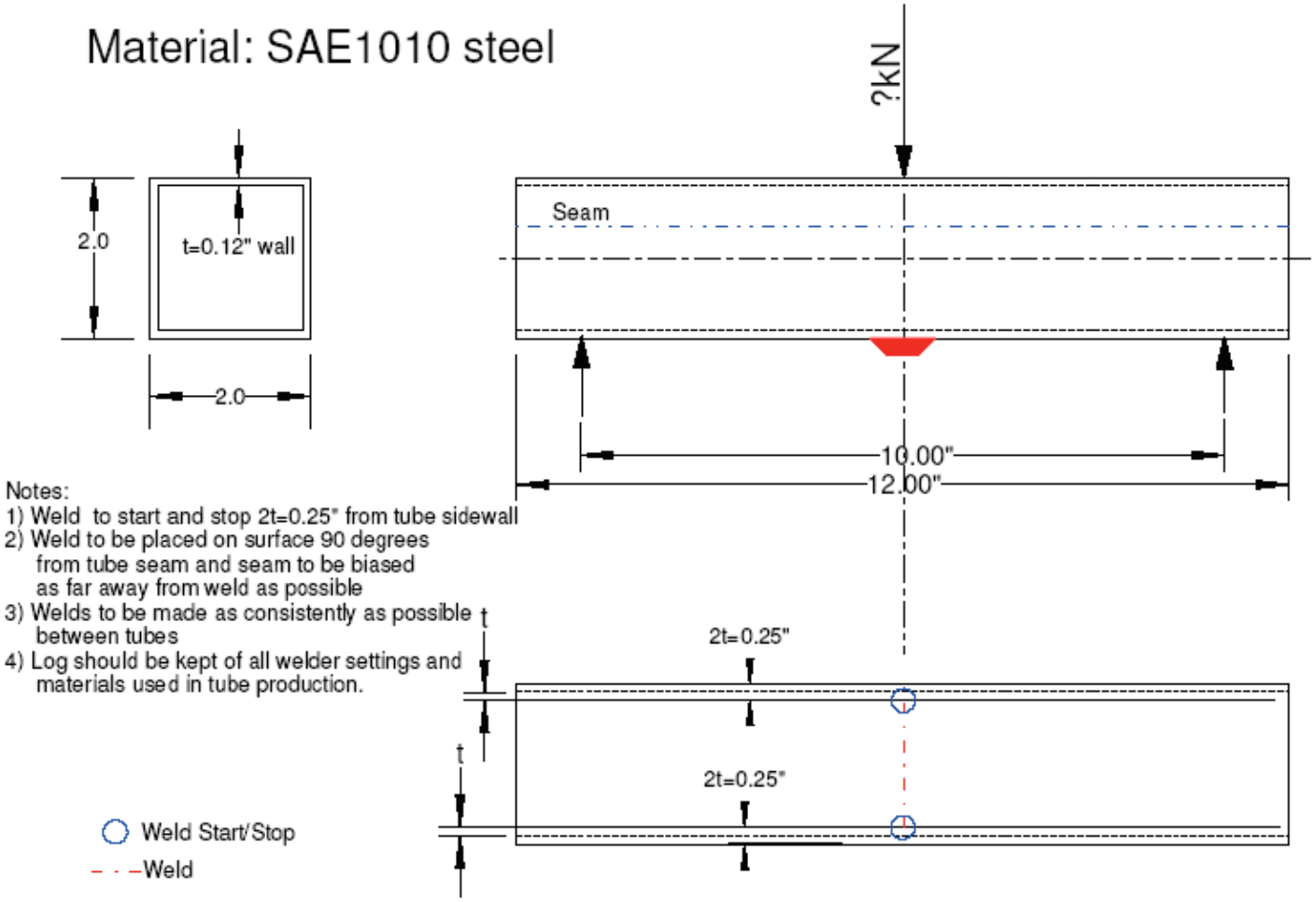
Stork Technimet Tests on Tube Material



Next Steps for WC V

- Continue testing existing tubes to get a number of valid tests
- Test individual attachments
- Have FE participants re-run analyses with new properties
- Possibly obtain new higher strength material and fabricate & test new specimens
- More testers?

Iowa Tube work … Stephens at



Test Tube Material

- Thin walled cold rolled 1010 steel tubes
  - 2 x 2 x 1/8 x 12 in.
  - **Weld operation**
  - 23 Volts, 130 Amps
  - Mild Steel #ER-705-3
  - 0.035 in diameter
  - Gas coverage = 75% argon, 25%Co_2

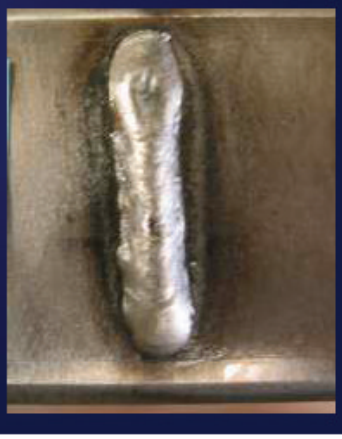
  Flow rate = 30 cfm

- Peening processes
  - Shot peening
    - CW14 cut wire conditioned
    - Peened with 8A intensity to 100% coverage
    - Shot peening included weld and ½ in to either side of the weld
  - Laser Peening

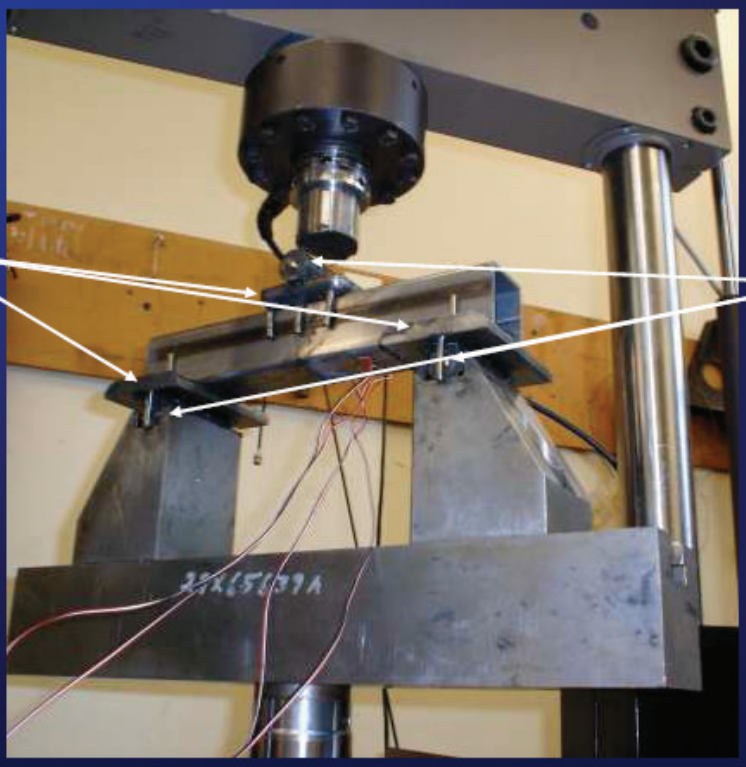
    intensity = 8 GW/cm^2

    pulse duration = 18 ns

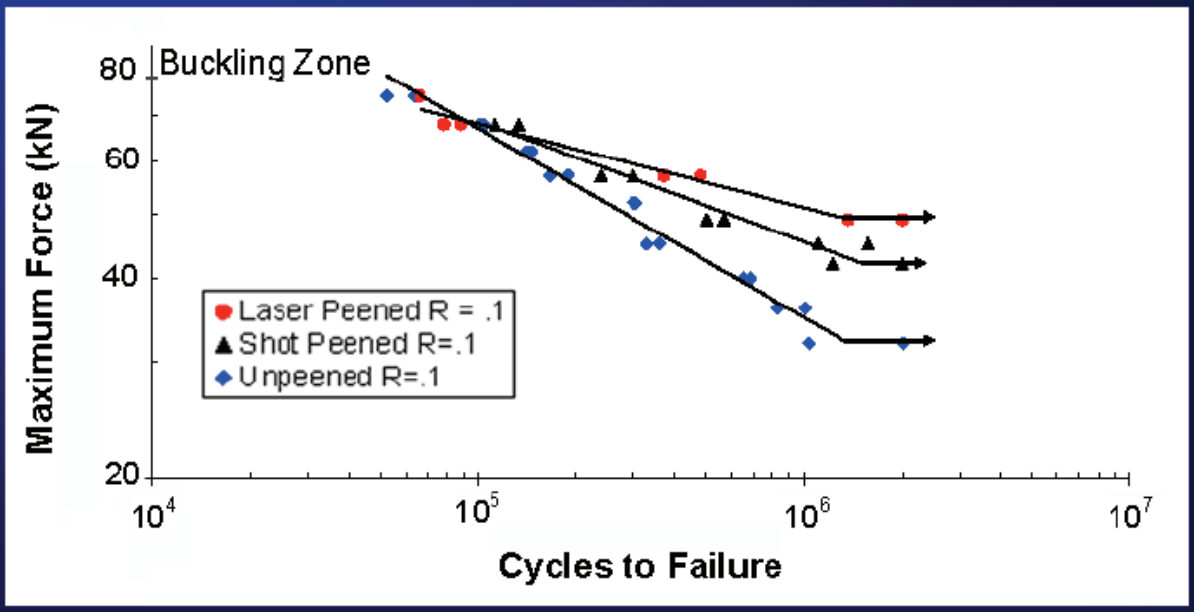
    two peening layers



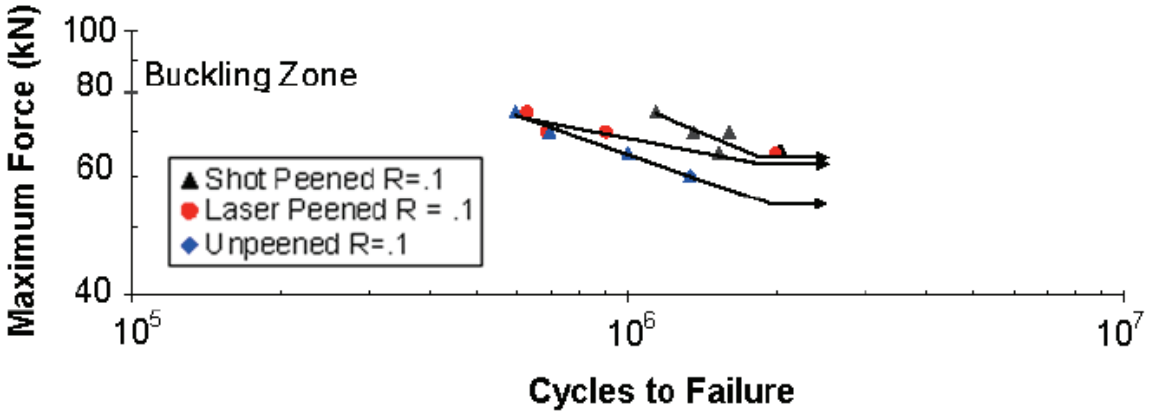
Test set-up



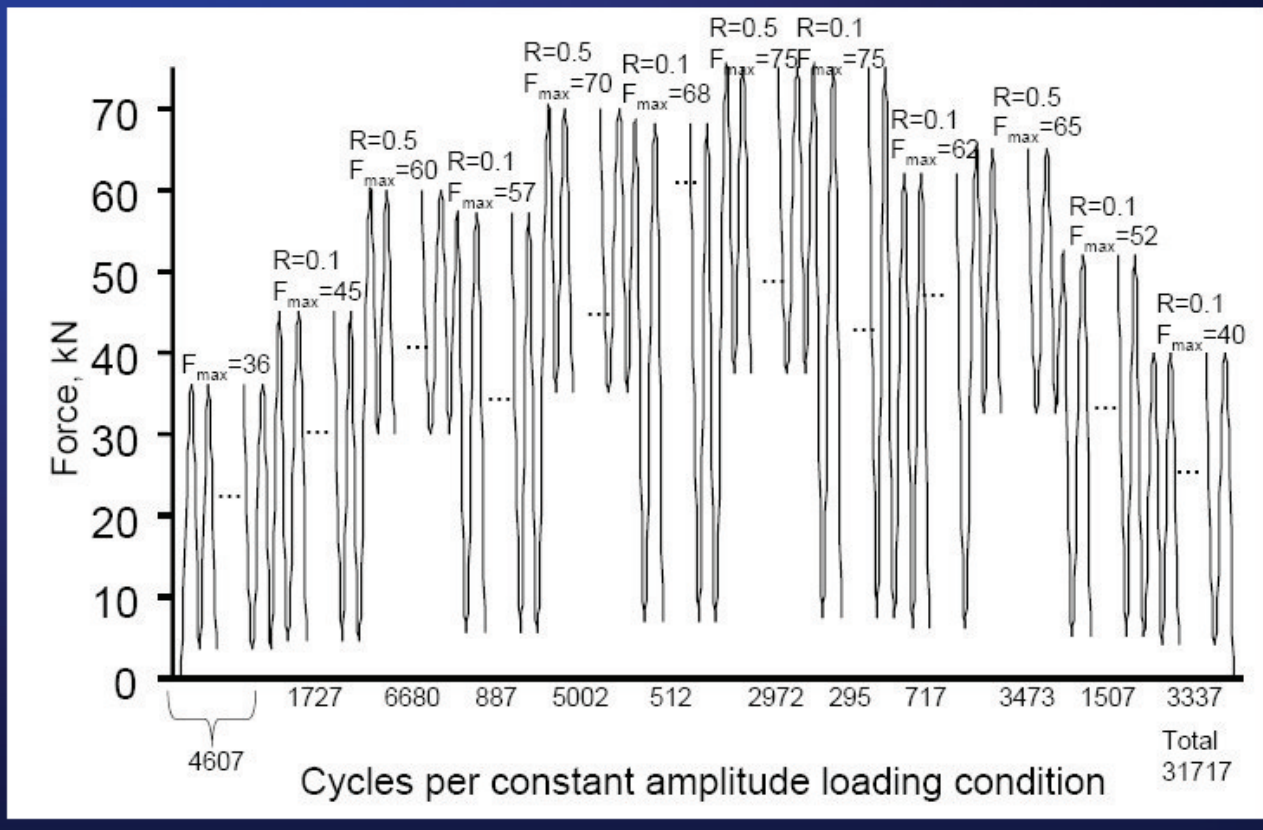
Constant Amplitude Test Results
R = 0.1



Constant Amplitude Test Results
R = 0.5



Variable Amplitude Test: 12 Level Spectrum

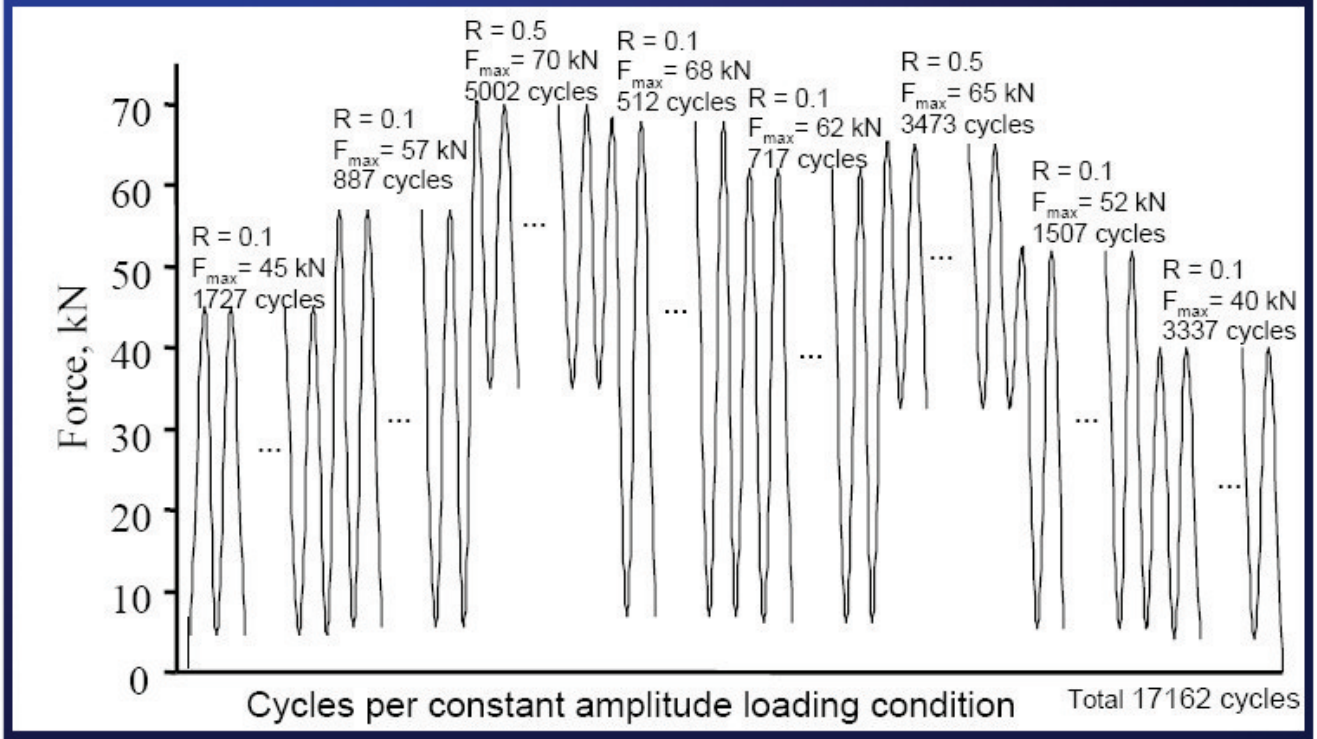


Variable Amplitude Test Results

12 Level Spectrum Variable Amplitude Tests

Surface Treatment	Blocks Completed	Average Blocks Completed	Average Cycles Completed	Average Fatigue Life Increase
As welded	19.6	17.6	556 936	
As welded	15.5			
Shot peened	27.5	20.7	655 645	
Shot peened	17.6			18%
Shot peened	16.9			
Laser peened	19.7	18.8	594 369	7%
Laser peened	17.8			

Variable Amplitude Test: 8 Level Spectrum

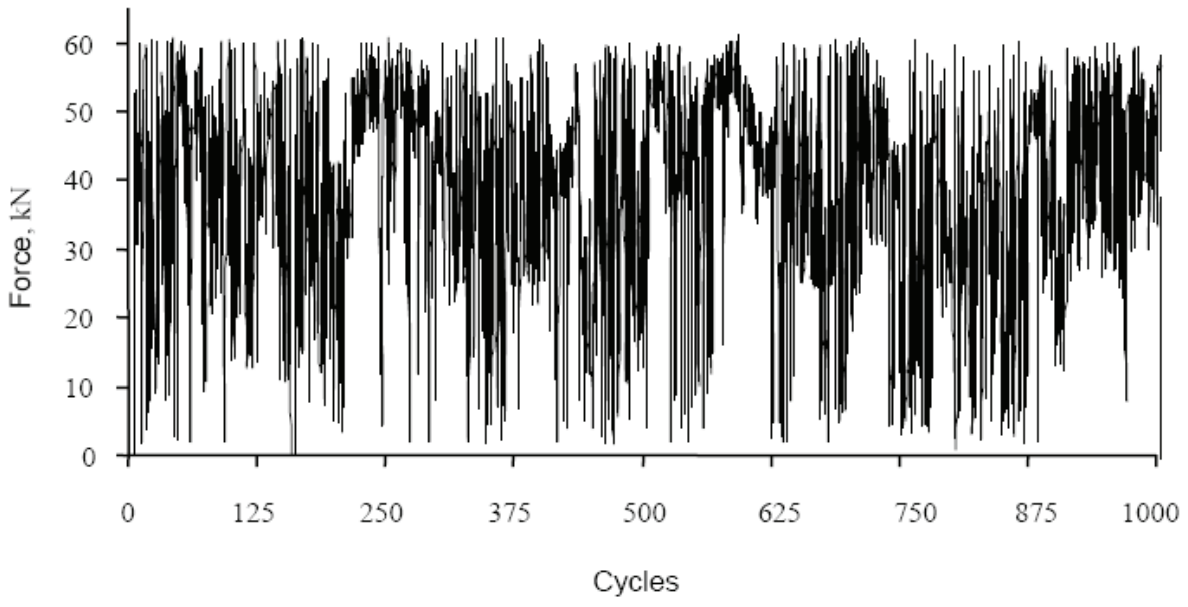


Variable Amplitude Test Results

8 Level Spectrum Variable Amplitude Tests

Surface Treatment	Blocks Completed	Average Blocks Completed	Average Cycles Completed	Average Fatigue Life Increase
As welded	25.1	24.5	419 900	
As welded	23.8			
Shot peened	37.3	31.2	548 132	27%
Shot peened	32.1			
Shot peened	26.4			
Laser peened	29.3	28.3	484 555	11%
Laser peened	27.2			

Variable Amplitude Test: Random Spectrum

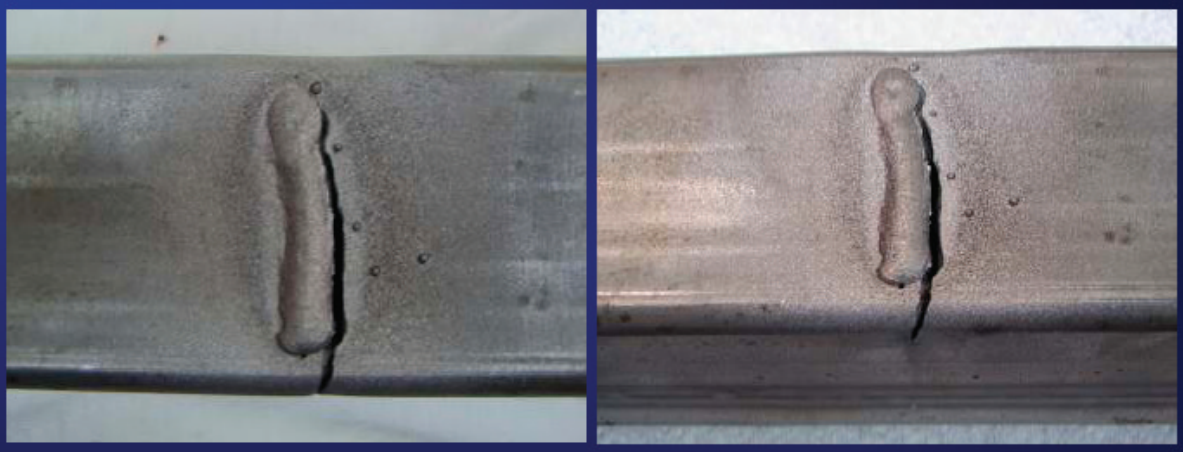


Variable Amplitude Test Results

Random Generated Spectrum Variable Amplitude Test

Surface Treatment	Blocks Completed	Cycles Completed	Fatigue Life Increase
As welded	716	716 270	
Shot peened	674	674 349	-9%
Laser peened	805	805 704	13%

Crack Appearance



Shot peened specimen, 12 level variable amplitude test, completed 27.5 blocks

Fatigue Crack Surface Photographs

As-welded specimen, 12 level variable amplitude test, completed 19.6 blocks

Conclusions

- Significant effect of shot peening in constant amplitude loading
- Effects of shot peening under variable amplitude loading are insignificant.
- Where next? (Stephens)