FOIA/PA NO: 2015-0413

OFFICIAL RECORDS TO BE MADE PUBLICLY AVAILABLE IN ADAMS

SUBSURFACE ET TESTING

1. Introduction

An evaluation of the ability of the standard ET probes used for Reactor Vessel Head Inspection (RVHI) to find subsurface indications was performed.

The effort is intended to determine the ability of this technique to find slag inclusions near the surface in the weld.

2. ET Process

Two probes were evaluated in this effort.

2.1. CRDM ID Probe

This inspection was performed in accordance with the procedures used for RVHI efforts. Acquisition was governed by WDI-STD-1042. Analysis by WDI-ET-004.

This is a 0.25" diameter X-point probe designed to operate between 50 and 500 KHz.

A X-point probe is a +Point type probe that is rotated 45° and operated in driver pickup mode.

The inspection process operates this probe at 400 and 100 KHz. It was calibrated using the block shown in Figure 1. This is a 0.040" deep EDM notch.

The data was acquired at an interval of 0.020" to enhance the impedance plane plots. Per WDI-ET-004, the Derivative C-scans were adjusted to calculate the values at an interval of 0.040".

The procedure instructs the operator to obtain a peak-to-peak magnitude of 250 to 1,200 ECU's at 400 KHz and 100 to 1,200 ECU's for 100 KHz. ECU's are the amplitude units in the IntraSpect software. They are the raw A/D values.

The C-scan color pallet thresholds are renormalized by adjusting the color pallet thresholds so that at least one data point in each C-scan of interest is at the maximum color value.

This reference notch has a nominal length of 0.500" as opposed to the nominal 0.250" length of the reference notch contained in the standard CRDM calibration block.

However, since there is such a wide range of allowable amplitudes and the C-scans are renormalized, this has no impact on the results.

Phase adjustment is to set the reference notch 15° from horizontal with the convention that circumferential flaws form down and to the right and axial/radial flaws form up and to the left.

2.2. CRDM J-weld Probe

This inspection was performed in accordance with the procedures used for RVHI efforts. Acquisition was governed by WDI-STD-010. Analysis by WDI-ET-004.

These tools use an X-point ET probe. It has a diameter of 0.12" and is designed to operate between 75 and 500 KHz.

It is calibrated in the same fashion as the ID probe.

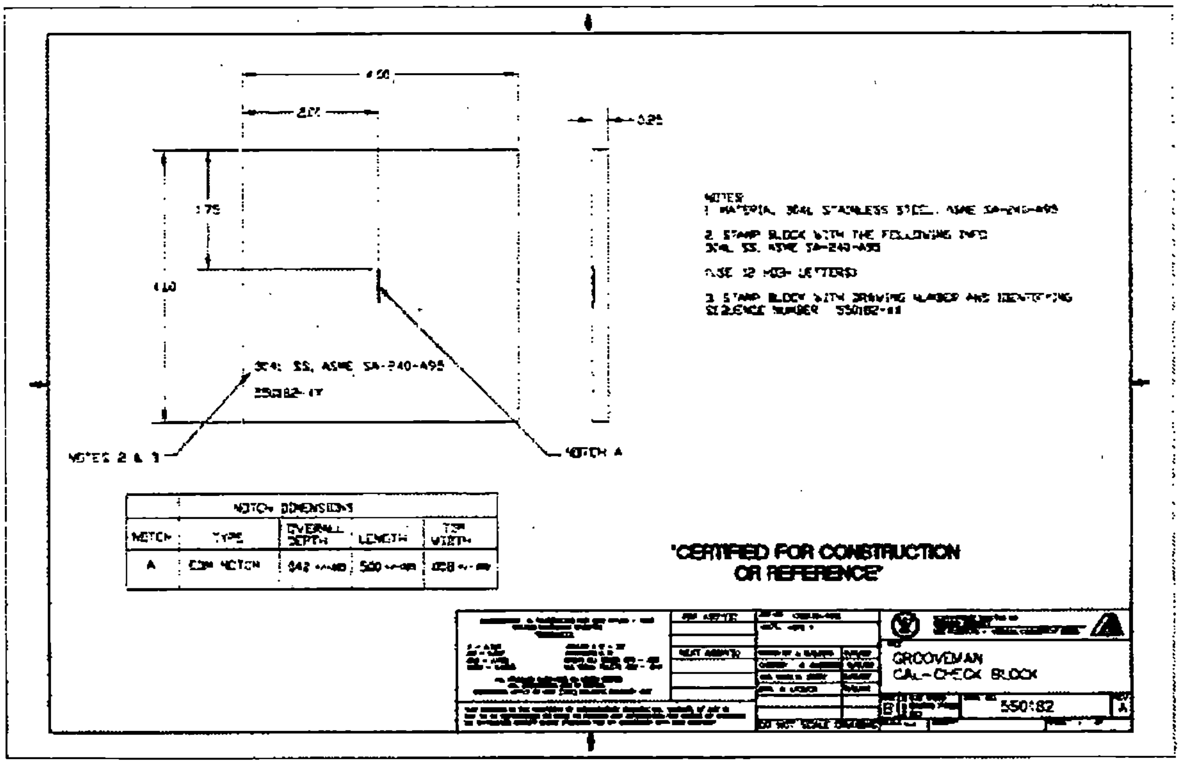

Figure 1 Typical J-weld Calibration Check Block

3. Cold Spray Sample for Subsurface Flaws

The sample consisted of two SS 304 plates connected by shallow TIG weld with cold spray coatings of 316 SS approximately 30-60 mils thick. There were four different regions of differing thickness targets.

Figure 2 Cold Spray Surface Condition

Figure 3 Side view of cold spray sample

Figure 4 Bottom side of sample showing TIG weld seam

4. ID Probe Results

4.1. Calibration Scans

The calibration scans are shown in Figure 5 through Figure 9.

In each image the impedance plane and strip chart data is displayed. The left side C-scan is either the magnitude data or the vertical component data. The right side C-scan is the first spatial derivative of the magnitude or vertical data.

The peak-to-peak magnitude and phase angle for the indication is at the bottom of the window below the impedance plane.

4.2. Sample Scans

The sample scans are shown in Figure 9 through Figure 24 and summarized in Table 1.

The Magnitude and Vertical data is shown for both frequencies and all four regions.

Table 1 ID Probe Results

	400KHz			100KHz		
	Pk-Pk M	% of Ref	Φ	Pk-Pk M	% of Ref	Φ
Calibration	861.0	N/A	195.8	902.2	N/A	195.2
Region 1	270.2	31	265.7	550.0	61	237.4
Region 2	148.4	17	284.7	367.7	41	254.4
Region 3	298.8	34	251.2	623.6	69	231.1
Region 4	N/A	N/A	N/A	147.2	16	286.9

From these results the thickness proceeds from the thinnest to the thickest in the following sequence: 3, 1, 2, 4.

The 400 KHz does not detect the indication at the thickest region (~0.060").

The 100 KHz does detect the indication in all regions showing a "flaw like" signal as defined by WDI-ET-004.

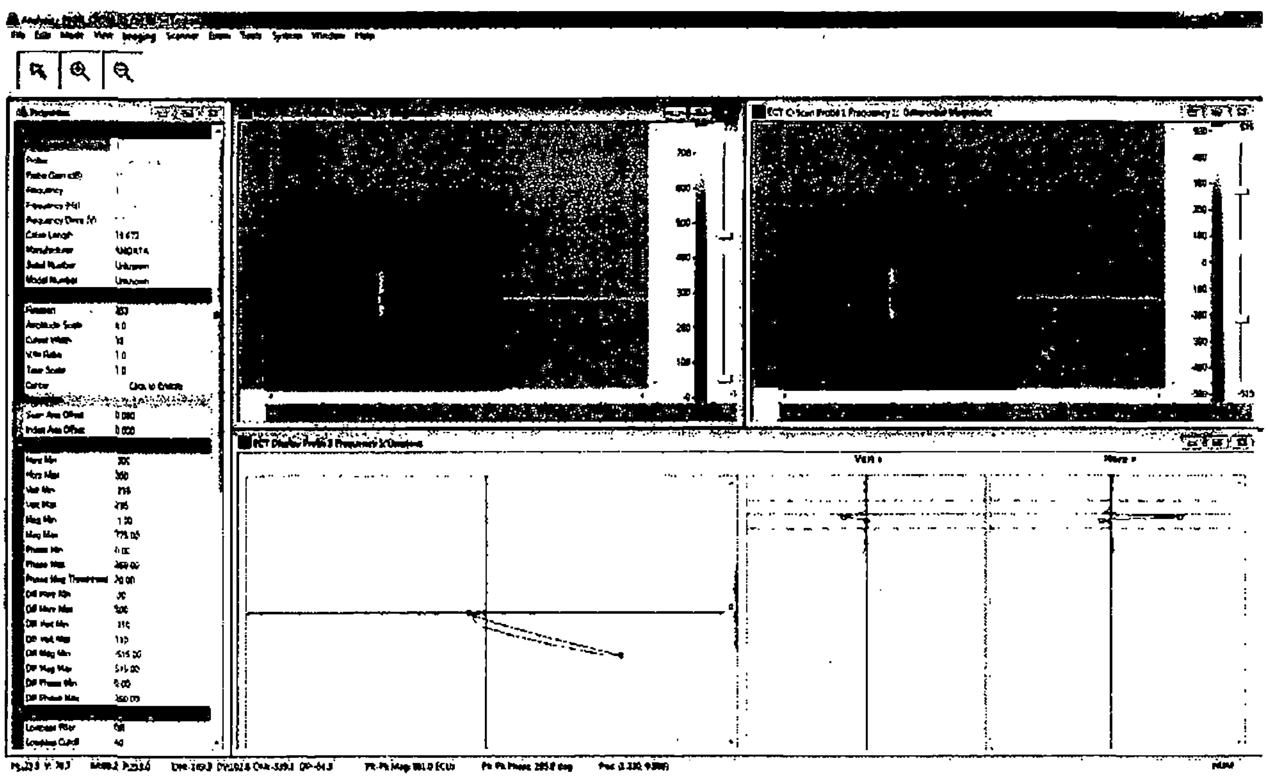

Figure 5 ID Probe Calibration, 400 KHz, Magnitude C-scans

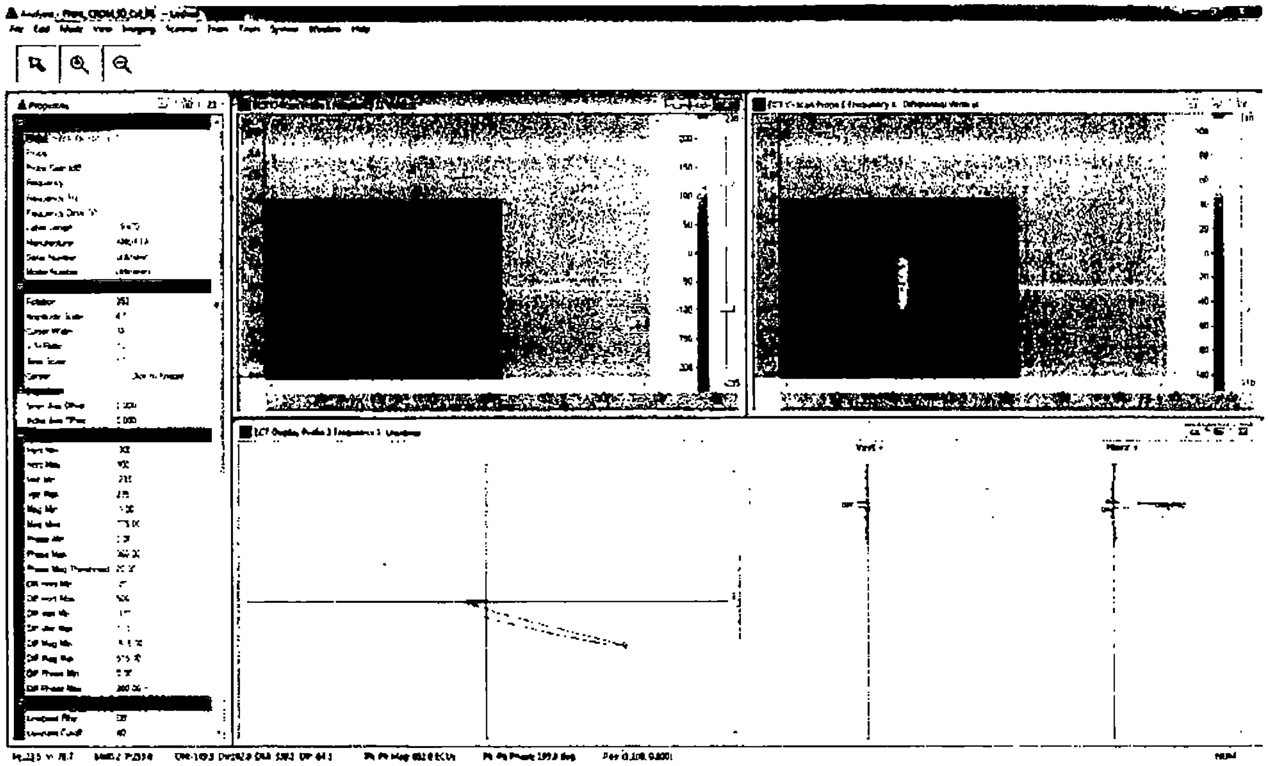

Figure 6 ID Probe Calibration, 400 KHz, Vertical C-scans

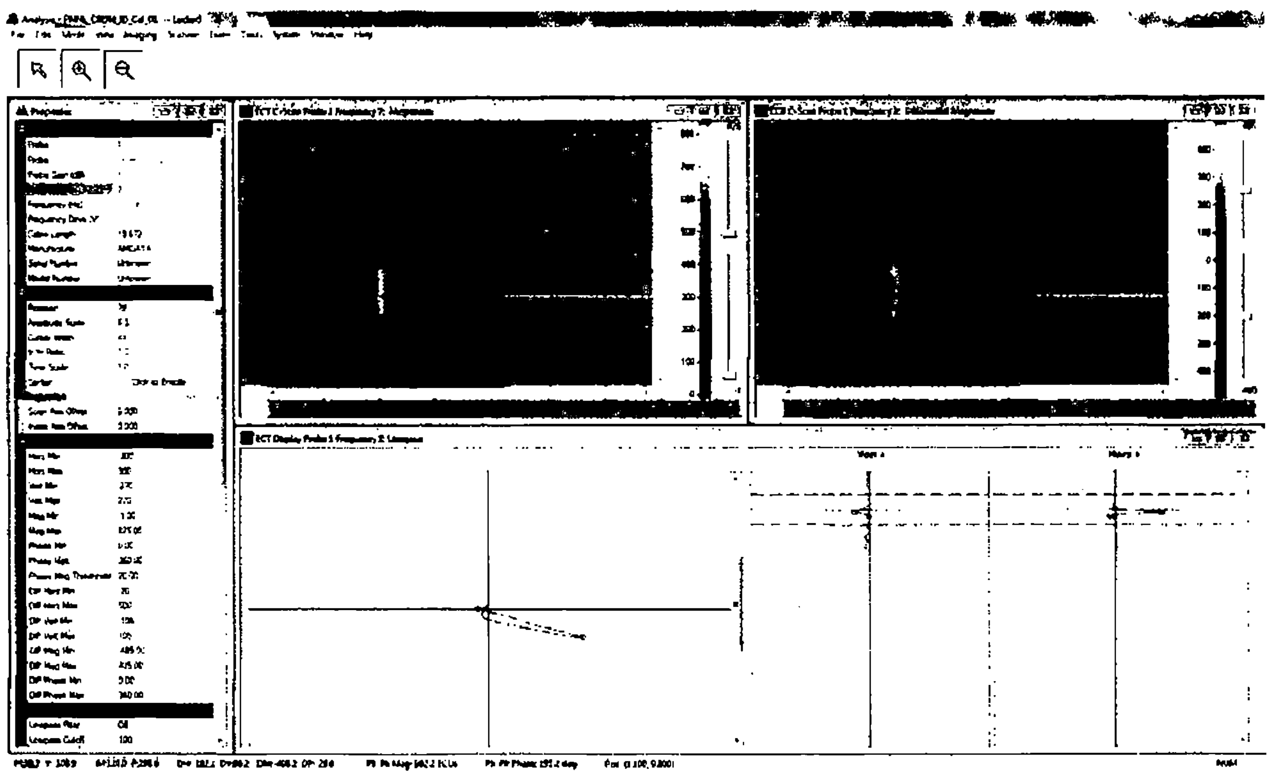

Figure 7 ID Probe Calibration, 100 KHz, Magnitude C-scans

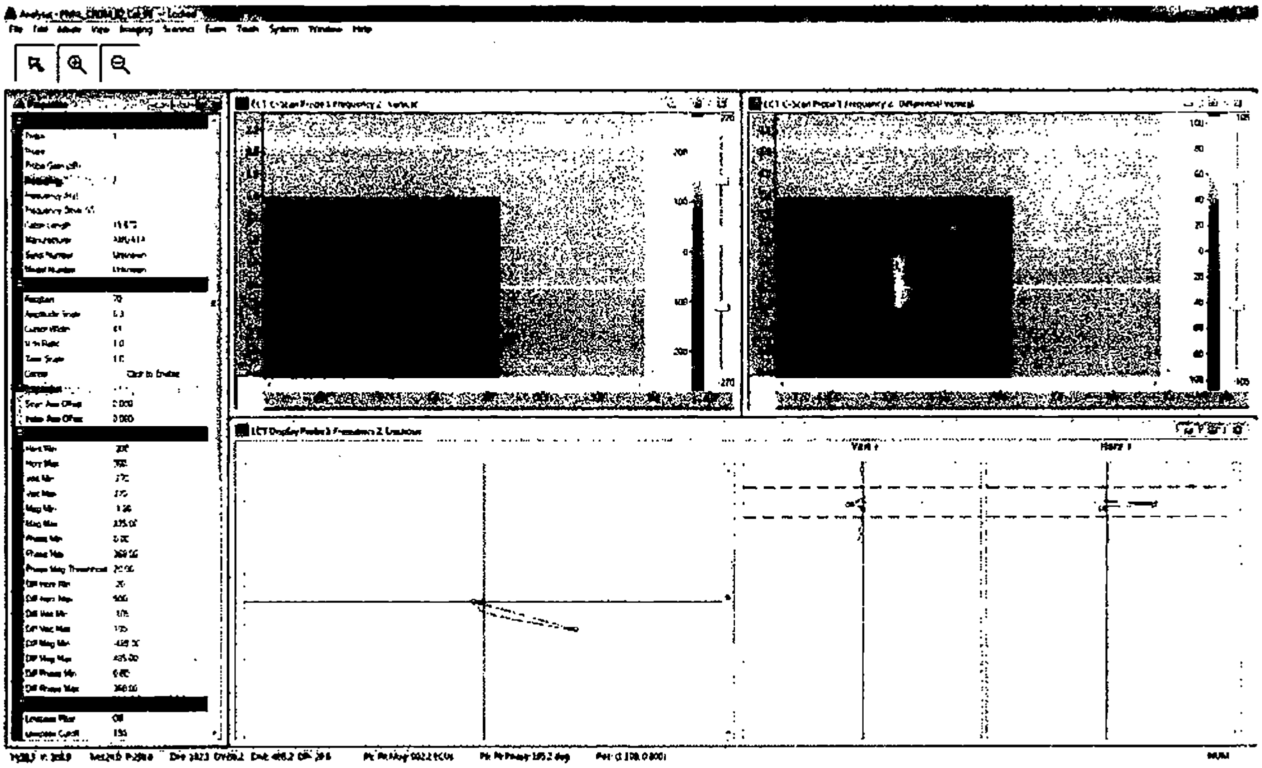

Figure 8 ID Probe Calibration, 100 KHz, Vertical C-scans

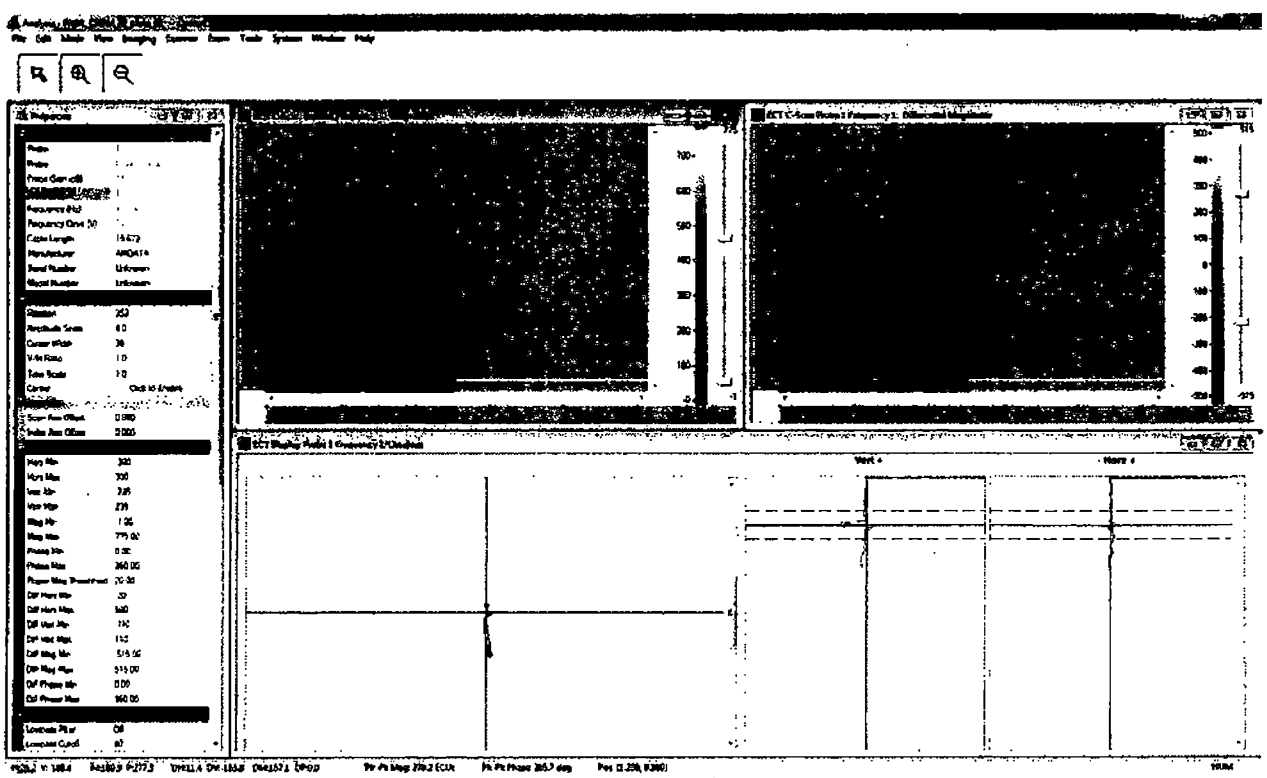

Figure 9 ID Probe Plate, 400 KHz, Magnitude C-scans, Region 1

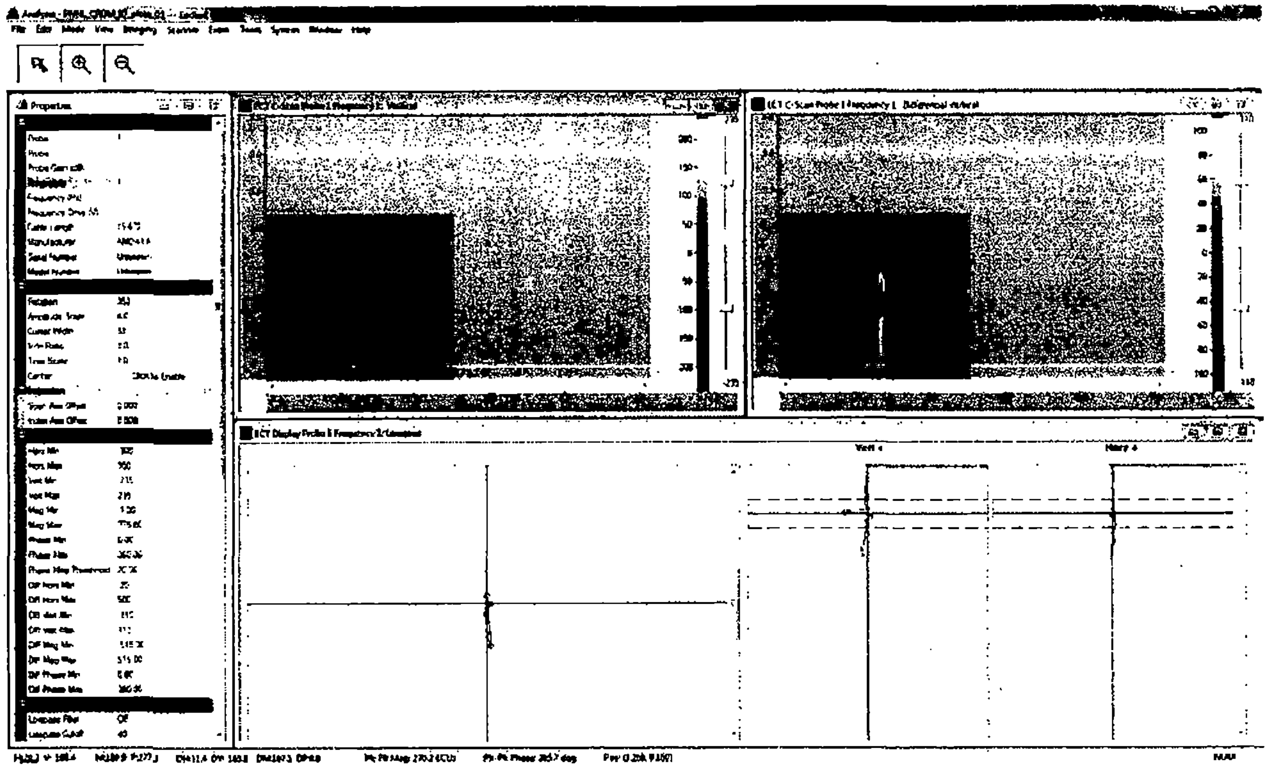

Figure 10 ID Probe Plate, 400 KHz, Vertical C-scans, Region 1

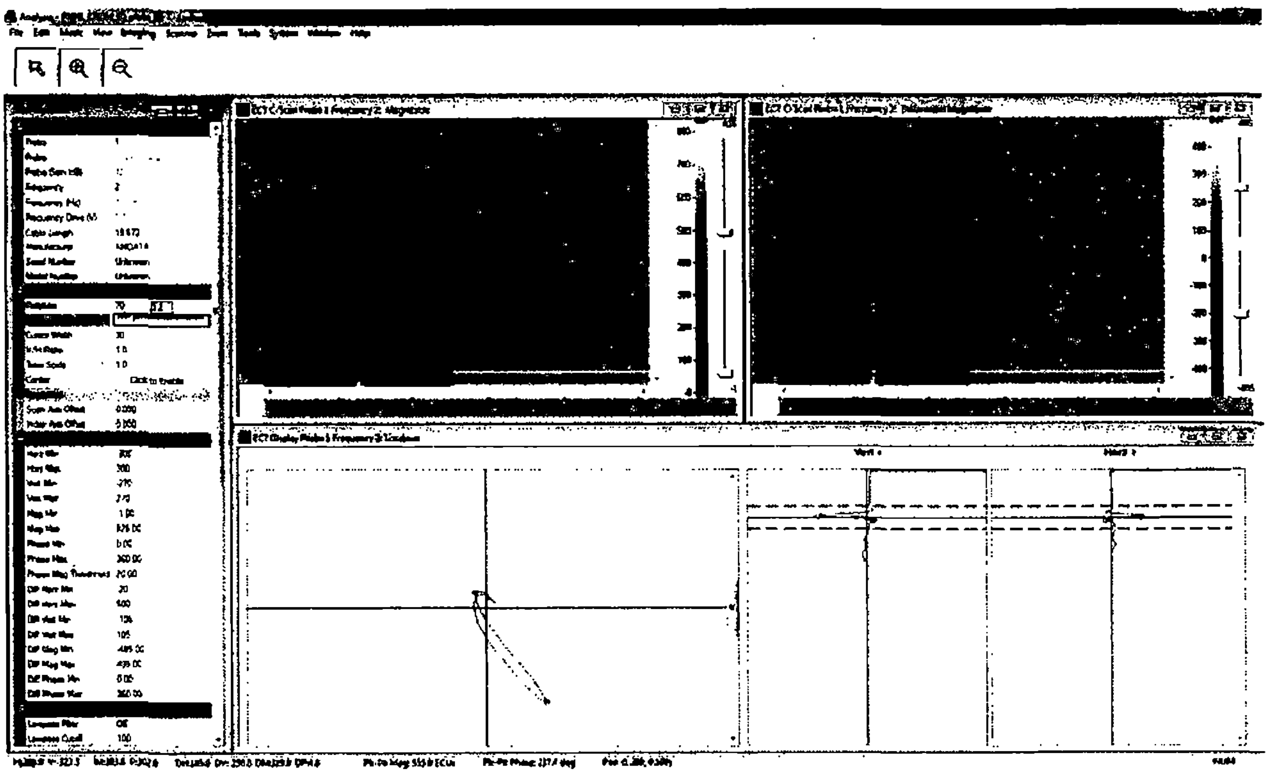

Figure 11 ID Probe Plate, 100 KHz, Magnitude C-scans, Region 1

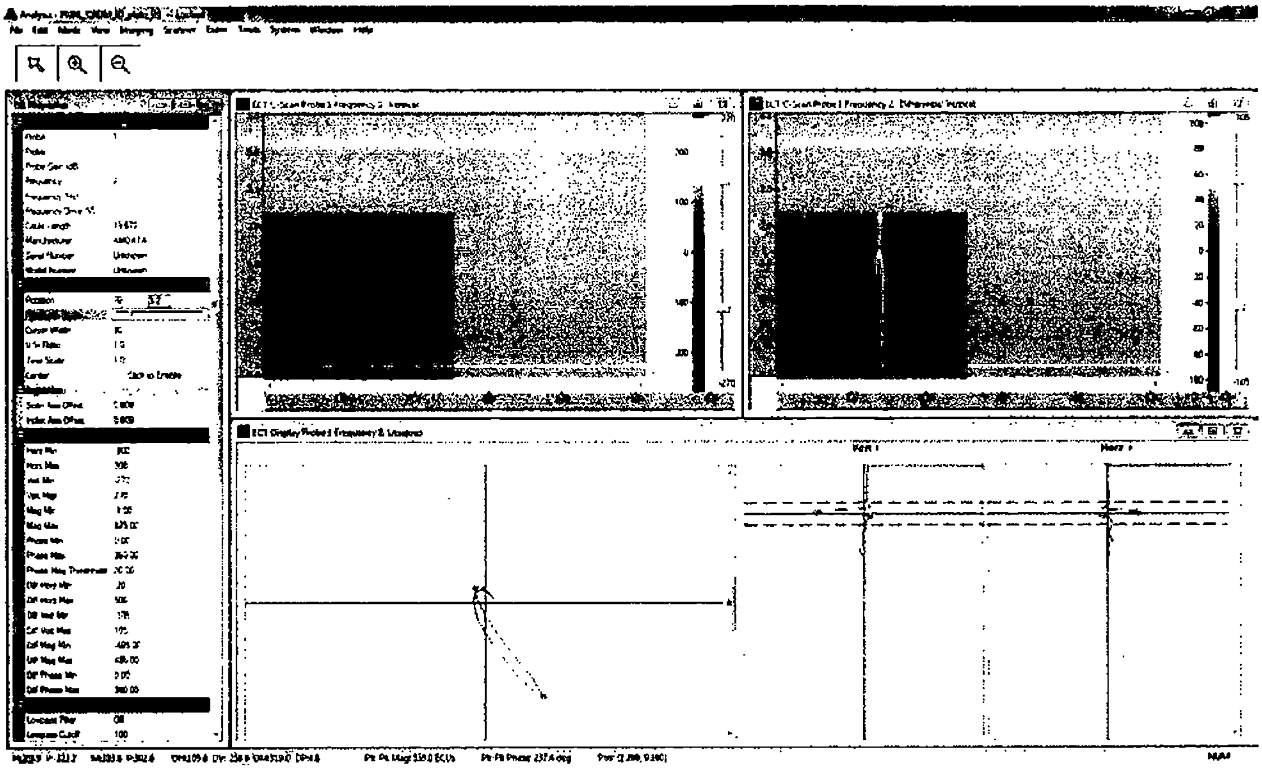

Figure 12 ID Probe Plate, 100 KHz, Vertical C-scans, Region 1

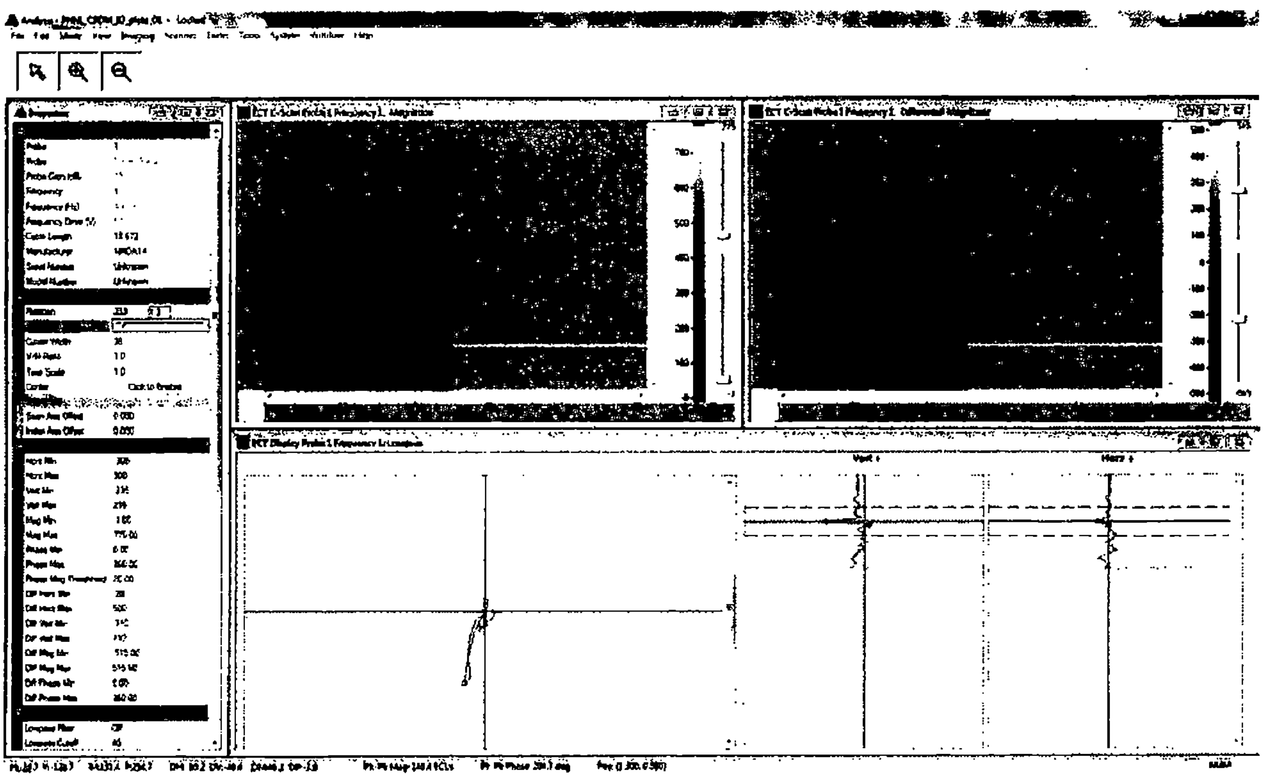

Figure 13 ID Probe Plate, 400 KHz, Magnitude C-scans, Region 2

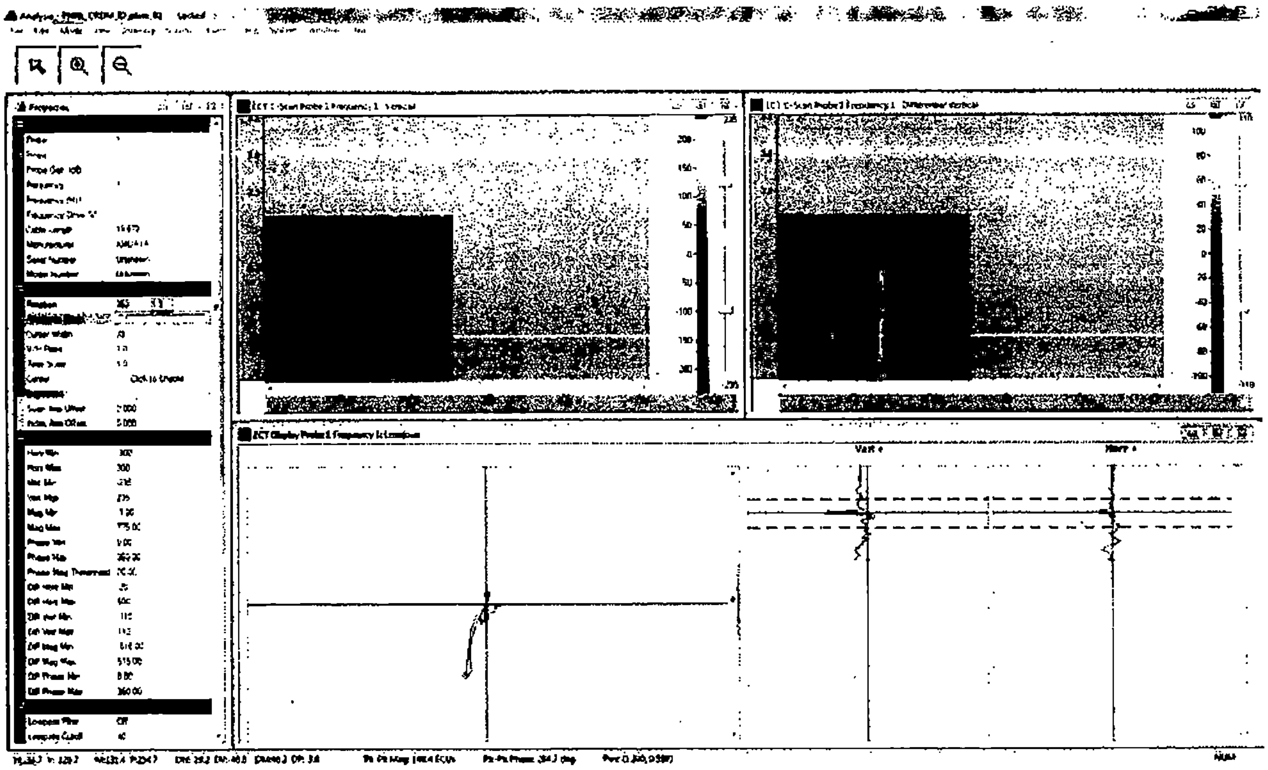

Figure 14 ID Probe Plate, 400 KHz, Vertical C-scans, Region 2

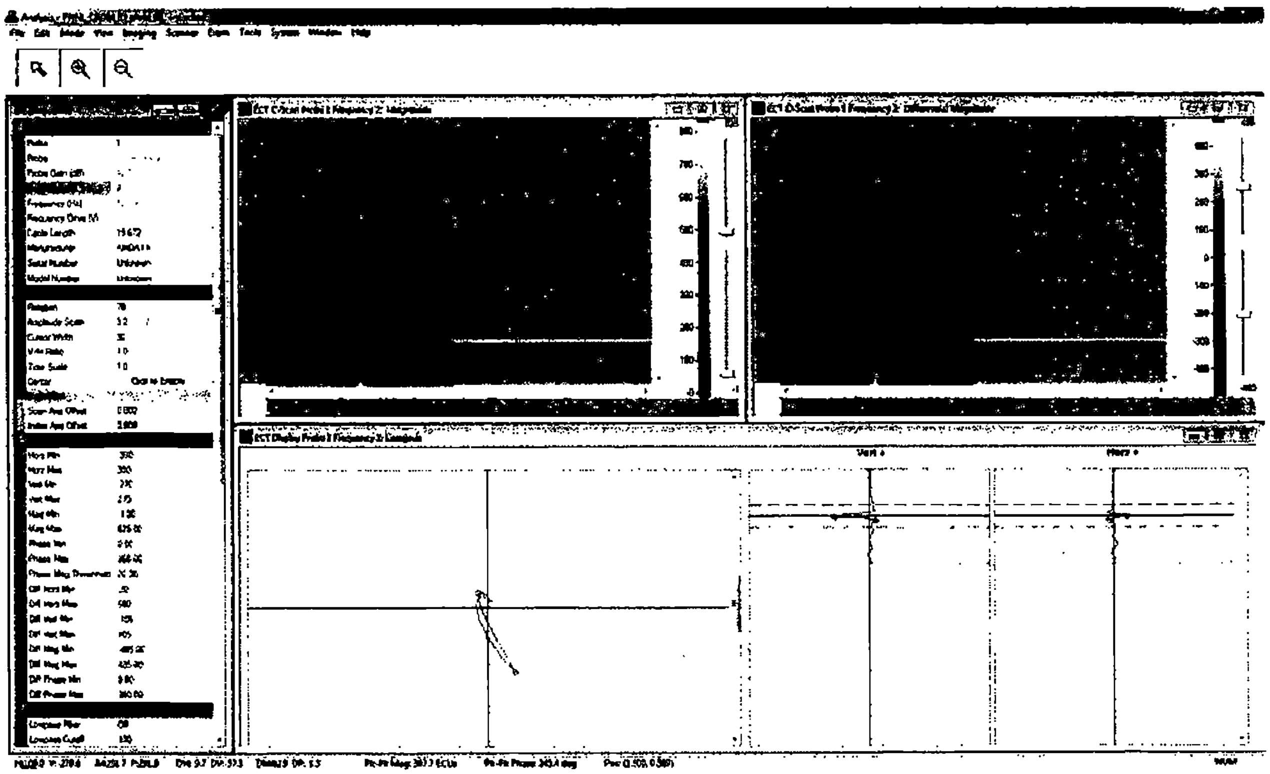

Figure 15 ID Probe Plate, 100 KHz, Magnitude C-scans, Region 2

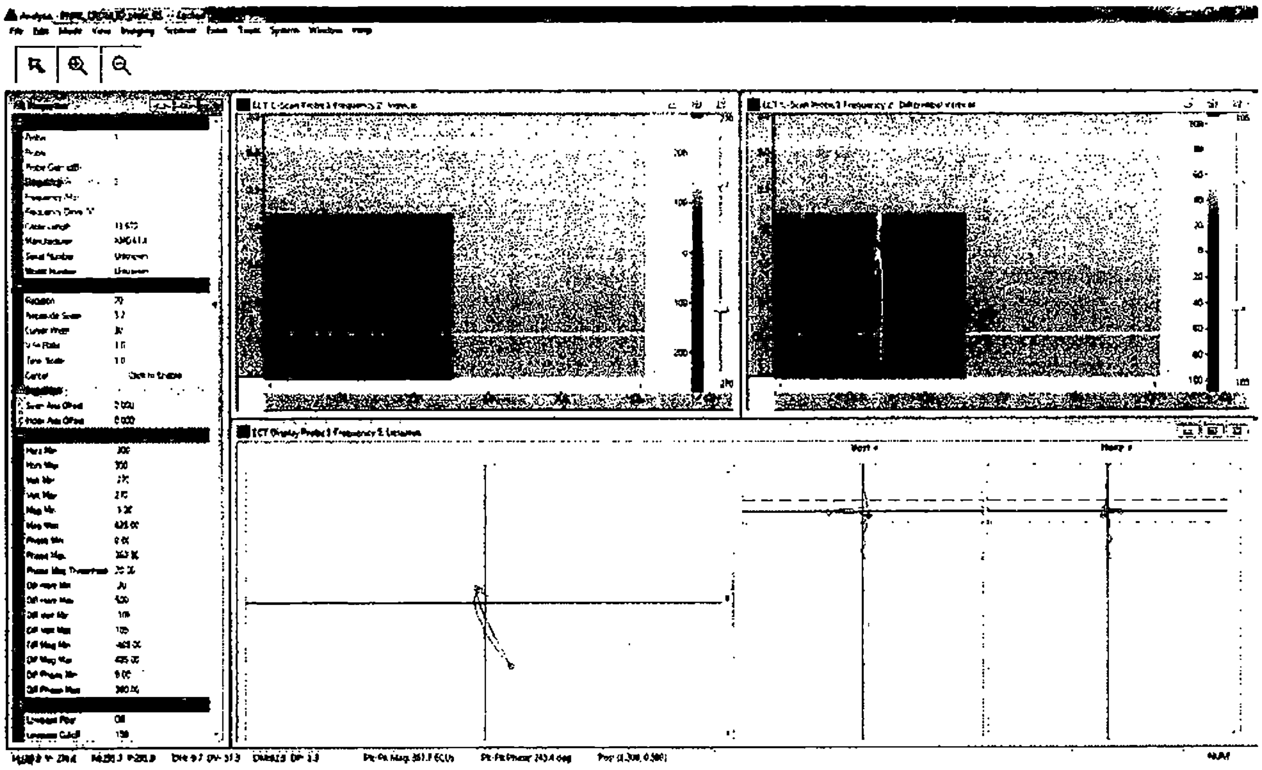

Figure 16 ID Probe Plate, 100 KHz, Vertical C-scans, Region 2

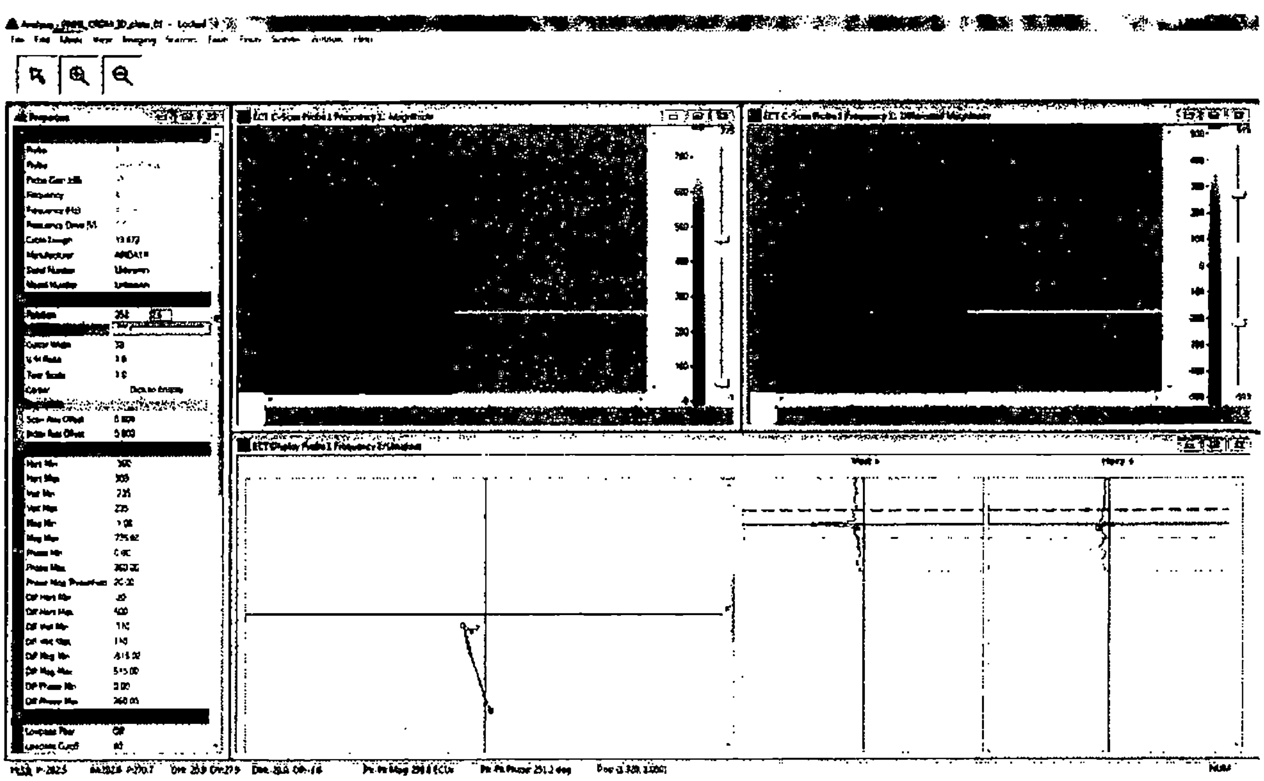

Figure 17 ID Probe Plate, 400 KHz, Magnitude C-scans, Region 3

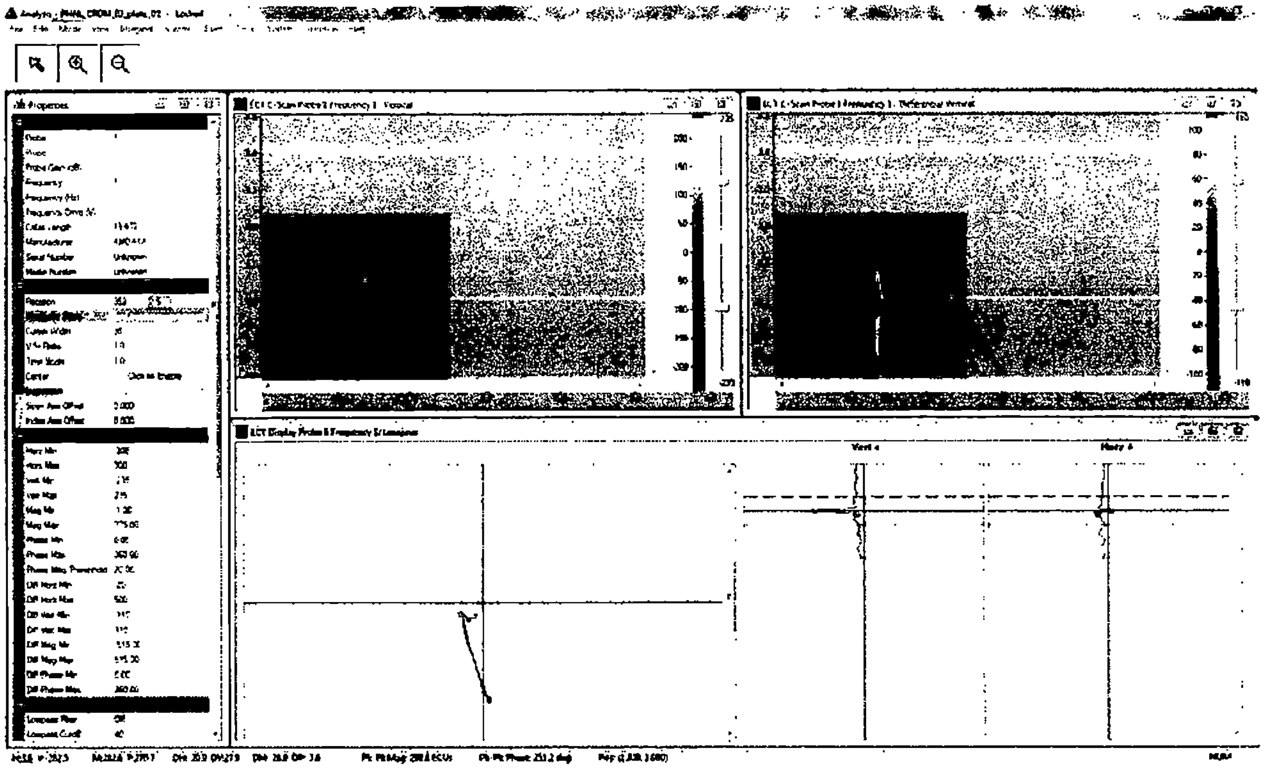

Figure 18 ID Probe Plate, 400 KHz, Vertical C-scans, Region 3

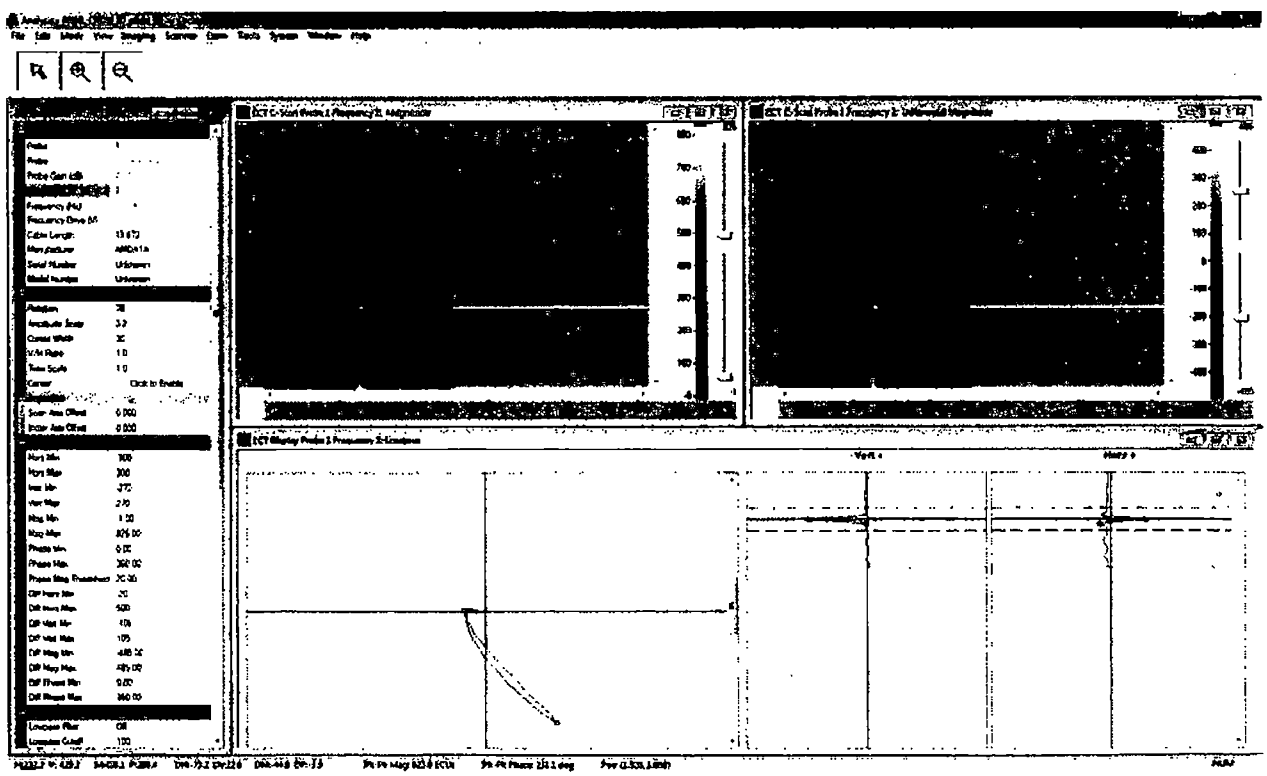

Figure 19 ID Probe Plate, 100 KHz, Magnitude C-scans, Region 3

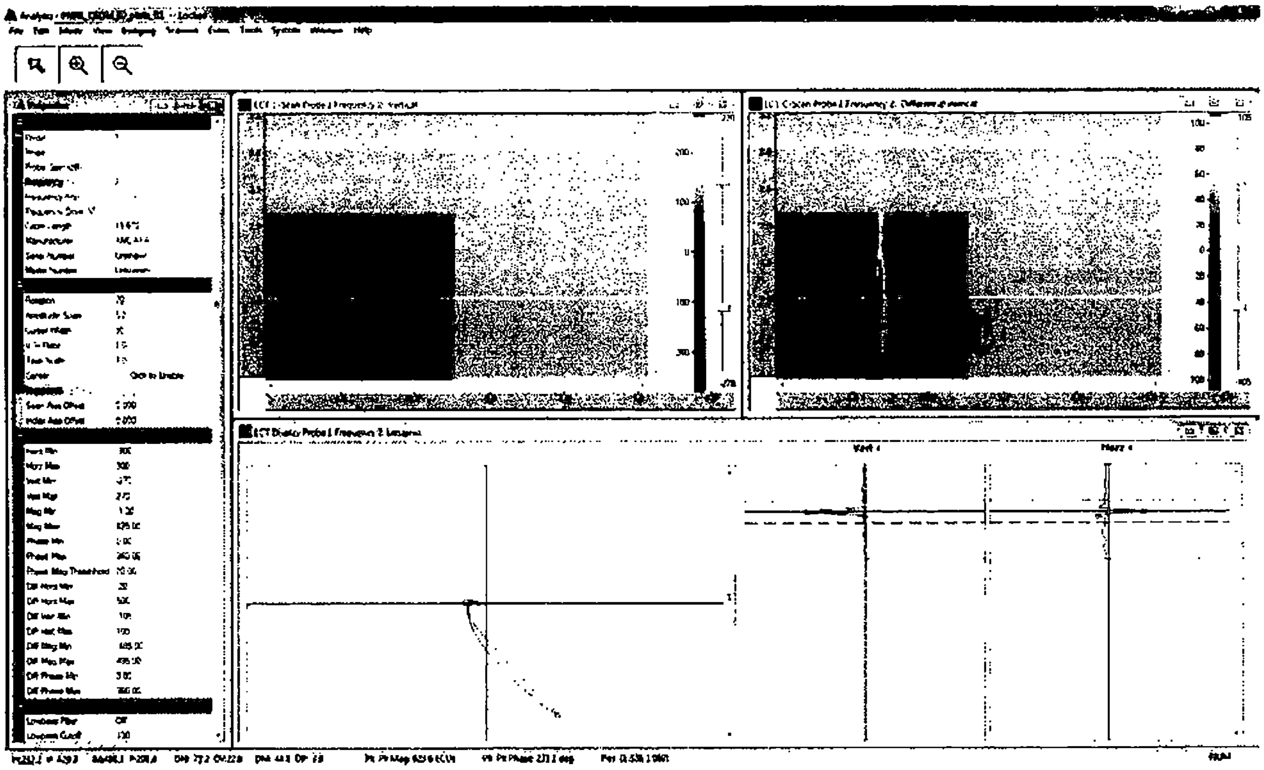

Figure 20 ID Probe Plate, 100 KHz, Vertical C-scans, Region 3

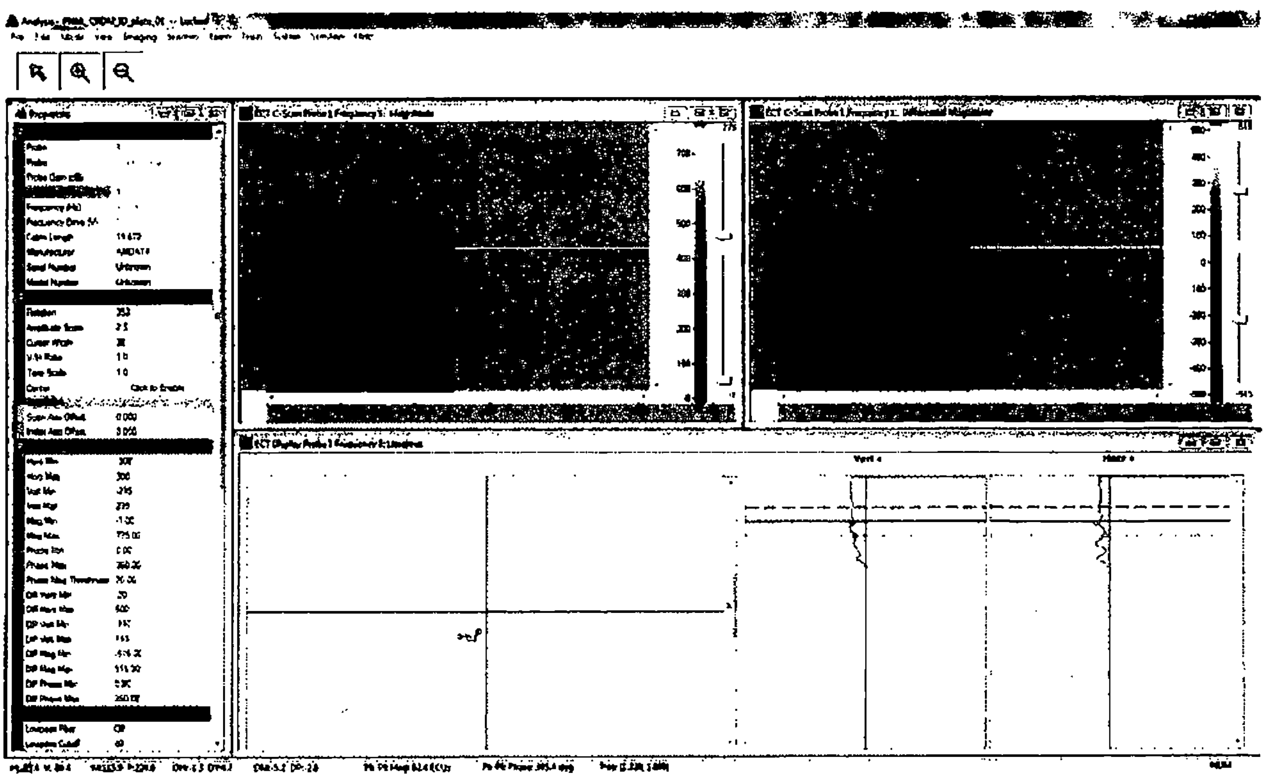

Figure 21 ID Probe Plate, 400 KHz, Magnitude C-scans, Region 4

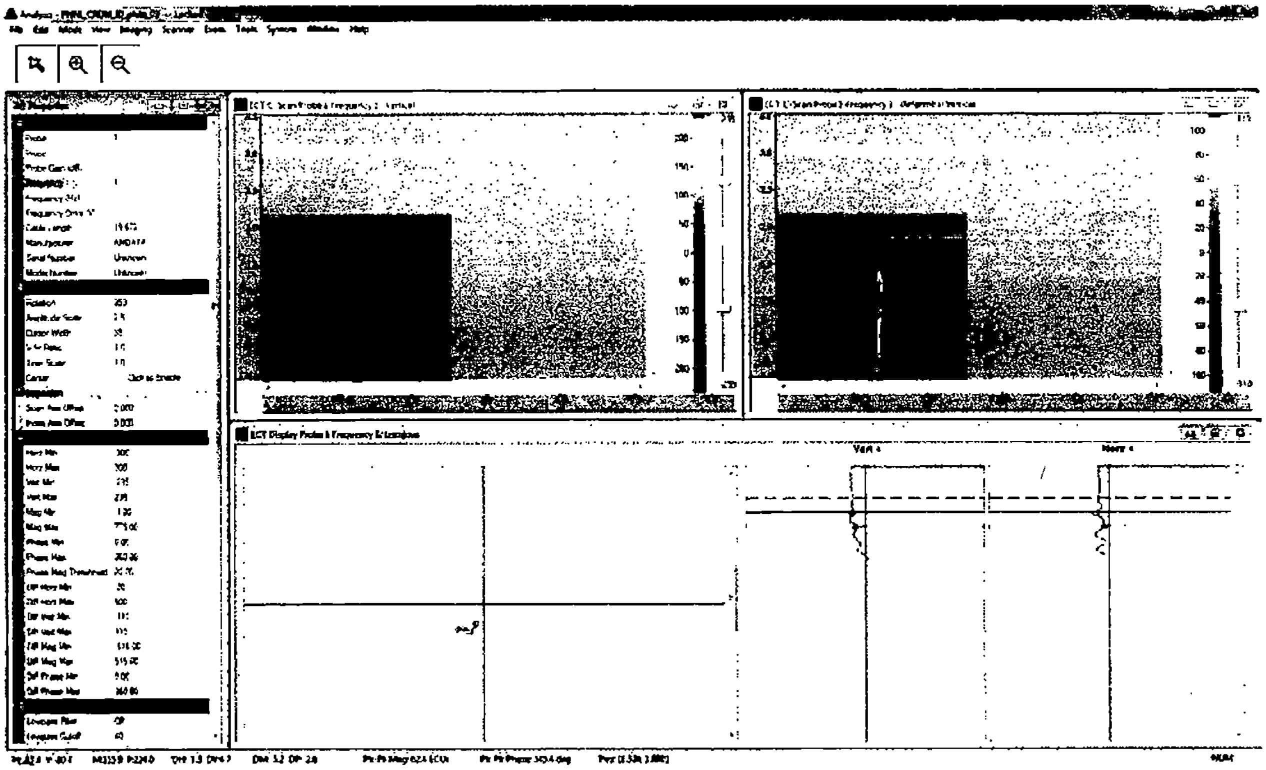

Figure 22 ID Probe Plate, 400 KHz, Vertical C-scans, Region 4

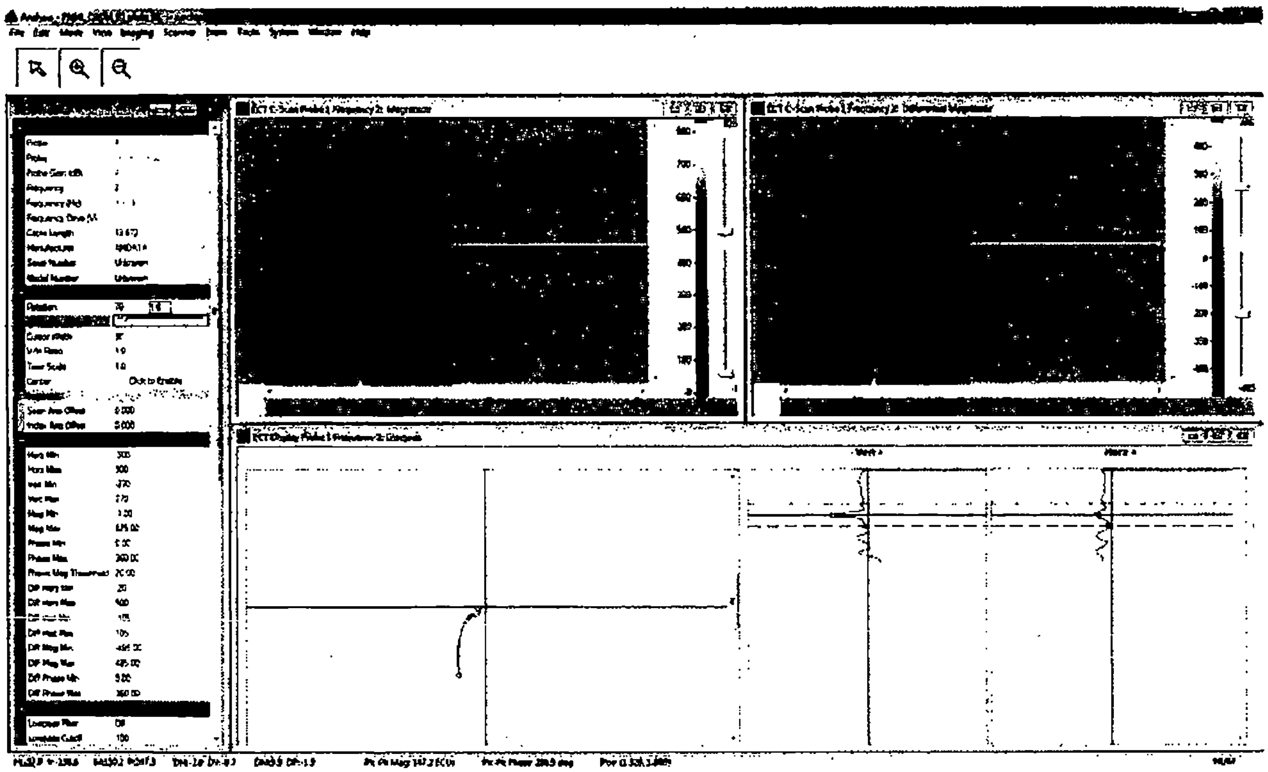

Figure 23 ID Probe Plate, 100 KHz, Magnitude C-scans, Region 4

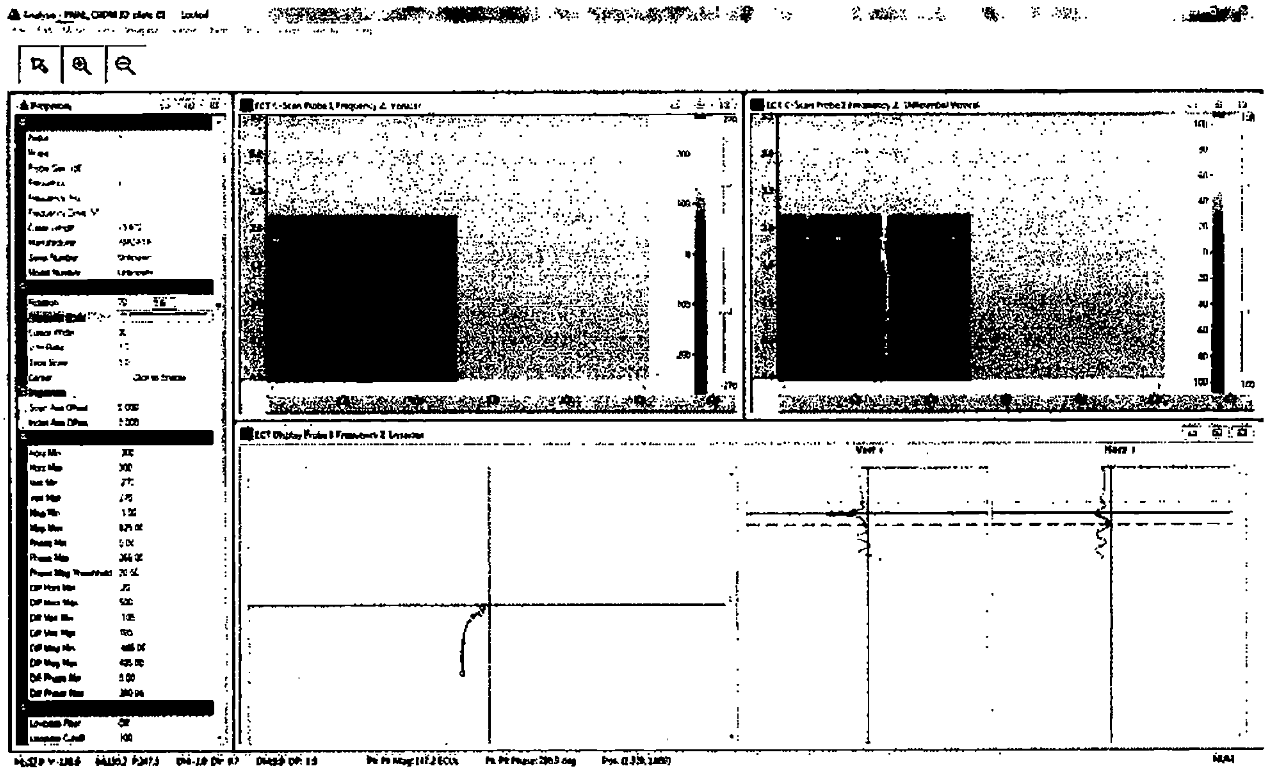

Figure 24 ID Probe Plate, 100 KHz, Vertical C-scans, Region 4

5. J-weld Probe Results

5.1. Calibration Scans

The calibration scans are shown in Figure 5 through Figure 9.

In each image the impedance plane and strip chart data is displayed. The left side C-scan is either the magnitude data or the vertical component data. The right side C-scan is the first spatial derivative of the magnitude or vertical data.

The peak-to-peak magnitude and phase angle for the indication is at the bottom of the window below the impedance plane.

5.2. Sample Scans

The sample scans are shown in and summarized in Table 2.

The Magnitude and Vertical data is shown for both frequencies and all four regions.

Table 2 J-weld Probe Results

	400KHz			200KHz		
	Pk-Pk M	% of Ref	Φ	Pk-Pk M	% of Ref	Φ
Calibration	852.4	N/A	196.0	1412.9	N/A	195.1
Region 1	357.9	42	252.5	950.8	68	237.1
Region 2	180.4	21	290.1	494.5	35	265.1
Region 3	374.8	44	257.0	846.6	60	242.2
Region 4	N/A	N/A	N/A	N/A	N/A	N/A

Neither frequency detects the indication at the thickest region (~0.060"). This is likely due to the fact that this probe design is a higher frequency and smaller diameter.

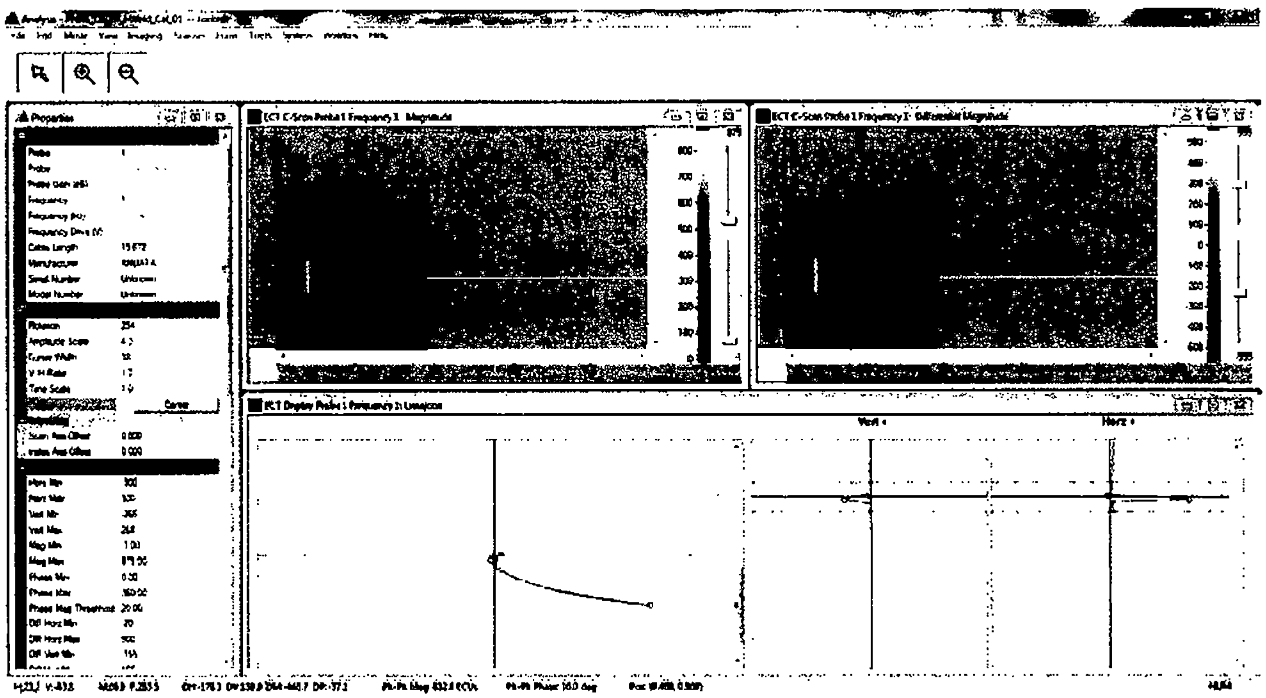

Figure 25 J-weld Probe Calibration, 400 KHz, Magnitude C-scans

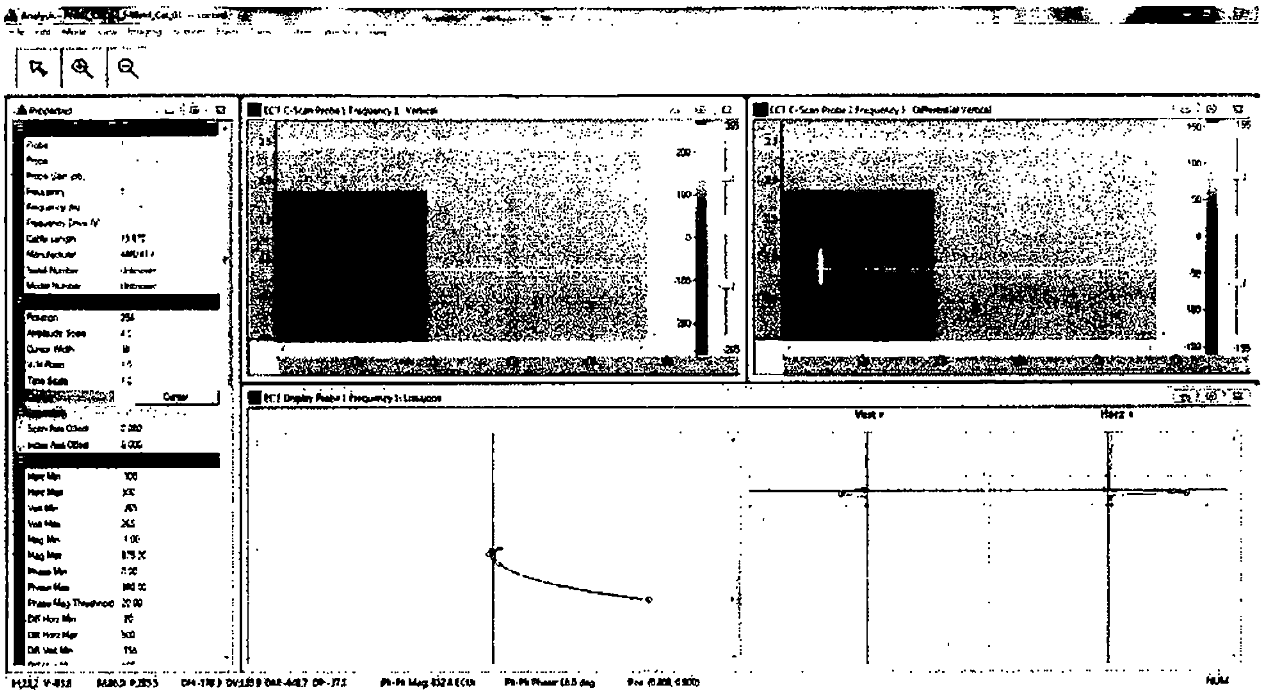

Figure 26 J-weld Probe Calibration, 400 KHz, Vertical C-scans

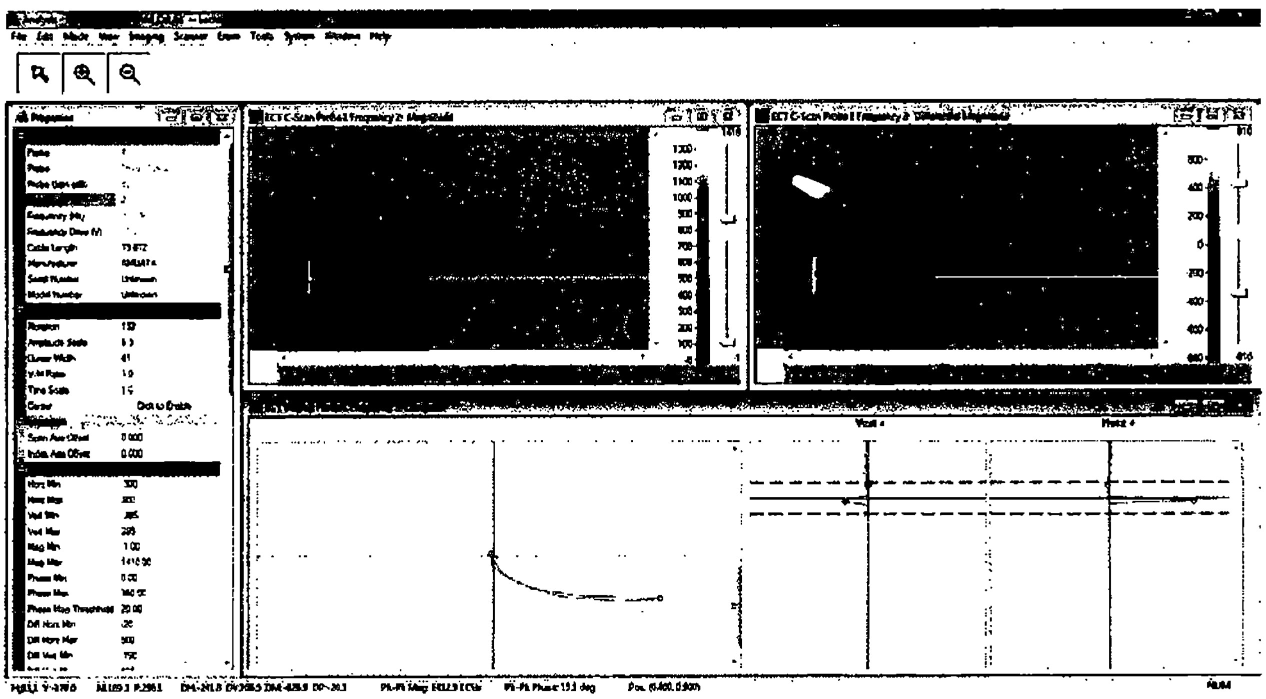

Figure 27 J-weld Probe Calibration, 200 KHz, Magnitude C-scans

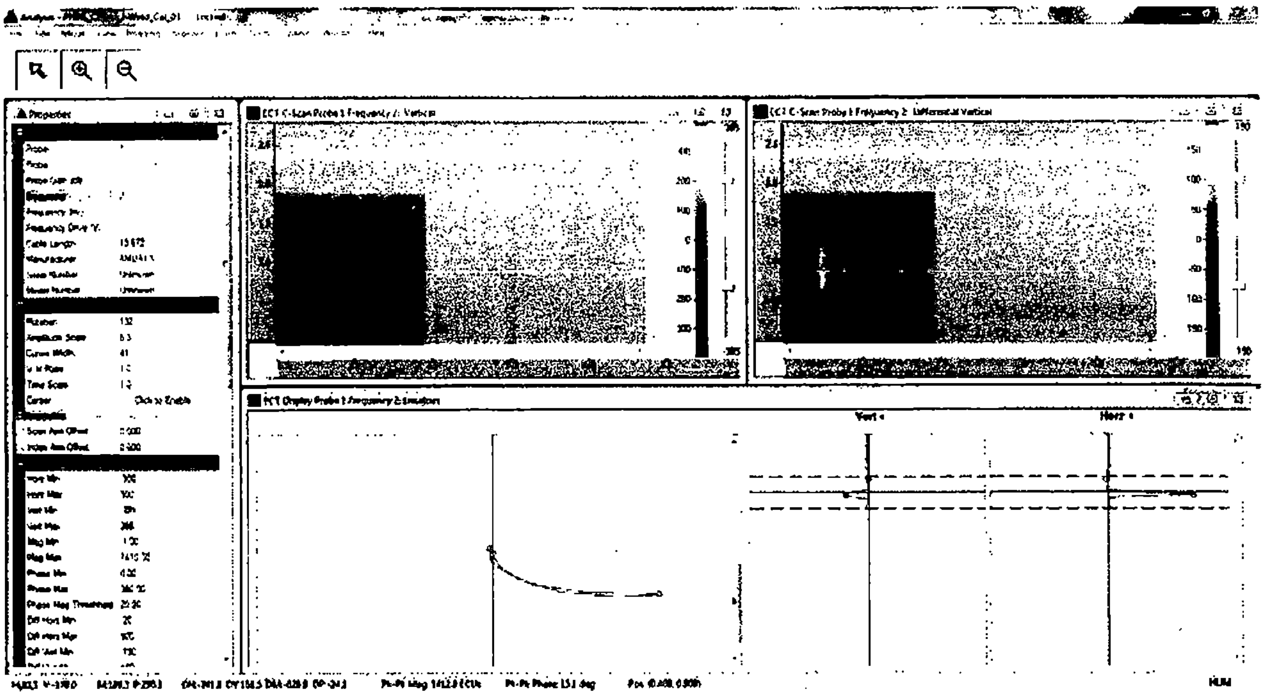

Figure 28 J-weld Probe Calibration, 200 KHz, Vertical C-scans

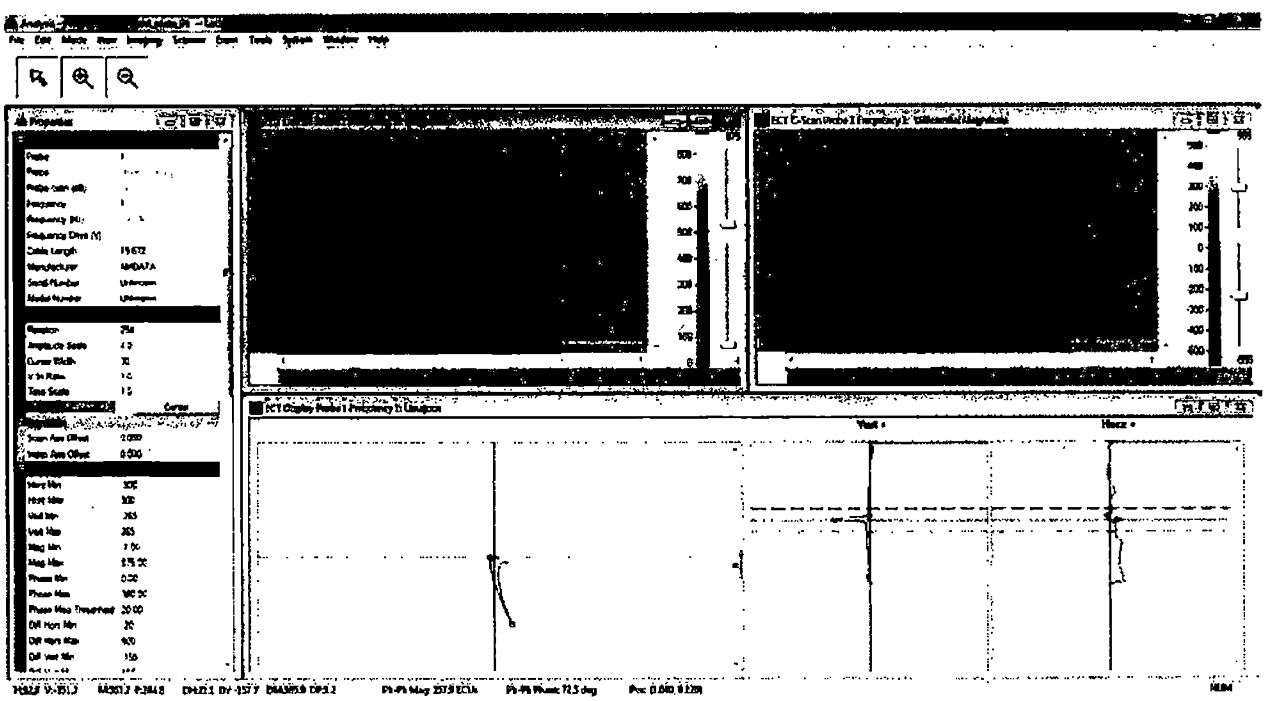

Figure 29 J-weld Probe Plate, 400 KHz, Magnitude C-scans, Region 1

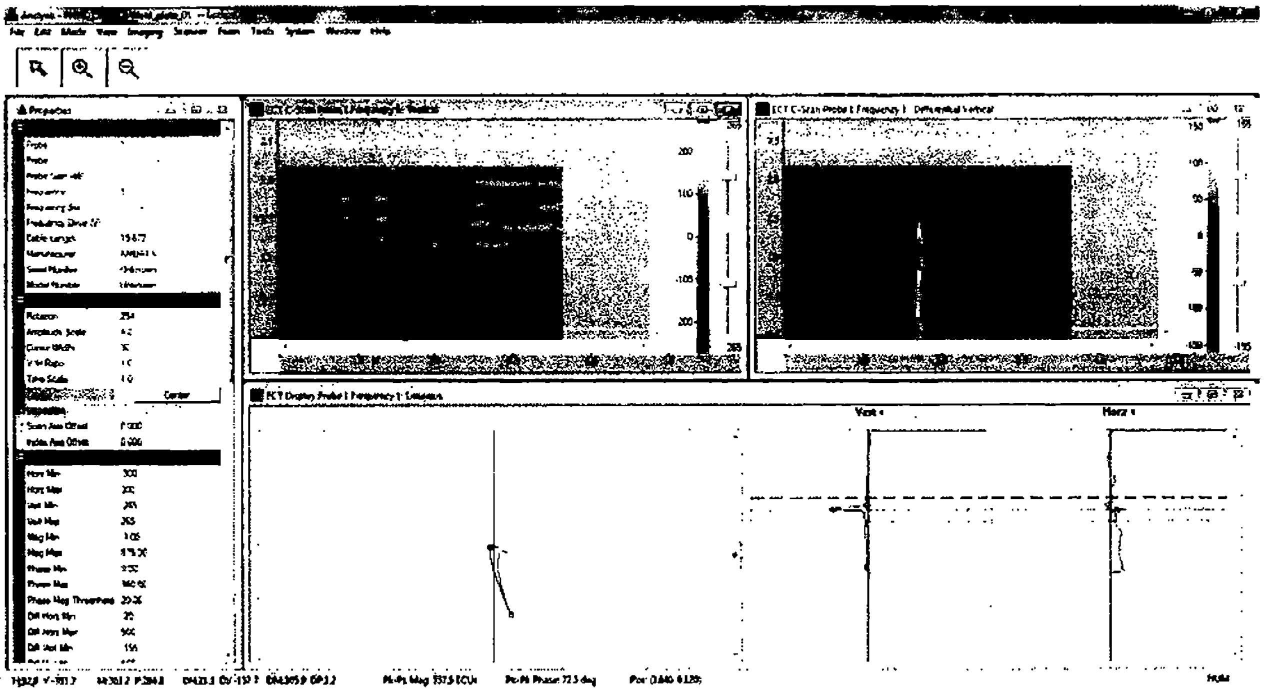

Figure 30 J-weld Probe Plate, 400 KHz, Vertical C-scans, Region 1

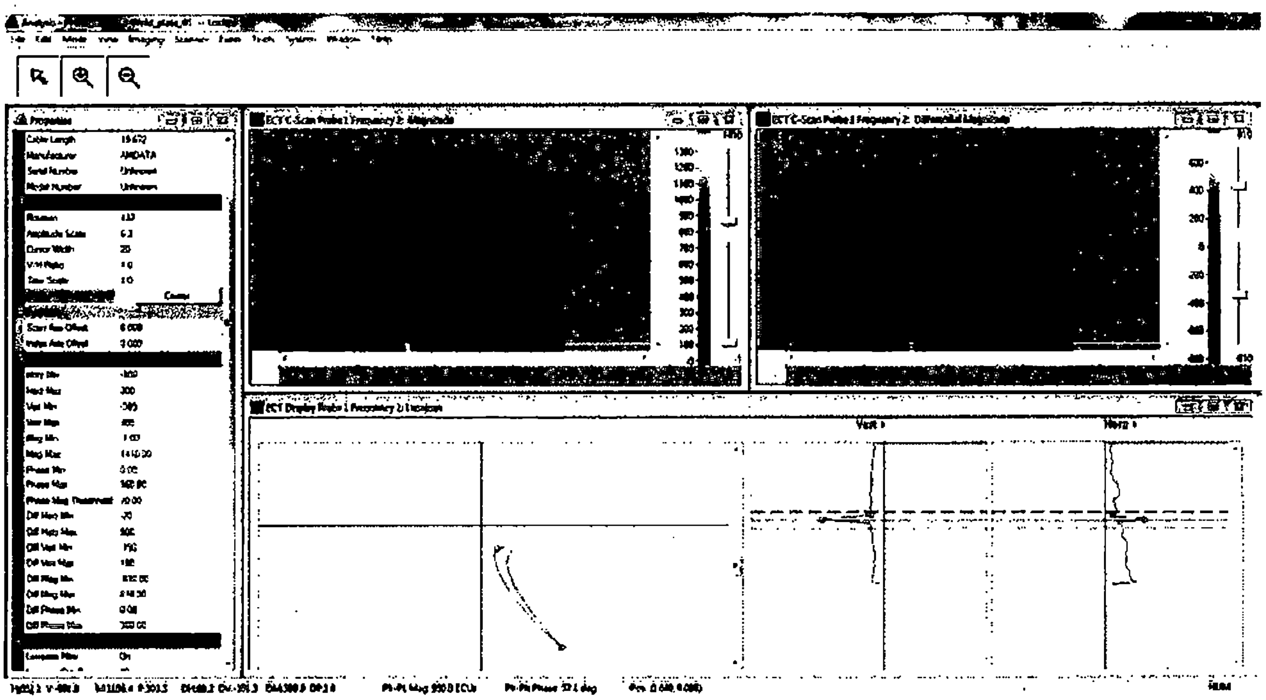

Figure 31 J-weld Probe Plate, 200 KHz, Magnitude C-scans, Region 1

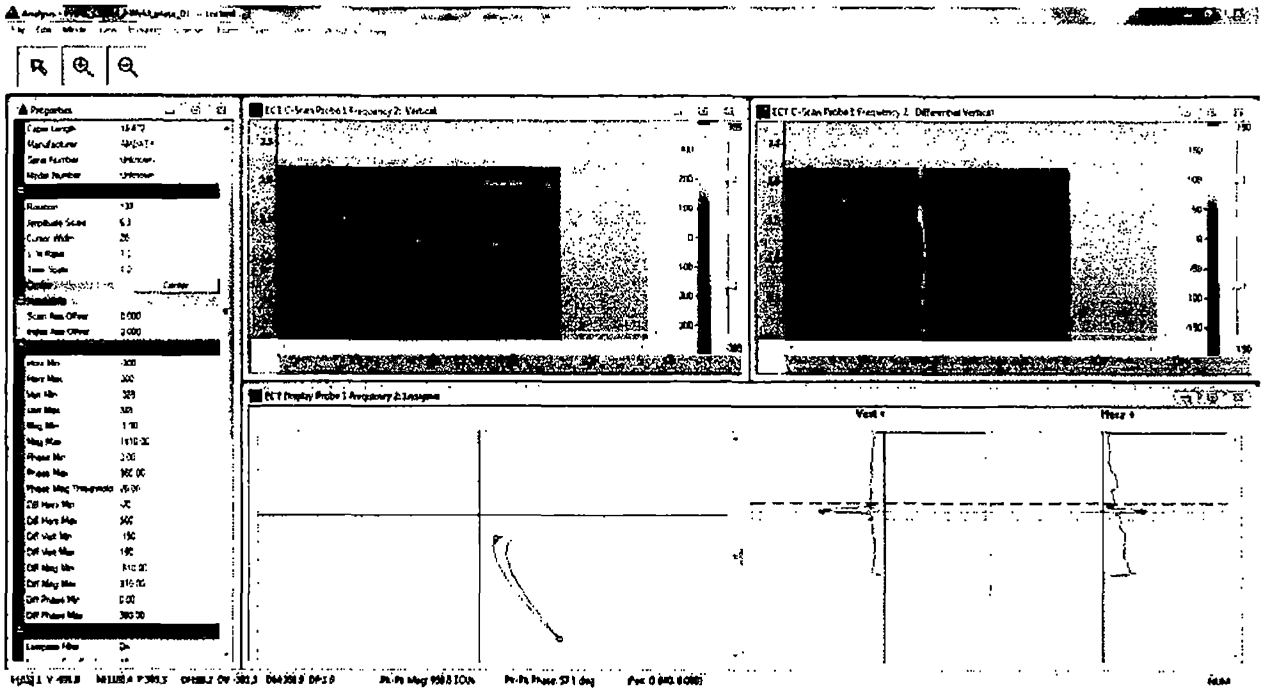

Figure 32 J-weld Probe Plate, 200 KHz, Vertical C-scans, Region 1

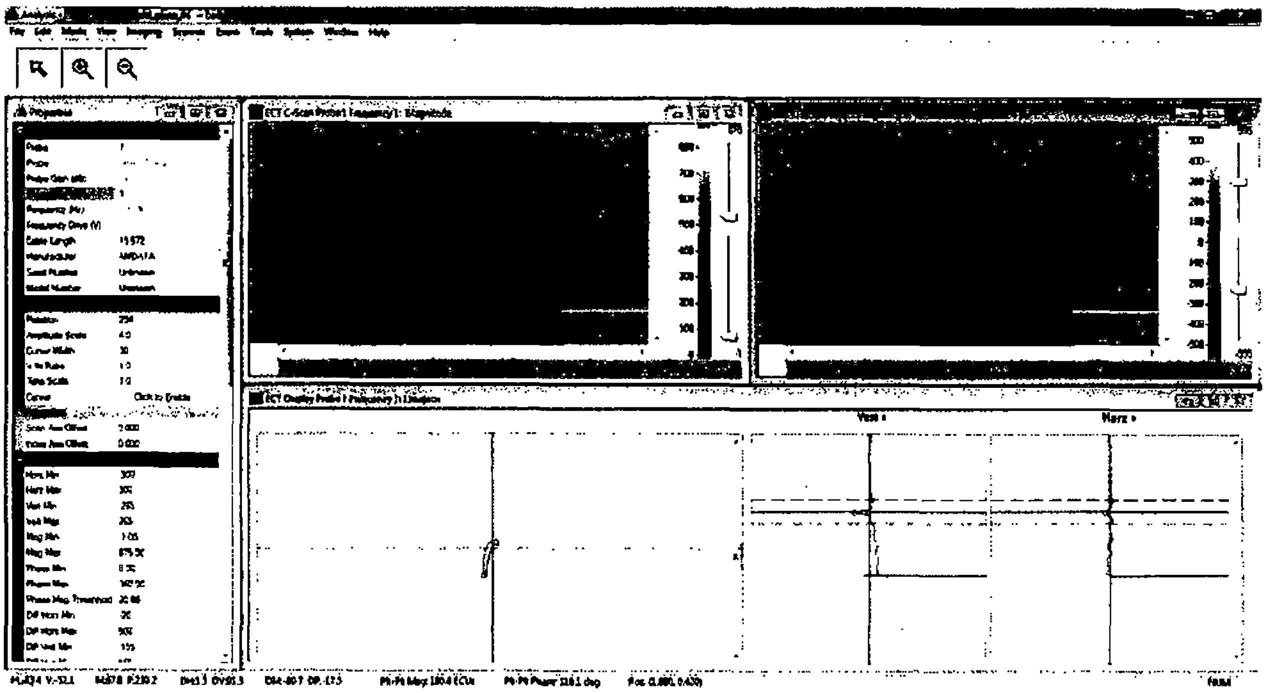

Figure 33 J-weld Probe Plate, 400 KHz, Magnitude C-scans, Region 2

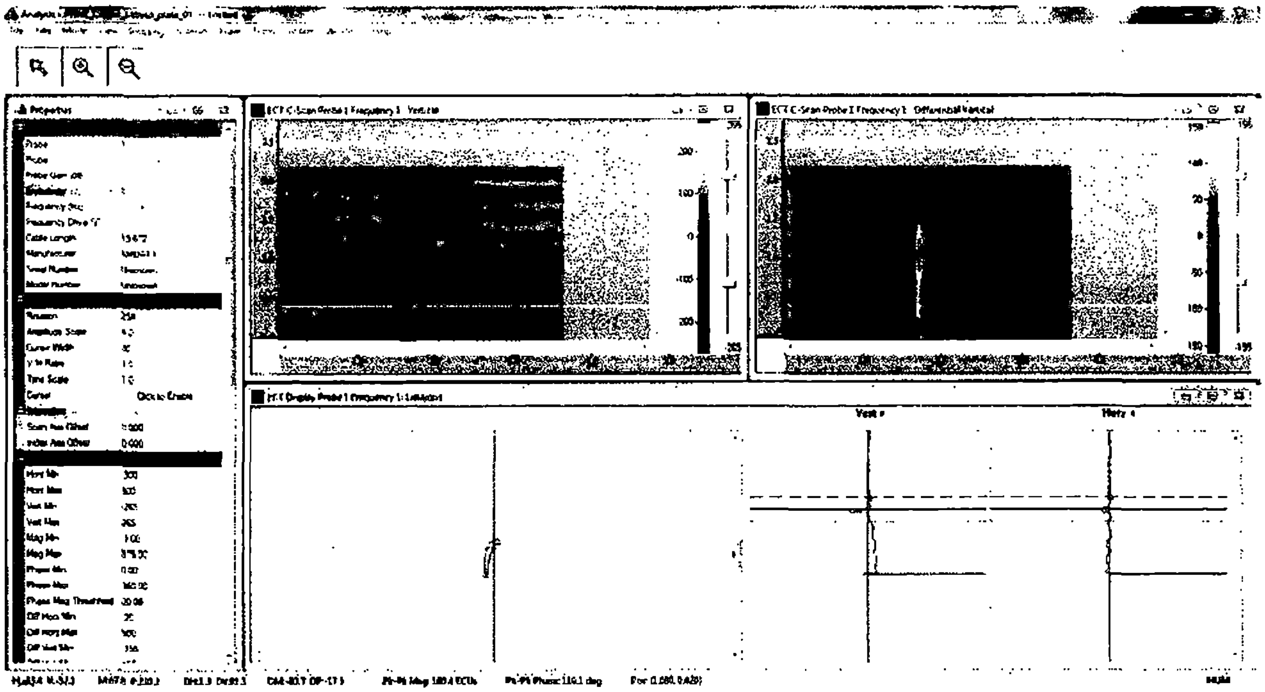

Figure 34 J-weld Probe Plate, 400 KHz, Vertical C-scans, Region 2

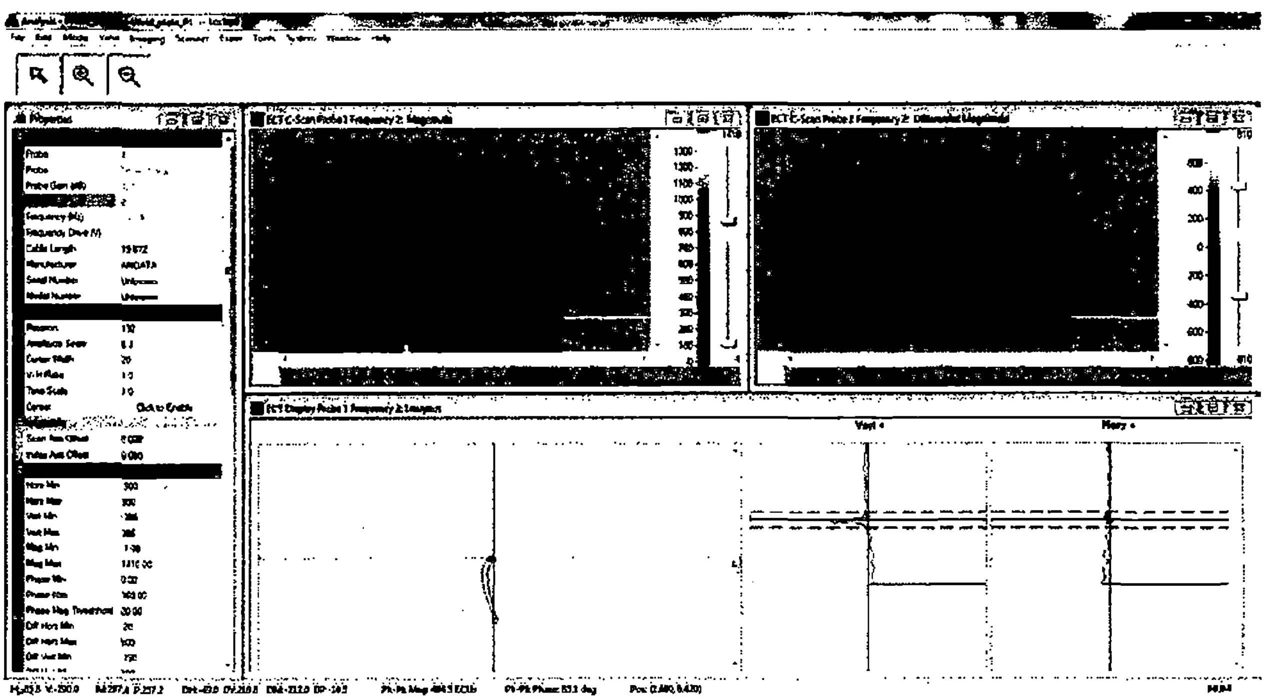

Figure 35 J-weld Probe Plate, 200 KHz, Magnitude C-scans, Region 2

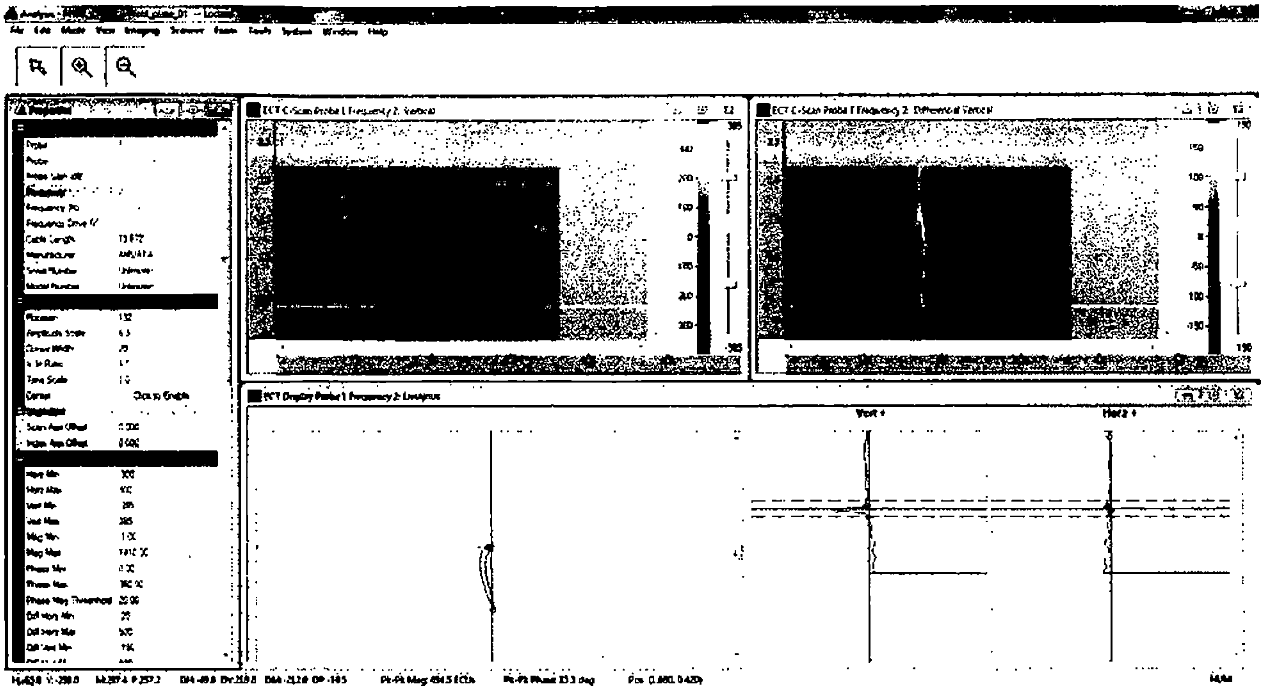

Figure 36 J-weld Probe Plate, 200 KHz, Vertical C-scans, Region 2

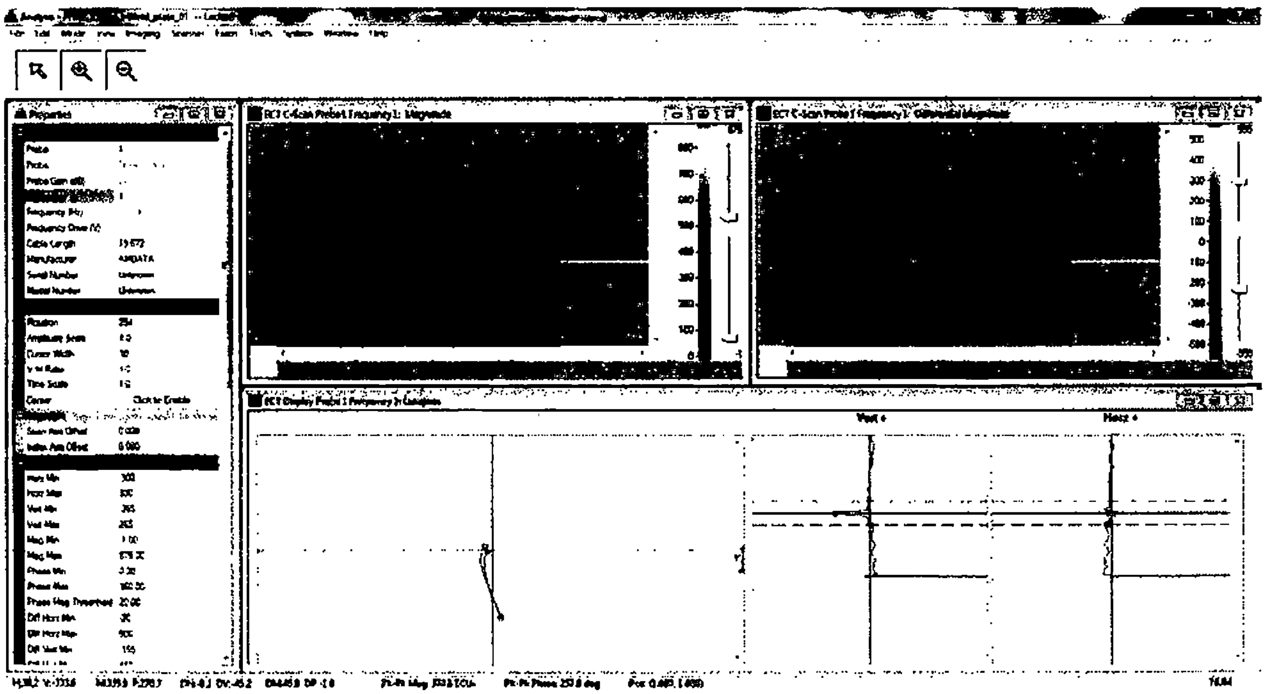

Figure 37 J-weld Probe Plate, 400 KHz, Magnitude C-scans, Region 3

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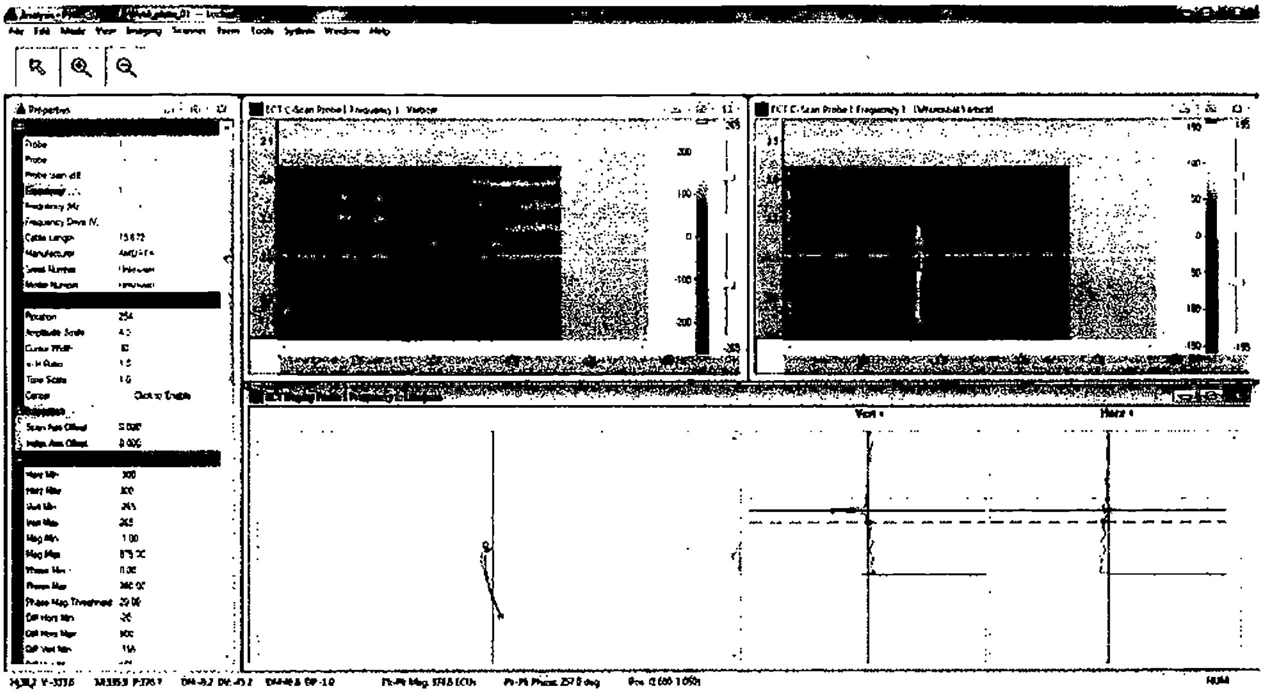

Figure 38 J-weld Probe Plate, 400 KHz, Vertical C-scans, Region 3

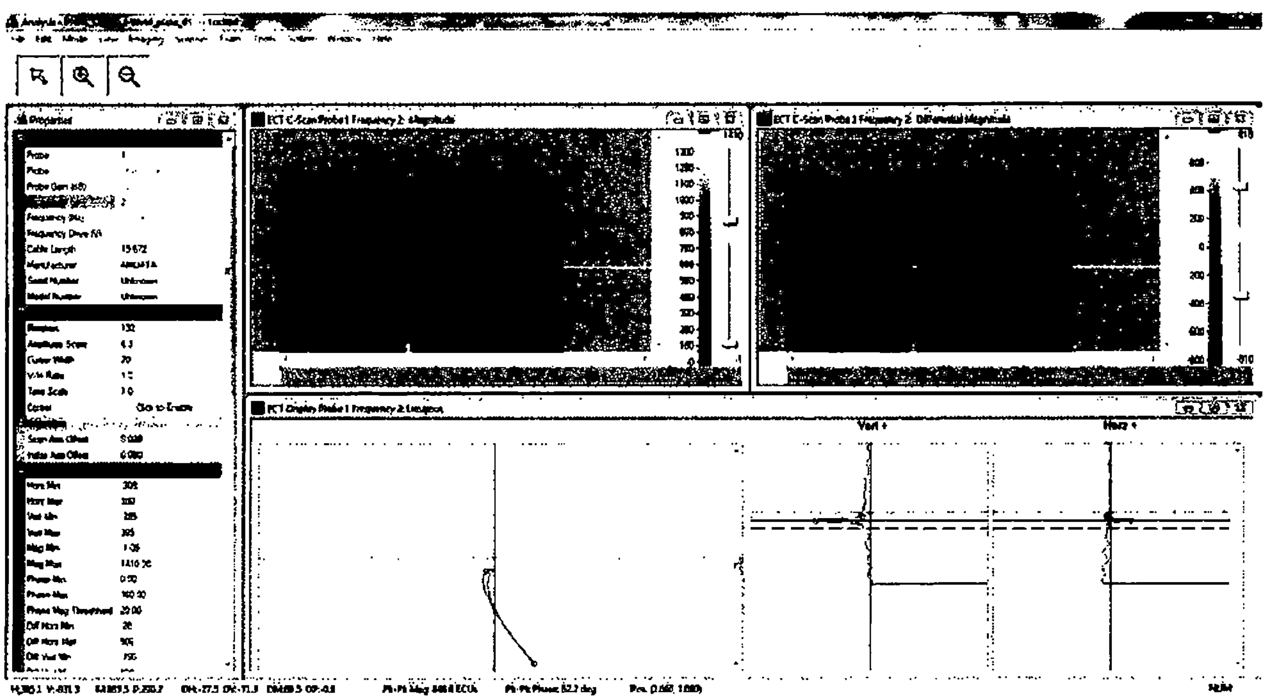

Figure 39 J-weld Probe Plate, 200 KHz, Magnitude C-scans, Region 3

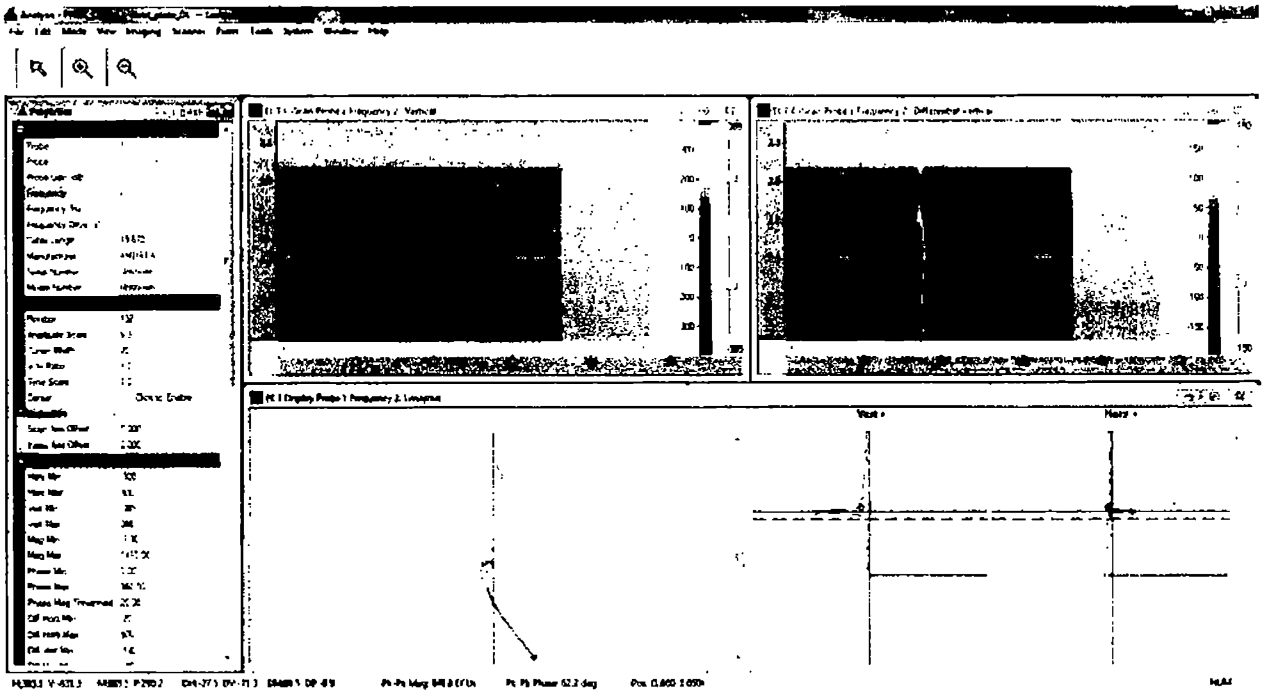

Figure 40 J-weld Probe Plate, 200 KHz, Vertical C-scans, Region 3

Pages 25-40
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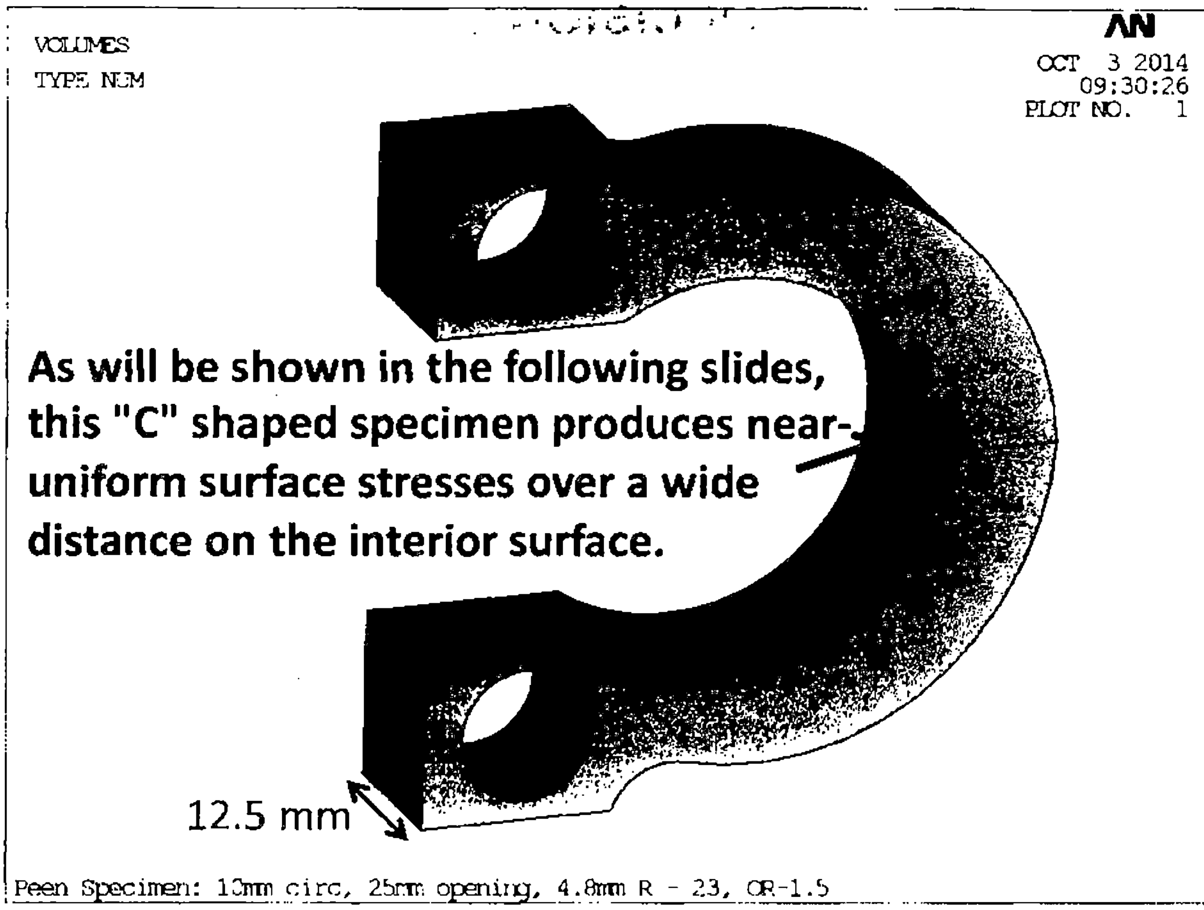
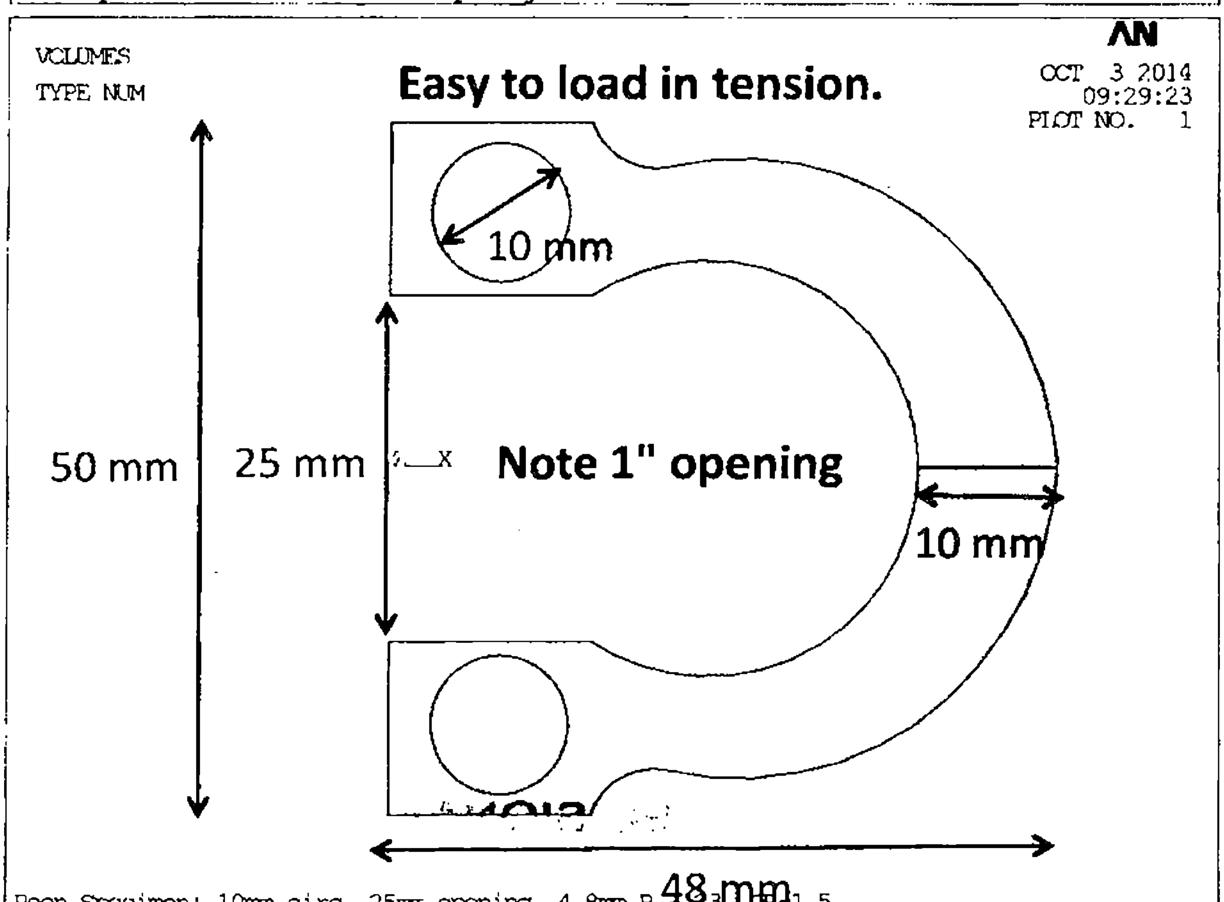
Exemption 4
(Confidential Commercial or Financial
Information)

Peening Specimen Design Status
November 3, 2014

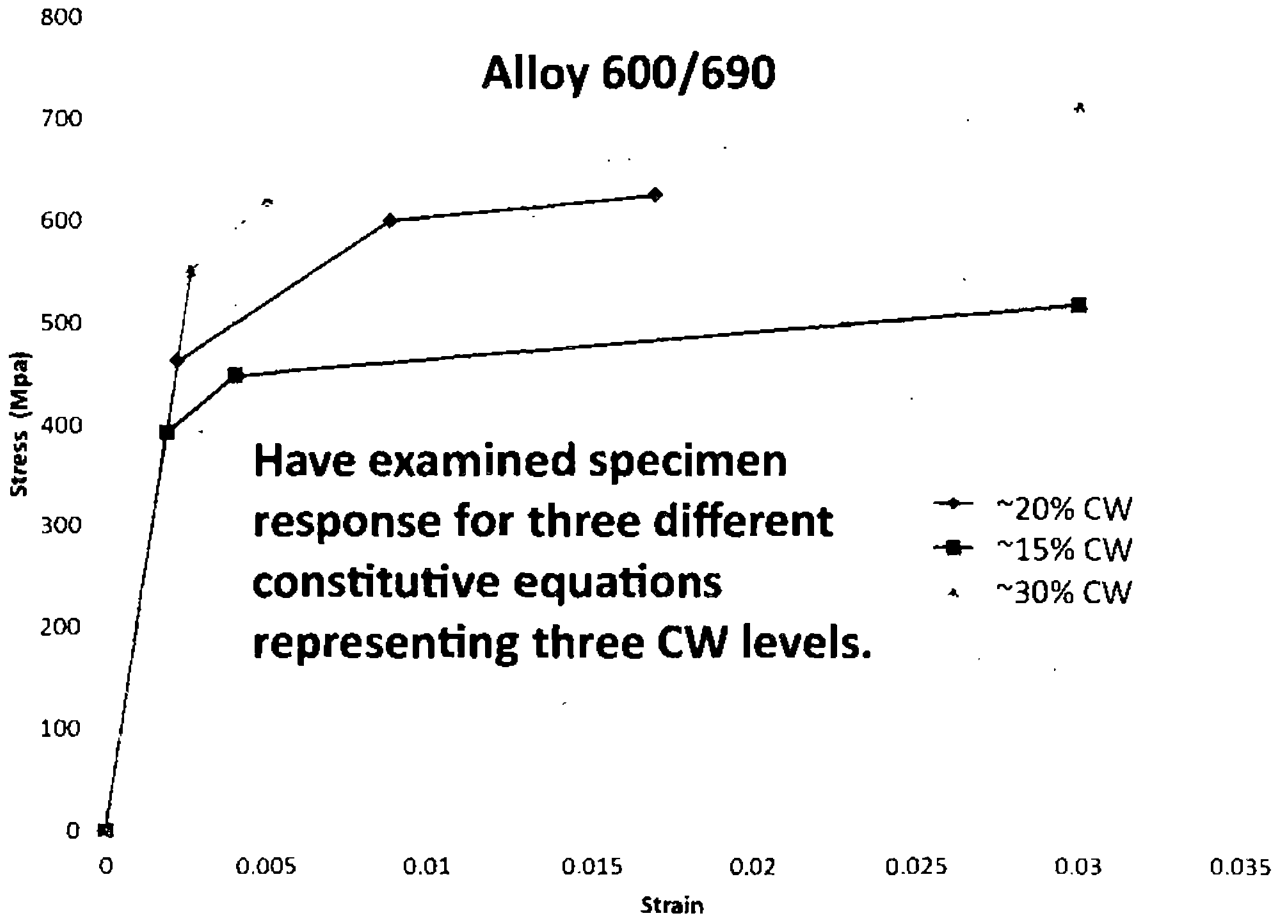
Mychailo Toloczko
John Deibler

PNNL


VOLUMES
TYPE NUM
AN
OCT 3 2014
09:30:26
PLOT NO. 1
As will be shown in the following slides, this "C" shaped specimen produces near-uniform surface stresses over a wide distance on the interior surface.
12.5 mm
Peen Specimen: 10mm circ, 25mm opening, 4.8mm R - 23, CR-1.5


VOLUMES
TYPE NUM
Easy to load in tension.
AN
OCT 3 2014
09:29:23
PLOT NO. 1
10 mm
50 mm
25 mm
Note 1" opening
10 mm
48 mm
Peen Specimen: 10mm circ, 25mm opening, 4.8mm R

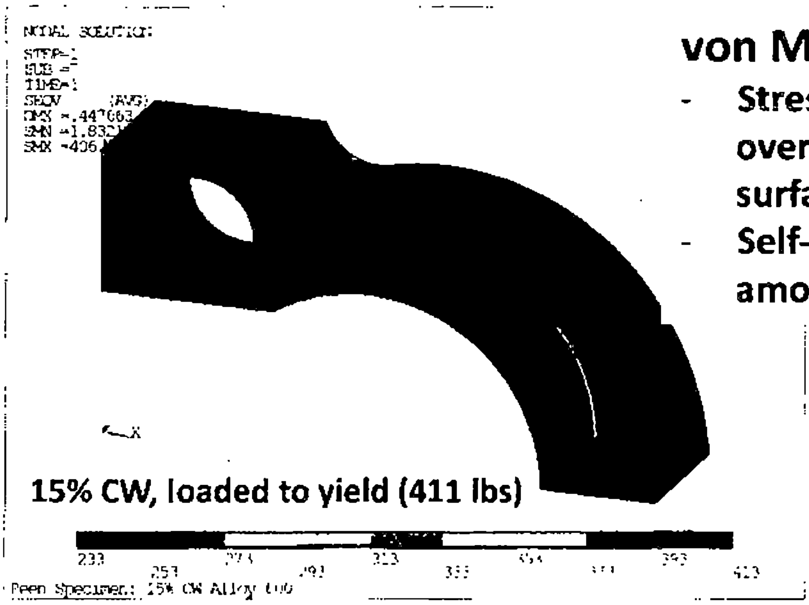
Constitutive equations used for finite element modelling



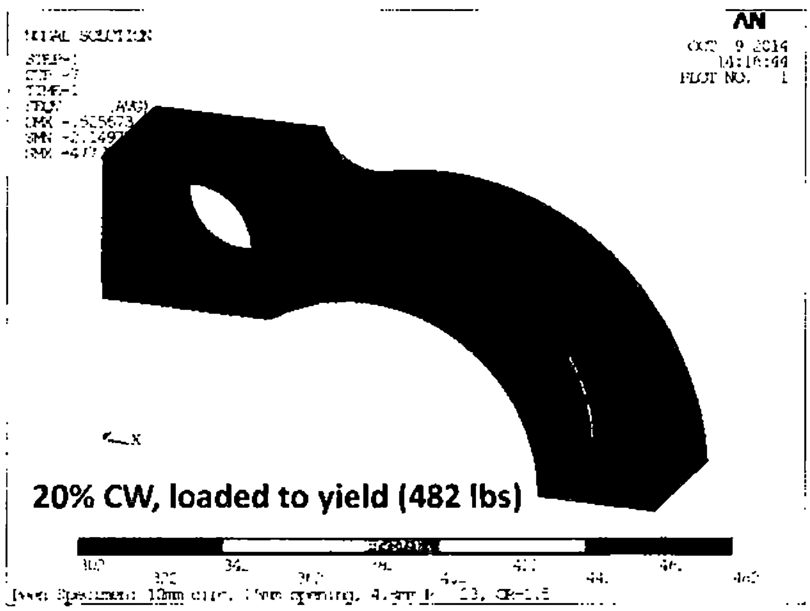
Have examined specimen response for three different constitutive equations representing three CW levels.

von Mises stress

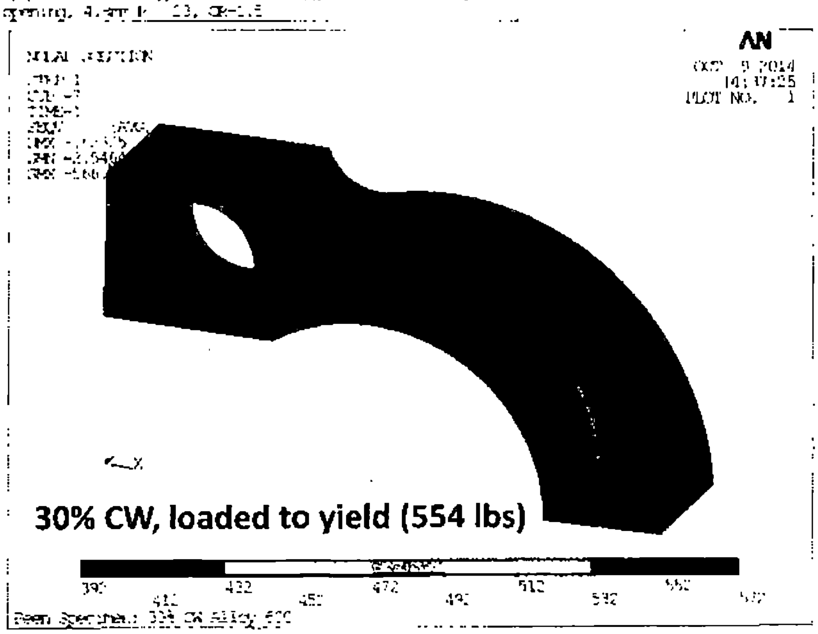
- Stress almost uniformly distributed over ~1" of height on interior surface.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



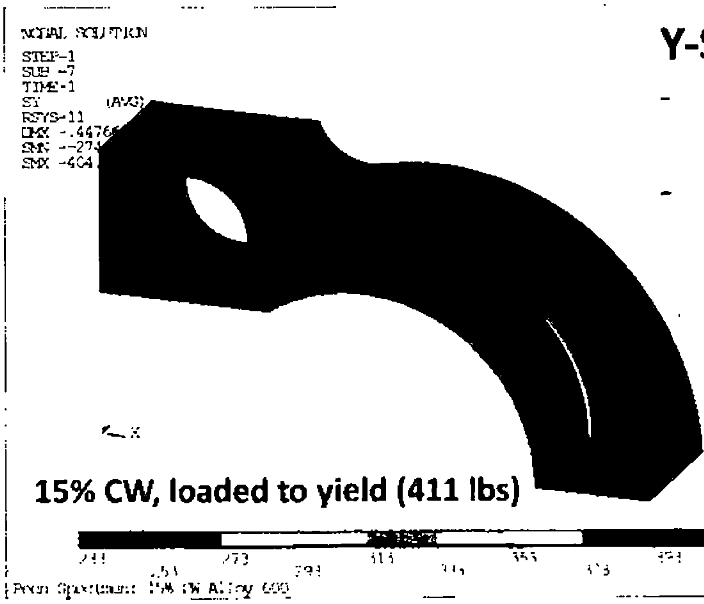
20% CW, loaded to yield (482 lbs)



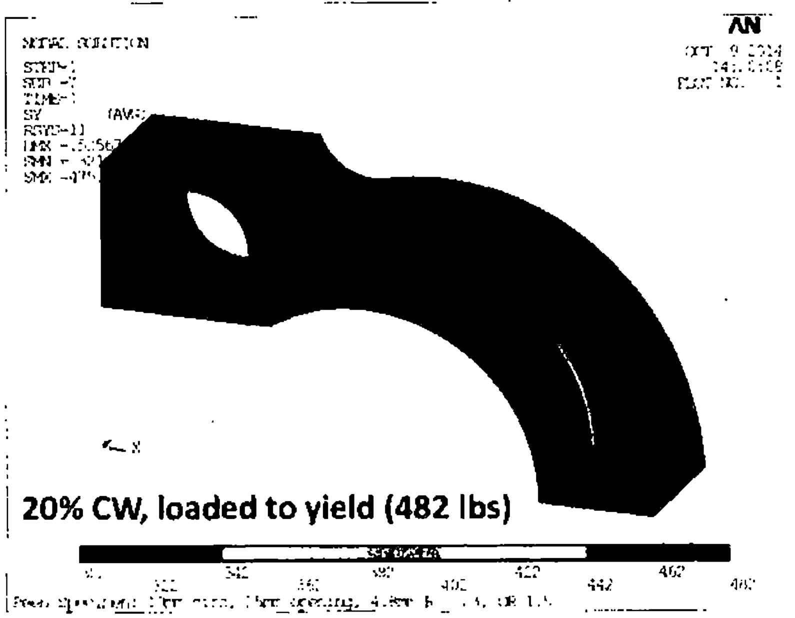
30% CW, loaded to yield (554 lbs)

Y-Stress

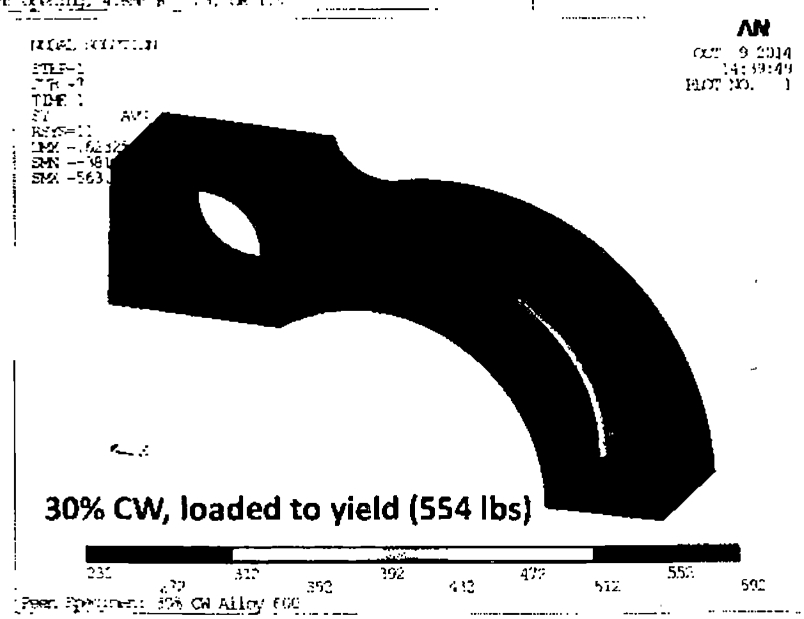
- Peak stress in same location as peak von Mises stress.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



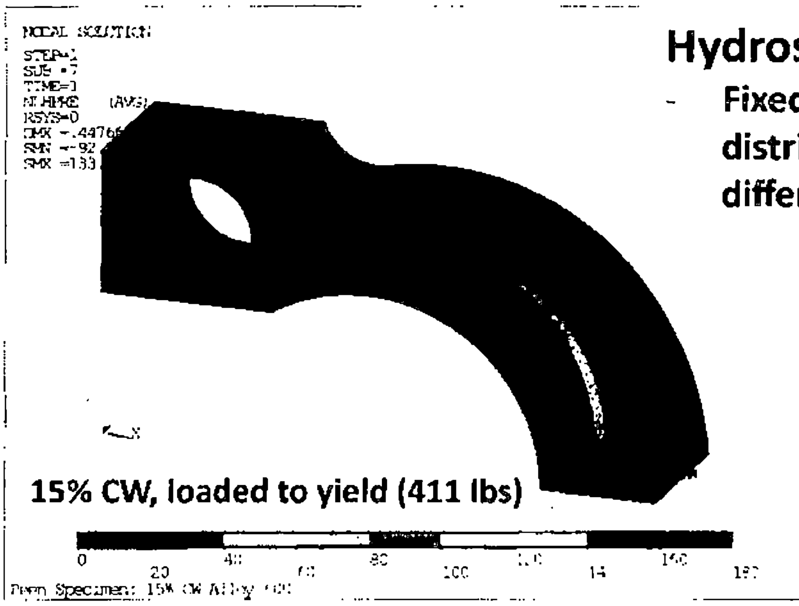
20% CW, loaded to yield (482 lbs)



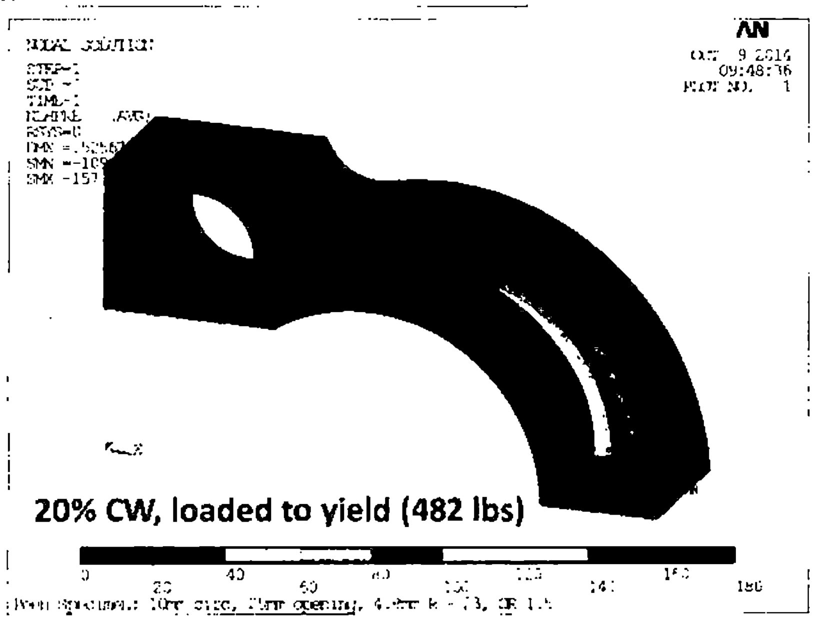
30% CW, loaded to yield (554 lbs)

Hydrostatic Stress

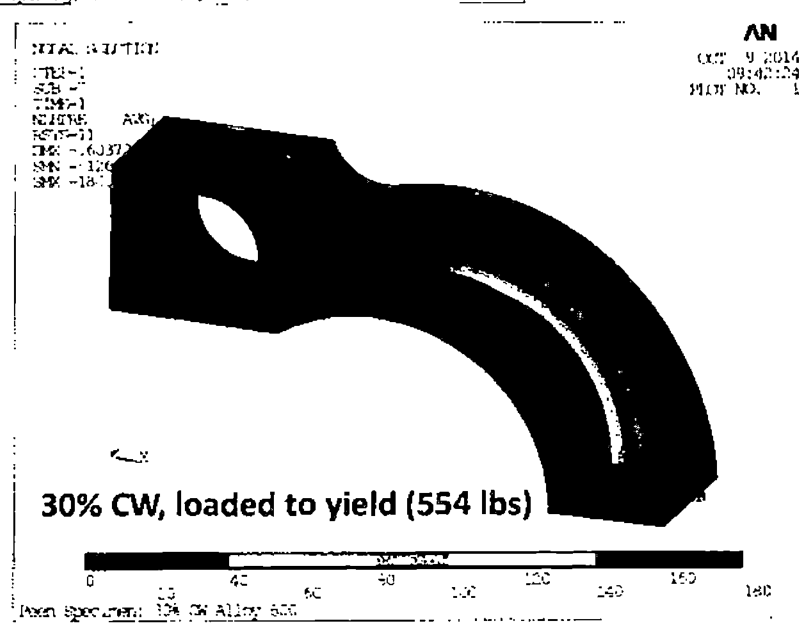
- Fixed scale, but self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



20% CW, loaded to yield (482 lbs)

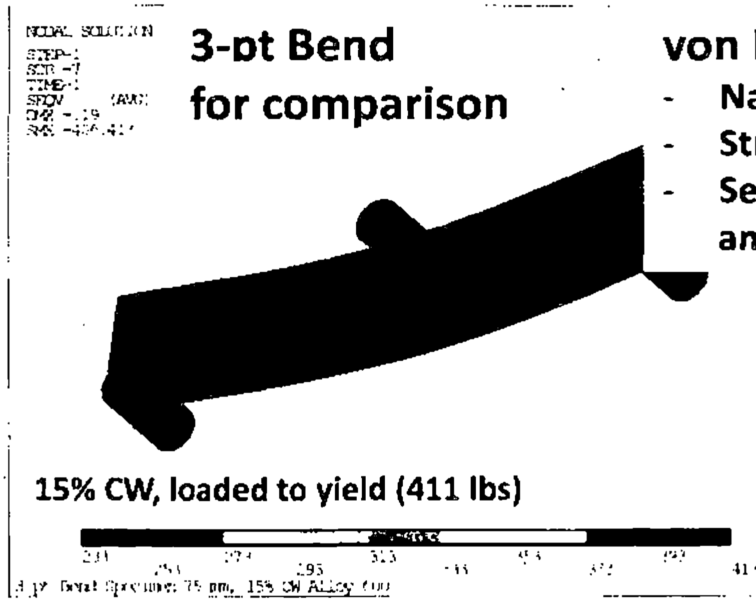


30% CW, loaded to yield (554 lbs)

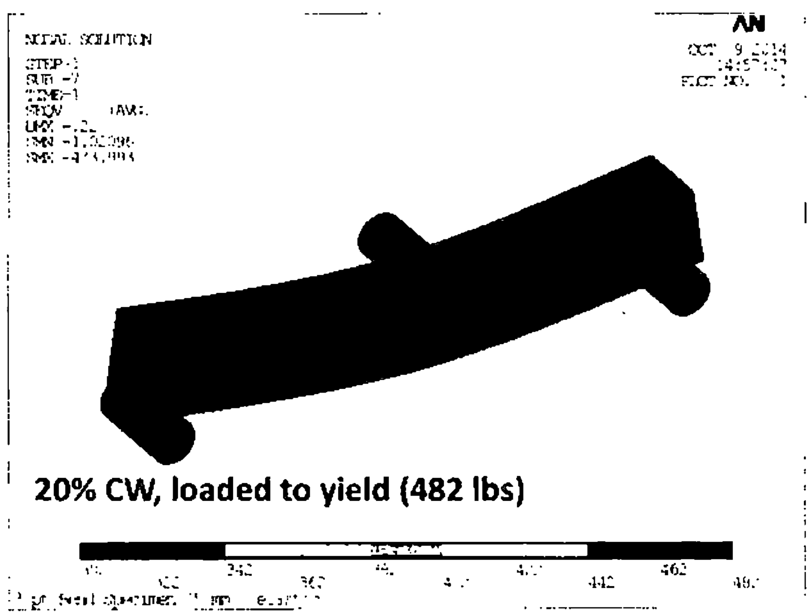
3-pt Bend for comparison

von Mises Stress

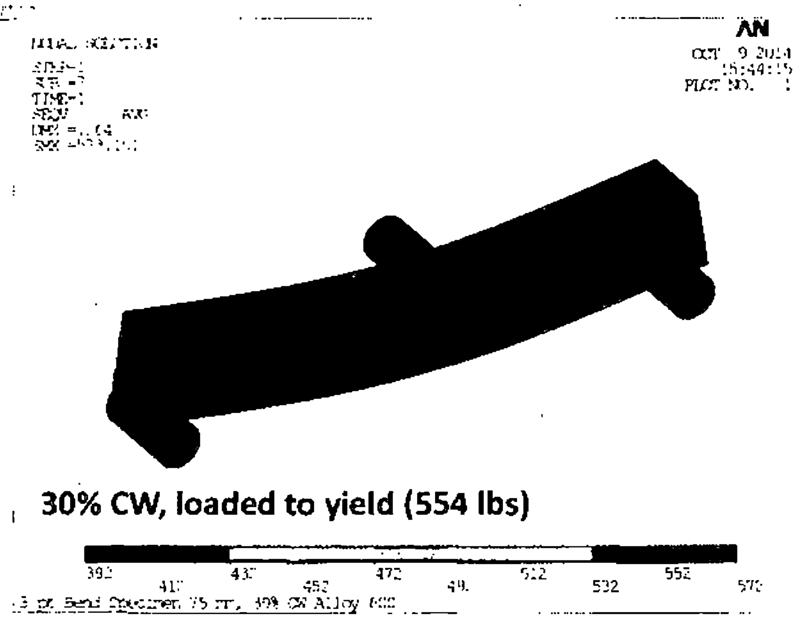
- Narrow spatial distribution of stress.
- Strong stress gradient.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



20% CW, loaded to yield (482 lbs)

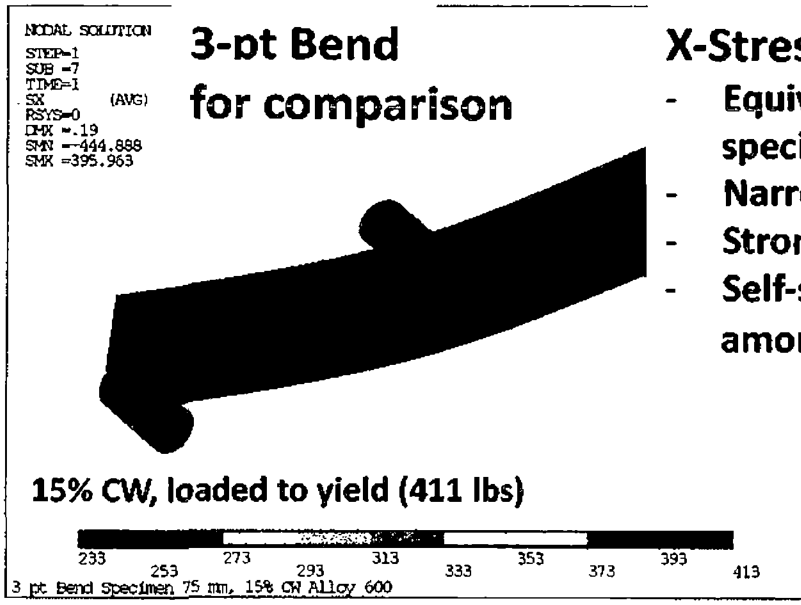


30% CW, loaded to yield (554 lbs)

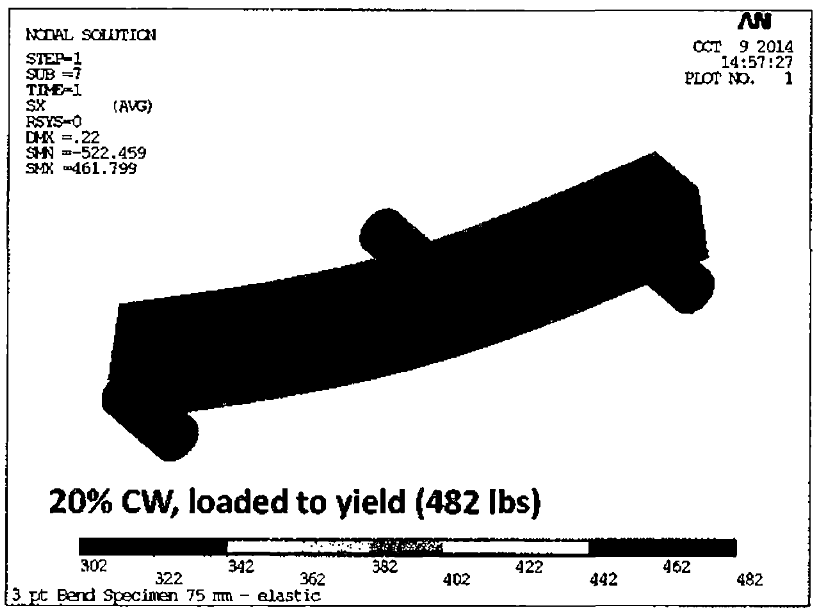
3-pt Bend for comparison

X-Stress

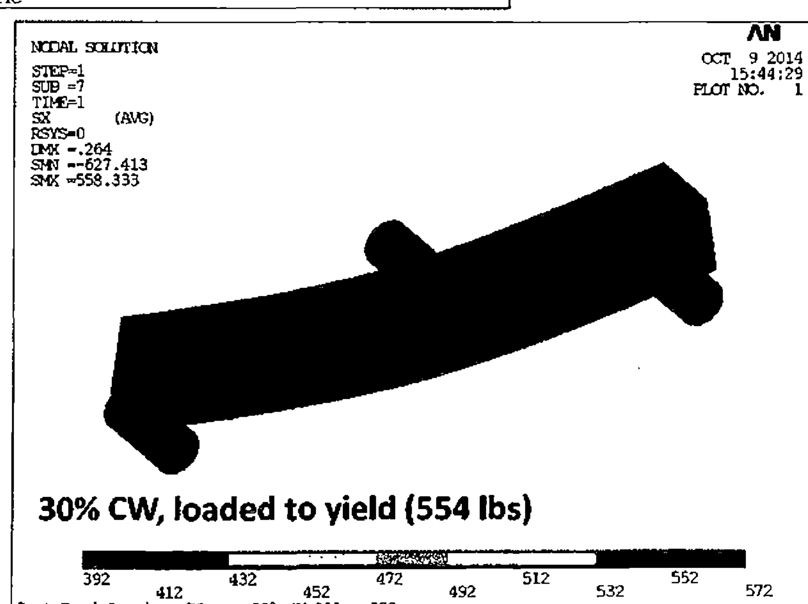
- Equivalent to Y-stress direction on "C" specimen.
- Narrow spatial distribution of stress.
- Strong stress gradient.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



20% CW, loaded to yield (482 lbs)

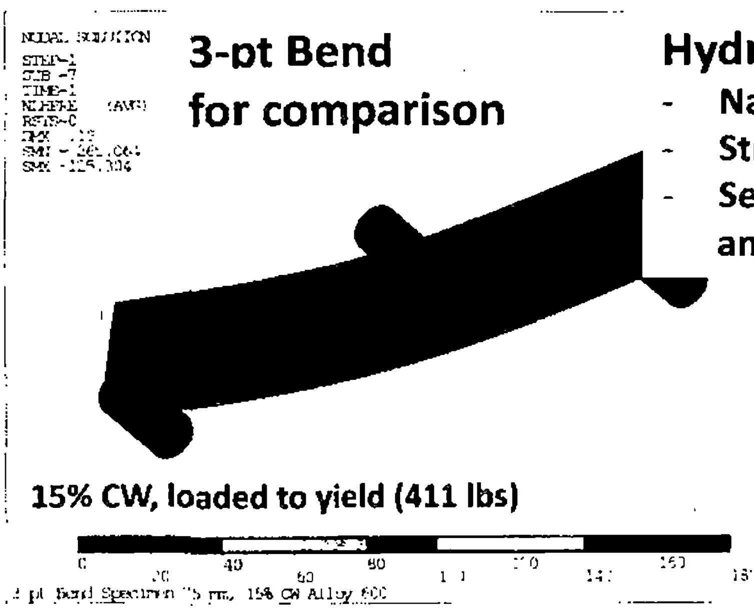


30% CW, loaded to yield (554 lbs)

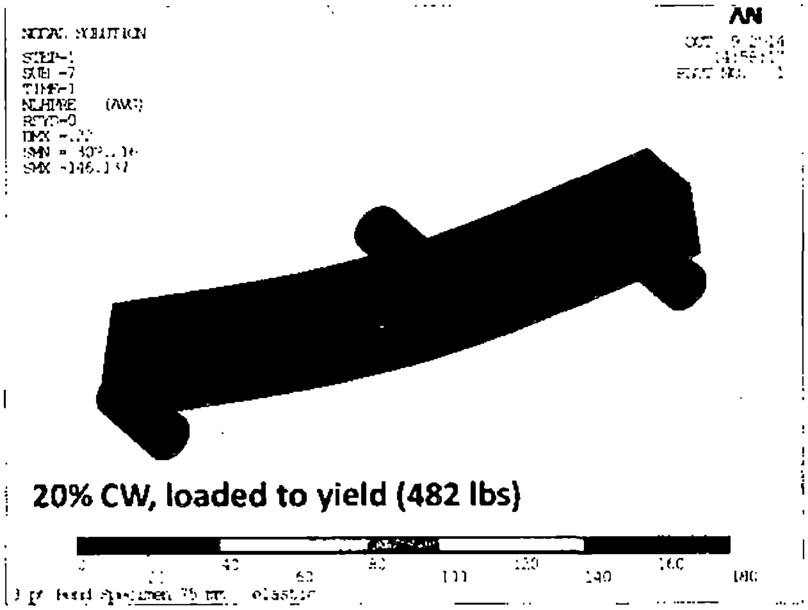
3-pt Bend for comparison

Hydrostatic Stress

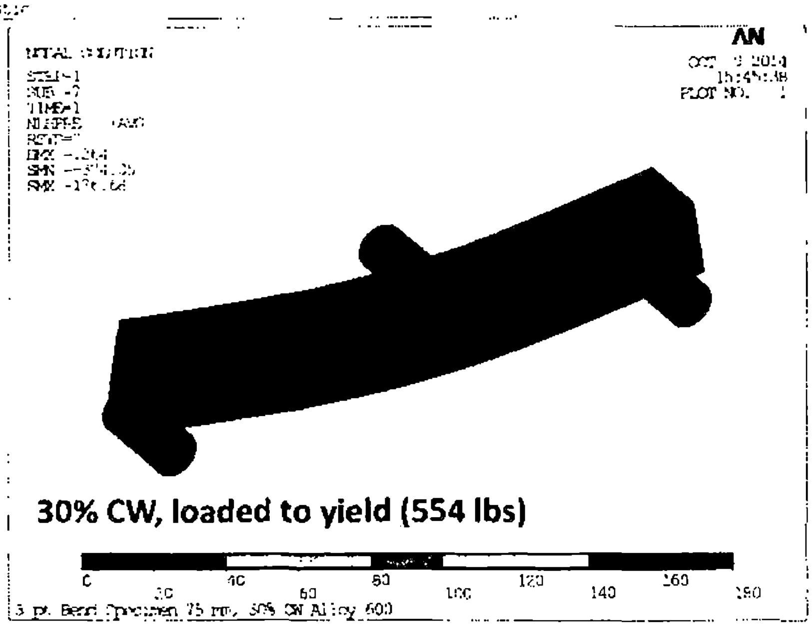
- Narrow spatial distribution of stress.
- Strong stress gradient.
- Self-similar stress distributions among the three different CW levels.



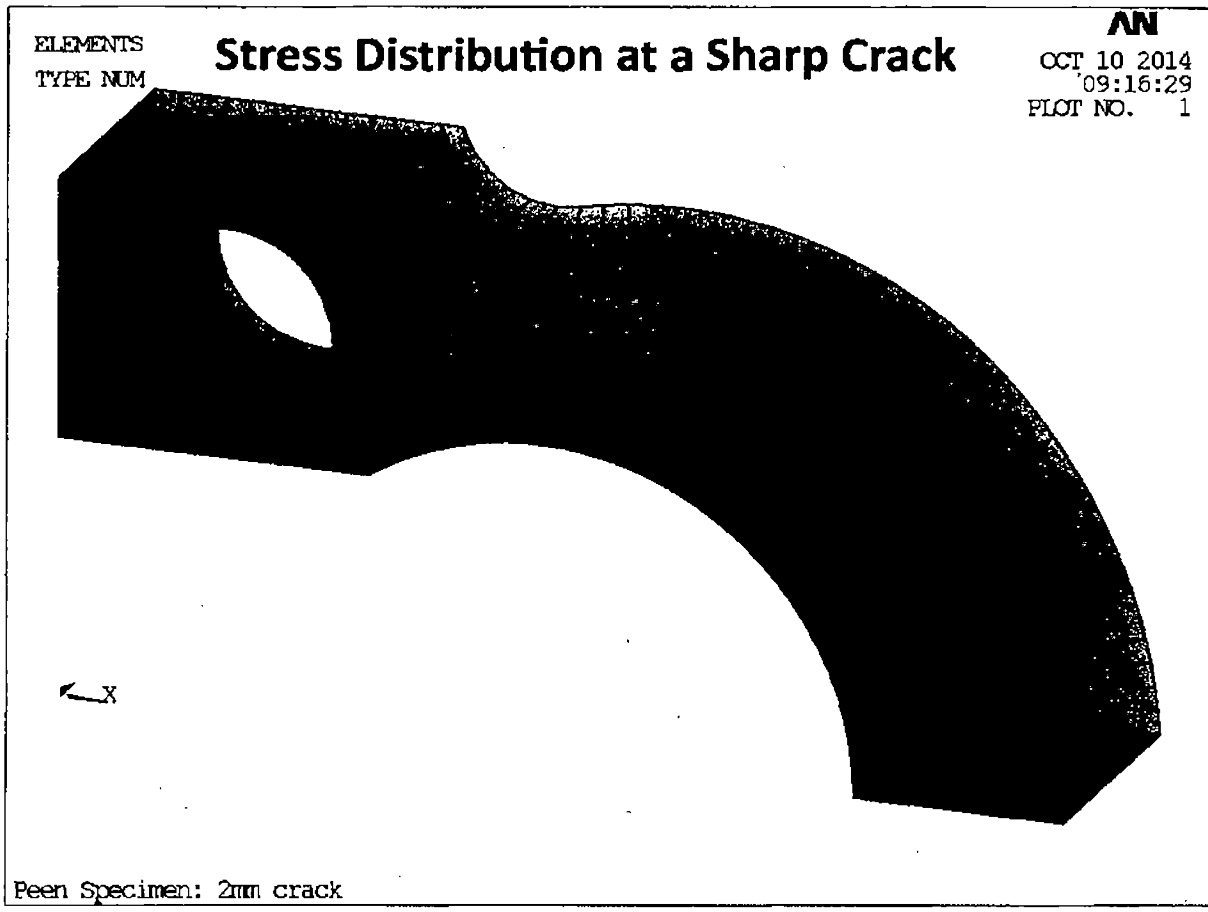
15% CW, loaded to yield (411 lbs)

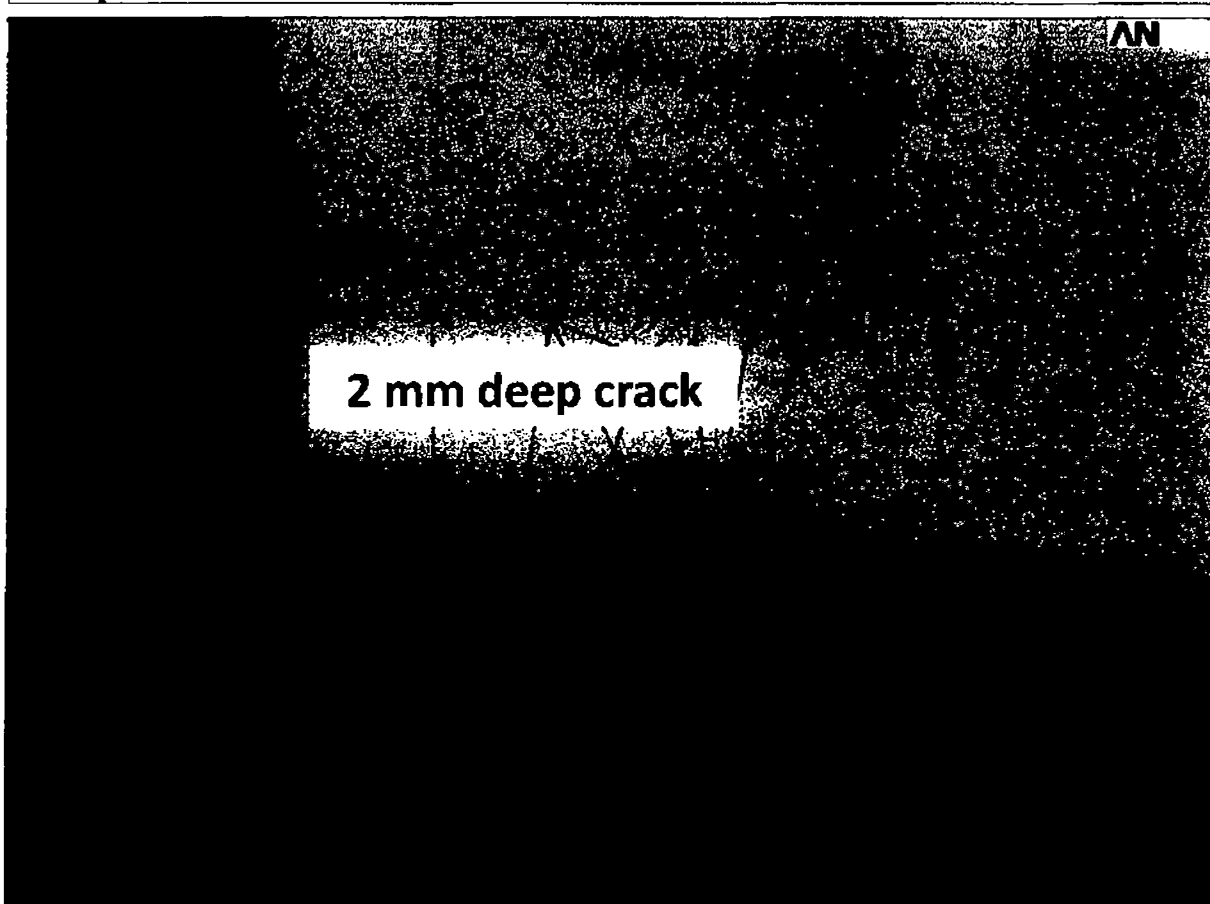


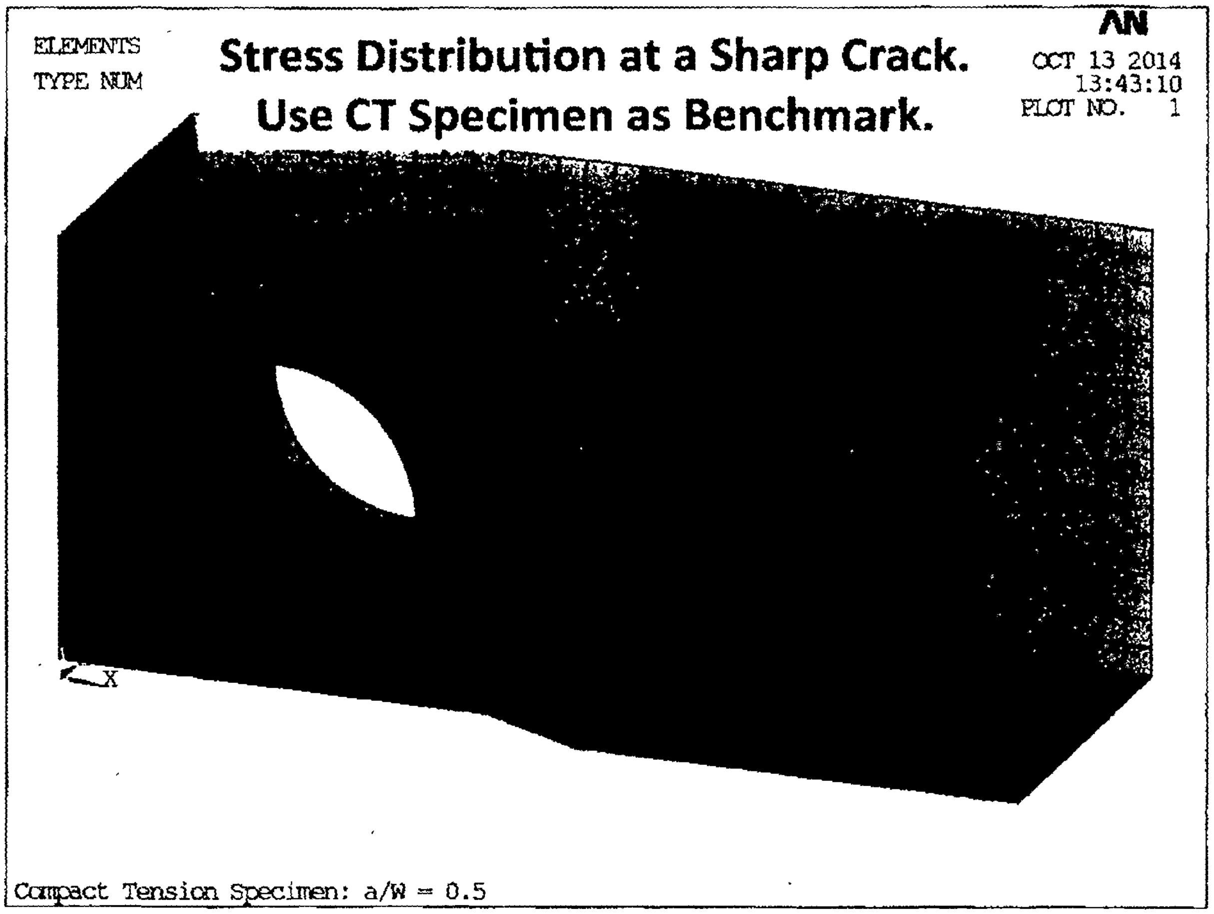
20% CW, loaded to yield (482 lbs)

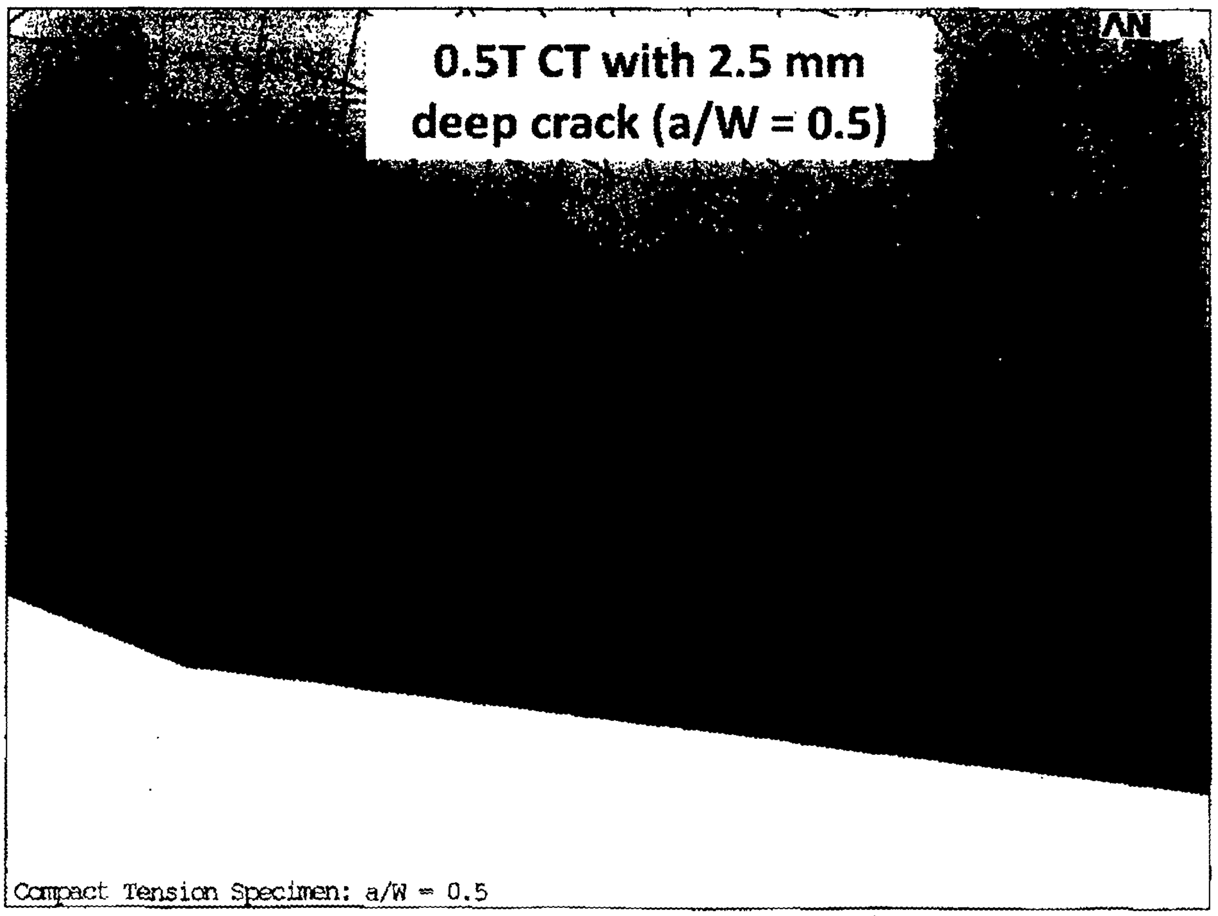


30% CW, loaded to yield (554 lbs)


ELEMENTS
TYPE NUM
Stress Distribution at a Sharp Crack
AN
OCT 10 2014
09:16:29
PLOT NO. 1
X
Peen Specimen: 2mm crack

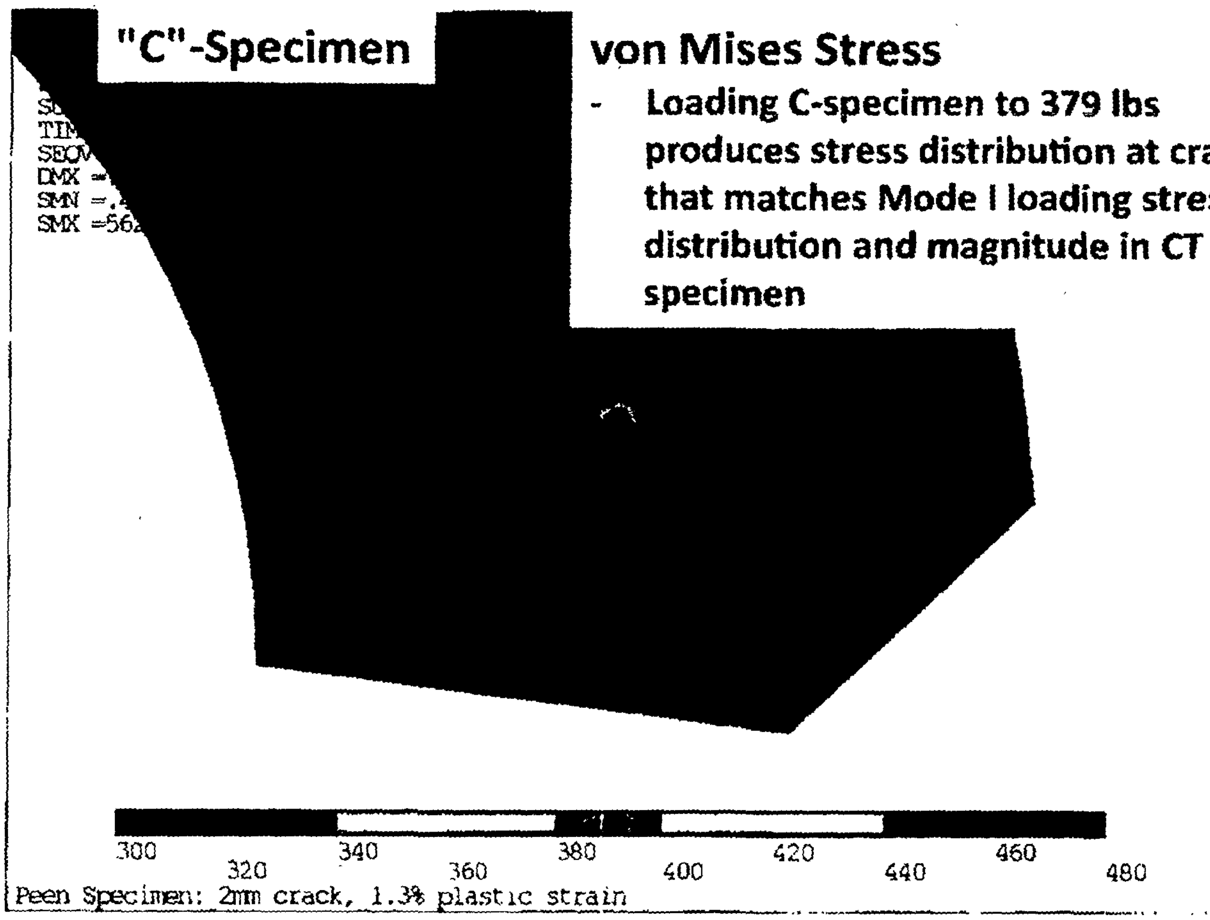

AN
2 mm deep crack

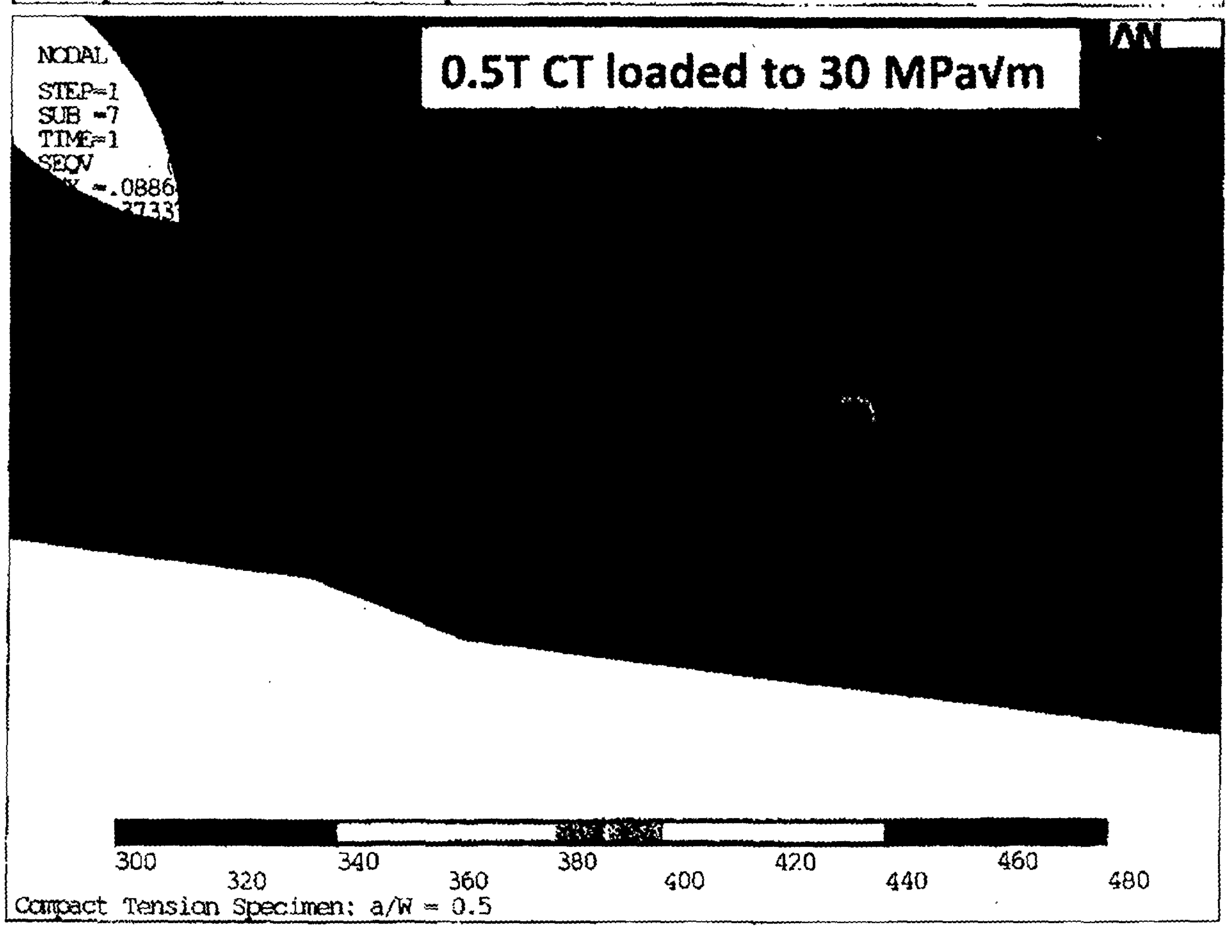

ELEMENTS
TYPE NUM
Stress Distribution at a Sharp Crack.
Use CT Specimen as Benchmark.
AN
OCT 13 2014
13:43:10
PLOT NO. 1
X
Compact Tension Specimen: a/W = 0.5


AN
0.5T CT with 2.5 mm
deep crack (a/W = 0.5)
Compact Tension Specimen: a/W = 0.5

von Mises Stress

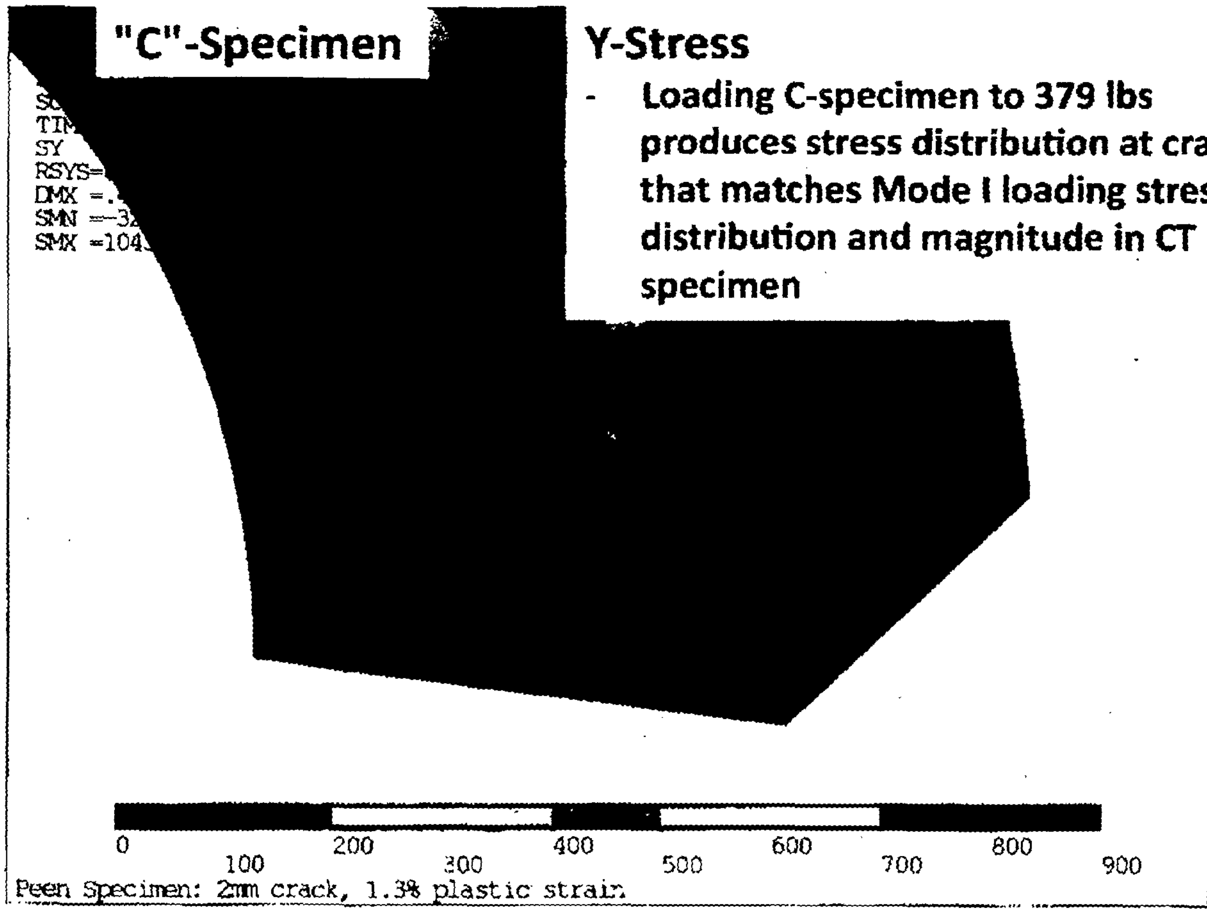
- Loading C-specimen to 379 lbs produces stress distribution at crack that matches Mode I loading stress distribution and magnitude in CT specimen

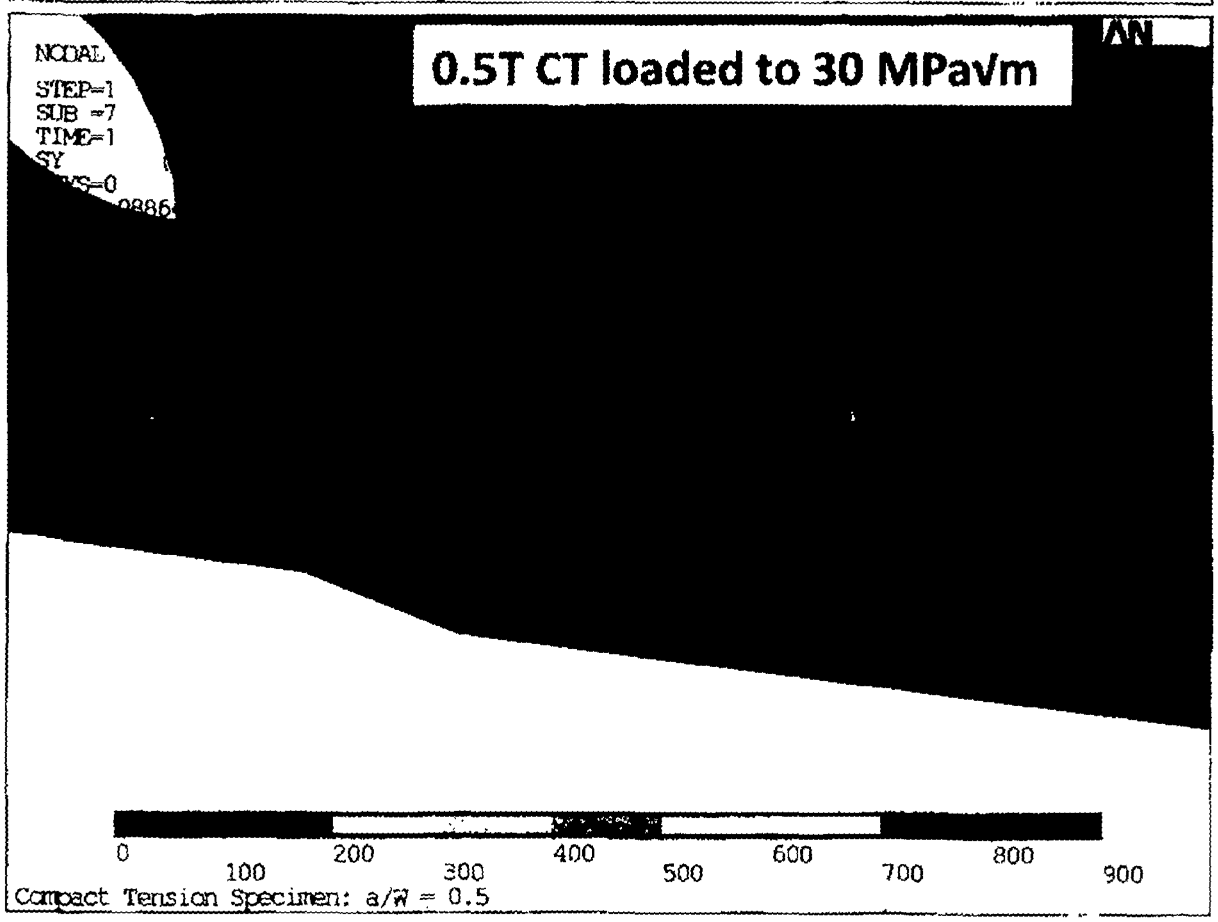




Y-Stress

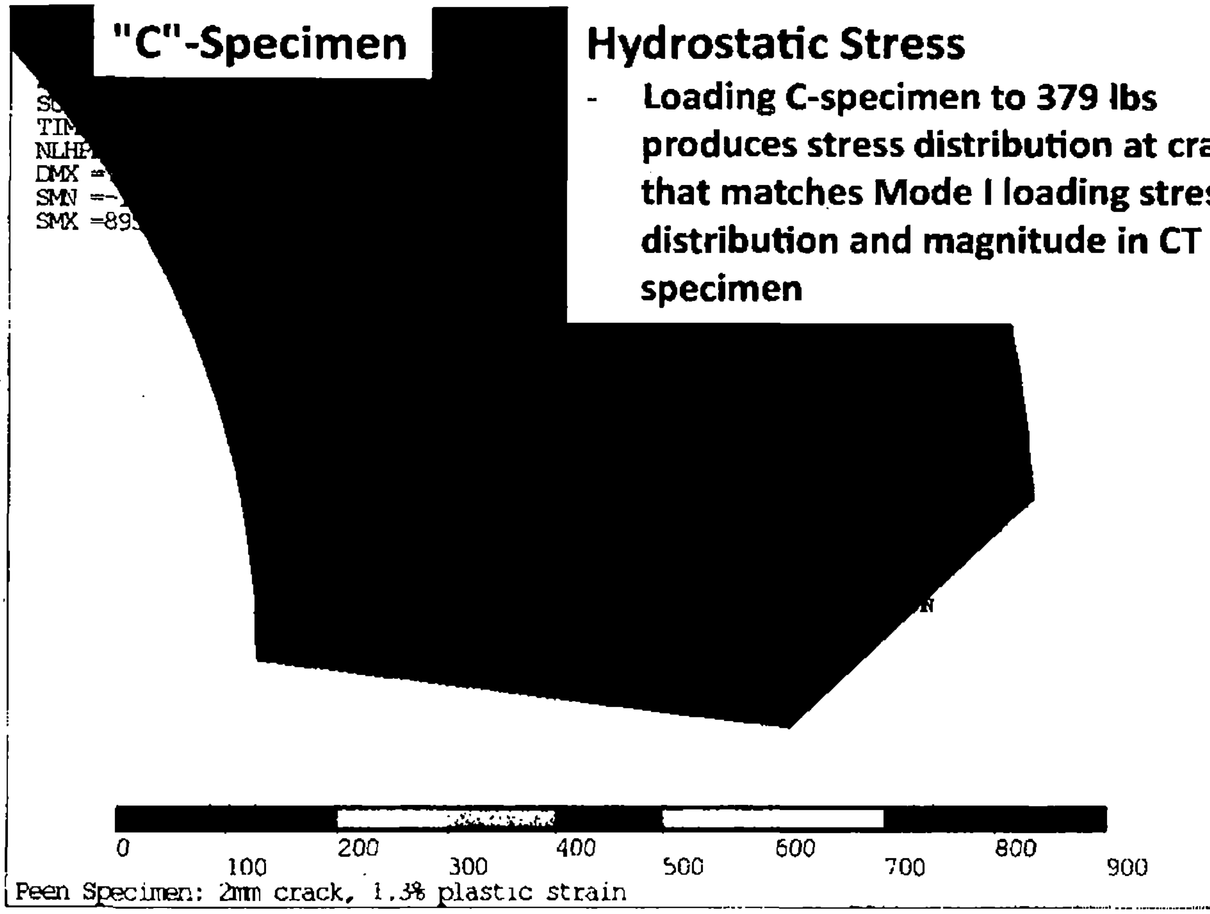
- **Loading C-specimen to 379 lbs produces stress distribution at crack that matches Mode I loading stress distribution and magnitude in CT specimen**

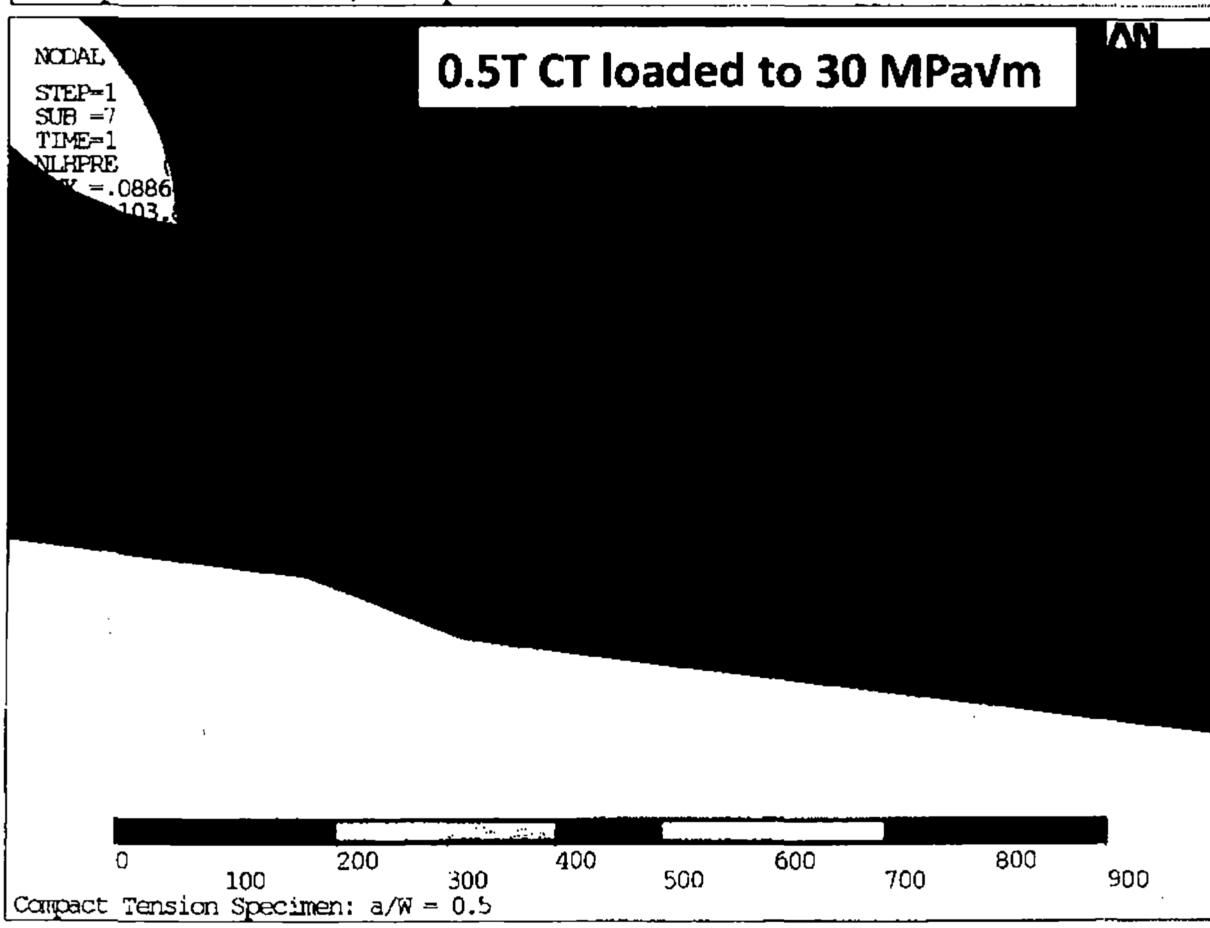




Hydrostatic Stress

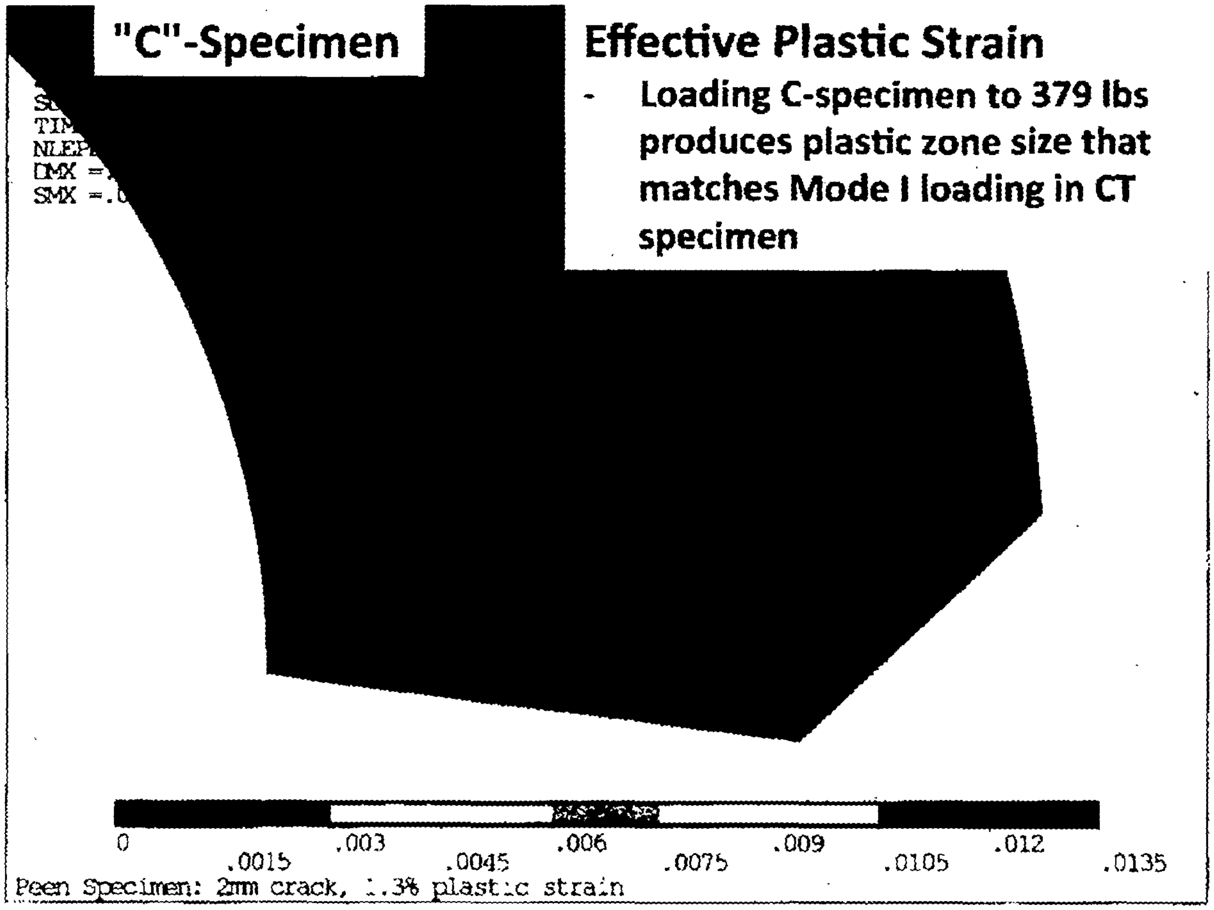
- Loading C-specimen to 379 lbs produces stress distribution at crack that matches Mode I loading stress distribution and magnitude in CT specimen

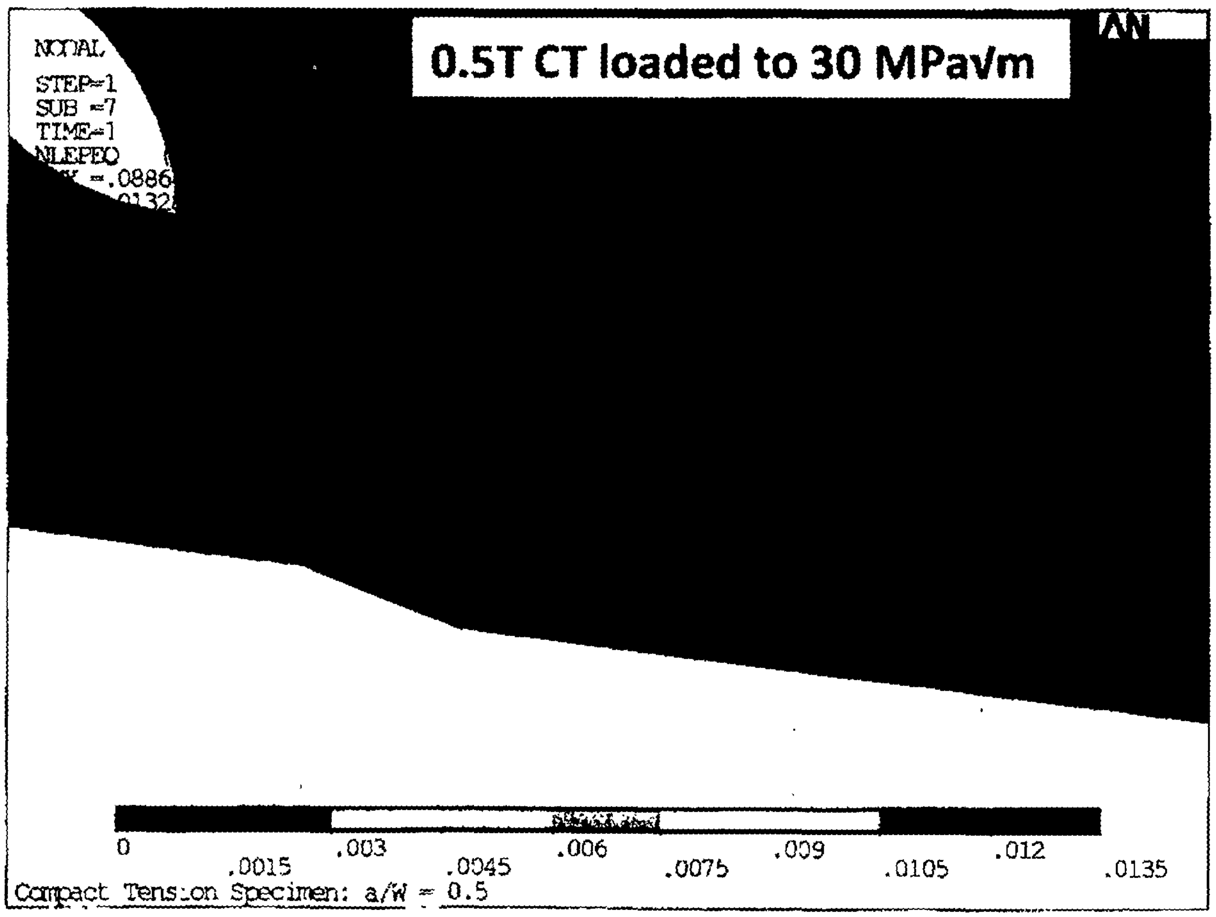




Effective Plastic Strain

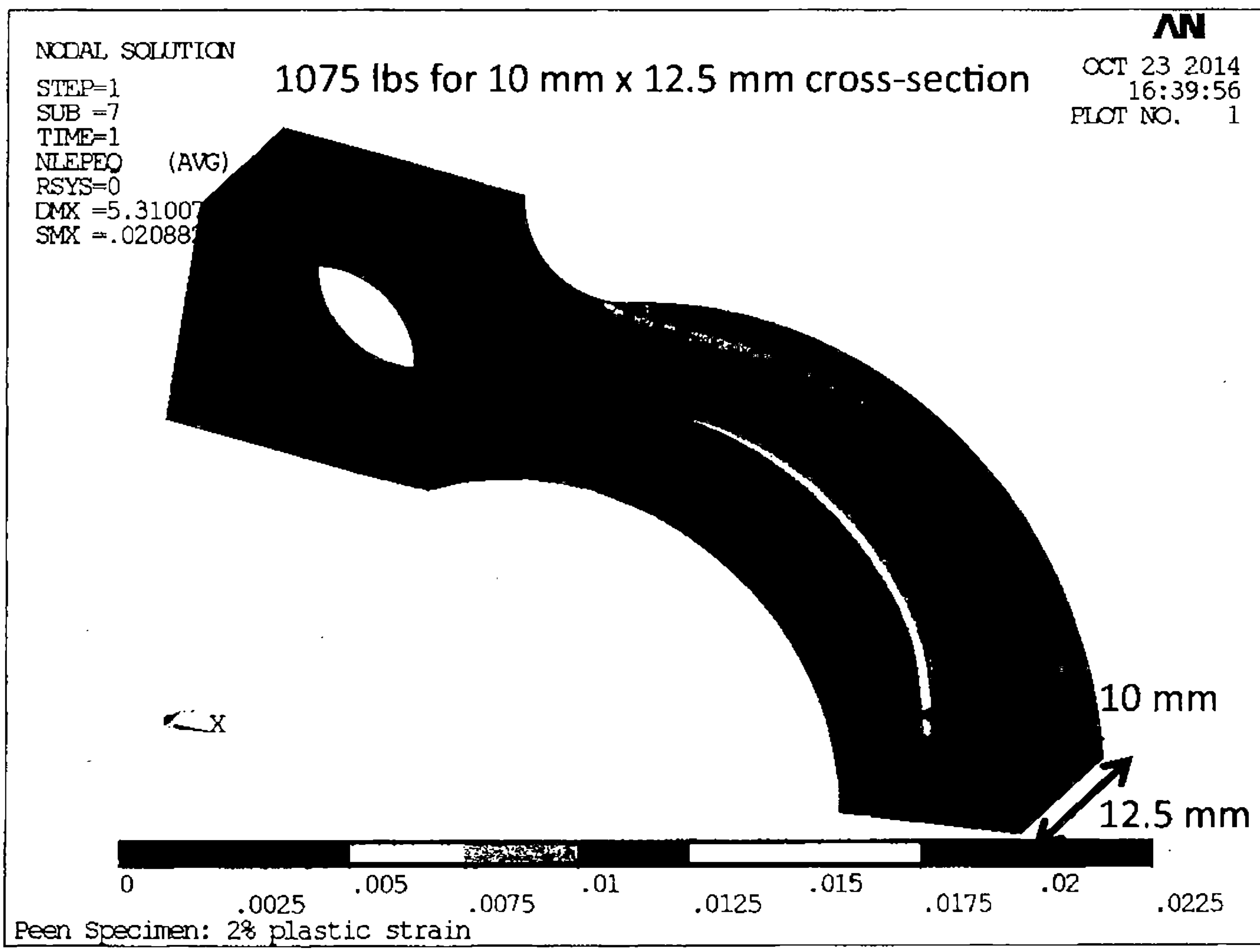
- Loading C-specimen to 379 lbs produces plastic zone size that matches Mode I loading in CT specimen





Application of 2% Peak Plastic Strain

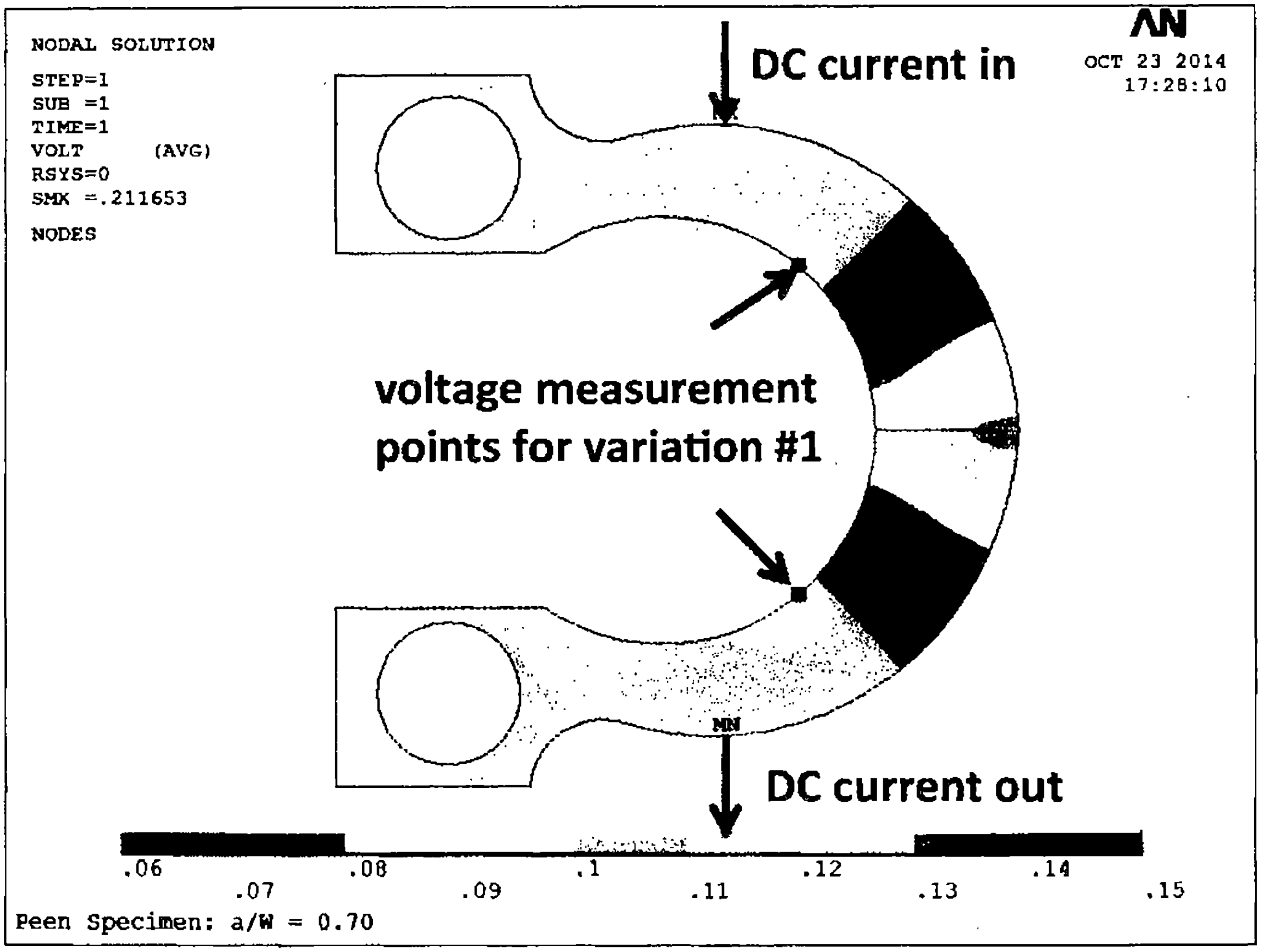
- **Unclear if this level of strain would be needed, but it can be achieved if needed with a very reasonable load.**
- **Strains are still well distributed.**



"C"-Specimen DCPD signal versus crack length FEM analysis

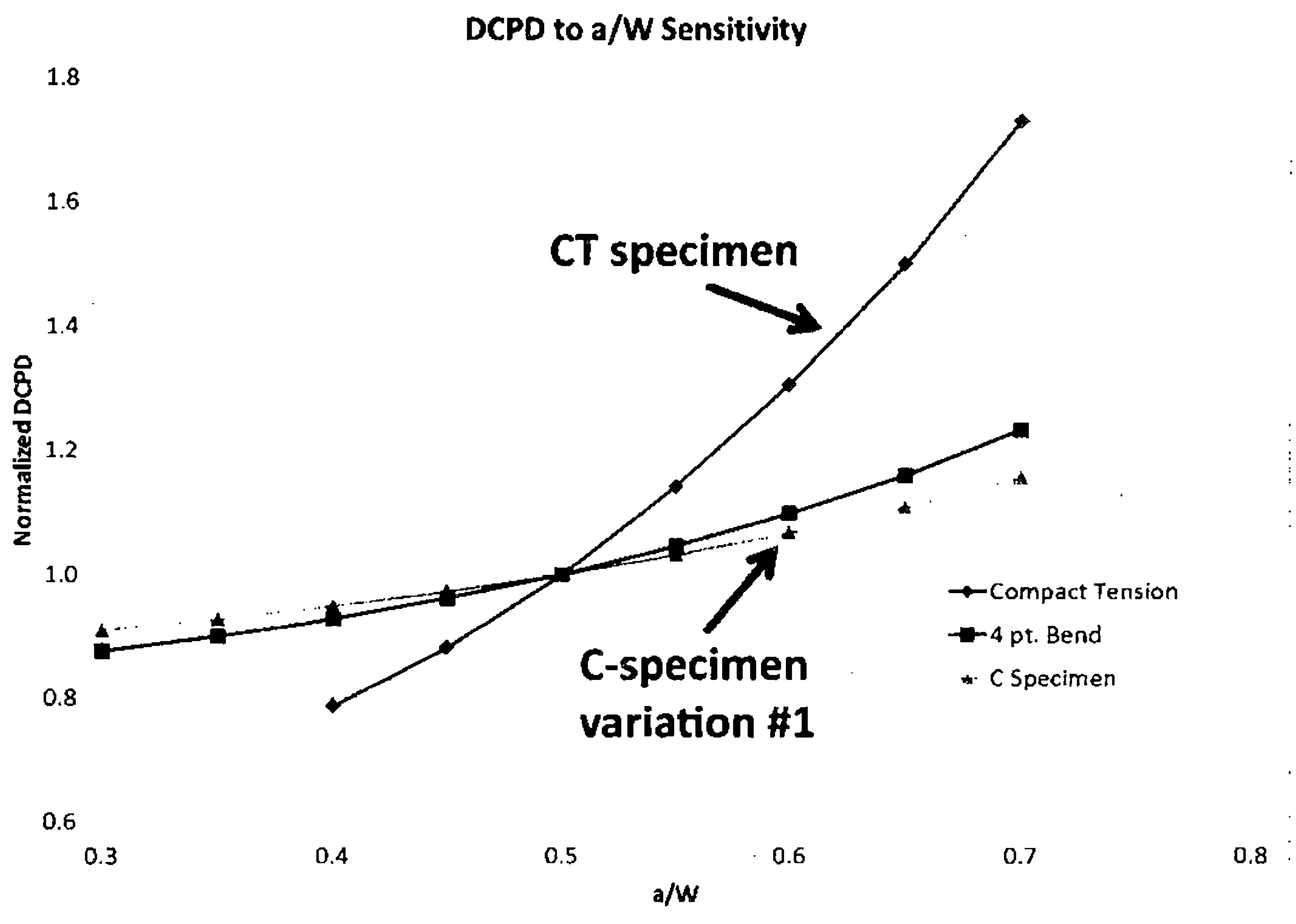
Have tried several variations in voltage measurement location.

2D model - Variation #1

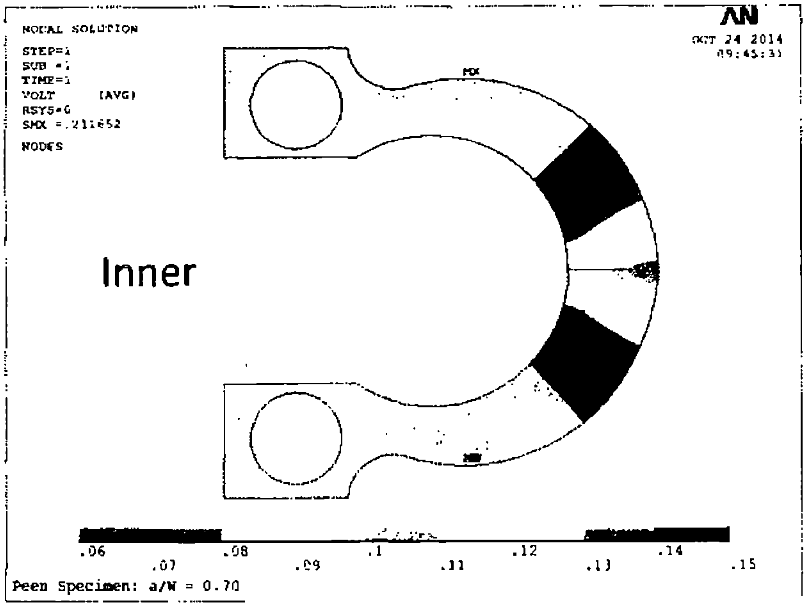


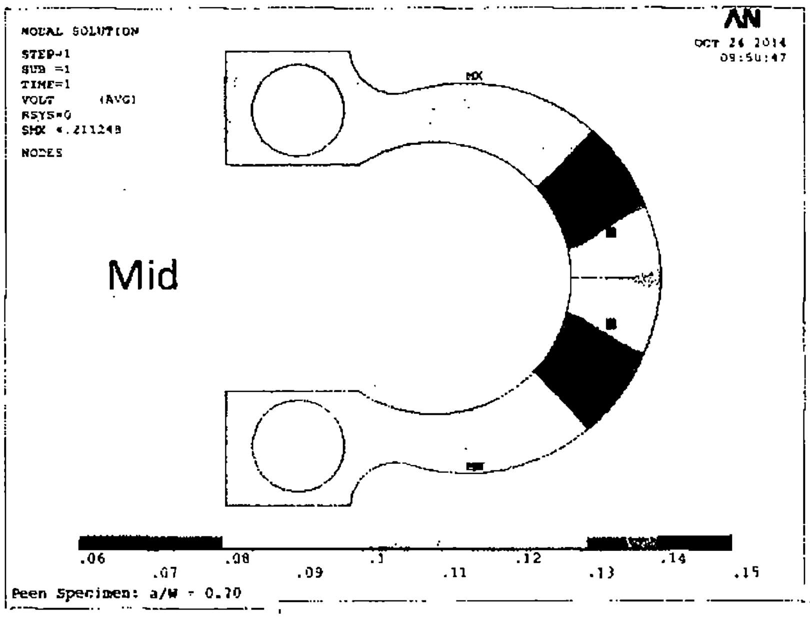
Comparison to CT specimen DCPD Sensitivity

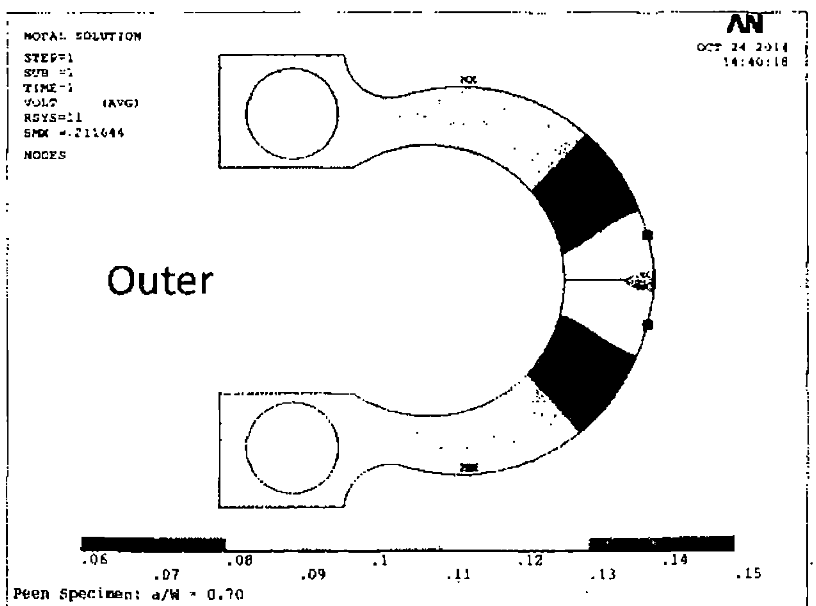
Variation #1 shows lower sensitivity than for a CT specimen.



Try several variants in DCPD voltage measurement location.

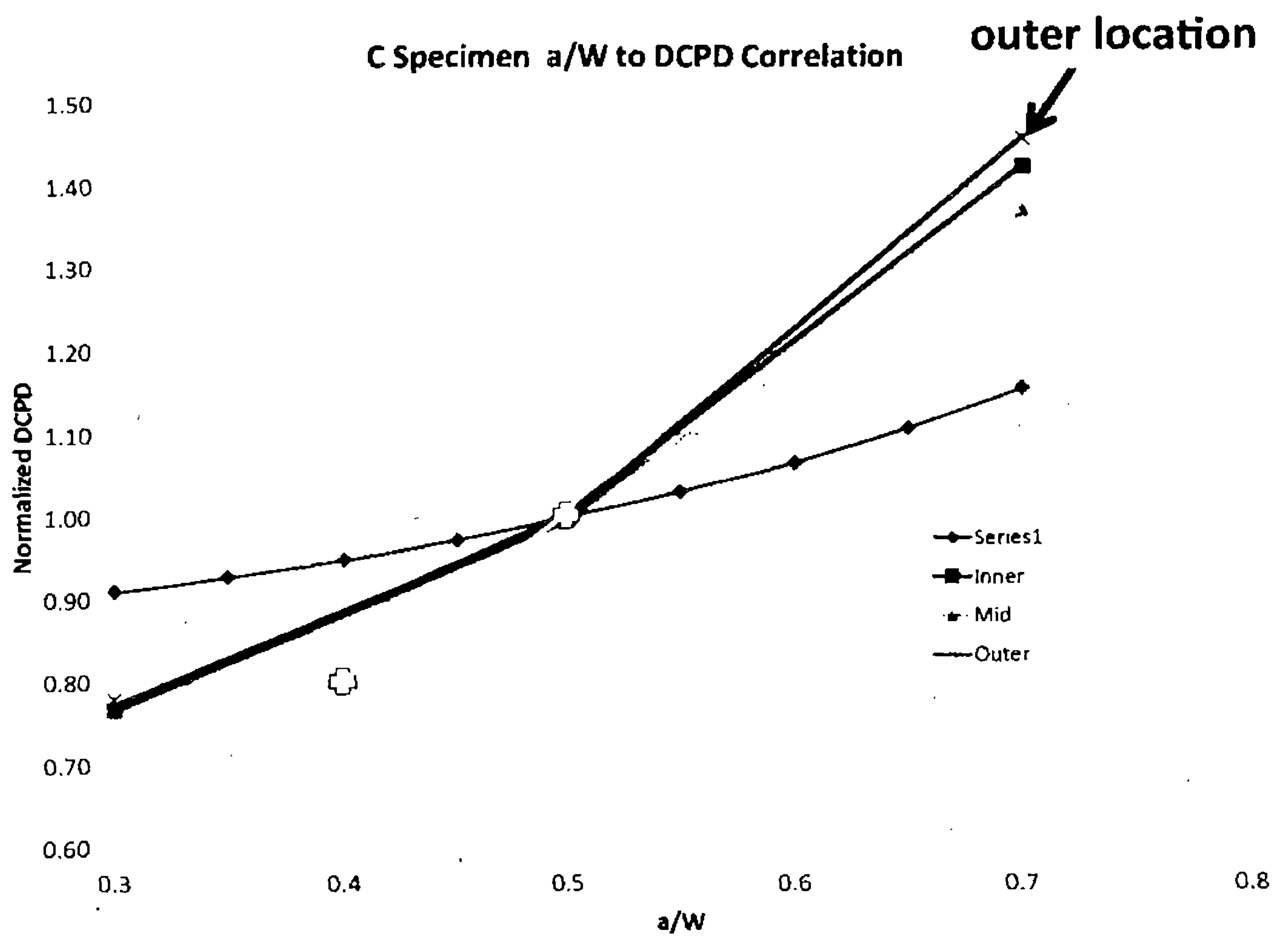






Comparison to CT specimen DCPD Sensitivity

- DCPD probes attached to back side of specimen on either side of the crack plane shows best sensitivity among variants that have been analyzed.
- Approaching that of CT specimen sensitivity.
- Can likely be improved further if needed.

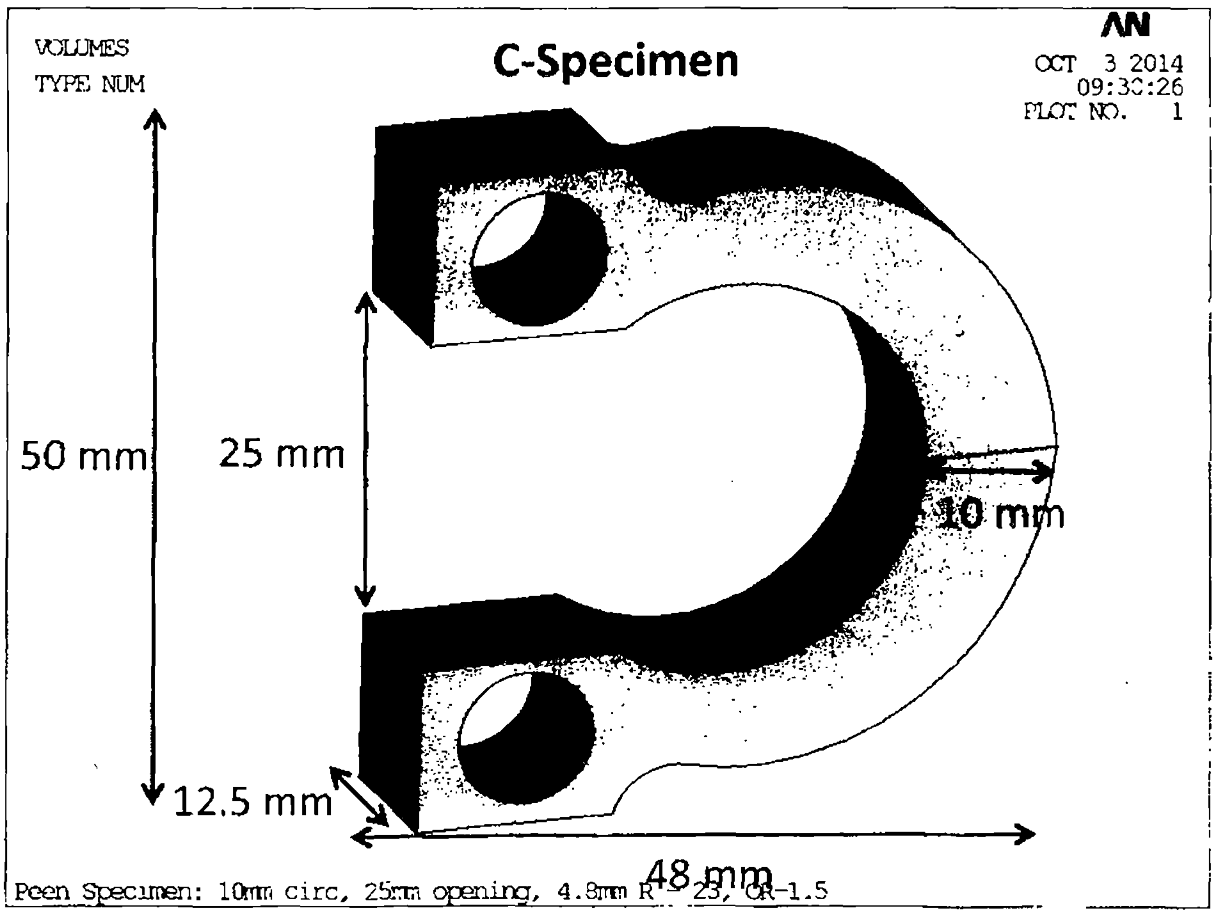


C-Specimen Summary and Discussion

- Easy to load multiple specimens in tension.
- Required loads are easily attained using existing load frame and servo system.
- Produces a very uniform surface stress distribution.
- Crack-tip stress and strain distributions closely match that of a 0.5T CT.
- Good DCPD sensitivity, approaching that of a CT specimen.

Questions/Discussion

- Can peening tools effectively access the interior surface?
- Is there a need to peen a preloaded specimen to simulate plant conditions were tensile stresses are assumed to exist prior to peening?



PREDECISIONAL

4-Pt Bend Peening Specimen Design Status

October 20, 2014

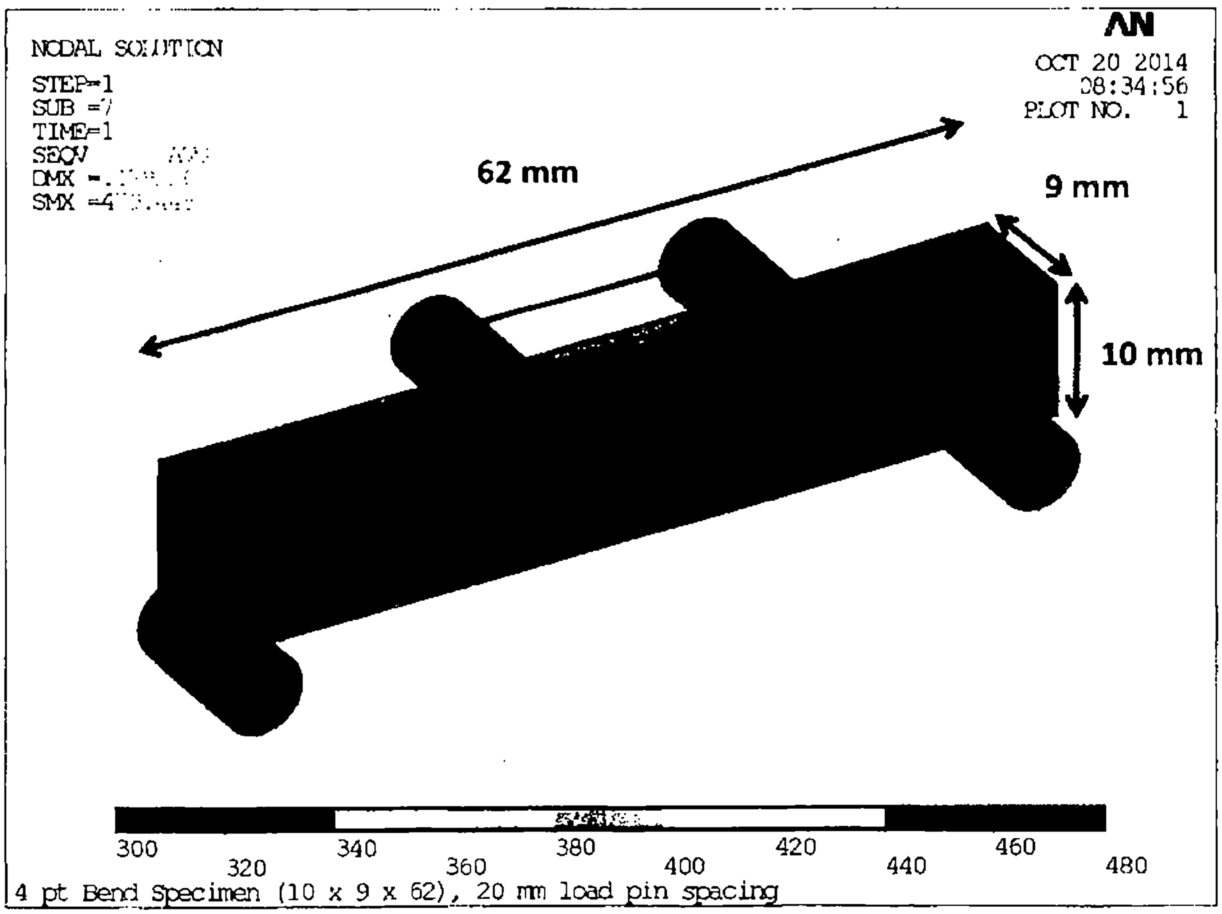
Mychailo Toloczko
John Deibler
Thak-Sang Byun

PNNL

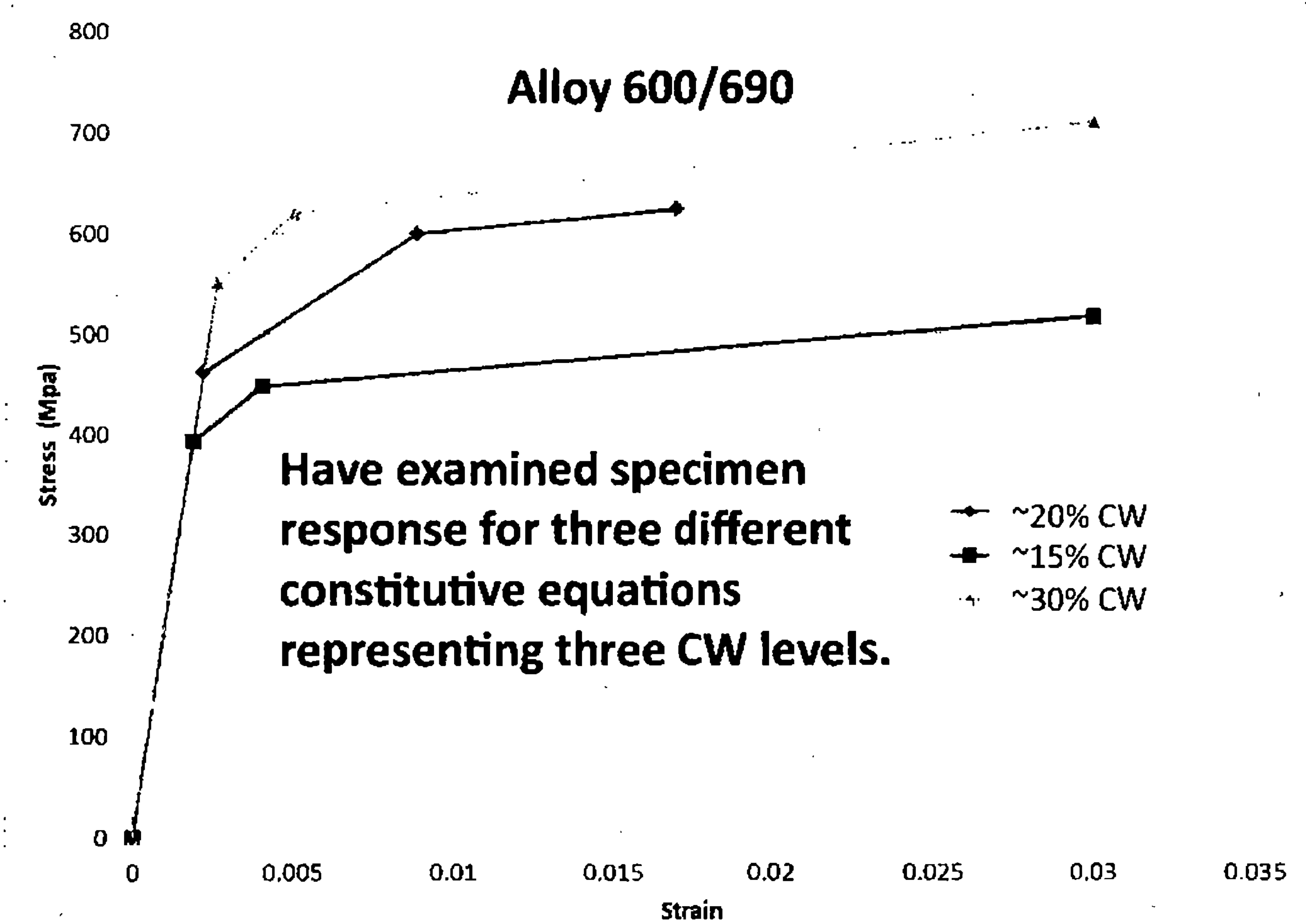
PREDECISIONAL

4-pt Bend Specimen

- Width of uniformly stressed/strained region follows space between upper load pins.
- Loading required to reach yield for a highly CW alloy 600 specimen (~550 MPa) for a 10 mm x 9 mm x 62 mm specimen with 20 mm upper pin spacing is ~2000 lbs. This is a little higher than desired for the servo loading system.
- An acceptable maximum load of ~1500 lbs can be achieved for a 13 mm upper pin spacing. Uniform stress region will be ~13 mm long.

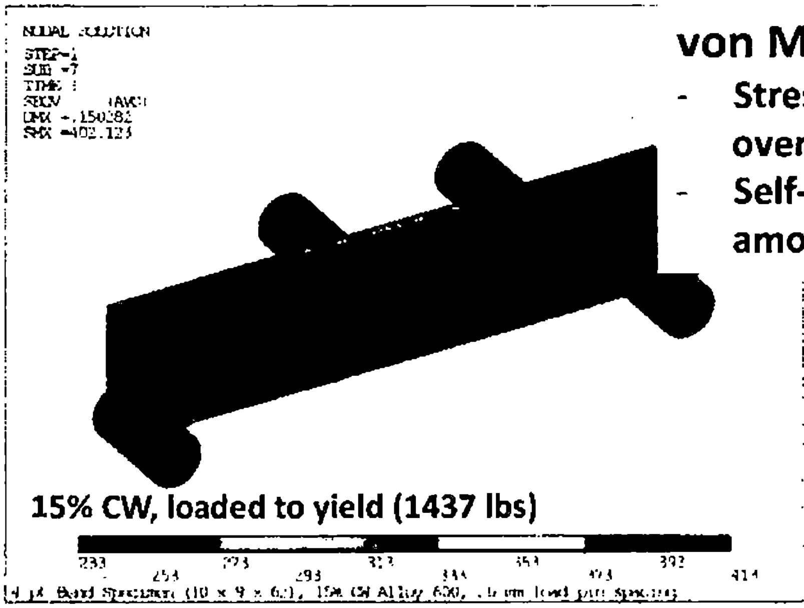


Constitutive equations used for finite element modeling

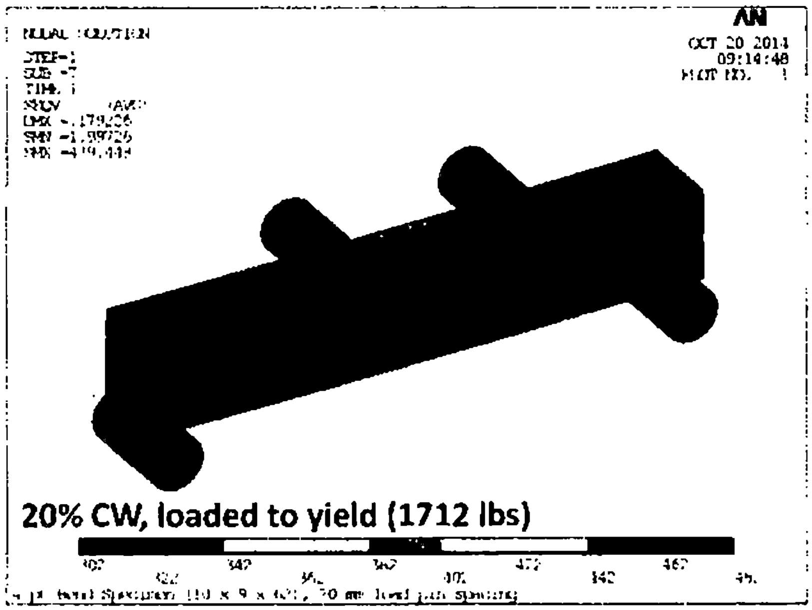


von Mises stress

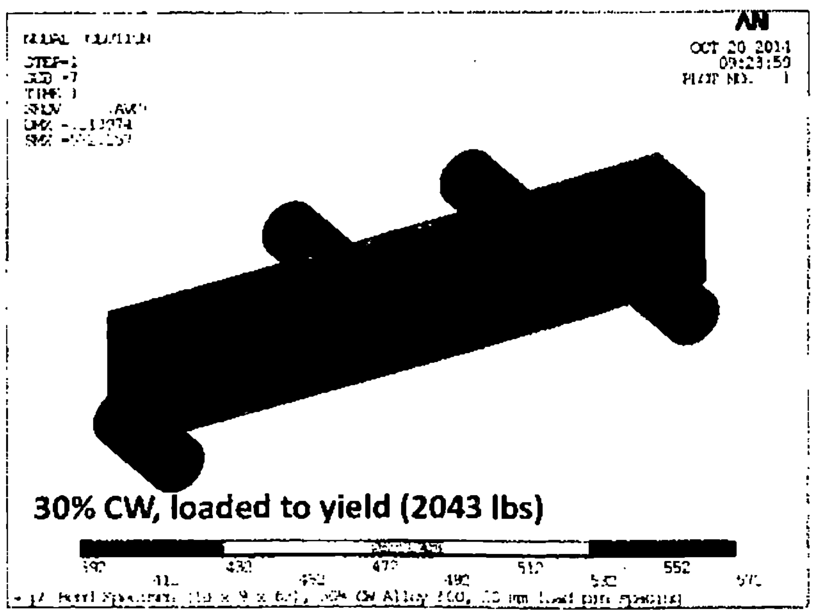
- Stress almost uniformly distributed over width between the upper pins.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (1437 lbs)



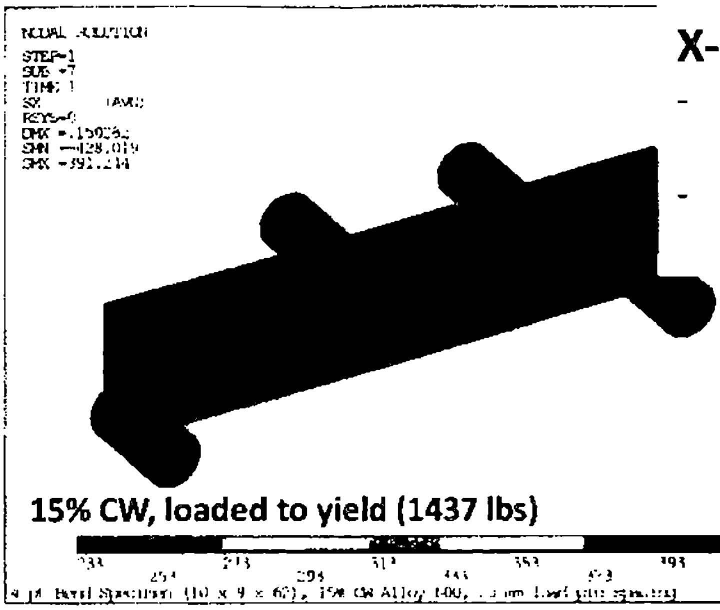
20% CW, loaded to yield (1712 lbs)



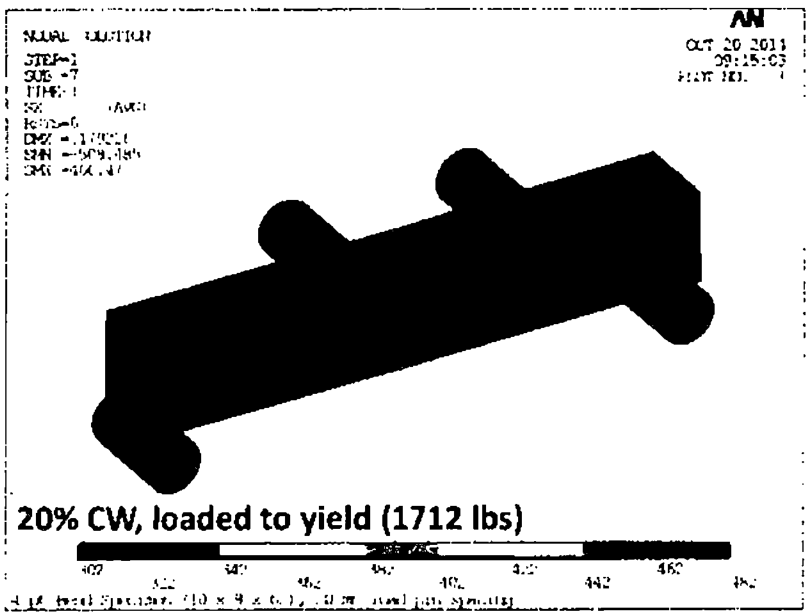
30% CW, loaded to yield (2043 lbs)

X-stress

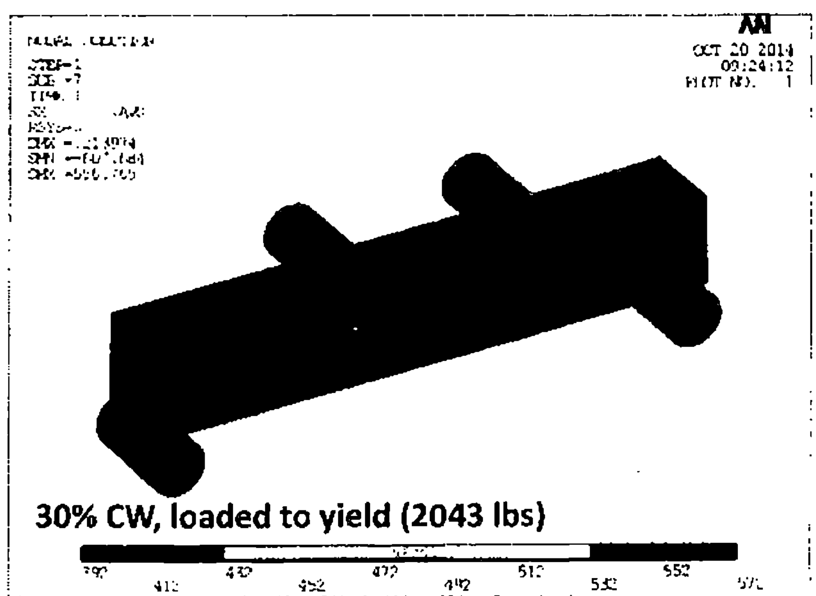
- Stress almost uniformly distributed over width between the upper pins.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (1437 lbs)



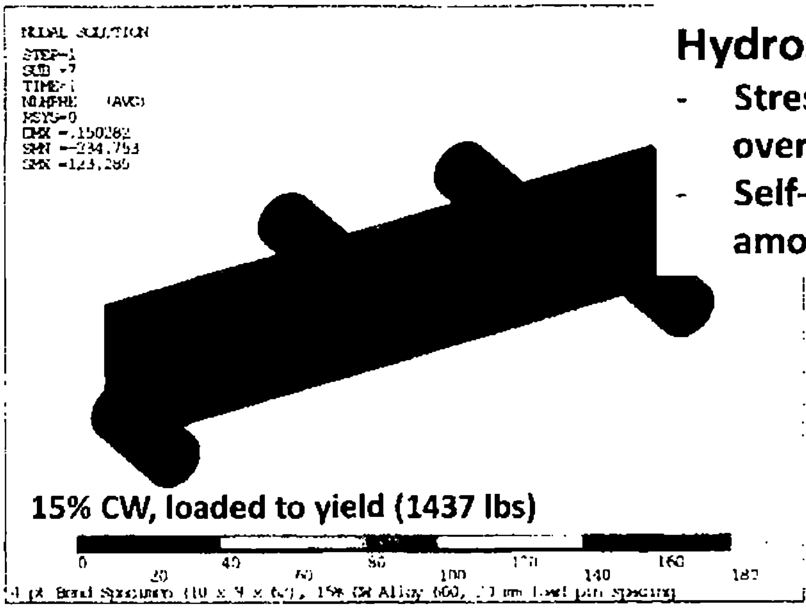
20% CW, loaded to yield (1712 lbs)



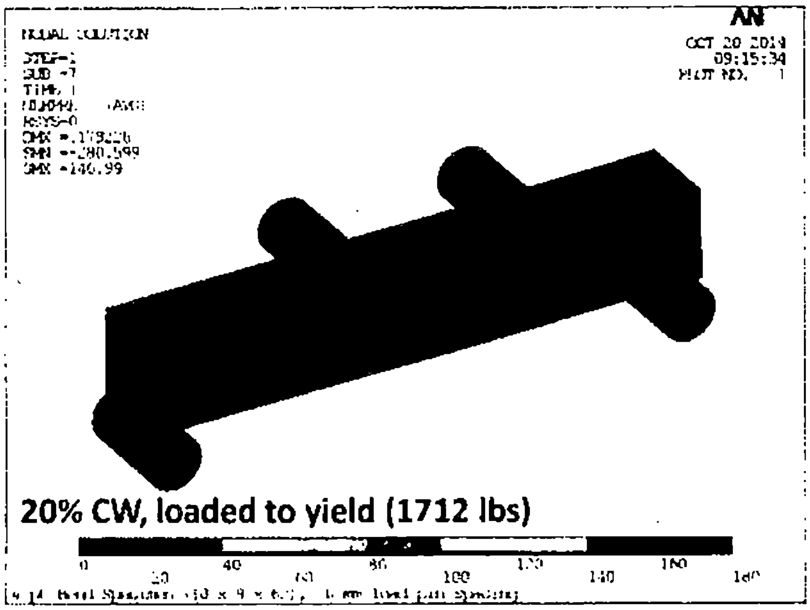
30% CW, loaded to yield (2043 lbs)

Hydrostatic stress

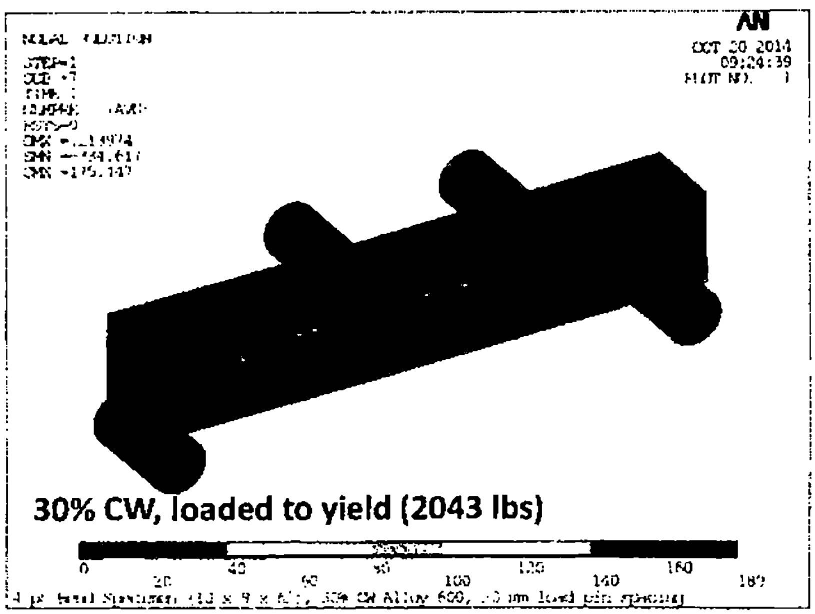
- Stress almost uniformly distributed over width between the upper pins.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (1437 lbs)



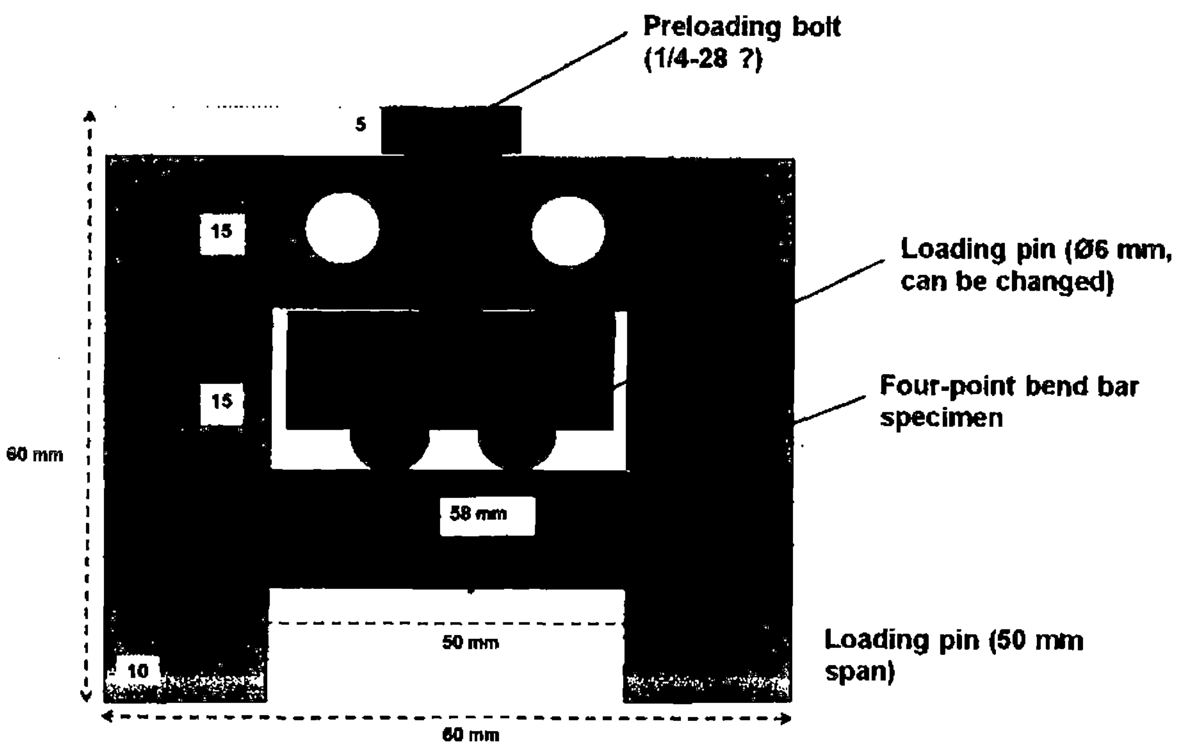
20% CW, loaded to yield (1712 lbs)



30% CW, loaded to yield (2043 lbs)

4-pt Bend Load Train Unit

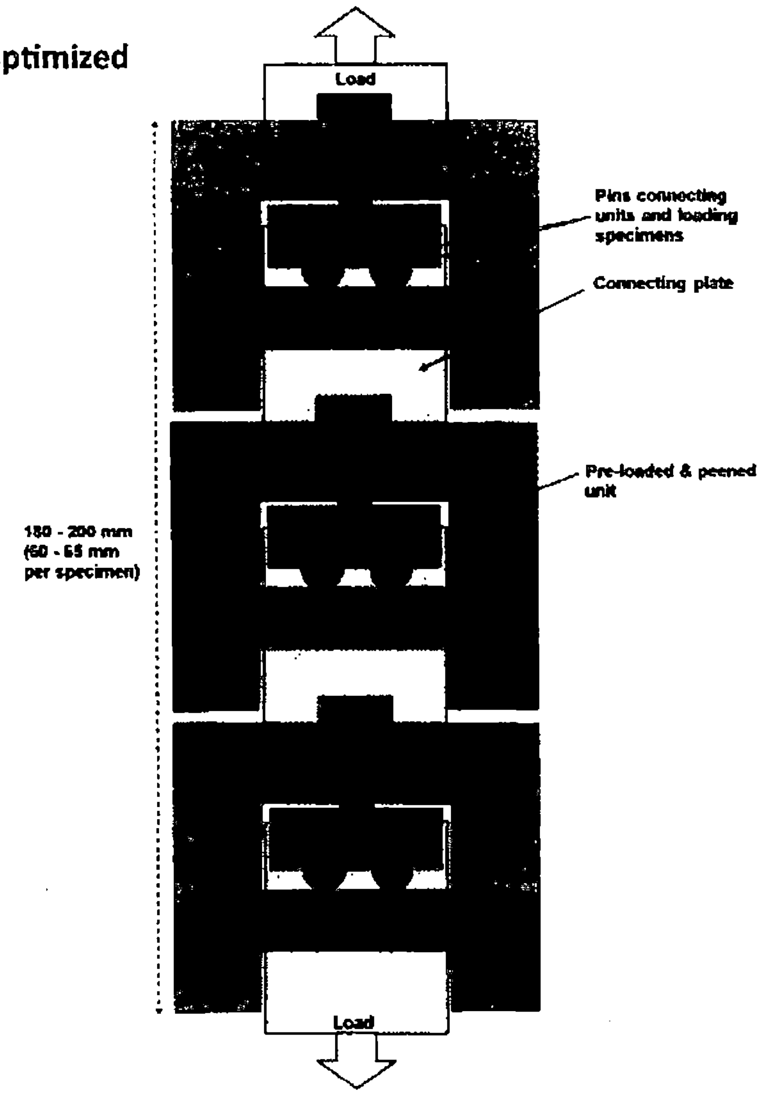
- Can preload the specimen with a bolt.
- Stressed/strained surface is accessible for peening.
- Unit height of load train unit is ~2.5". Can load 9-10 specimens per string, or 27-30 specimens per autoclave.
- As with the tensile initiation specimen system, all specimens carry same load, so different strength specimens are simultaneously all loaded to their yield (or beyond) by tailoring the specimen thickness (B value).



4-pt Bend Load Train Unit

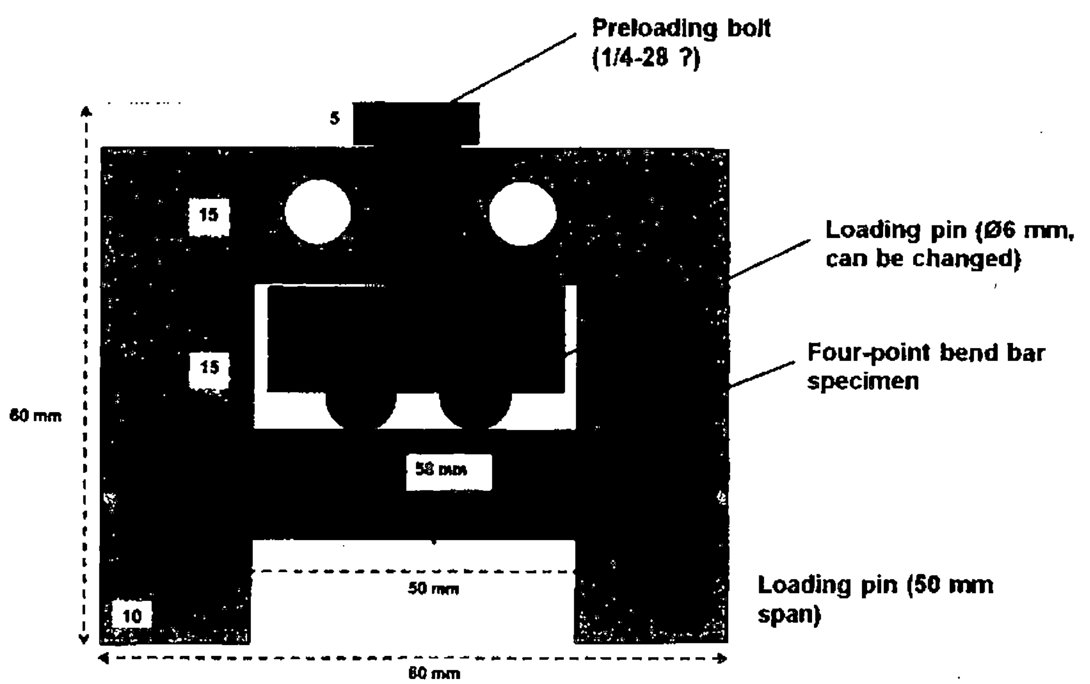
- Preload can be maintained all the way up to the point where load is applied using the test frame loading system.
- Servo loading system would apply ≥105% of preload thus taking the load off the preload bolt.
- During power failure, bolt would act as a position-stop to maintain a baseline load.
- Additional straps would be needed to prevent load train collapse if a specimen fails.

Early concept, not optimized



4-pt Bend Summary/Discussion

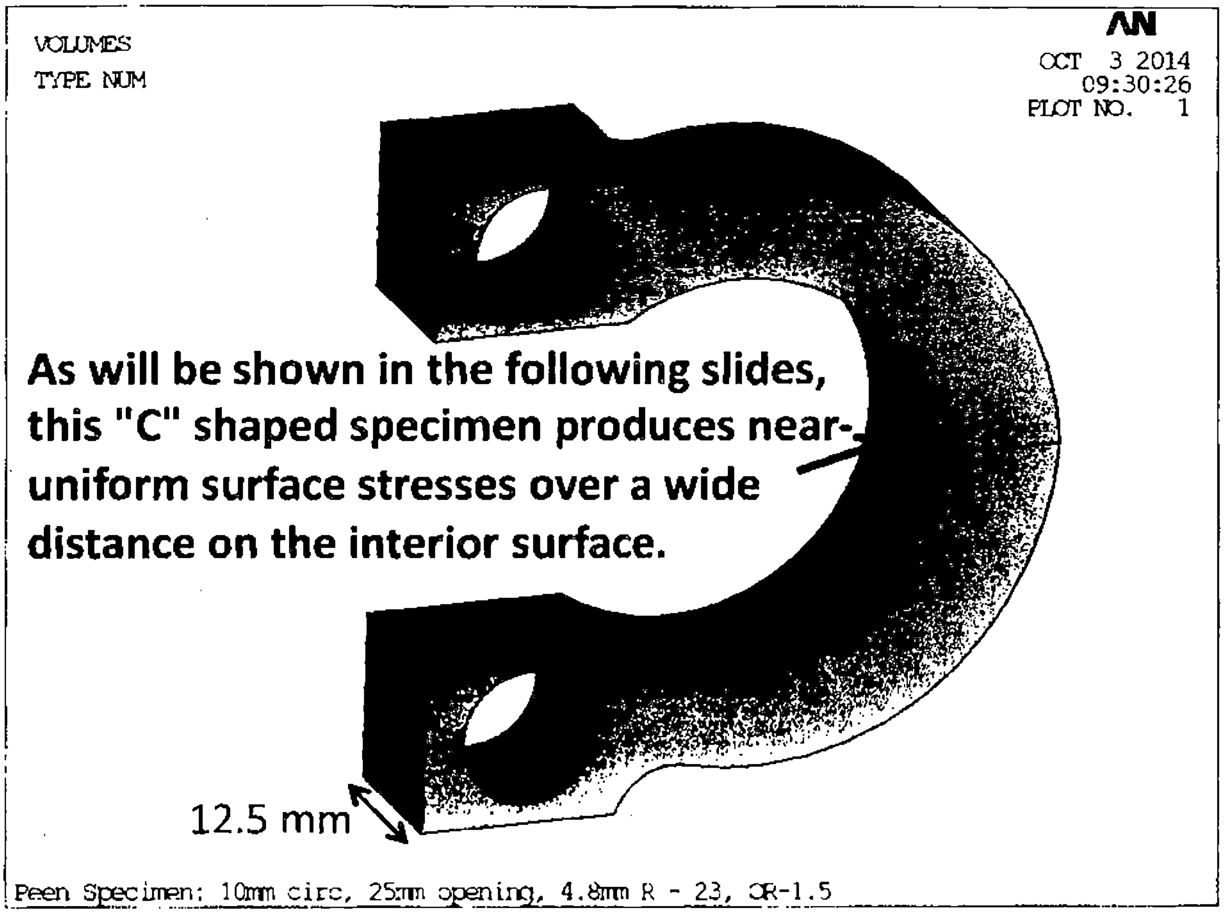
- 4-pt bend produces a uniform stress state having a length that matches the spacing between the two upper pins.
- Maximum reasonable load is achieved with ~13 mm spacing, thus uniform stress width would be ~13 mm.
- Have determined a way to series-load 4-pt bend specimens in a tension load train.
- 4-pt bend fixture appears to allow good access for peening.
- Preloading can be accomplished and will maintain baseline load in the event of a power outage that requires unloading the servo system.
- Most obvious disadvantage at this point is the relatively small uniform stress region, however other issues may arise when trying to create and use an actual fixture.

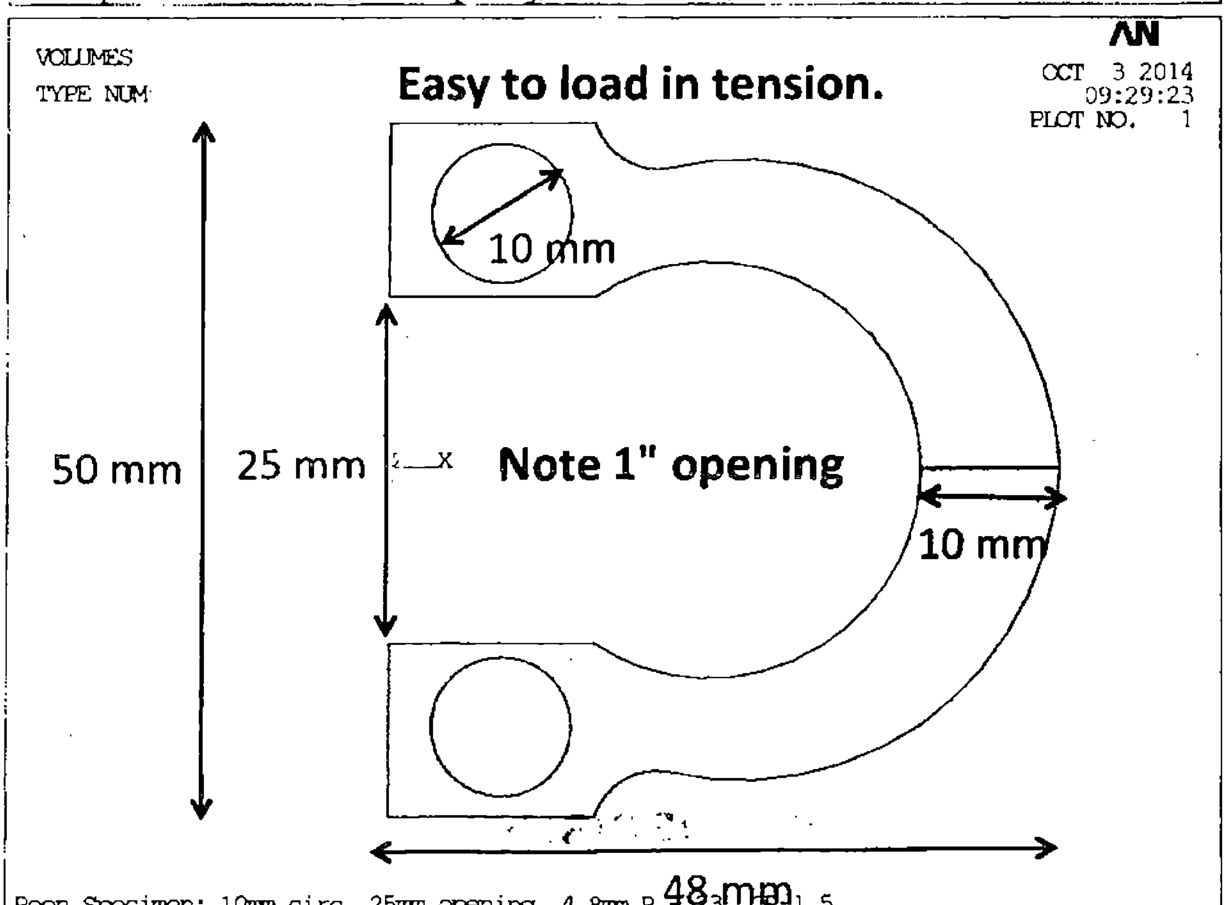


Peening Specimen Design Status
October 15, 2014

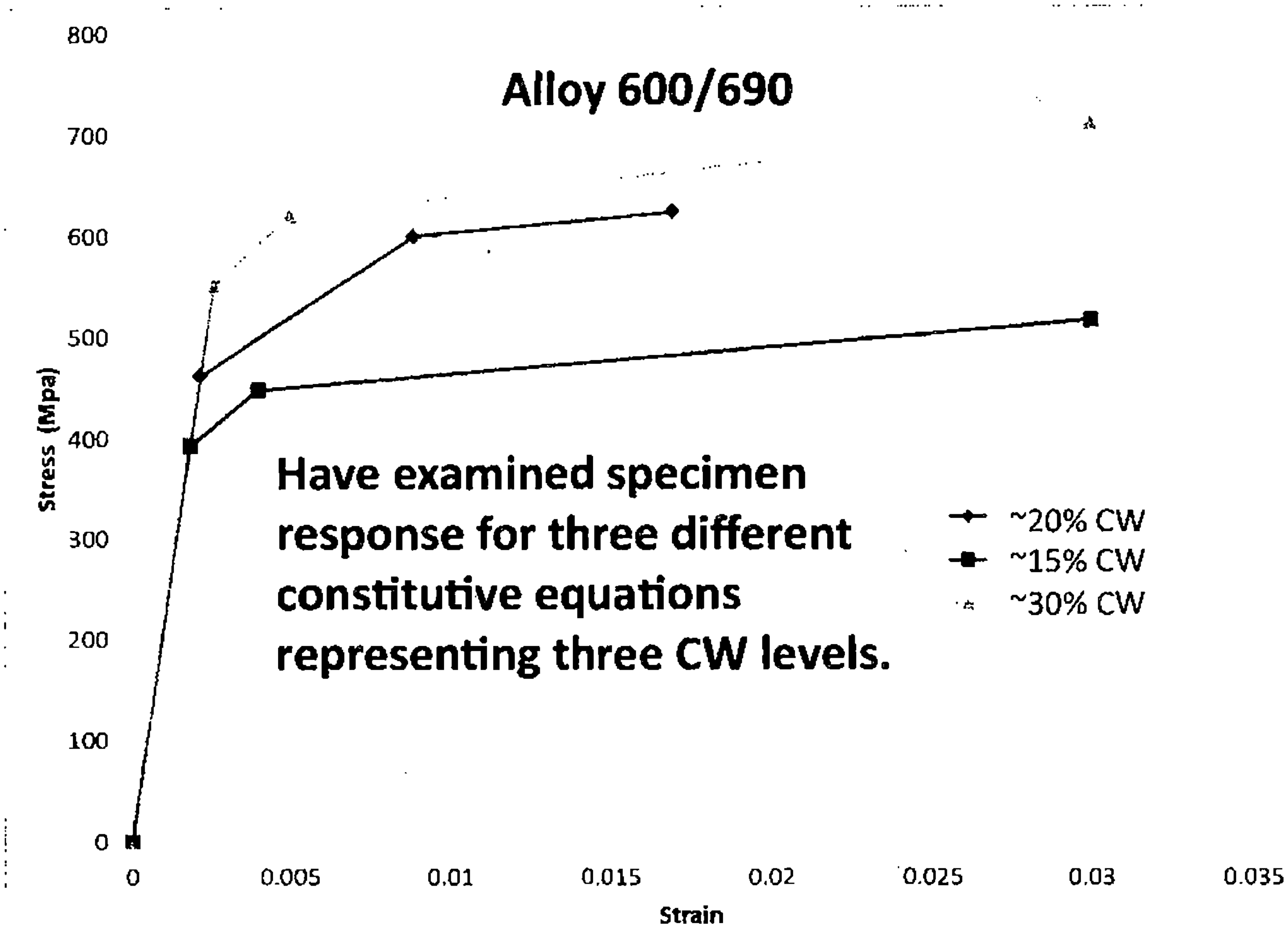
Mychailo Toloczko
John Deibler

PNNL


VOLUMES
TYPE NUM
AN
OCT 3 2014
09:30:26
PLOT NO. 1
As will be shown in the following slides, this "C" shaped specimen produces near-uniform surface stresses over a wide distance on the interior surface.
12.5 mm
Peen Specimen: 10mm circ, 25mm opening, 4.8mm R - 23, CR-1.5

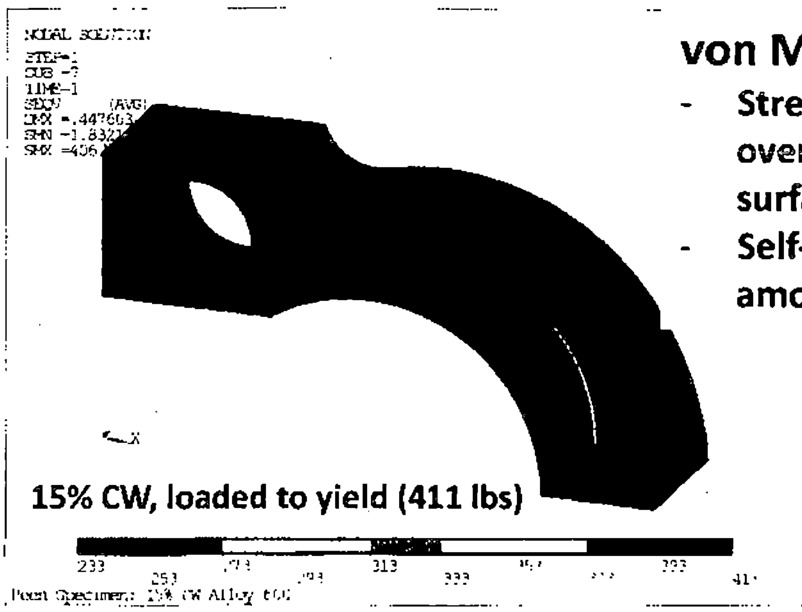

VOLUMES
TYPE NUM
Easy to load in tension.
AN
OCT 3 2014
09:29:23
PLOT NO. 1
10 mm
50 mm
25 mm
Note 1" opening
10 mm
48 mm
Peen Specimen: 10mm circ, 25mm opening, 4.8mm R

Constitutive equations used for finite element modelling

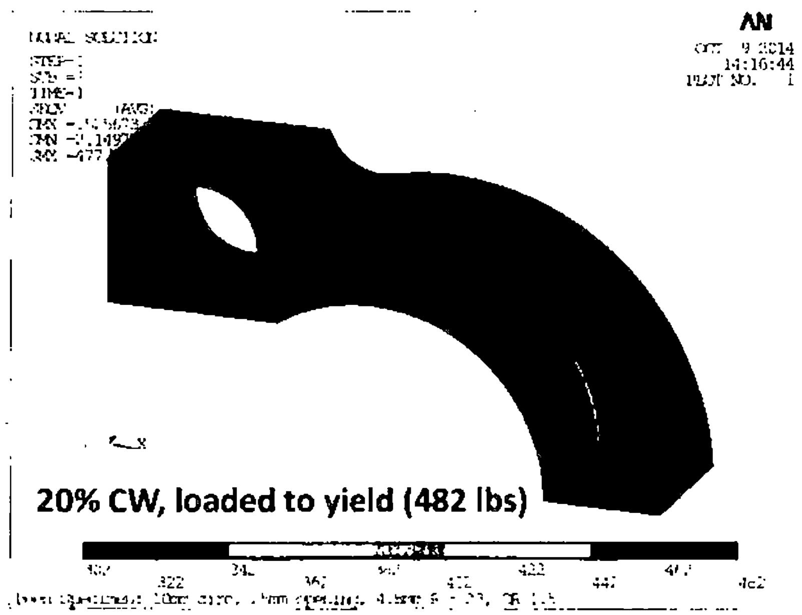


von Mises stress

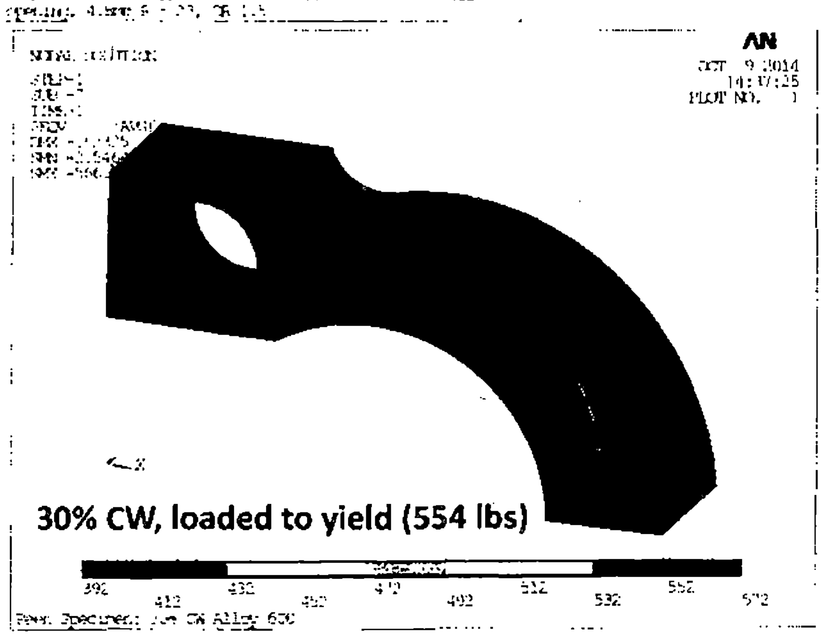
- Stress almost uniformly distributed over ~1" of height on interior surface.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



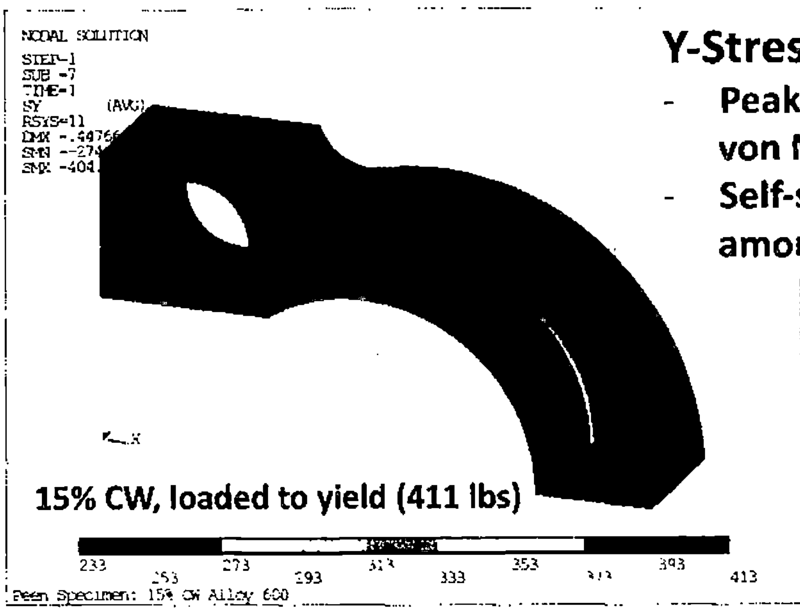
20% CW, loaded to yield (482 lbs)

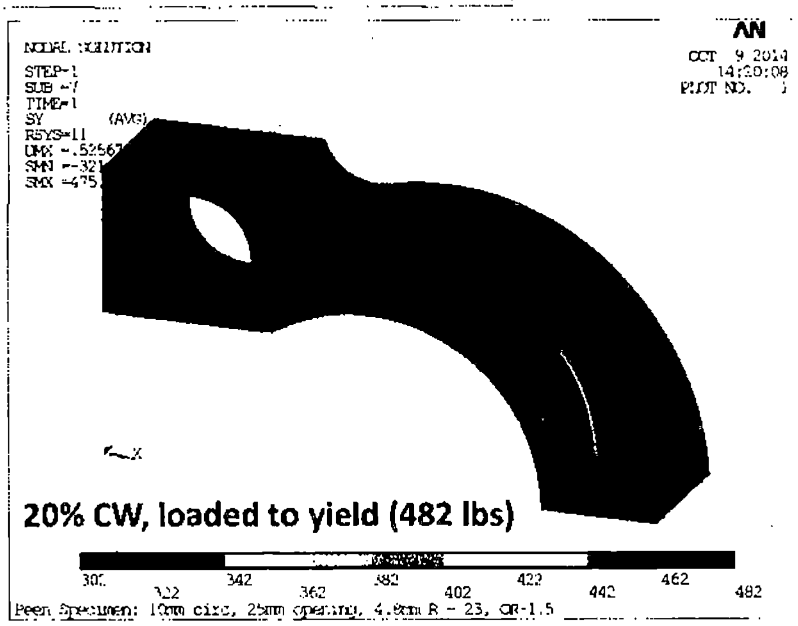


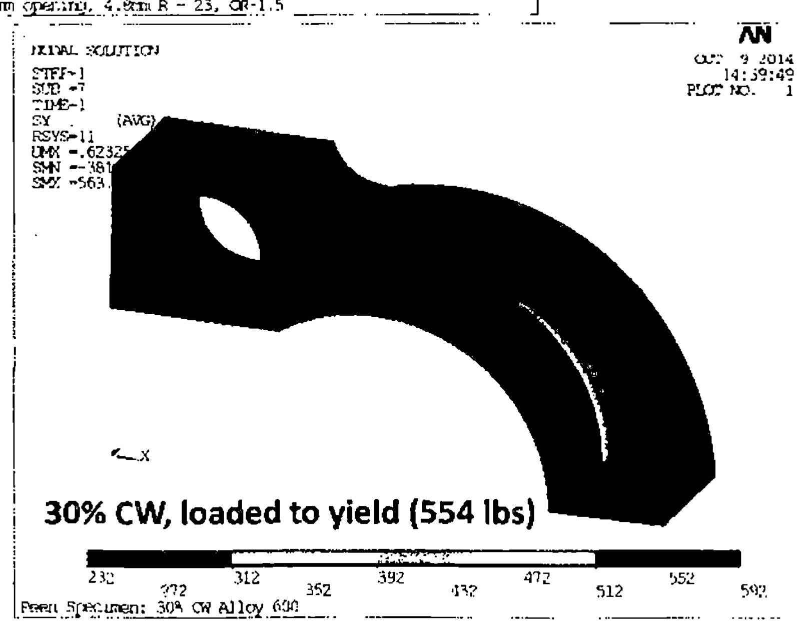
30% CW, loaded to yield (554 lbs)

Y-Stress

- Peak stress in same location as peak von Mises stress.
- Self-similar stress distributions among the three different CW levels.

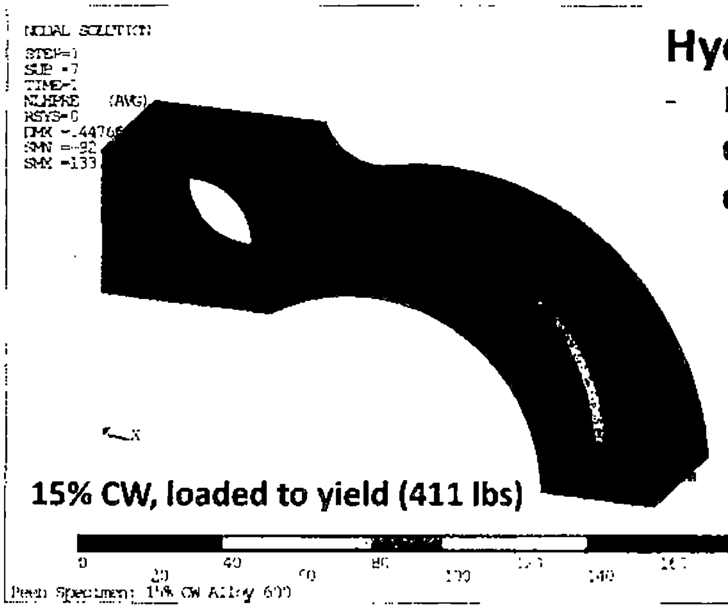




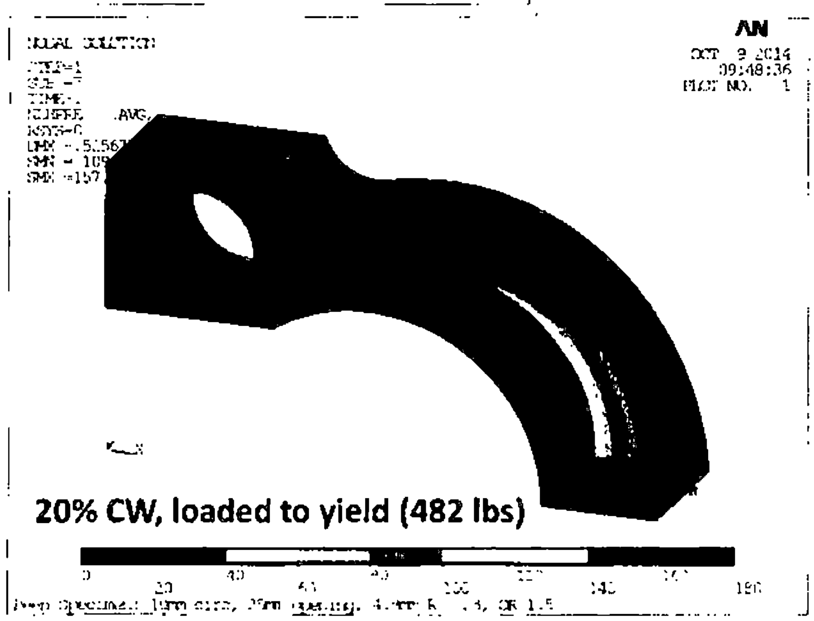


Hydrostatic Stress

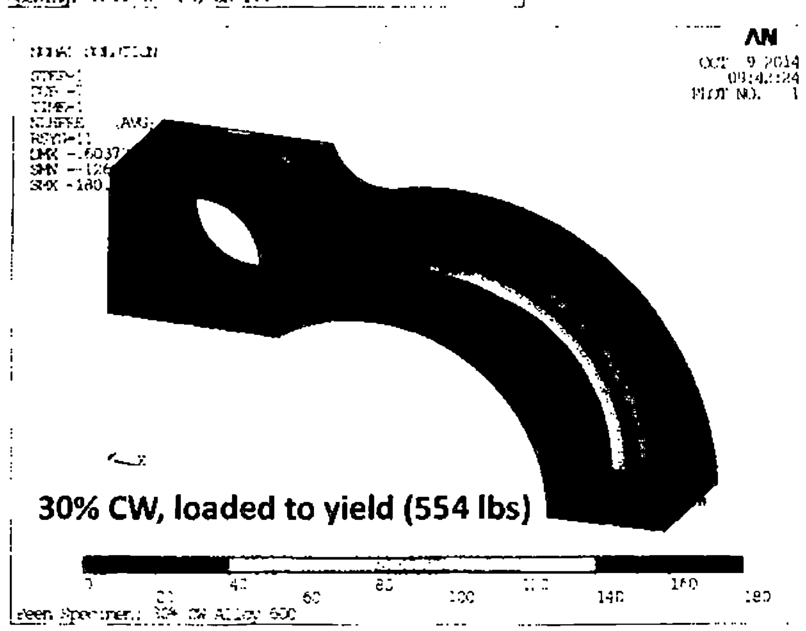
- **Fixed scale, but self-similar stress distributions among the three different CW levels.**



15% CW, loaded to yield (411 lbs)



20% CW, loaded to yield (482 lbs)

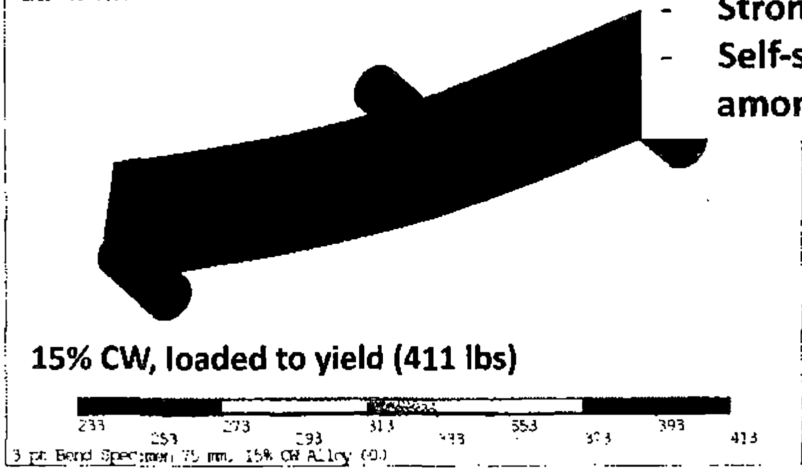


30% CW, loaded to yield (554 lbs)

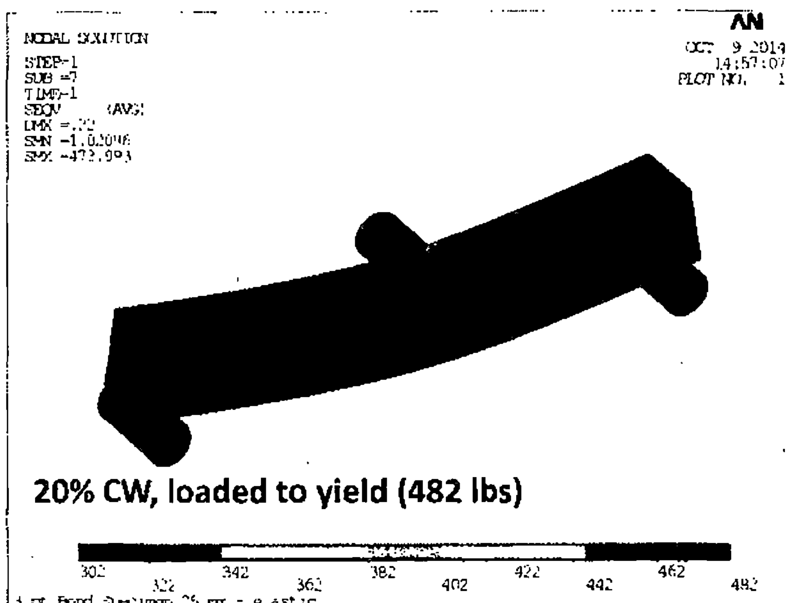
3-pt Bend for comparison

von Mises Stress

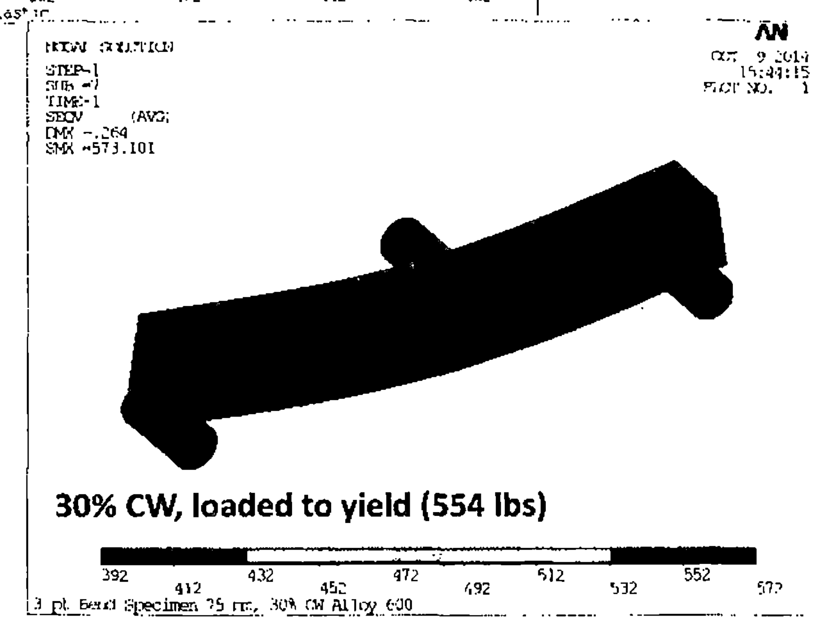
- **Narrow spatial distribution of stress.**
- **Strong stress gradient.**
- **Self-similar stress distributions among the three different CW levels.**



15% CW, loaded to yield (411 lbs)



20% CW, loaded to yield (482 lbs)

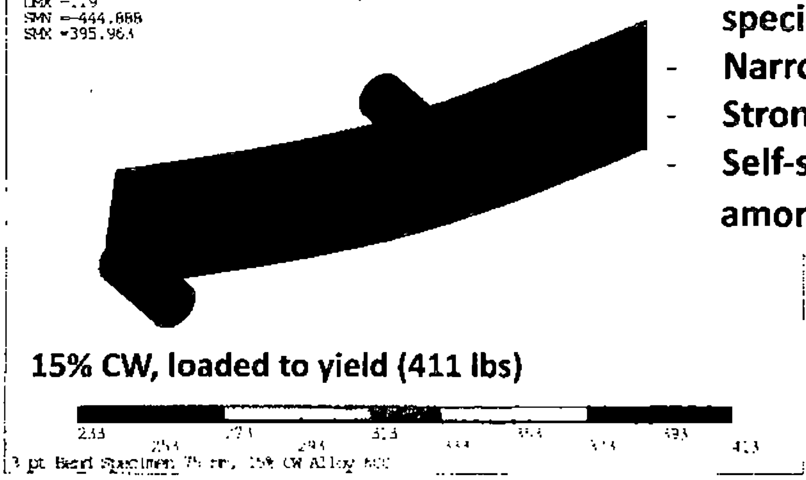


30% CW, loaded to yield (554 lbs)

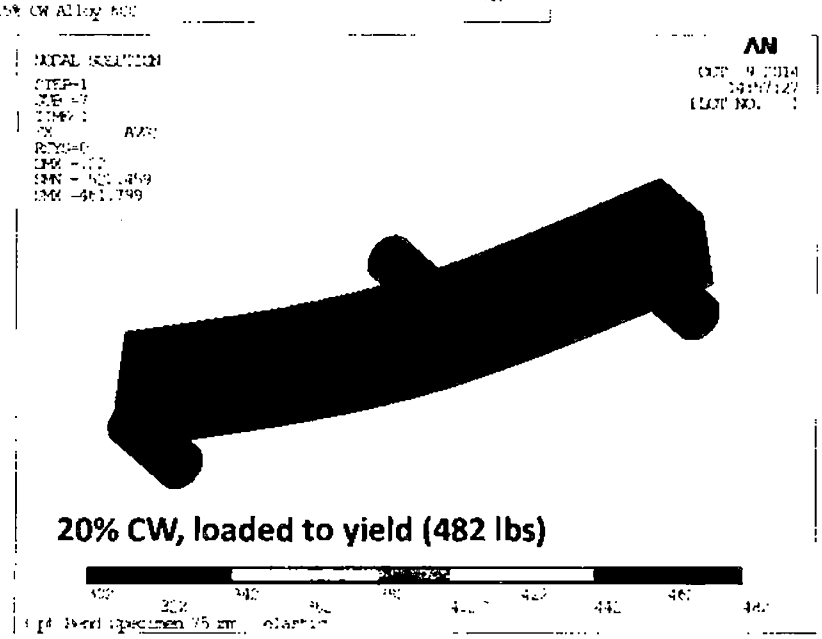
3-pt Bend for comparison

X-Stress

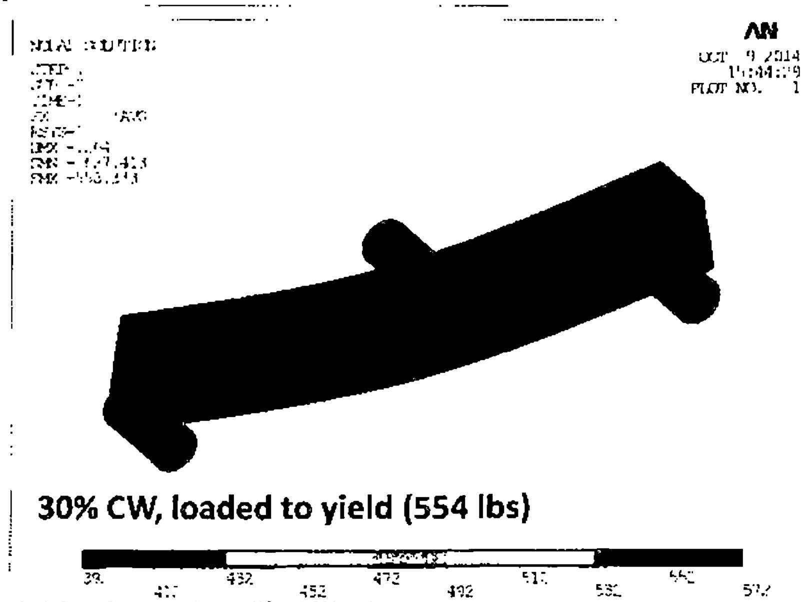
- Equivalent to Y-stress direction on "C" specimen.
- Narrow spatial distribution of stress.
- Strong stress gradient.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (411 lbs)



20% CW, loaded to yield (482 lbs)

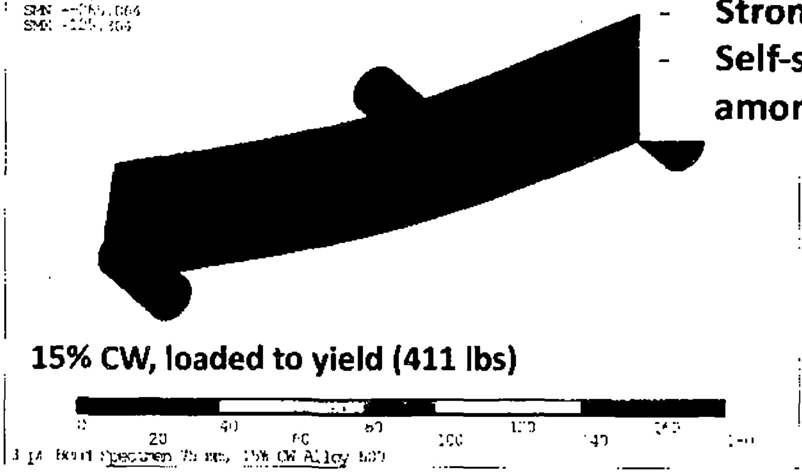


30% CW, loaded to yield (554 lbs)

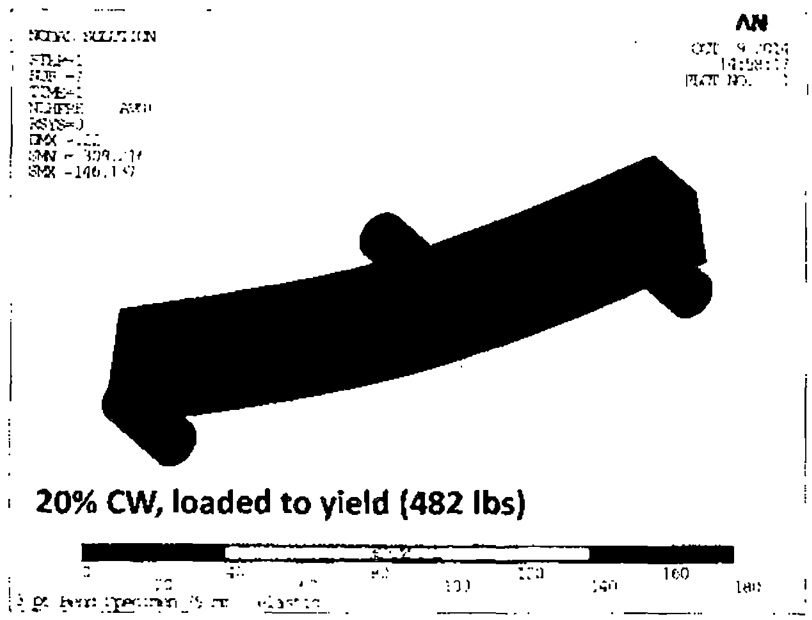
3-pt Bend
for comparison

Hydrostatic Stress

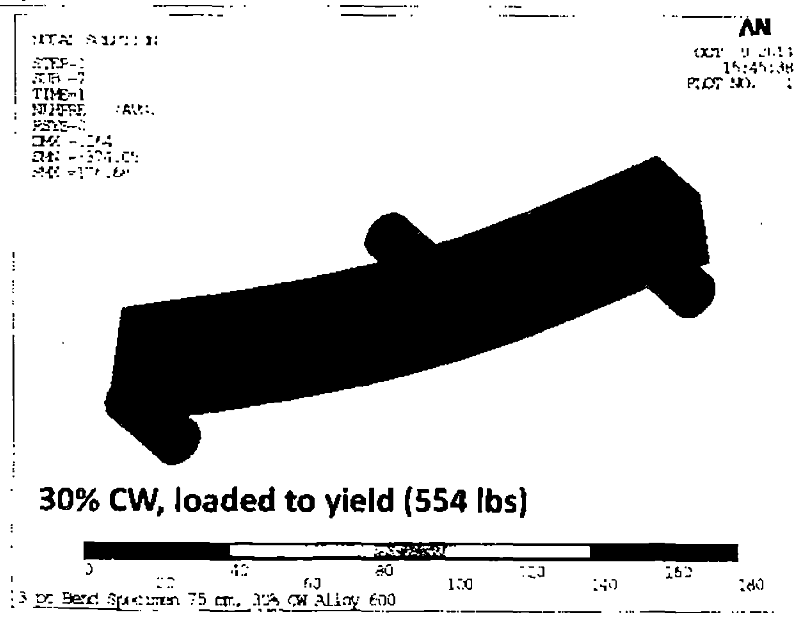
- Narrow spatial distribution of stress.
- Strong stress gradient.
- Self-similar stress distributions among the three different CW levels.



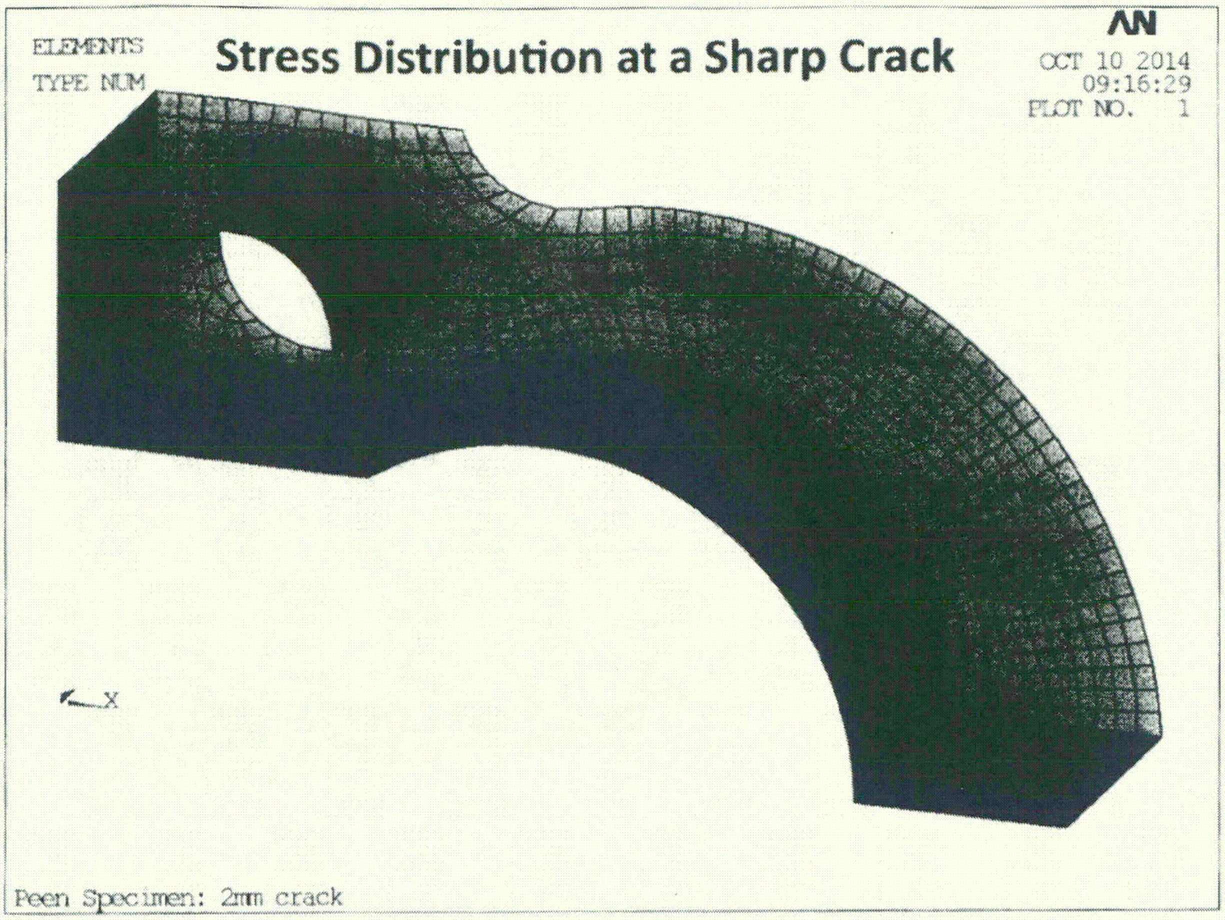
15% CW, loaded to yield (411 lbs)

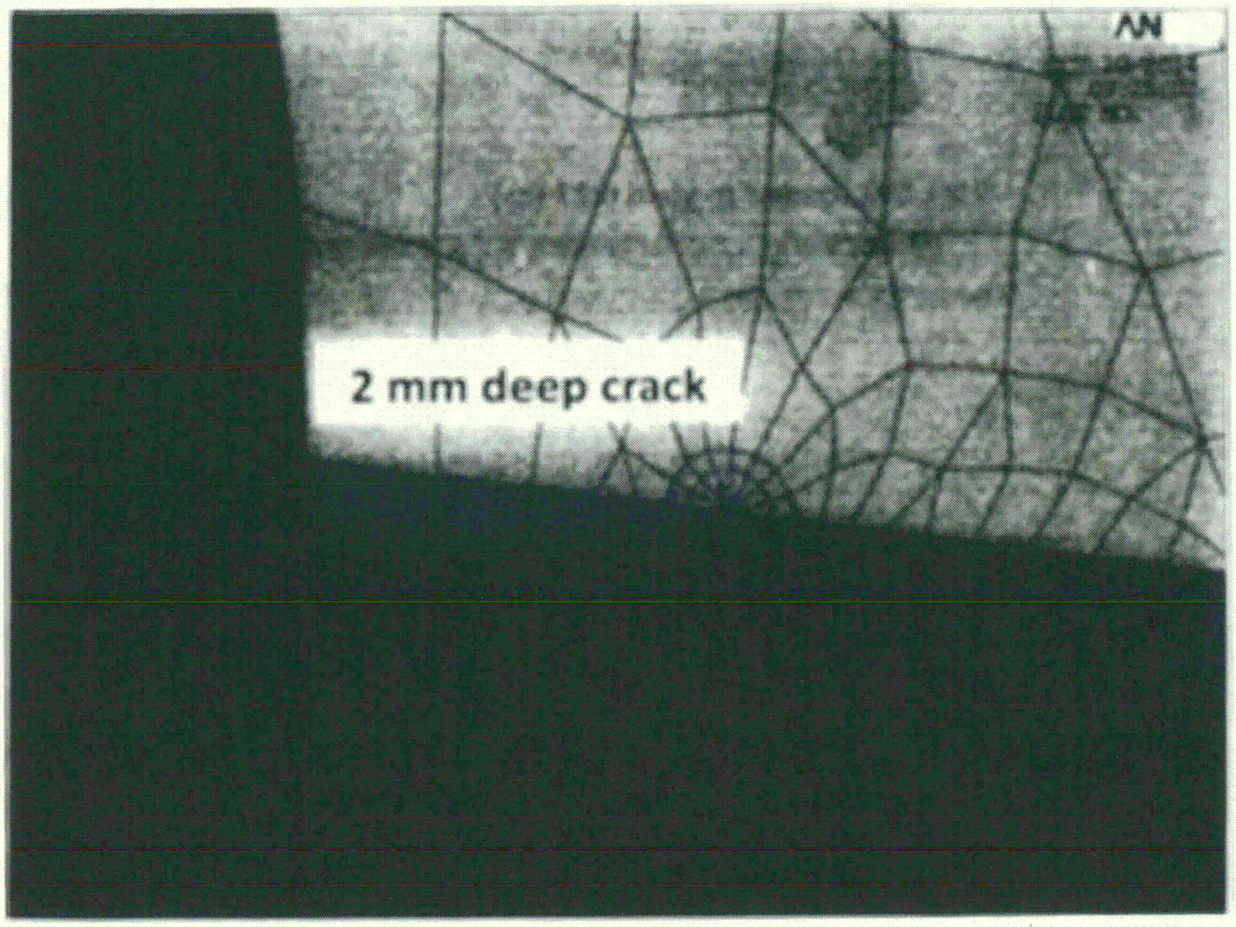


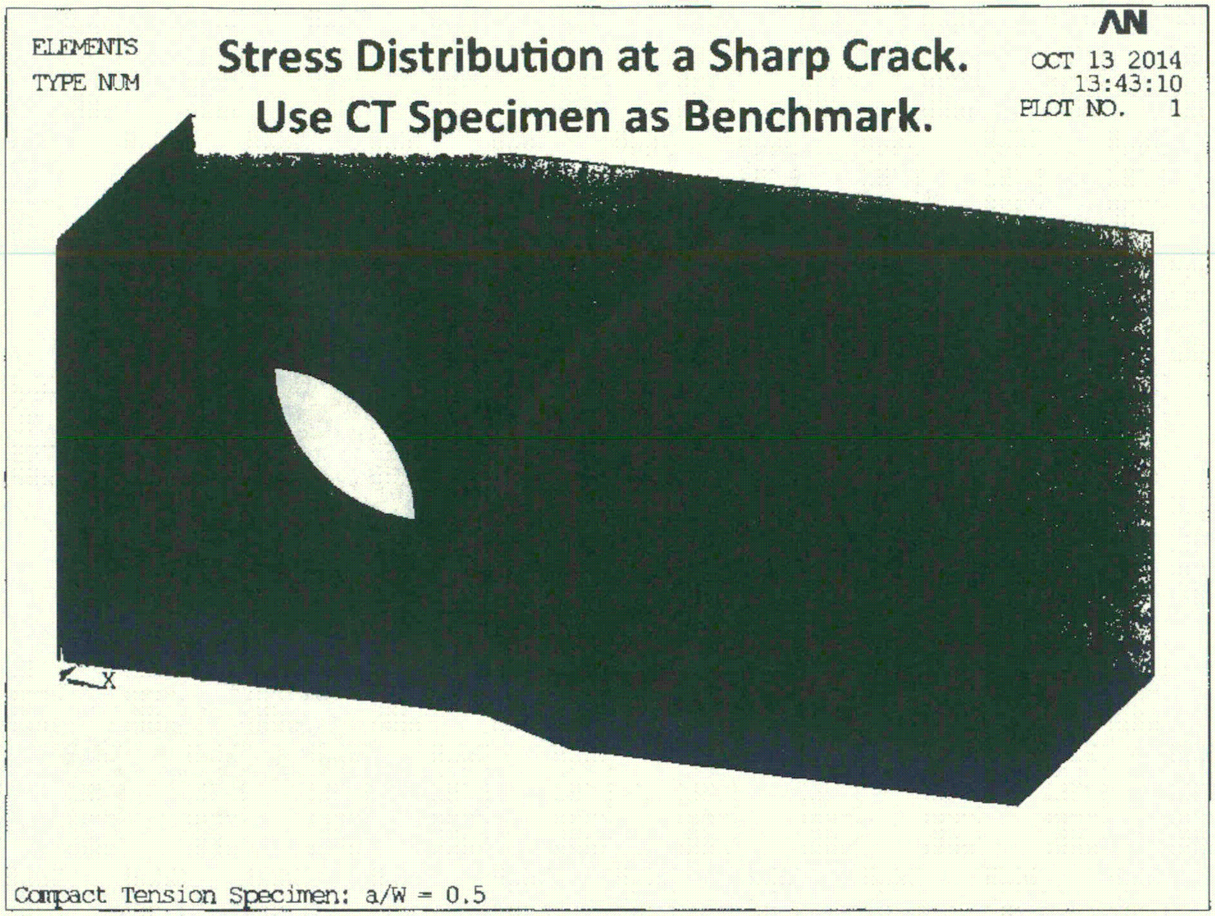
20% CW, loaded to yield (482 lbs)

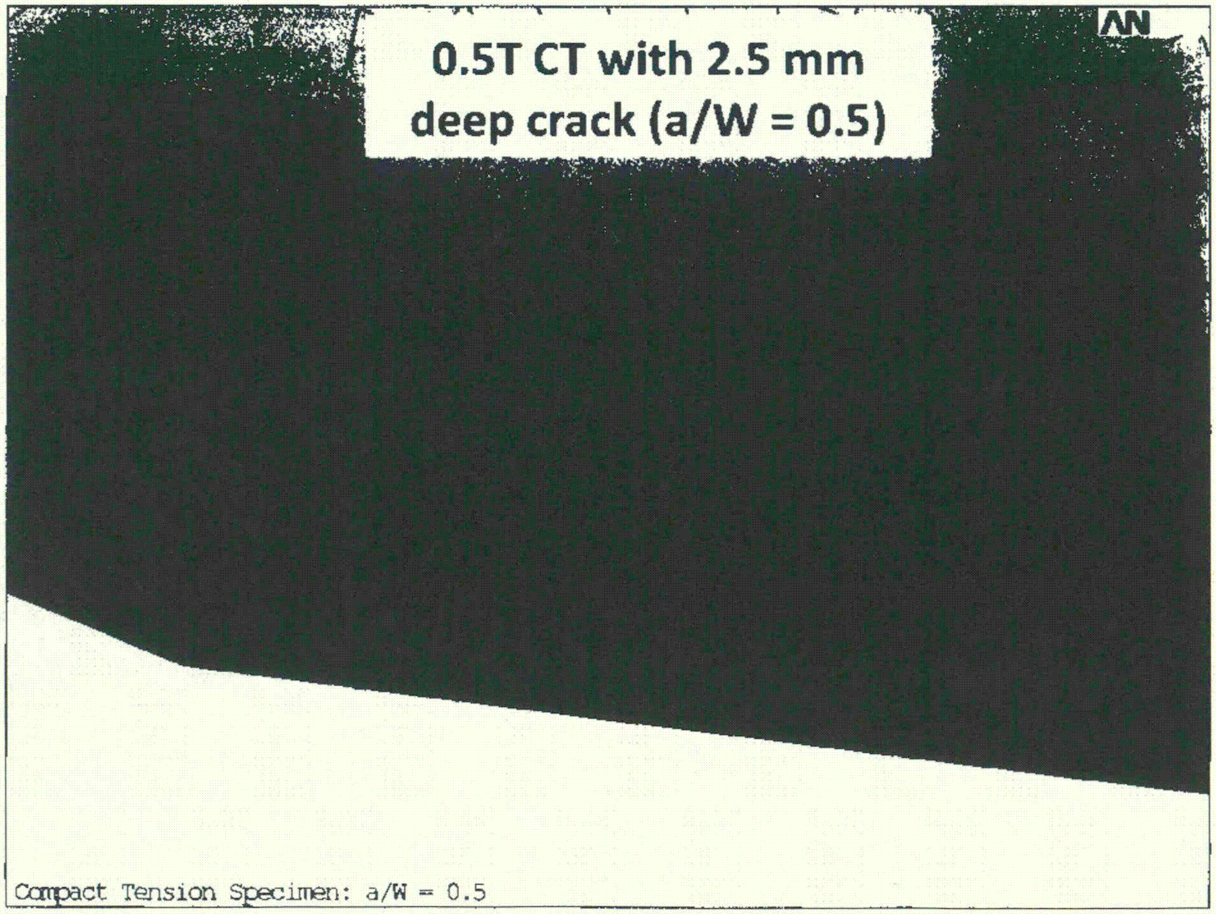


30% CW, loaded to yield (554 lbs)


ELEMENTS
TYPE NUM
Stress Distribution at a Sharp Crack
AN
OCT 10 2014
09:16:29
PLOT NO. 1
X
Peen Specimen: 2mm crack


AN
2 mm deep crack

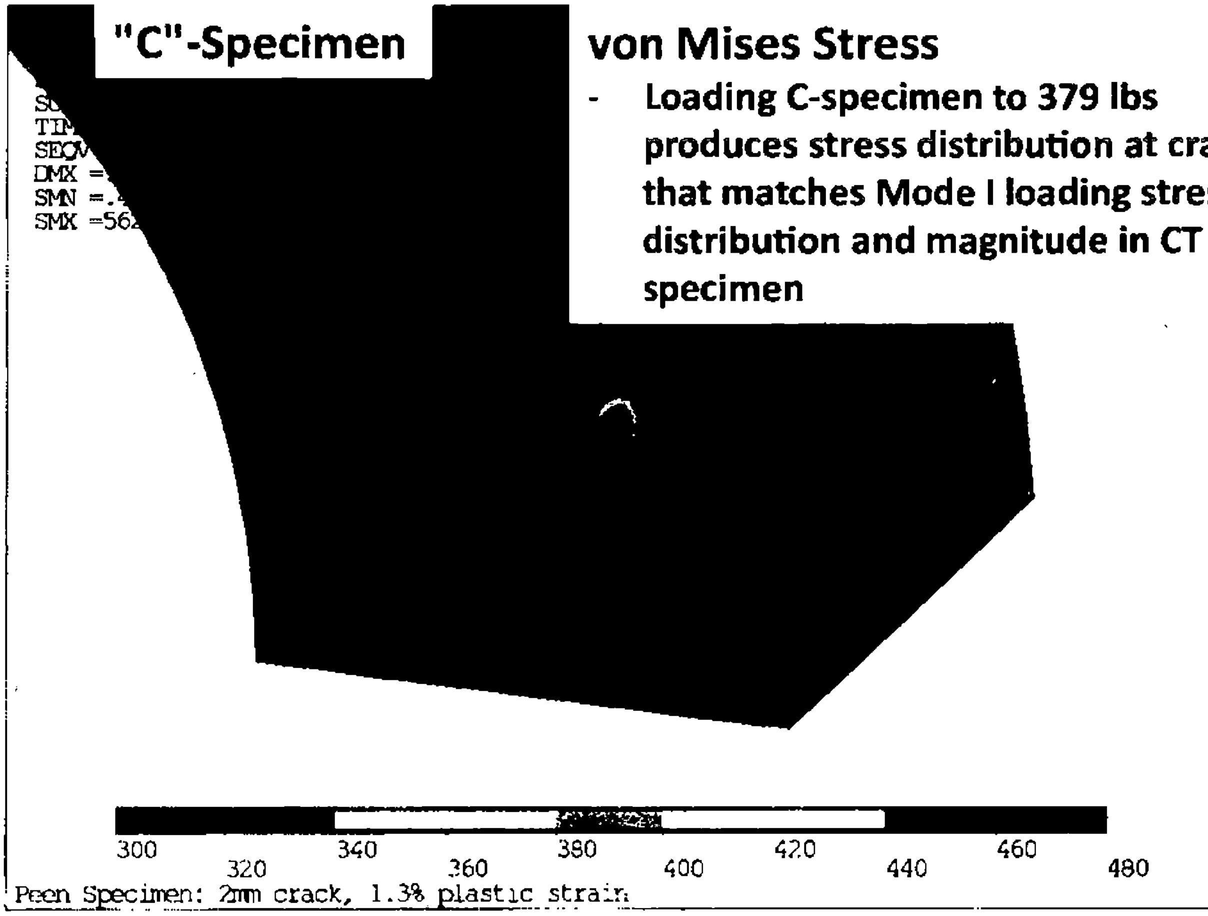

ELEMENTS
TYPE NUM
Stress Distribution at a Sharp Crack.
Use CT Specimen as Benchmark.
AN
OCT 13 2014
13:43:10
PLOT NO. 1
X
Compact Tension Specimen: a/W = 0.5


0.5T CT with 2.5 mm
deep crack (a/W = 0.5)
AN
Compact Tension Specimen: a/W = 0.5

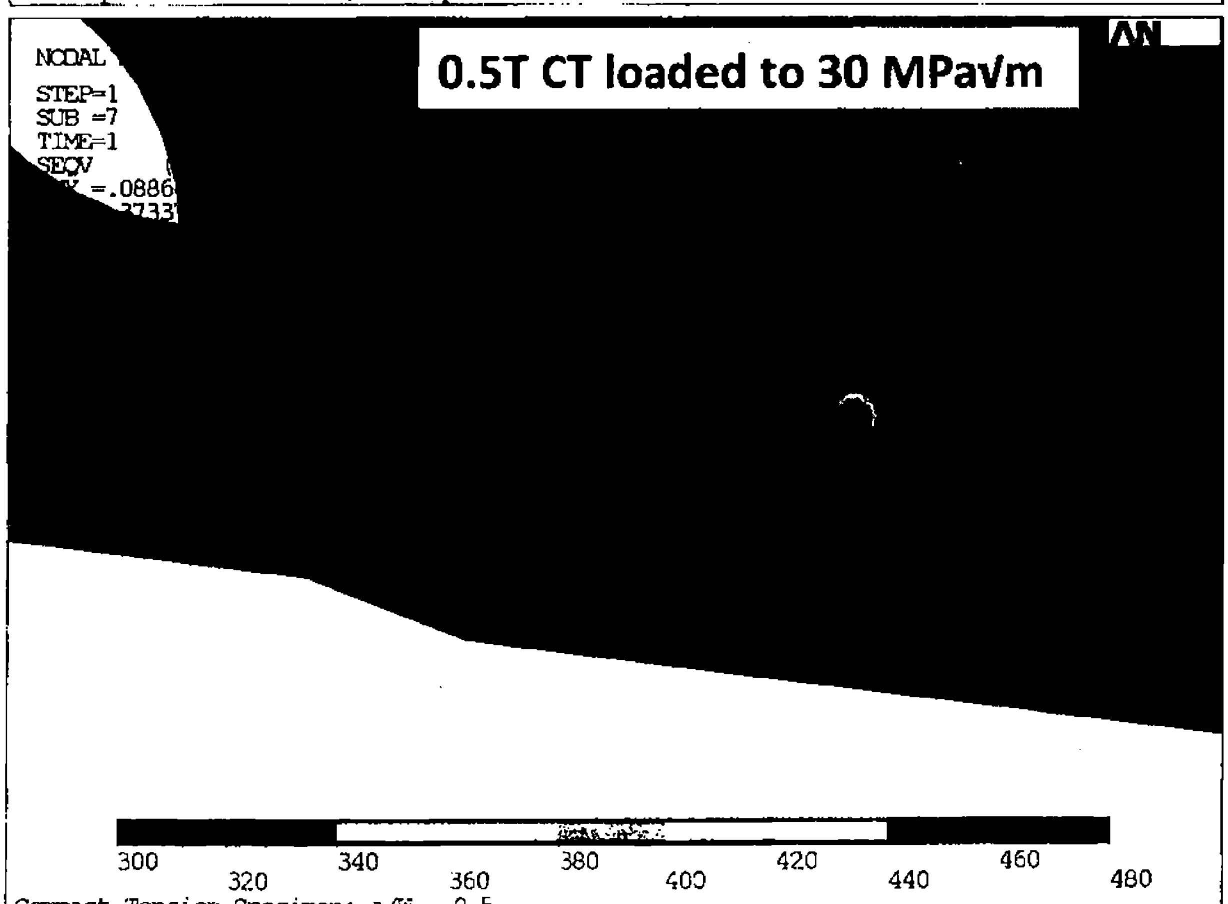
"C"-Specimen

von Mises Stress

- Loading C-specimen to 379 lbs produces stress distribution at crack that matches Mode I loading stress distribution and magnitude in CT specimen

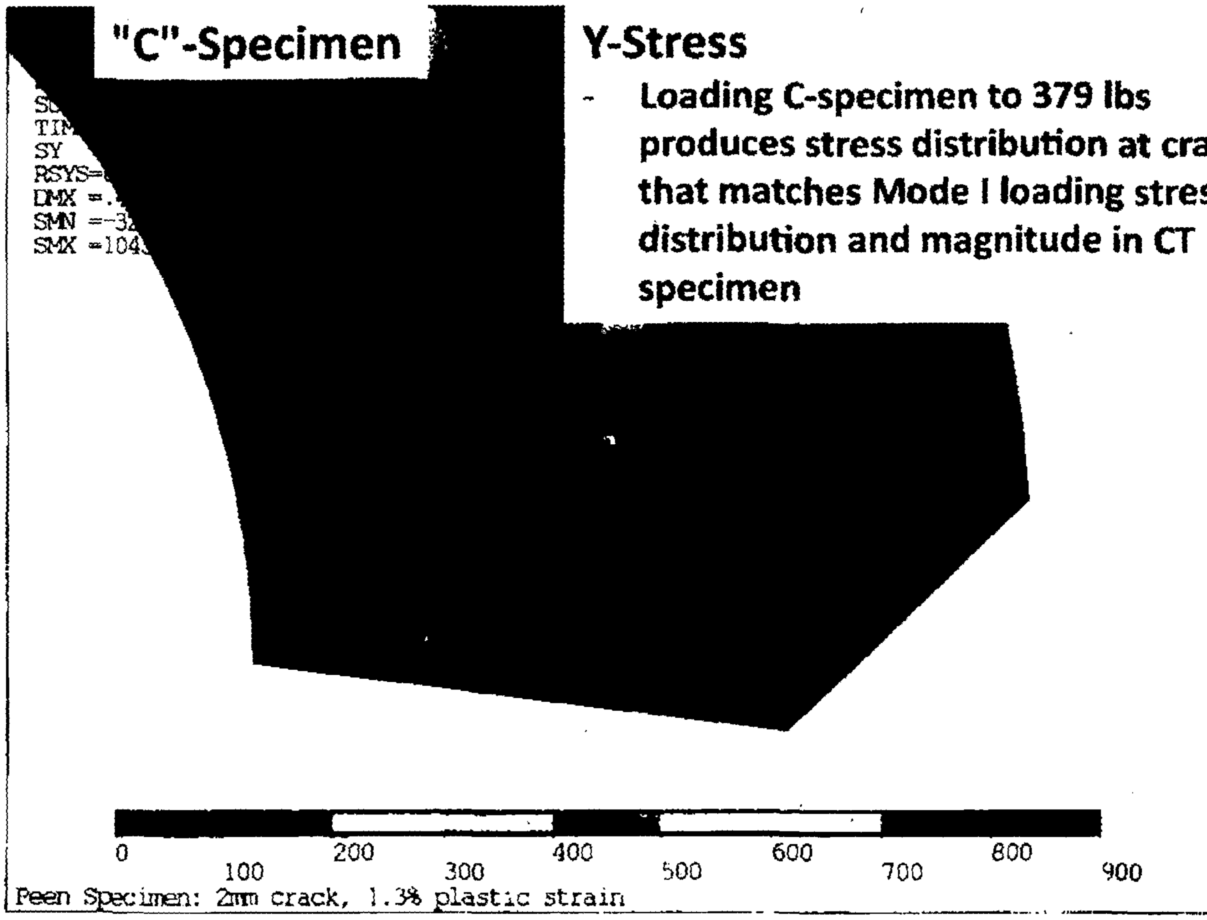


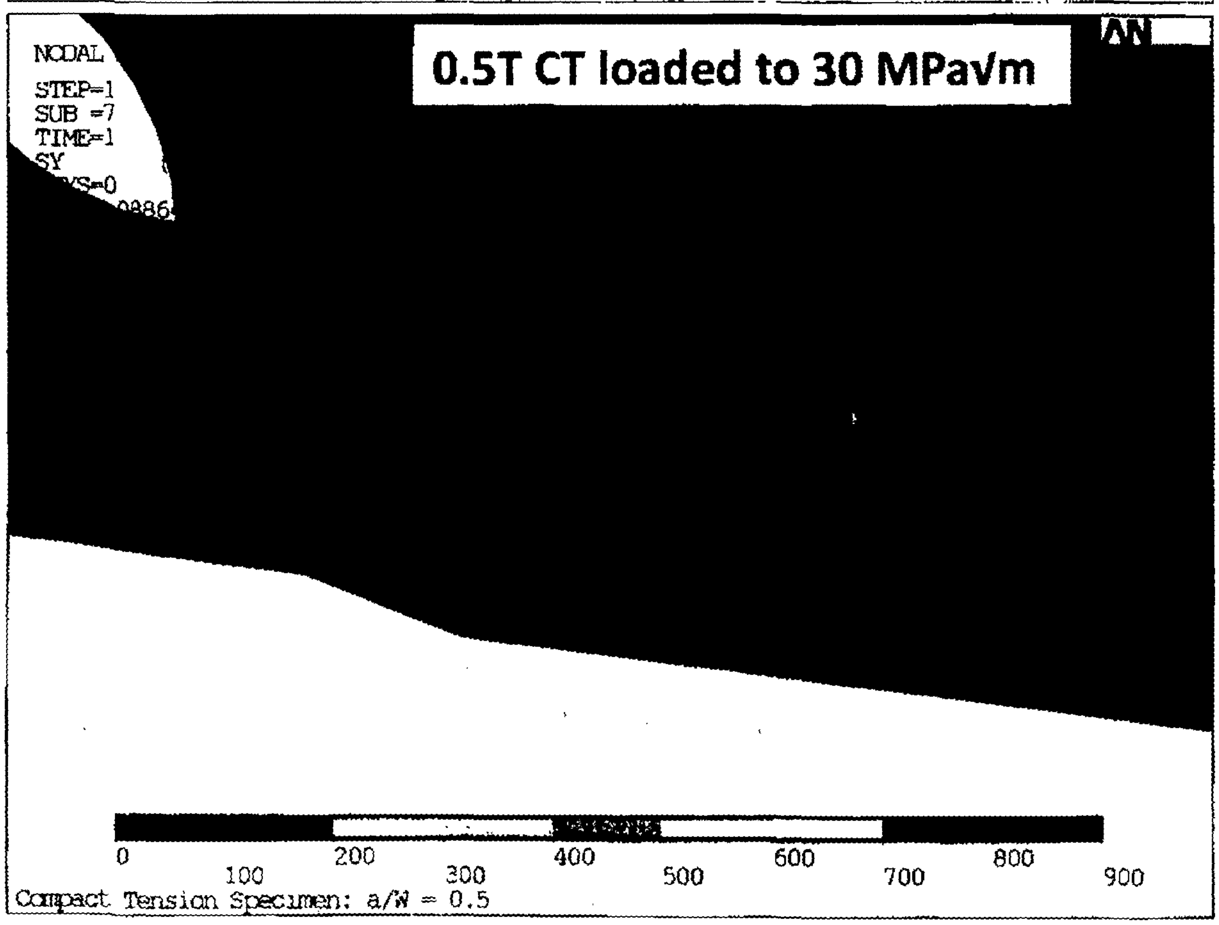
0.5T CT loaded to 30 MPa√m



Y-Stress

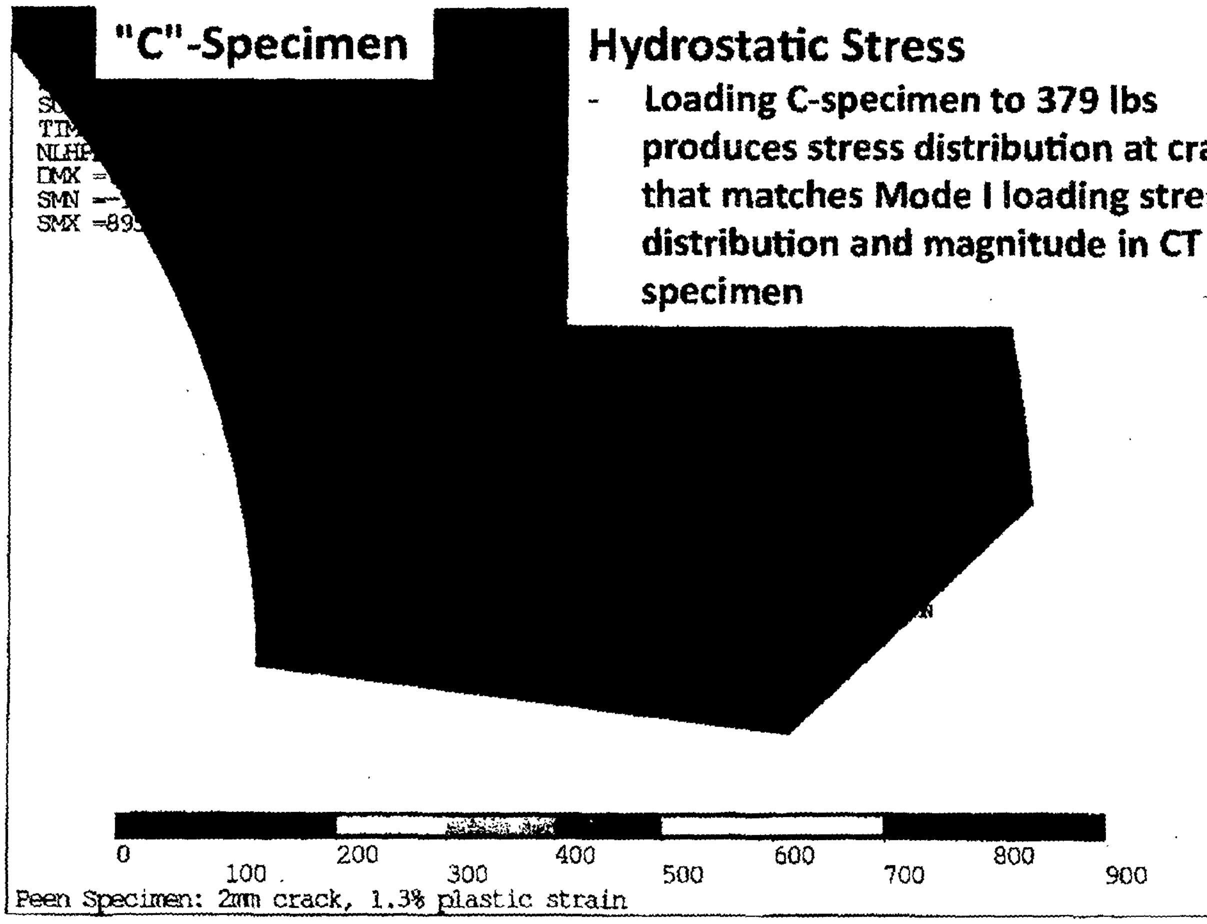
- Loading C-specimen to 379 lbs produces stress distribution at crack that matches Mode I loading stress distribution and magnitude in CT specimen

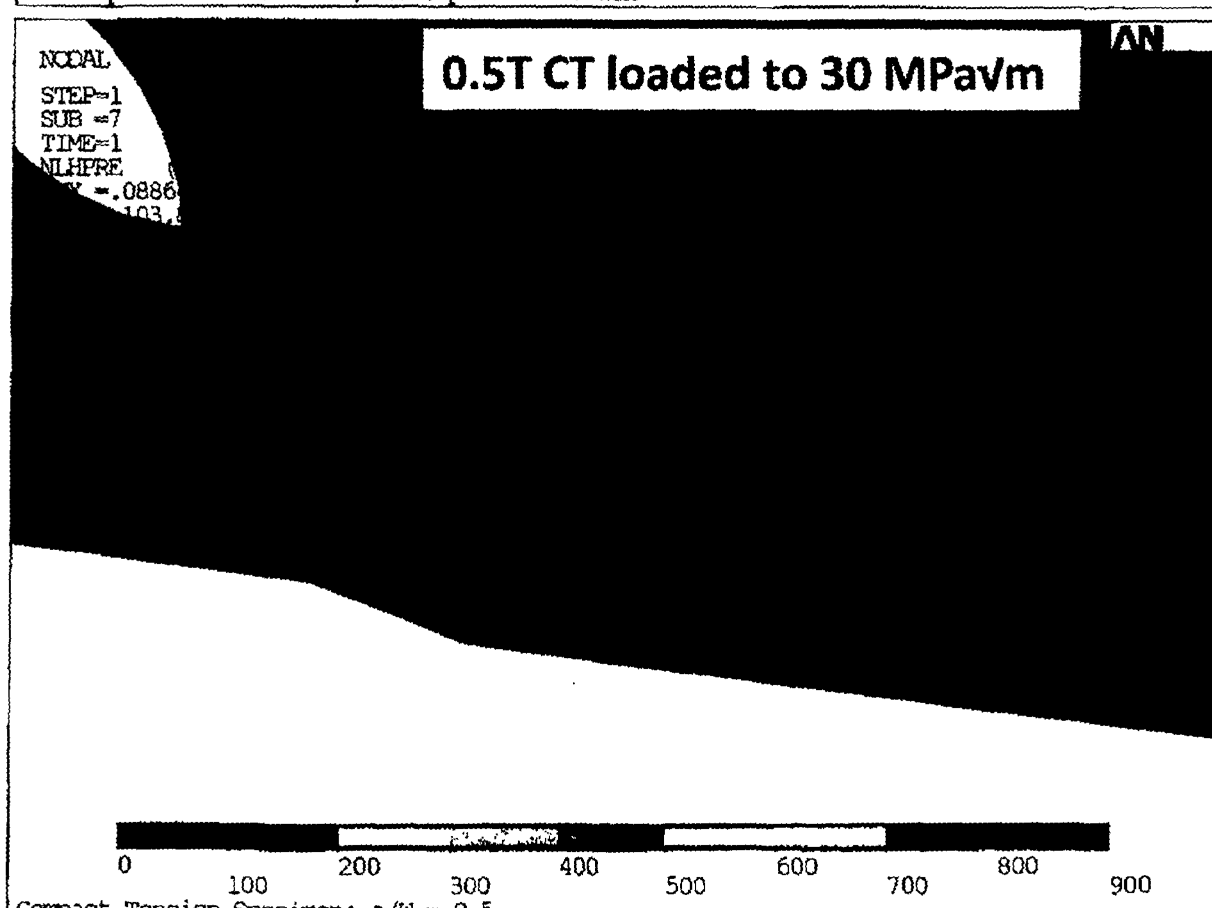




Hydrostatic Stress

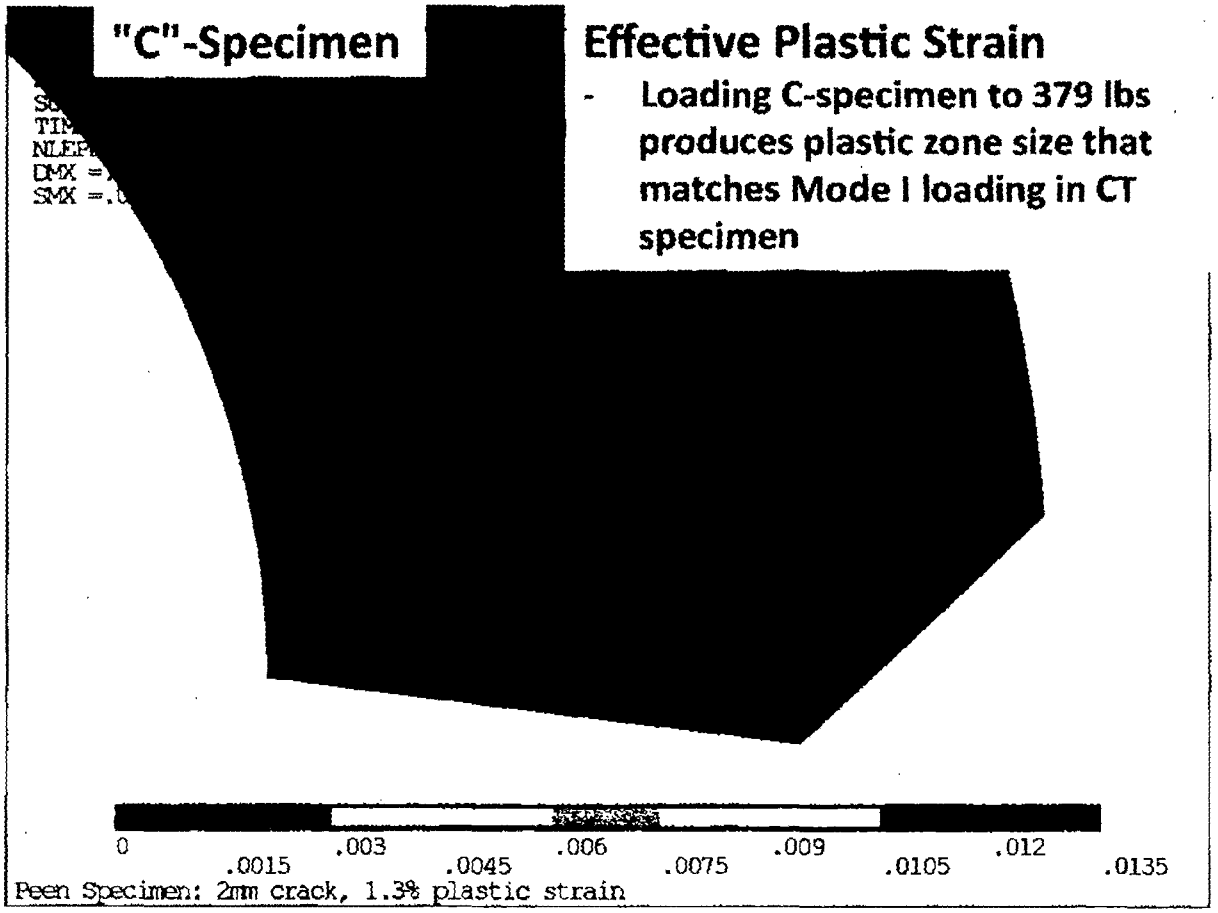
- Loading C-specimen to 379 lbs produces stress distribution at crack that matches Mode I loading stress distribution and magnitude in CT specimen

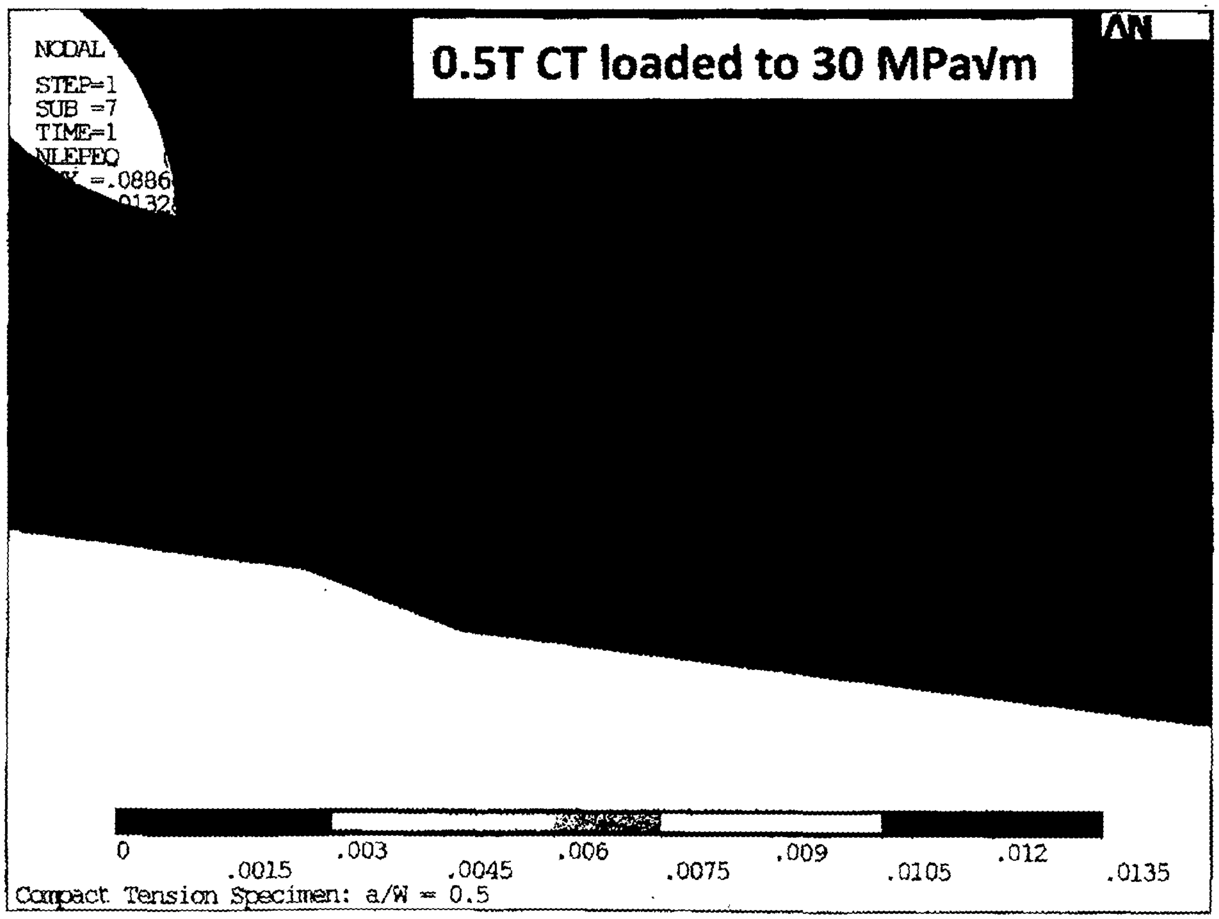




Effective Plastic Strain

- Loading C-specimen to 379 lbs produces plastic zone size that matches Mode I loading in CT specimen



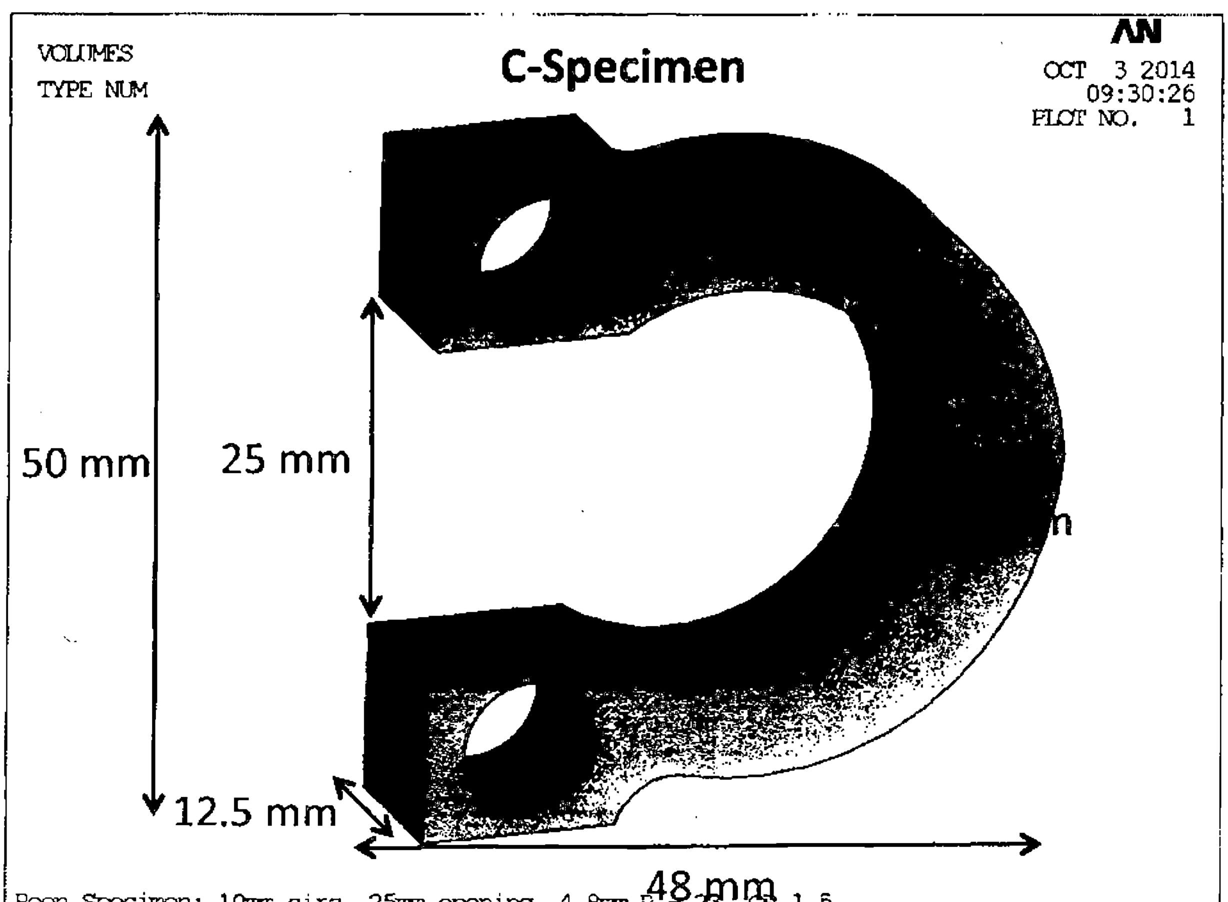


C-Specimen Summary and Discussion

- Easy to load multiple specimens in tension.
- Required loads are easily attained using existing load frame and servo system.
- Produces a very uniform surface stress distribution.
- Crack-tip stress and strain distributions closely match that of a 0.5T CT.
- Now modelling sensitivity of DCPD to crack length.

Questions/Discussion

- Can peening tools effectively access the interior surface?
- Is there a need to peen a preloaded specimen to simulate plant conditions were tensile stresses are assumed to exist prior to peening?



4-Pt Bend Peening Specimen Design Status

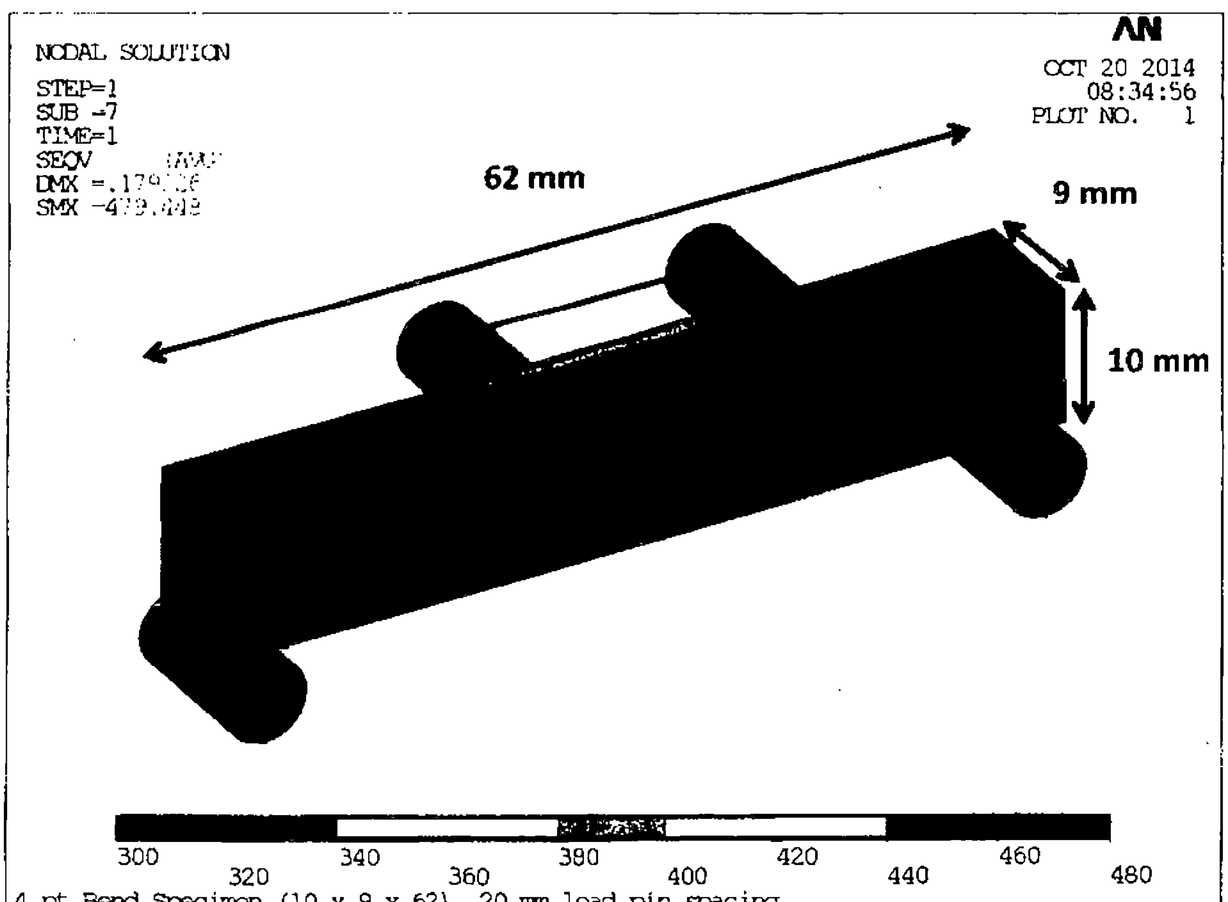
November 3, 2014

Mychailo Toloczko
John Deibler
Thak-Sang Byun

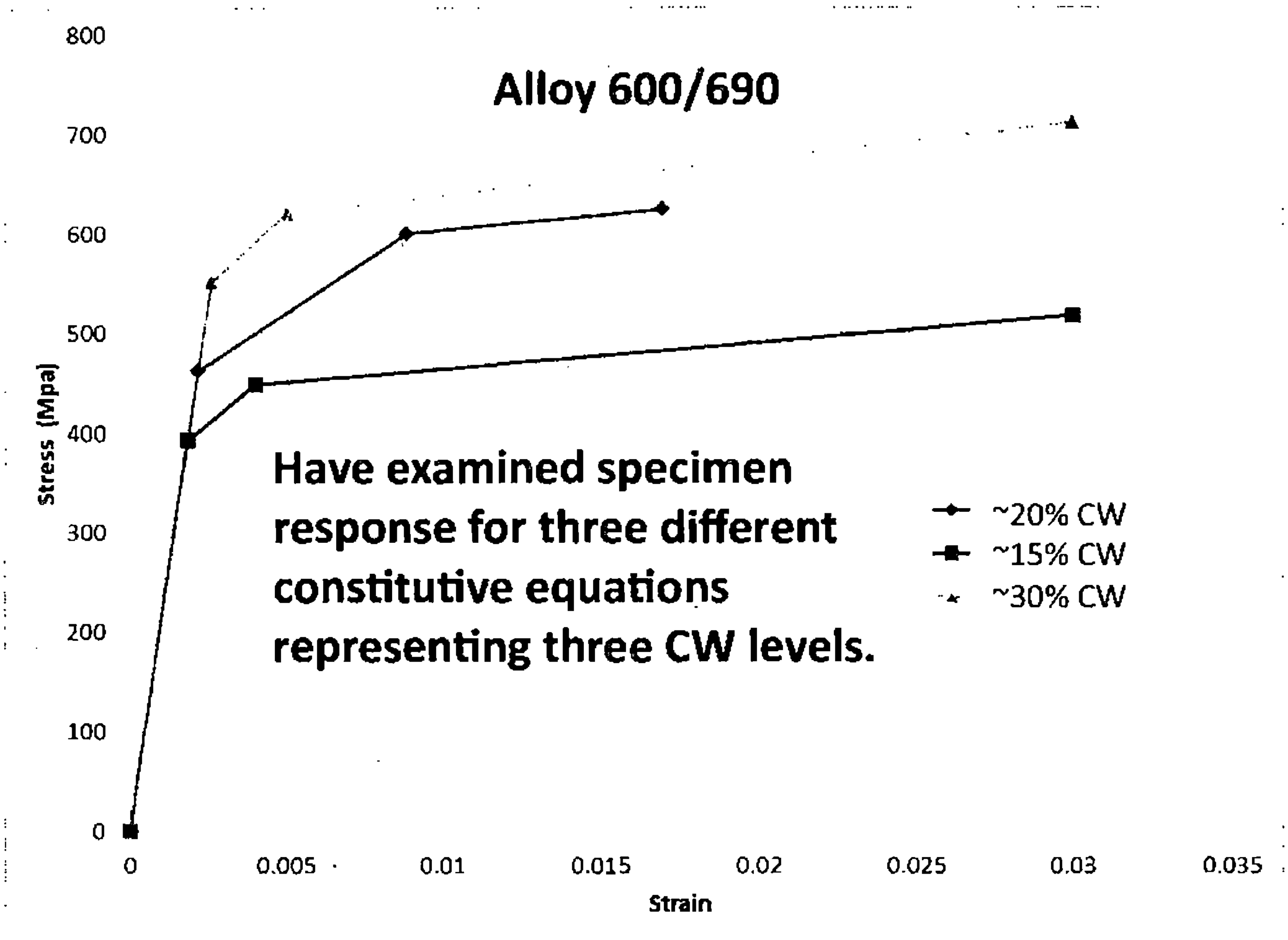
PNNL

4-pt Bend Specimen

- Width of uniformly stressed/strained region follows space between upper load pins.
- Loading required to reach yield for a highly CW alloy 600 specimen (~550 MPa) for a 10 mm x 9 mm x 62 mm specimen with 20 mm upper pin spacing is ~2000 lbs. This is a little higher than desired for the servo loading system.
- An acceptable maximum load of ~1500 lbs can be achieved for a 13 mm upper pin spacing. Uniform stress region will be ~13 mm long.

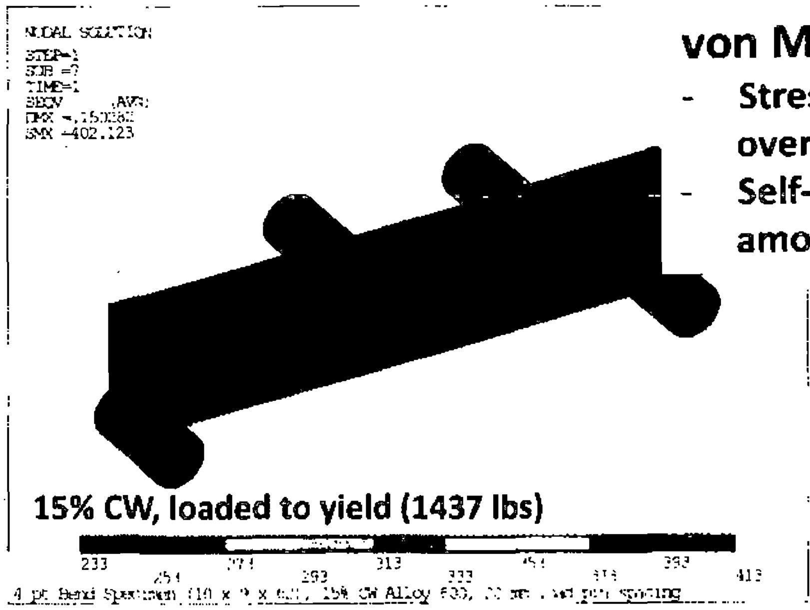


Constitutive equations used for finite element modeling

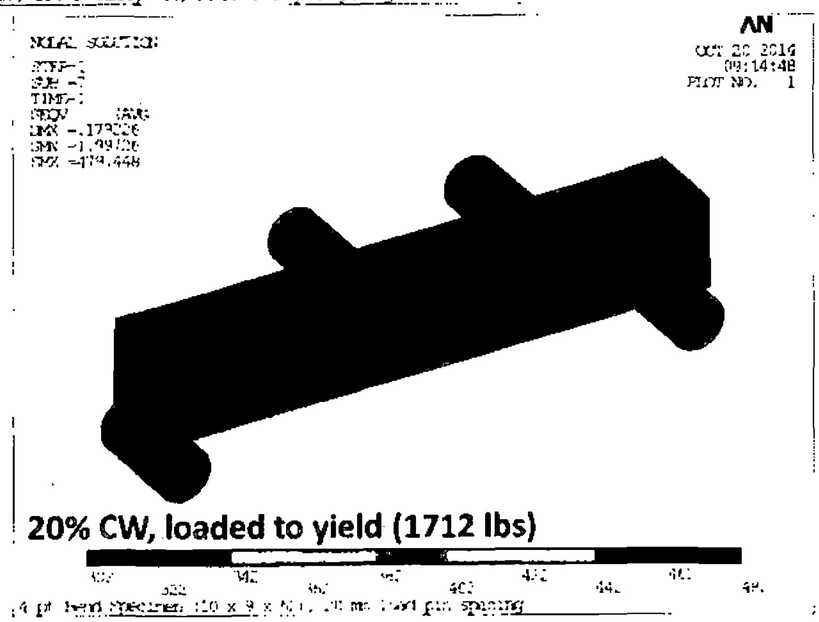


von Mises stress

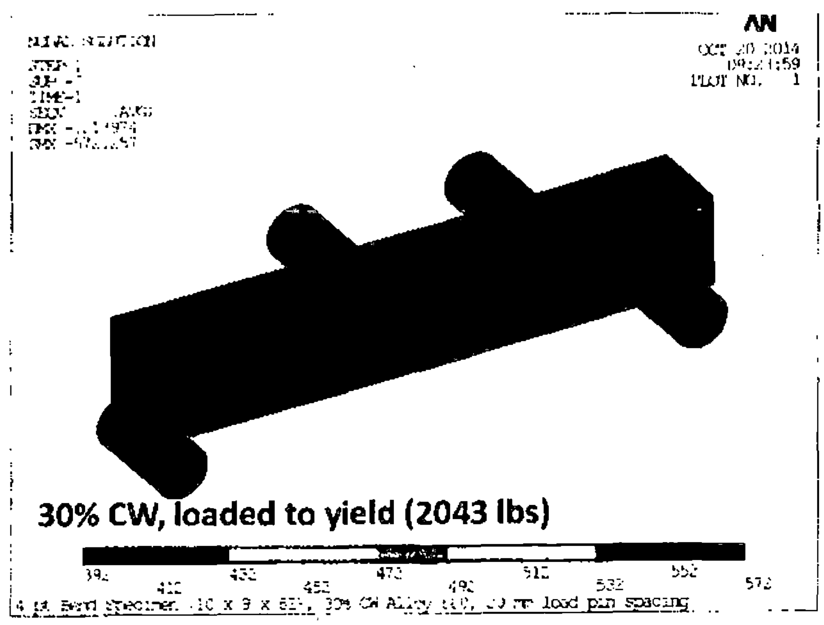
- Stress almost uniformly distributed over width between the upper pins.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (1437 lbs)



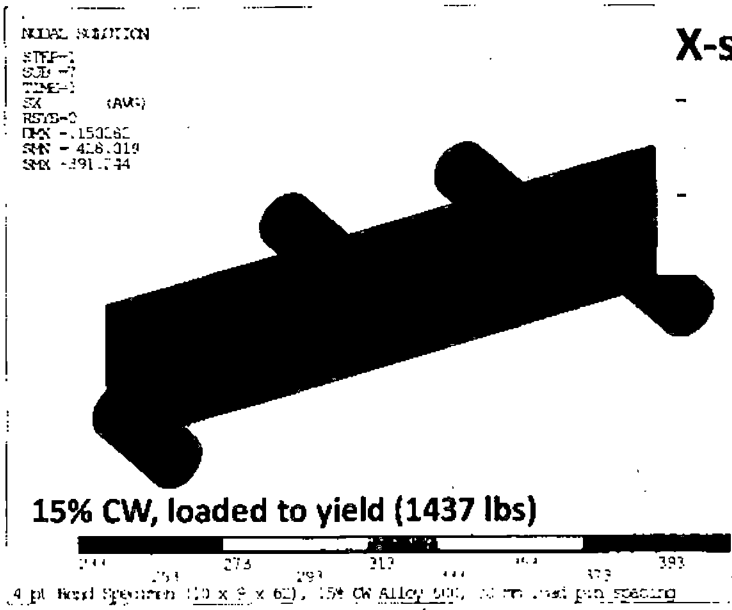
20% CW, loaded to yield (1712 lbs)



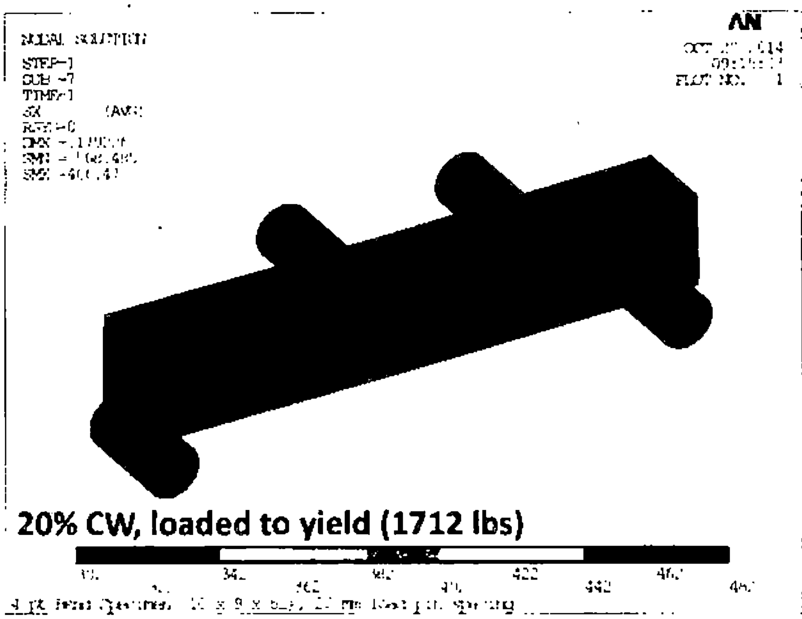
30% CW, loaded to yield (2043 lbs)

X-stress

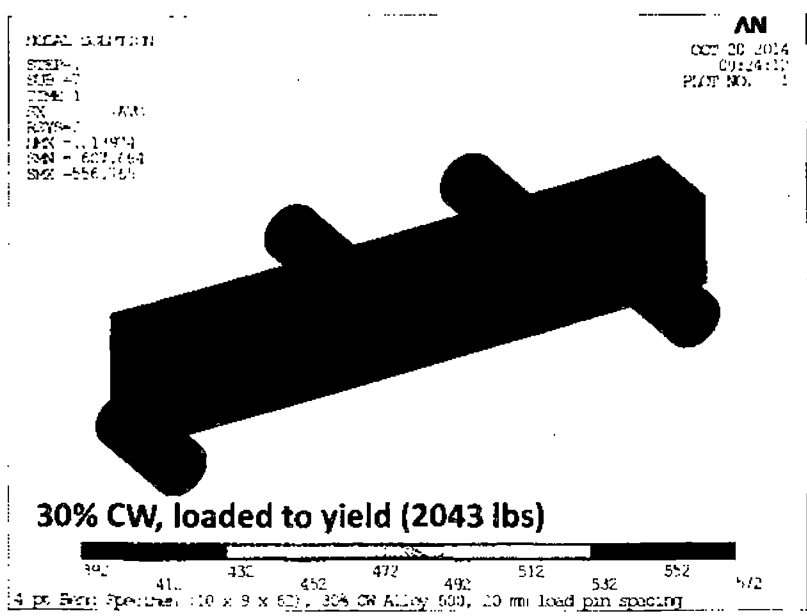
- Stress almost uniformly distributed over width between the upper pins.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (1437 lbs)



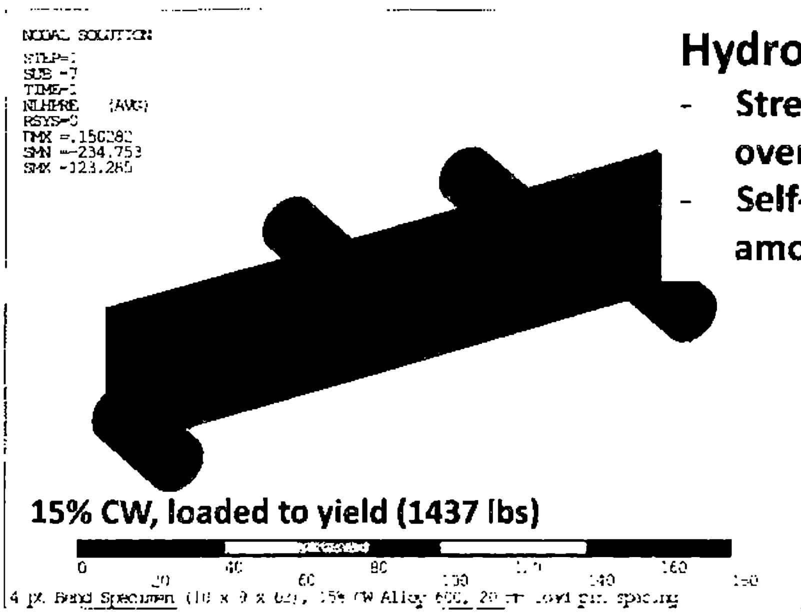
20% CW, loaded to yield (1712 lbs)



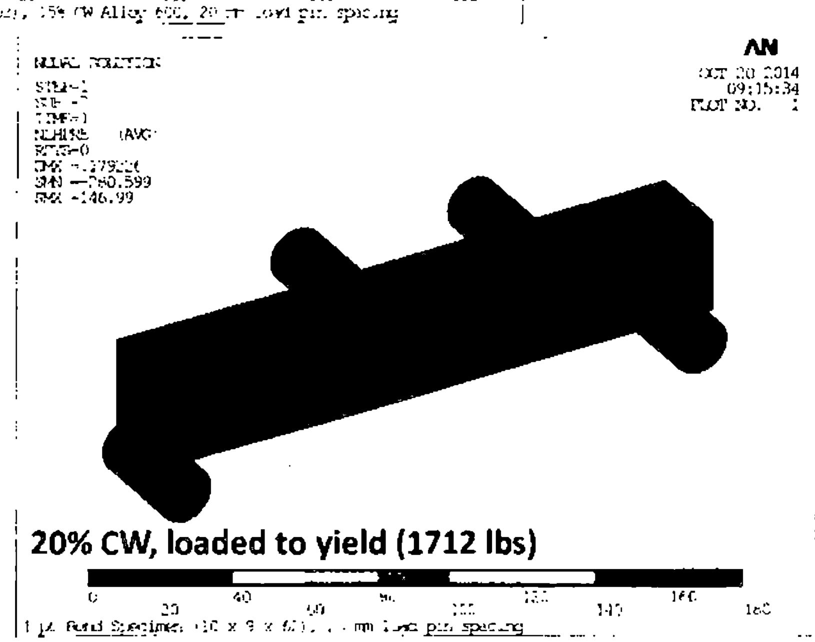
30% CW, loaded to yield (2043 lbs)

Hydrostatic stress

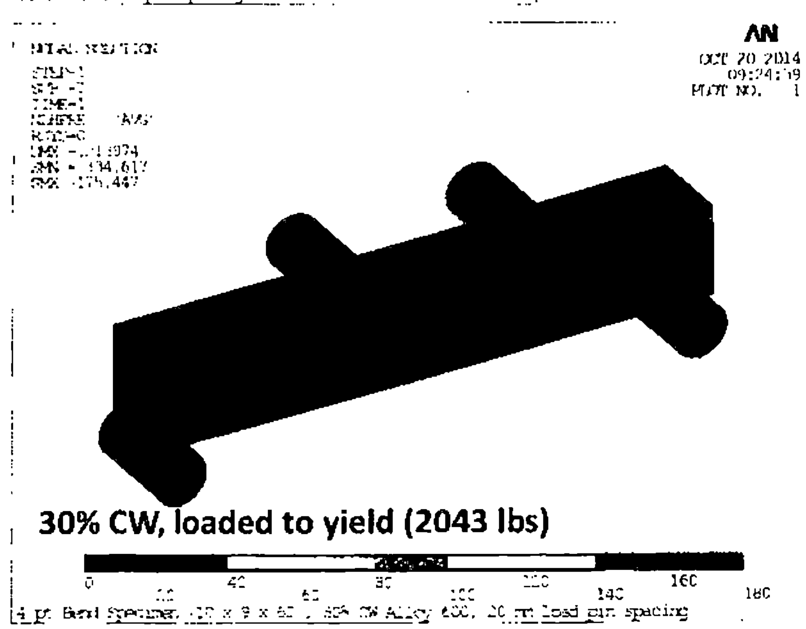
- Stress almost uniformly distributed over width between the upper pins.
- Self-similar stress distributions among the three different CW levels.



15% CW, loaded to yield (1437 lbs)



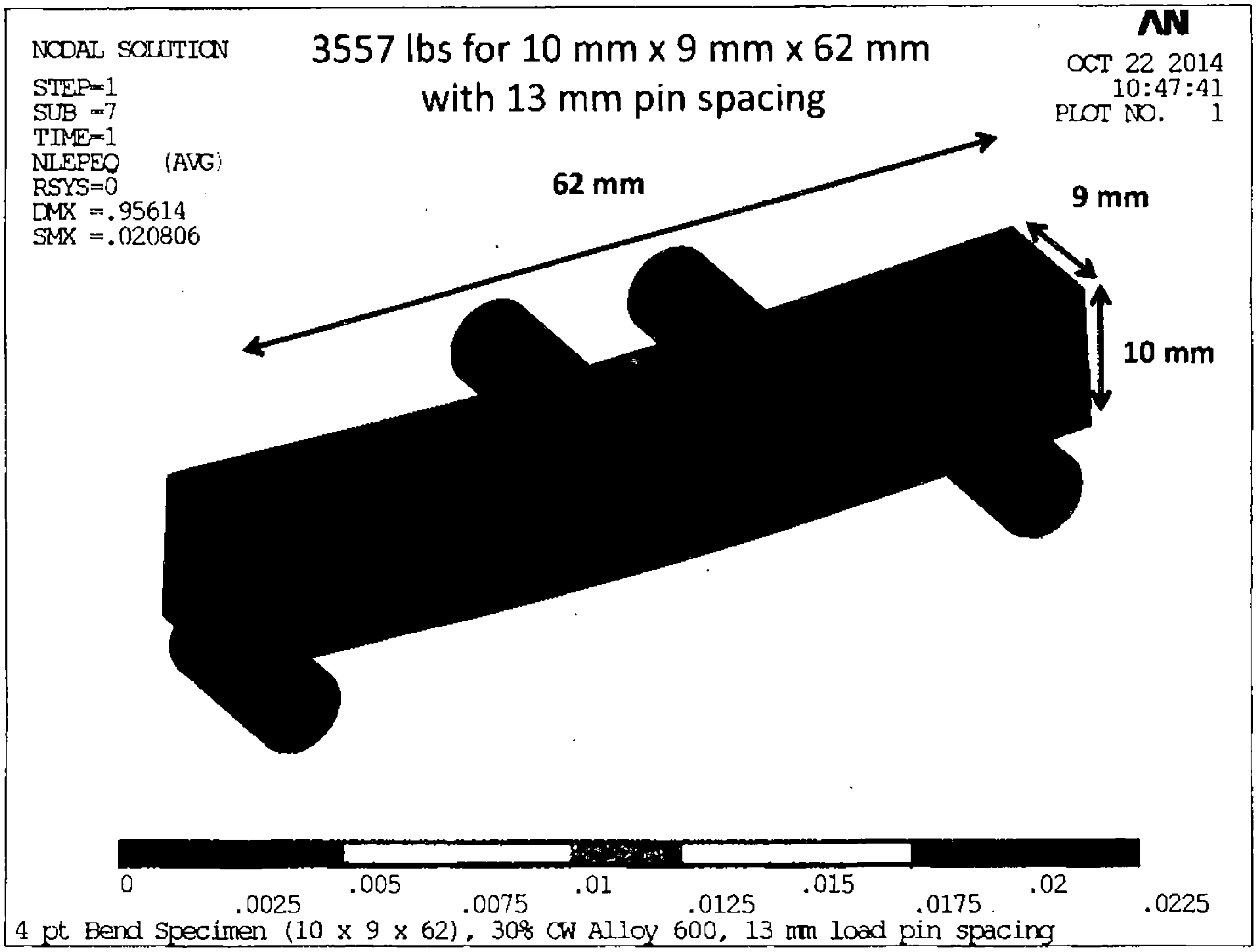
20% CW, loaded to yield (1712 lbs)



30% CW, loaded to yield (2043 lbs)

Application of 2% Peak Plastic Strain

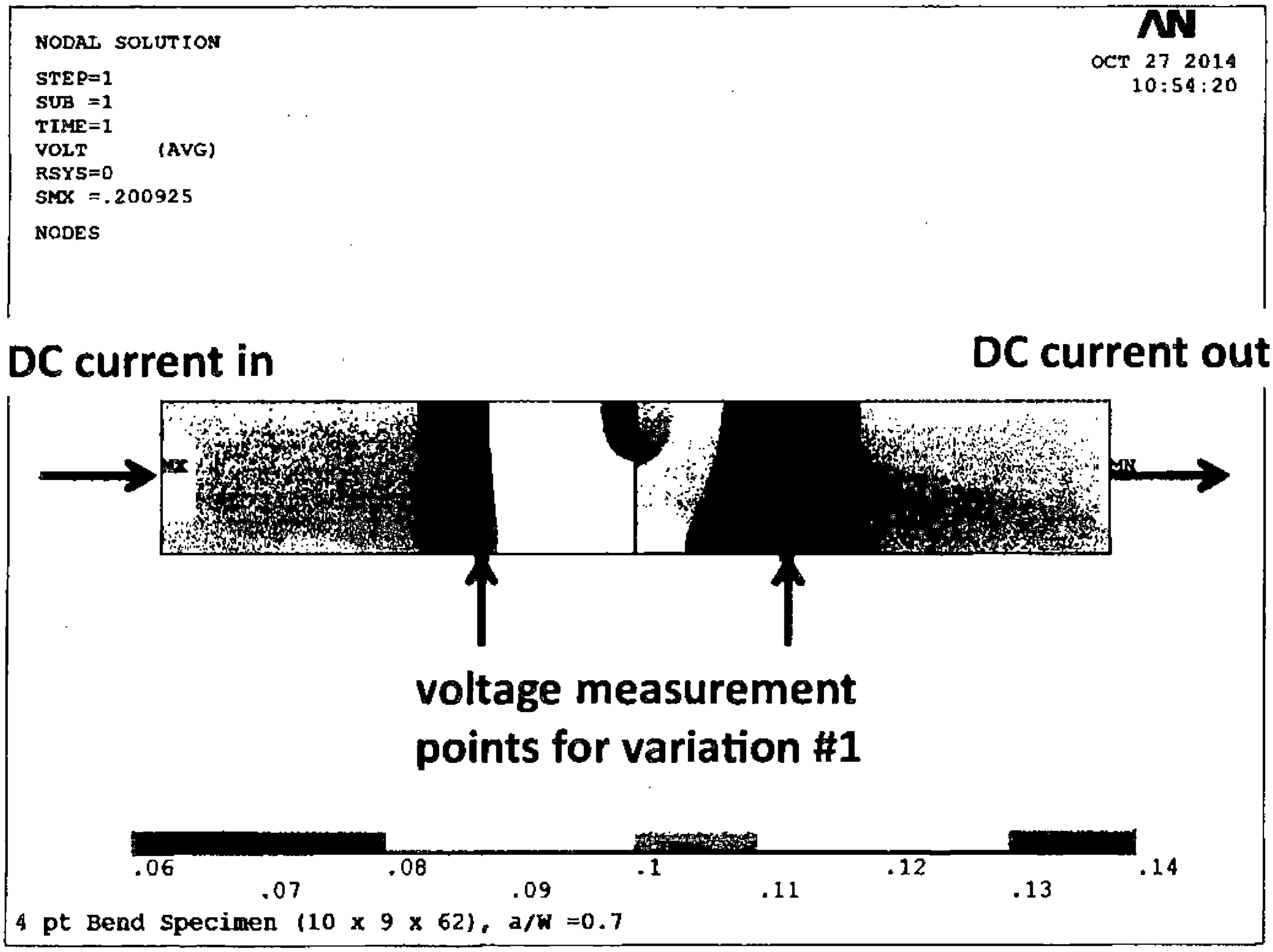
- Pushing the specimen into plastic strain requires very high loads.
- Strains become very localized.
- Unclear if such plastic strains would be needed, but would not be possible with available equipment.



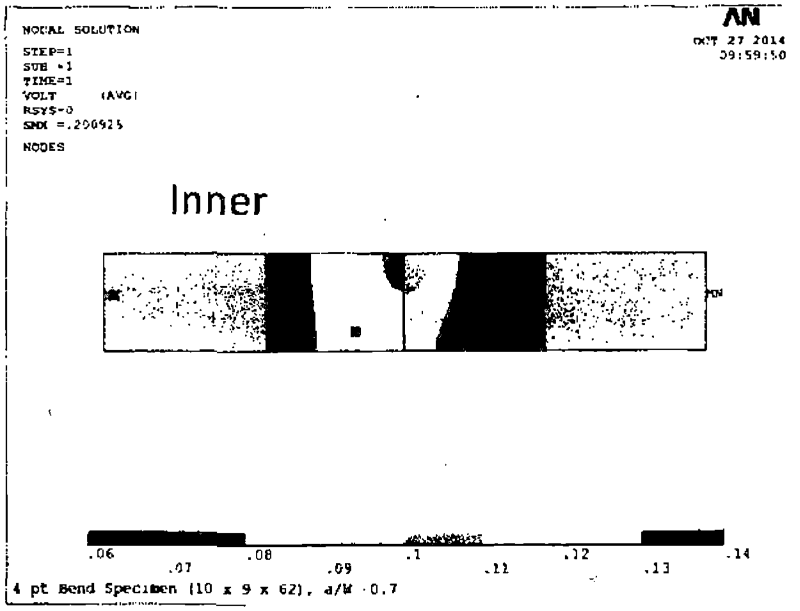
4-pt Bend Specimen DCPD signal versus crack length FEM analysis

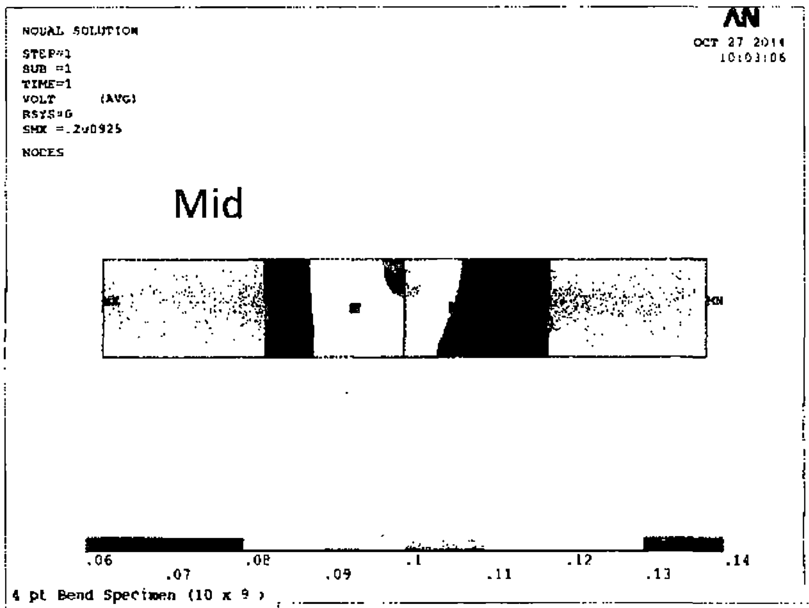
Have tried several variations in voltage measurement location.

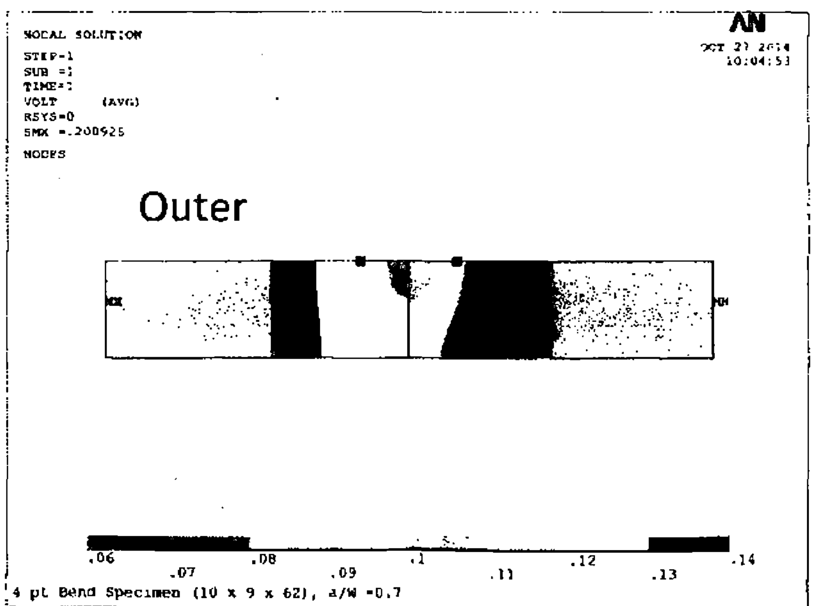
2D model - Variation #1



Try several variants in DCPD voltage measurement location.

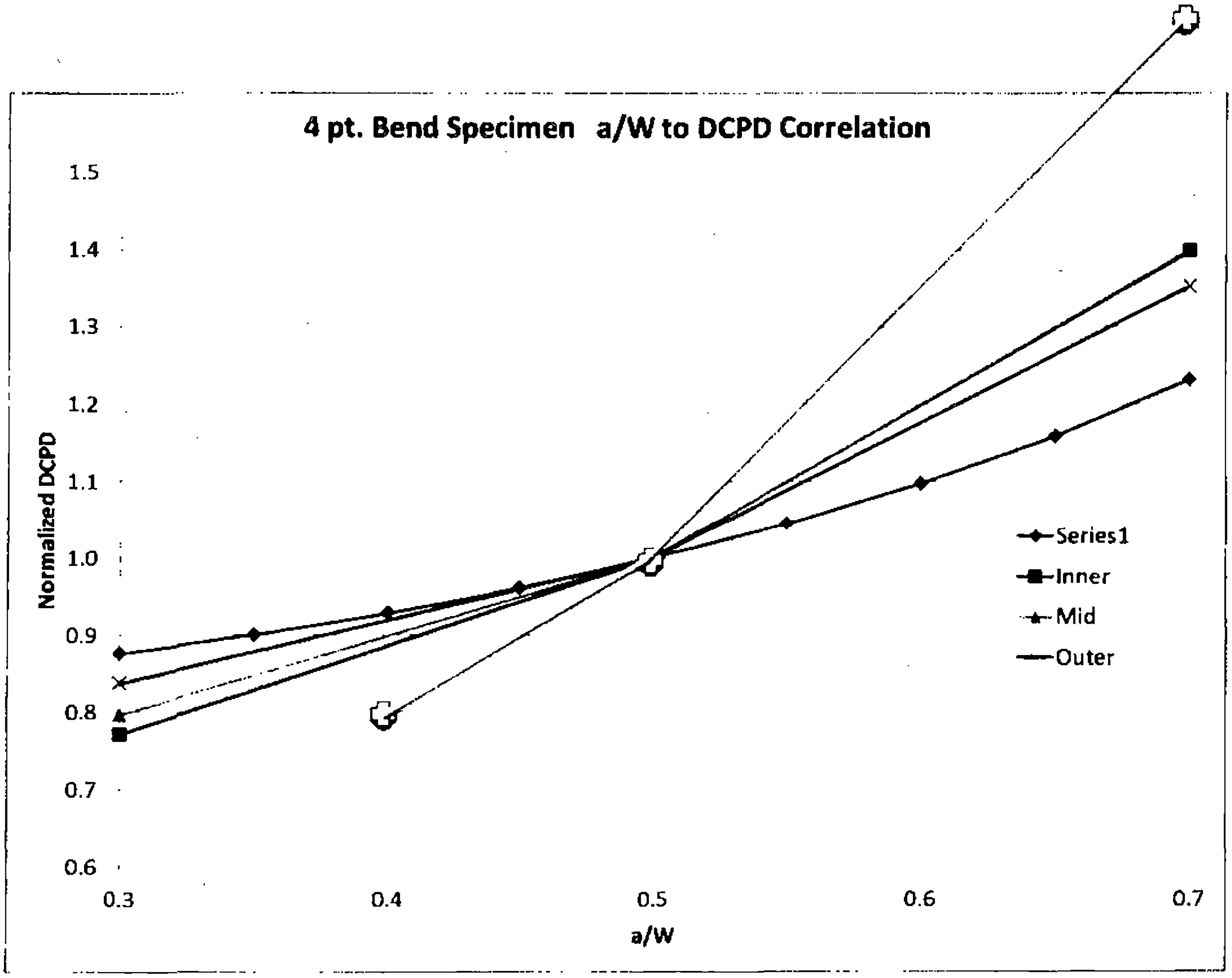






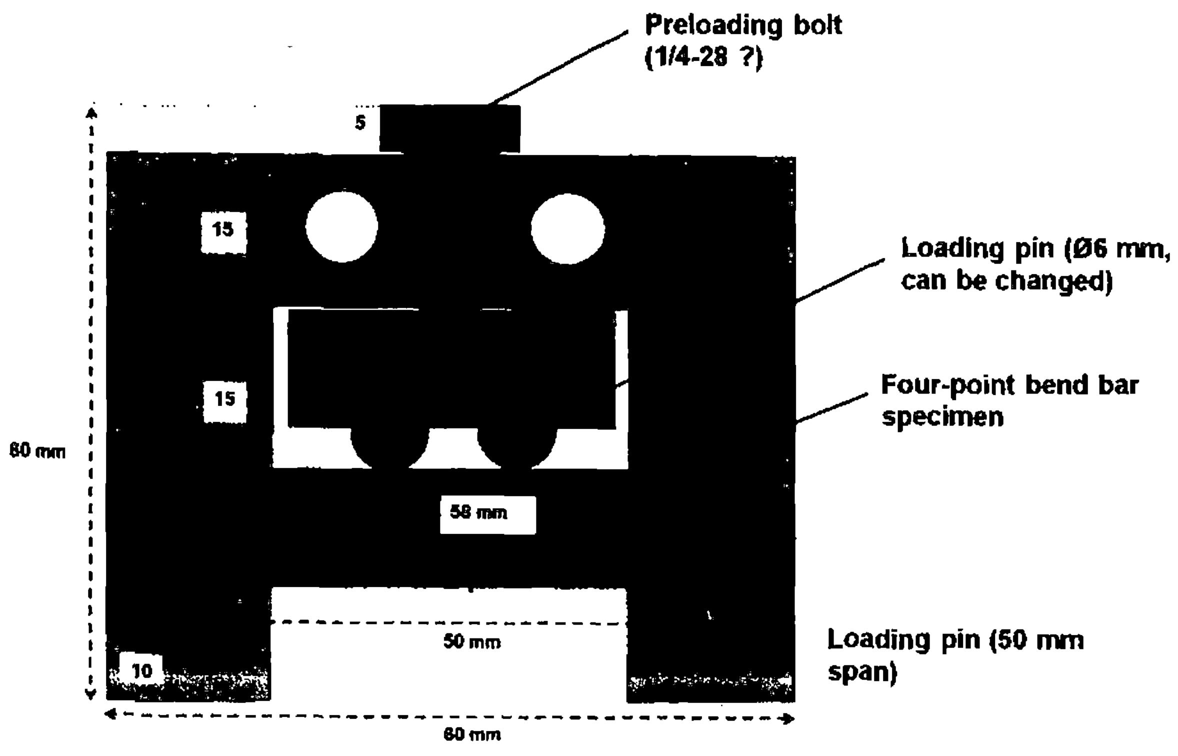
Comparison to CT specimen DCPD Sensitivity

- DCPD probes attached on side of specimen near front surface show best sensitivity in FEM.
- Approaching that of CT specimen sensitivity.
- Can likely be improved further if needed.



4-pt Bend Load Train Unit

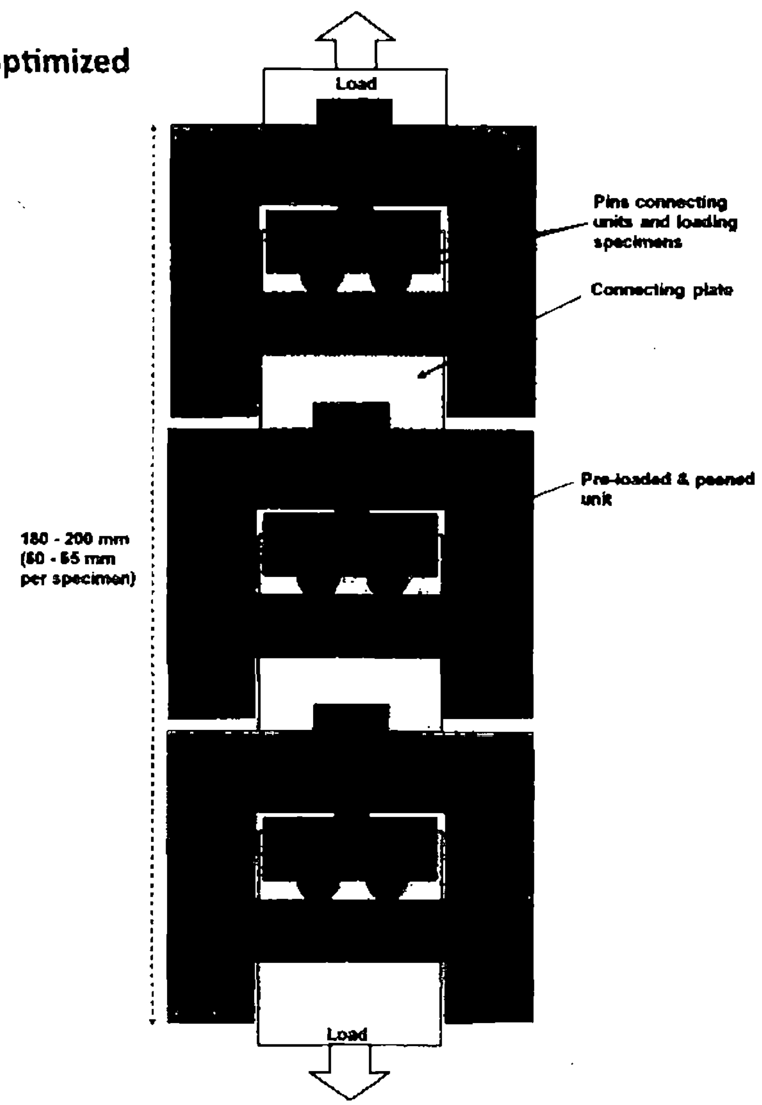
- Can preload the specimen with a bolt.
- Stressed/strained surface is accessible for peening.
- Unit height of load train unit is ~2.5". Can load 9-10 specimens per string, or 27-30 specimens per autoclave.
- As with the tensile initiation specimen system, all specimens carry same load, so different strength specimens are simultaneously all loaded to their yield (or beyond) by tailoring the specimen thickness (B value).



4-pt Bend Load Train Unit

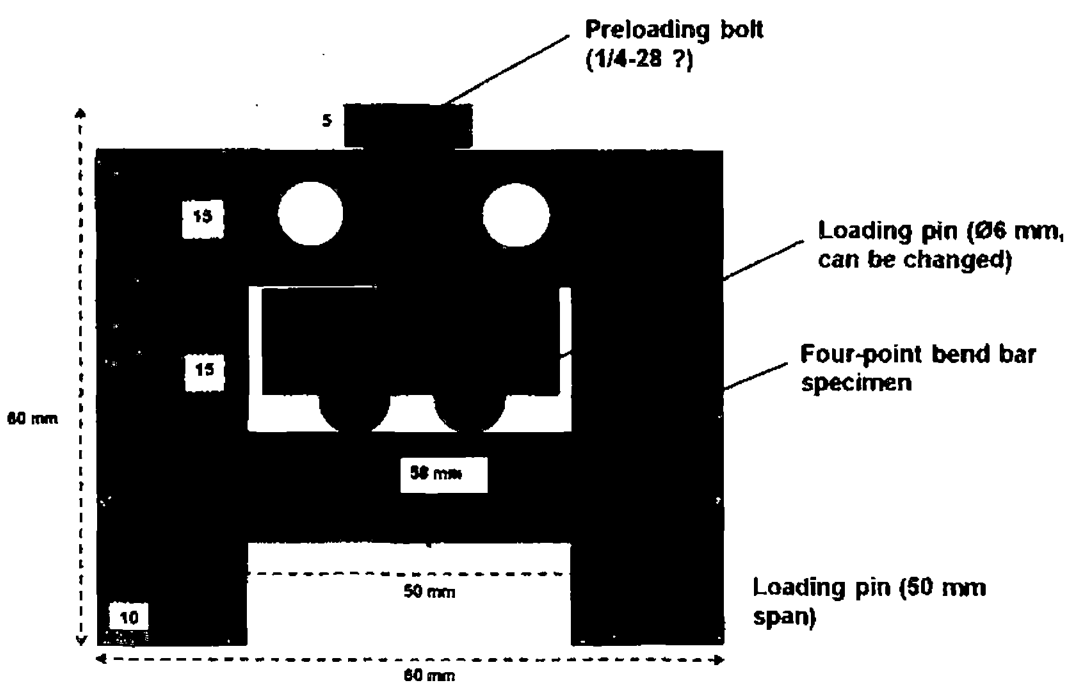
- Preload can be maintained all the way up to the point where load is applied using the test frame loading system.
- Servo loading system would apply ≥105% of preload thus taking the load off the preload bolt.
- During power failure, bolt would act as a position-stop to maintain a baseline load.
- Additional straps would be needed to prevent load train collapse if a specimen fails.

Early concept, not optimized



4-pt Bend Summary/Discussion

- 4-pt bend produces a uniform stress state having a length that matches the spacing between the two upper pins.
- Maximum reasonable load is achieved with ~13 mm spacing, thus uniform stress width would be ~13 mm.
- Have determined a way to series-load 4-pt bend specimens in a tension load train.
- 4-pt bend fixture appears to allow good access for peening.
- Good DCPD sensitivity, approaching that of a CT specimen.
- Preloading can be accomplished and will maintain baseline load in the event of a power outage that requires unloading the servo system.
- Most obvious disadvantage at this point is the relatively small uniform stress region, however other issues may arise when trying to create and use an actual fixture.



Notes on suggested changes to the "materials and SCC testing" aspects for the NRC Peening SOW and a draft version of new text is provided for individual tasks.

Task 4a (NEW)
A new task has been added to develop and qualify an appropriate test specimen to evaluate the effectiveness of peening on SCC crack initiation. In order to limit the impact of this step on the timing of the overall program, scoping tests would be performed on an existing NRC-owned or PNNL-owned SCC test system.

Task 4a: Design and Evaluation of a Specimen for Assessing Effect of Peening on SCC – New test specimens will be designed and evaluated to establish their effectiveness to assess the effect of peening on SCC initiation and SCC crack arrest. This task will begin with finite element modeling of specimen concepts with a goal of producing a specimen that can be fitted with DCPD instrumentation to monitor for cracking and can be peened. A key aspect of specimen design will be to produce peak stresses in the region where SCC initiation is desired to occur. Several specimens will then be fabricated and tested to demonstrate initiation response using an available PNNL-owned or NRC-owned test system.

Task 4b
This is now the task where the large autoclave system is constructed for crack initiation testing. Due to the required changes in specimen design, the number of test specimens has been reduced to an estimated 27. The parts cost to build this system will be ~$260K.

Task 4b: Fabrication of Test System for Peening SCC Initiation Study – An SCC initiation test system will be engineered, components will be procured and the system operation will be validated through testing. The completed system will enable simultaneous testing of not less than 27 specimens under PWR primary water conditions at 360C with in-situ crack detection. A technical letter report (TLR) will be provided documenting the assembly, evaluation and verification of the equipment prior to use on specimens developed to evaluate the effectiveness of peening. The NRC will review and approve the TLR prior to testing to evaluate the effectiveness of peening.

Task 4c/5b/6b/9b/12b (NEW, all optional)
These tasks cover all aspects needed to perform studies of the effect of peening on SCC crack arrest. A second autoclave system would be constructed and would utilize a small autoclave that could later be retrofitted with a large autoclave system as needed. A test matrix is proposed that would evaluate the effect of peening on a crack with a depth of ~0.3 mm that is well within the peened depth and a crack at ~1.0 mm depth that is closer to the limit of the peened depth. Two cold-worked alloy 600 and alloy 182 specimens will be tested to produce cracks of each depth for a total of 8 specimens. Crack growth rates would be measured on these specimens before and after peening. The first step would be to grow an SCC crack and determine the propagation response at a constant stress intensity (K). Because it takes more than ~0.3 mm to effectively transition to a fully engaged SCC crack, it would be necessary to remove material from the surface to bring the crack depth to the target value (i.e., 0.3 or 1.0 mm). Specimens would be

reinserted to verify crack growth rate response after removal of material. The specimens would then be peened, and testing would resume at exactly the same load and K value to assess whether the crack is arrested. The estimated parts cost for this test system is $170K.

<u>Task 4c: (Optional) Fabrication of Test System for Peening SCC Crack Arrest Study</u> – A 4 specimen test system will be engineered and procured to evaluate the effect of peening on SCC crack arrest. The system will be capable of in-situ testing of up to four specimens simultaneously under 360C PWR primary water conditions, and it will have the capability to be later retrofitted with a 27-36 specimen SCC initiation autoclave and load train. A technical letter report (TLR) documenting the assembly, evaluation and verification of the equipment prior to use on specimens developed to evaluate the effectiveness of peening. The NRC will review and approve the TLR prior to testing to evaluate the effectiveness of peening on crack arrest.

Section 4.0 Task 5a
Alloy 82 was removed from the matrix because it is categorized with alloy 182 but is more SCC resistant than alloy 182. The number of specimens had to be reduced to 27 to accommodate the anticipated size specimen that will be needed for the peening study. Since an even number of each of the remaining two types of materials (alloy 600 and alloy 182) cannot be put into the autoclave, the matrix is skewed to a larger number of alloy 182 specimens were greater variability in crack initiation time is expected to be seen. Extra specimens are included so as to mitigate any possible testing mishaps.

<u>Task 5a: Fabrication of Specimens for Peening SCC Initiation Study</u> – SCC test specimens will be produced to fill the initiation test system and, as possible, enable a statistical evaluation of time for crack nucleation. The samples will include at a minimum:

1. Twenty four (24) 15% cold worked alloy 600 specimens
2. Thirty (30) 15% cold worked alloy 182 specimens with the weld aligned in the most susceptible orientation

Three extra specimens of each material will also be machined to allow determination of the yield load of the specimens. The purpose of these samples is not to evaluate all aspects of peened surfaces, but rather to evaluate the worst case peened surface allowed by MRP-335 and the initiation testing approach. Assistance will be provided to the NRC for the transport of specimens to appropriate facilities for peening to be applied in accordance with MRP-335.

Task 5b (NEW, all optional) - see comments above.

<u>Task 5b: (Optional) Fabrication of Specimens for Peening SCC Crack Arrest Study</u> –12 SCC test specimens will be produced to evaluate the effect of peening on SCC crack arrest. The samples will include at a minimum:

1. Six (6) 15% cold worked alloy 600 specimens

2. Six (6) 15% cold worked alloy 182 specimens with the weld aligned in the most susceptible orientation

The purpose of these samples will be to evaluate the effect of peening on SCC crack arrest, the plan is for 8 specimens to be tested with additional specimens available in case of complications. It is suggested that two crack depths be evaluated using duplicate specimens. Crack depths would be one that is within the peening depth, e.g., 0.3 mm, and one that is near the limit of the peening depth, e.g., 1 mm.

Task 6a
Due to the required changes in specimen design, the number of test specimens has changed.

Task 6a: SCC Initiation Testing of Non-Peened Specimens - Crack initiation testing will be performed using the machine designed in Task 4b on 27 unpeened test specimens (12 alloy 600 and 15 alloy 182), half of the specimens produced in Task 5a.

Task 6b (NEW, all optional) - see comments above.

Task 6b: (Optional) SCC Crack Growth Rate Measurement of Unpeened Crack Arrest Specimens - Crack growth rate testing will be performed using the machine designed and constructed in Task 4c on 8 unpeened crack arrest specimens that were produced in Task 5b. After determining the SCC growth rates at constant K, the specimens will be provided to the NRC for subsequent peening.

Task 9b (NEW, all optional) - see comments above.

Task 9b: (Optional) Ship Crack Arrest Specimens for Peening – This task occurs at a later date due to the longer time needed to prepare these specimens. The crack arrest specimens will be shipped to different facilities, as described by written letter from the NRC. The NRC shipping order letter will be based on information provided by the Task 8 TLR. The NRC will be responsible to ensure that each sample is peened in accordance with the Task 8 TLR. Once peened, all of the specimens will be shipped back PNNL for testing.

Task 12a
Due to the required changes in specimen design, the number of test specimens has changed.

Task 12a: Perform SCC Initiation Testing on Peened Specimens – Crack initiation testing will be performed using the machine designed in Task 4b on 27 peened test specimens (12 alloy 600 and 15 alloy 182), half of the specimens produced in Task 5a. The full test length shall continue until either all specimens have initiated cracks or five times the 75th percentile of the crack initiation time of the specimens in Task 6a. If any peened specimens develop indications of cracking, additional metallurgical analysis may be conducted (as authorized by the NRC) for up to two cracked peened specimens.

Task 12b (NEW, all optional) - see comments above.

Task 12b: (Optional) SCC Crack Arrest Testing of Peened Specimens - The peened crack arrest specimens will be reloaded to the identical K level where SCC growth rates were obtained on these same specimens. Testing will be performed in 360C PWR primary water using the machine designed in Task 4c on 8 crack arrest specimens that were peened in Task 9b. The specimens will be held at constant load for a minimum of 1000 hours. If no crack growth is detected over that time frame, the load may be increased slowly to indicate the critical K level for re-initiation of SCC. Test conditions will only be changed after discussion with, and approval of, the NRC. Results will be compared to those for the unpeened specimens generated in Task 6b.

Possible Task 16 - We expect there will be a need for some travel as part of this project, at least one annual trip to NRC headquarters for at least 2 staff.

Potential Timeline for "Materials Tasks"

The timeline has been pushed out to accommodate the need to design a new test specimen geometry and to add some room in the schedule for off-normal events. The total time for the Task Order is suggested to be 33 months. The length of time hinges on the need for a 5x factor of improvement. If the unpeened specimens initiate in 2-2.5 months, the total project time could decrease by as much as 5 months. Note that the optional task to evaluate the effect of peening on crack arrest is not a contributing factor to the increased amount of time needed.

Potential Timeline With Recommended *Milestones in Bold Italic*

Task Number(s)	Task Description or ***Deliverable/Milestone Description***	Goal Completion or ***Milestone Completion***
4a	Design and evaluate specimen to assess effect of peening	5 months after startup of contract
4b	DOE crack initiation testing rig completed	7 months after start of contract
4c	Optional - DOE crack arrest testing rig completed	7 months after start of contract
4d	TLR on specimen and testing rig verification (1) DOE Lab Draft (2) NRC review (3) DOE Lab Final	(1) 75 days after Task 4b/c (2) 10 days after draft received by NRC (3) 15 days after comments provided
4	***Crack initiation test rig(s) complete and operational.***	***9 months after start of contract***
5a	DOE acquires all crack initiation test specimens	4 months after completion of Task 4a
5b	Optional - DOE acquires all crack arrest test specimens	4 months after completion of Task 4a

Potential Timeline With Recommended ***Milestones in Bold Italic***		
Task Number(s)	Task Description or ***Deliverable/Milestone Description***	Goal Completion or ***Milestone Completion***
6a	DOE completes crack initiation testing of non-peened specimens	5 months after Task 5a completed
6b	Optional - DOE completes crack growth rate testing of non-peened crack arrest specimens	6 months after Task 5a completed
2, 3, 5, 7 & 8	***All specimens acquired and work completed to proceed with peening, including Task 8 documentation***	***9 months from start of contract***
9a	DOE Ship/ NRC Peen/DOE Ship	Process completed in 2 months
9b	Optional - Peening of crack arrest specimens	Process completed in 2 months
12a	DOE completes crack initiation testing on peened Task 5a samples	Test time depends on results in Task 6a, up to a maximum of 16 months. Begins 1 month after completion of Task 6 (if Task 9a is complete).
12b	Optional - DOE completes crack arrest studies on peened specimens from Task 5b	8 months after completion of peening in Task 9b
13	DOE completes TLR on crack initiation (1) DOE Lab Draft (2) NRC review (3) DOE Lab Final	(1) 30 days after Task 12 (2) 10 days after draft received by NRC (3) 10 days after comments provided

Estimated Schedule for Key Materials/SCC Items by Date (# months):
August 2014 (0) - Project Start
January 2015 (5) - New Initiation Specimen Design Evaluated and Established
May 2015 (9) - Test Systems Operational and Non-Peened Specimens Produced
June 2015 (10) - SCC Initiation and *Crack Arrest Testing* on Non-Peened Specimens Started
July 2015 (11) - Specimens Returned after Peening
Nov. 2015 (14) - SCC Initiation and *Crack Arrest Tests* Completed on Non-Peened Specimens
Dec. 2015 (15) - SCC Initiation and *Crack Arrest Testing* on Peened Specimens Started
August 2016 (24) - SCC *Crack Arrest Tests* Completed on Peened Specimens
March 2017 (31) - SCC Initiation Testing Completed on Peened Specimens
May 2017 (33) - Final TLR

Costs
With the need for a 33 month project, staff time estimates has been expanded into FY17. Time commitments for individual staff have been increased in several tasks.

ESTIMATED LABOR CATEGORIES AND LEVELS OF EFFORT

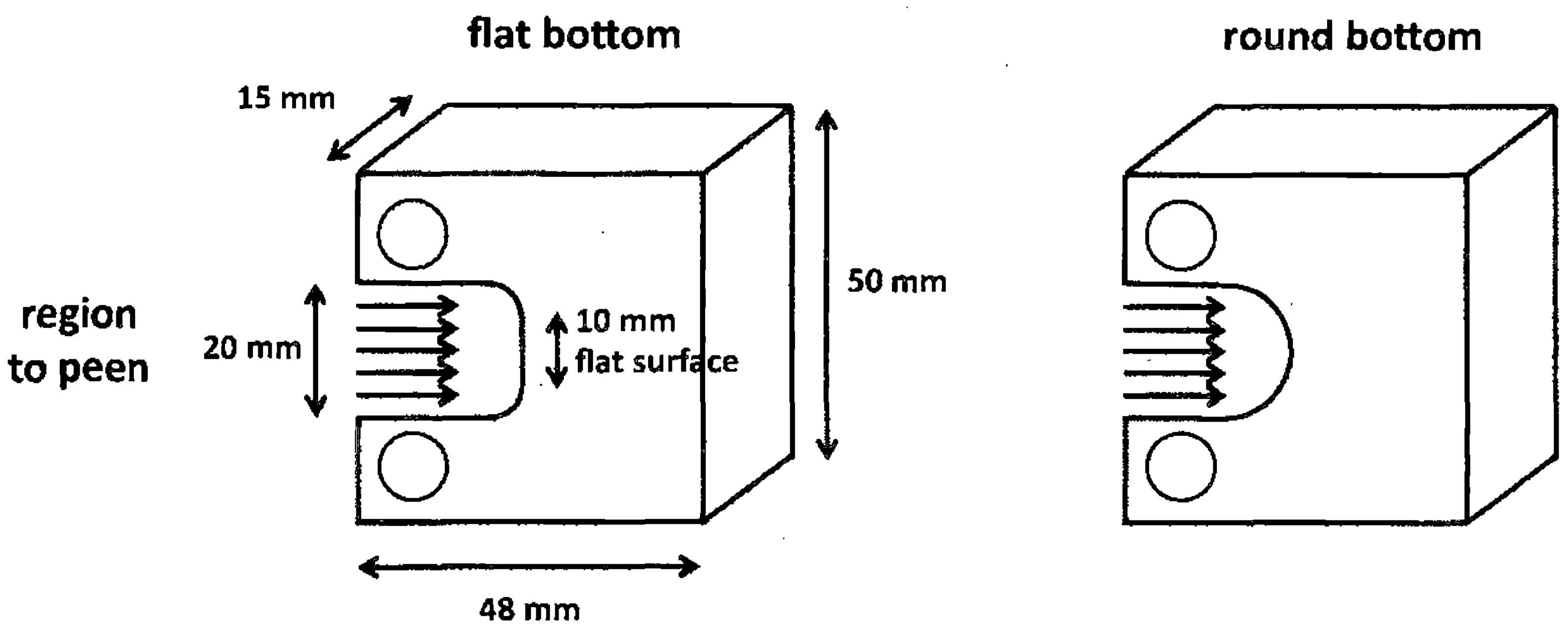
		FY14	FY15	FY16	FY17	Total
Task Number	**Labor Category**	**Est Labor Hours**	**Est Labor Hours**	**Est Labor Hours**	**Est Labor Hours**	
4a Test	Sci/Eng 4	40	40			80
Specimen	Technicians	100	100			200
Design/Eval	Machinist	30	30			60
	Metallographer	20	20			40
4b Initiation	Sci/Eng 4	60	80			140
Test System	Technicians	120	180			300
Const.	Crafts	60	100			160
4c Crack	*Sci/Eng 4*	*40*	*60*			*100*
Arrest Syst.	*Technicians*	*120*	*160*			*280*
Const.	*Crafts*	*50*	*90*			*140*
5a	Sci/Eng 4	30	50			80
Machine	Technicians	50	100			150
Initiation	Machinist	80	160			240
Specimens	Metallographer		80			80
5b Machine	*Sci/Eng 4*		*40*			*40*
Crack Arrest	*Technicians*		*60*			*60*
Specimens	*Machinist*		*100*			*100*
	Metallographer		*30*			*30*
6a Initiation	Sci/Eng 4		80			80
Test	Technicians		120			120
Unpeened	Sci/Eng 3		40			40
6b Test	*Sci/Eng 4*		*60*			*60*
Unpeened	*Technicians*		*100*			*100*
Crack Arrest	*Sci/Eng 3*		*20*			*20*
12a	Sci/Eng 4		70	120	40	240
Test Peened	Technicians		120	200	80	400
	Sci/Eng 3				80	80
12b	*Sci/Eng 4*			*40*	*60*	*100*
Test Peened	*Technicians*			*80*	*80*	*160*
Crack Arrest	*Sci/Eng 3*				*60*	*60*
13	Sci/Eng 6				50	50
TLR	Sci/Eng 4				150	150
Est. Totals	Sci/Eng 4	170	500	160	250	1080
Materials	Sci/Eng 3 - 6	0 - 0	60 - 0	0 - 0	80 - 50	140 - 50
Staff	Technicians	390	840	280	160	1670
	Machinist	110	290	0	0	400
	Metallographer		110	0	0	110

* *Optional Tasks are shown in Italics*

PNNL Concept for Assessing the Effect of Peening on SCC Crack Initiation

This concept leverages the use of a DCPD-instrumented compact tension type geometry to produce a specimen with high sensitivity to detection of crack initiation. It is thought that this geometry is amenable to assessing the effectiveness of peening.

As shown in the two drawings, the opening for peening could have a flat surface, or it could have a smooth arc. The specimen would not have any preexisting flaw. Stresses would be analyzed by FEM to assist in optimizing the geometry.

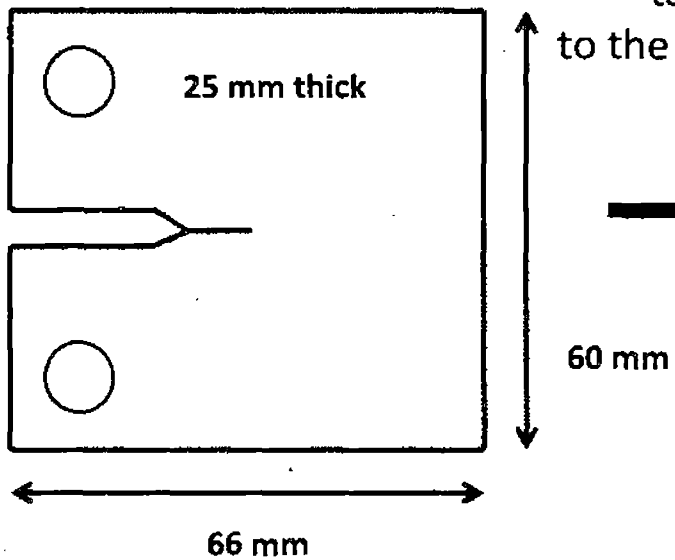


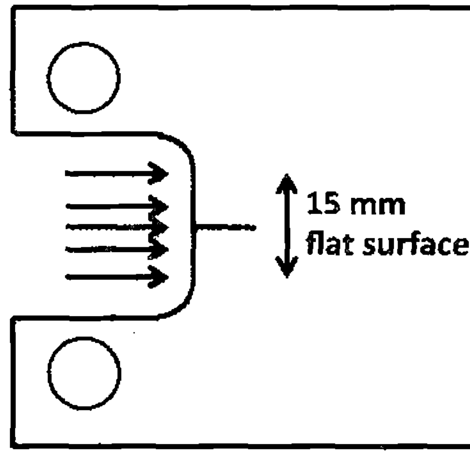
PNNL Concept #1 for Assessing the Effect of Peening on SCC Crack Growth Arrest

Step 1
Grow SCC crack in
1T CT specimen in
target environment

Step 2
Machine out material
to create flat surface
for peening and
tailor crack
to the desired depth

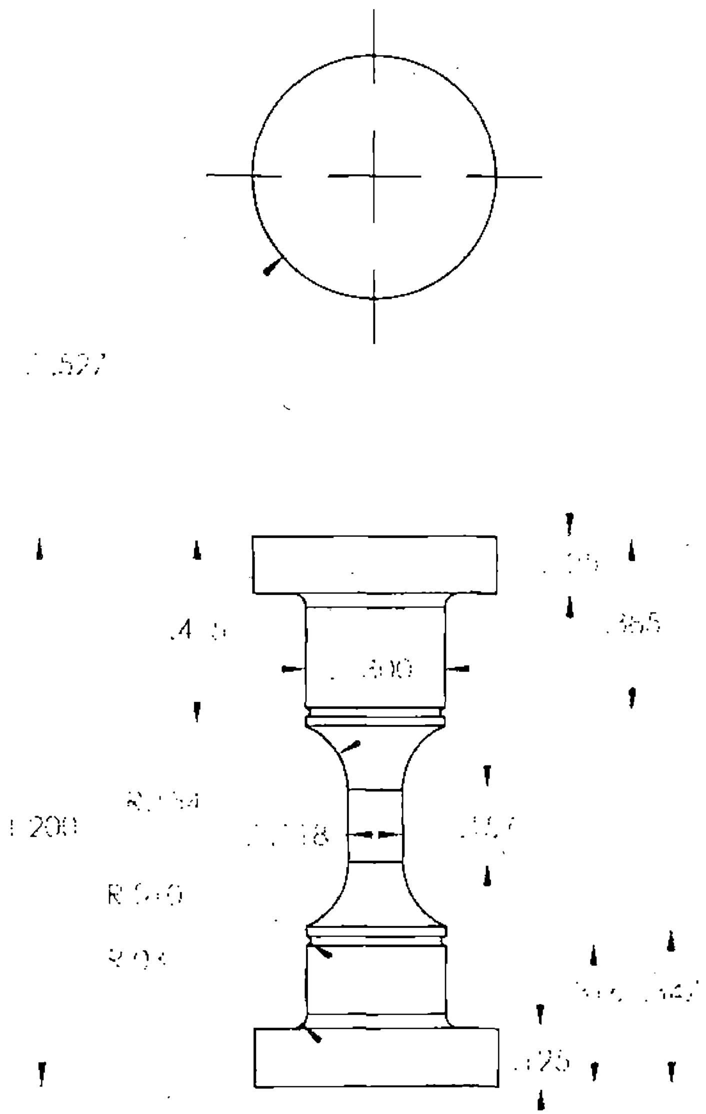
Step 3
Peen surface

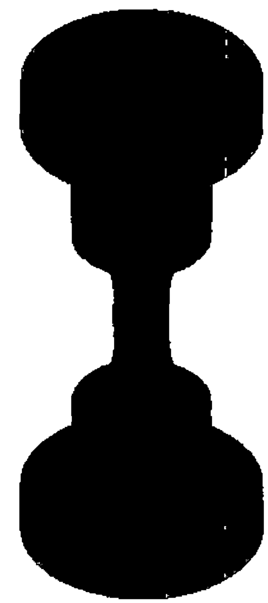




Step 4
Reinsert specimen
into environment
at constant load and
evaluate DCPD response

~~PREDECISIONAL~~





DRAWN BY AD GUZMAN
MATERIAL SUPPLIED
ENG APPR. ADG/RJS

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/32
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ± 0.001

PACIFIC NORTHWEST
NATIONAL LABORATORY

SIZE
A

Initiation_Sample_S_118gauge

SCALE: 2.5:1 6/14/2012 SHEET 1 OF 1

~~PREDECISIONAL~~

PNNL Concept #1 for Assessing the Effect of Peening on SCC Crack Growth Arrest

Step 1
Grow SCC crack in
1T CT specimen in
target environment

Step 2
Machine out material
to create flat surface
for peening and
tailor crack
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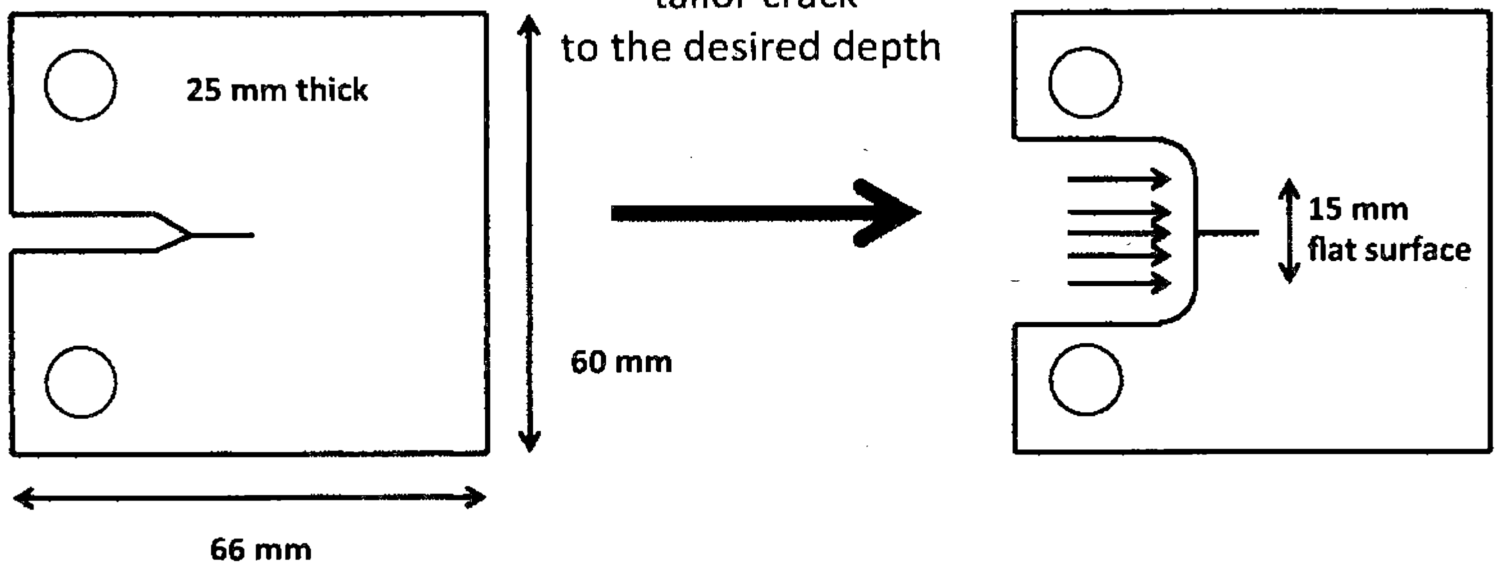
Step 3
Peen surface



Step 4
Reinsert specimen
into environment
at constant load and
evaluate DCPD response

~~PREDECISIONAL~~

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Tel (509) 375-2606
Fax (509) 375 6497
aaron.diaz@pnnl.gov

September 4, 2015

Carolyn Cooper
Contracting Officer
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Ms. Cooper:

Subject: Proposal for Agreement Number NRC-HQ-25-14-D-0001, "Technical Assistance in Support of Agency Environmental Reactor Programs", Task Order No. NRC-HQ-20-14-T-0025 "Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC", Modification No. 5, under EWA No. 65559

Our cost proposal for Modification No. 5 for the work statement for Pacific Northwest National Laboratory (PNNL) Project No. 66419, Task Order No. NRC-HQ-20-14-T-0025, "Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC", under EWA 65559, NRC Agreement Number NRC-HQ-25-14-D-0001 "Technical Assistance in Support of Agency Environmental Reactor Programs" is attached. The cost proposal covers the cost of the labor and expenses associated with the work statement included in your request for proposal (RFP) dated July 22, 2015.

Ms. Eva Eckert Hickey is the PNNL Program Manager for the EWA and Mr. Aaron Diaz is the Task Project Manager.

This task proposal includes the cost proposal for Task No. NRC-HQ-20-14-T-0025 (attachment 1), the schedule of deliverables (attachment 2), and a proposed staffing plan (attachment 3). We are including a resume for Jack Lareau who is an NDE and Nuclear ISI expert (attachment 4). Resumes for other key staff are already on file with the NRC for this task order.

The proposed period of performance is August 11, 2014 – February 15, 2019.

PNNL, to the best of its knowledge and belief, asserts that it has no current work, planned work, and where appropriate, past work for DOE and others (to mean - organizations in the same and/or similar technical area as the present and/or ongoing NRC project scope of work); and PNNL hereby asserts that it is not aware of any same/similar technical work that would give rise

~~PREDECISIONAL~~

to any potential OCOI as defined in the Atomic Energy Act of 1954, as amended, and in the NRC/DOE MOU.

Consistent with DOE's full cost recovery policy, DOE collects, as part of its standard indirect cost rate, a Laboratory Directed Research and Development (LDRD) cost levied on all monies received at the laboratory. The estimated amount of LDRD costs is identified in the proposal cost estimate section. DOE believes that LDRD efforts provide opportunities in research that are instrumental in maintaining cutting edge science capabilities that benefit all of the customers at the laboratory.

DOE will conclude that by approving and providing funds to DOE to perform the work under this proposal, you acknowledge that such activities are beneficial to your organization and consistent with appropriations acts that provide funds to you. Please note that the LDRD costs do not represent a new charge. Rather, the new Congressional requirement is for DOE to separately identify this indirect cost element.

If you have any questions, feel free to contact me at 509-375-2606.

Sincerely,

Aaron Diaz
Task Project Manager
Applied Physics Group

cc w/attach: Lori Bisping, PNNL
Jay Collins, NRC
Steve Cumblidge, NRC
Eva Hickey, PNNL
Tonya Keller, PNNL
Steve Schlahta, PNNL
Mychailo Toloczko, PNNL
Steve Unwin, PNNL

ATTACHMENT 1 - COST PROPOSAL

PART 1: DOE Laboratory Cost and Technical Proposal for NRC Work Cover Sheet			Date Proposal Sent September 2015 New Revision No. 5
Project Title. Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC			DOE Contractor Account Number DE-AC05-76RL01830
NRC Requisitioning Office: NRR			NRC Agreement Number: NRC-HQ-25-14-D-0001
DOE Laboratory: Pacific Northwest National Laboratory			NRC Agreement Modification Number: 5
DOE Site Address: Richland, WA			NRC Task Order Number: NRC-HQ-20-14-T-0025
COGNIZANT PERSONNEL	**E-MAIL ADDRESS**	**TELEPHONE NUMBER**	NRC Task Order Modification Number:
NRC COR: Jay Collins	jay.collins@nrc.gov	301-415-4038	NRC Common Cost Center Code
Other NRC Staff: Stephen Cumblidge	stephen.cumblidge@nrc.gov	301-415-2823	NRC B&R Number
DOE Project Manager Jeffrey W. Day	jeffrey.day@science.doe.gov	509-372-4629	NRC BOC
Laboratory Project Manager: Eva Hickey	eva.hickey@pnnl.gov	509-375-2065	**PERIOD OF PERFORMANCE**
Principal Investigator(s): Aaron Diaz	aaron.diaz@pnnl.gov	509-375-2606	Estimated Start Date: August 11, 2014
			Estimated End Date: February 15, 2019

PROPOSED COST BY FISCAL YEAR		
FY 2016	FY 2017	FY 2018
Total Estimated Cost $ 545,923	Total Estimated Cost $ 163,178	Total Estimated Cost $ 65,638
FY 2019	FY ______	FY ______
Total Estimated Cost $ 38,097	Total Estimated Cost	Total Estimated Cost
TOTAL PROPOSED COST	$ 812,837	

Signature - Approval Authority	Date
Approval Authority - Name, Email and Phone	

PART 2: TOTAL PROPOSED COST BREAKDOWN

[illegible]

Fiscal Year	FY 2016 Labor Category	Labor Rate	Proposed Direct Labor Hours	Total Estimated Cost
Direct Labor	Sr. SAE [illegible]	$ 112.81	70	$ [illegible]
	SAE 4 [illegible]	$ [illegible]	140	$ [illegible]
	SAE 3			
	SAE 2	$ [illegible]	40	$ 2,402.75
	SAE 1	$ [illegible]	24	$ [illegible]
	Sr. Advance [illegible]	$ [illegible]	134	$ 17,885.84
	E. Technician	$ [illegible]	53	$ [illegible]
	Technician	$ 50.[illegible]	343	$ 18,152.93
	Crafts	$ [illegible]	85	$ 6,161.46
	Project coordinator	$ [illegible]	40	$ 2,922.26
Total Labor Hours & Direct Labor			900	$ 75,098
Materials and [illegible]				$ 111,257
Travel				$ [illegible]
Subcontracts Consultants				$ 198,854
Overheads				$ 58,930
Total Direct Costs				$ 480,366
General and Administrative Expense Final Rate [illegible]				$ 75,057
Total Proposed Cost				$ 530,022
DOE Added Factor [illegible]				$ 15,901
Total Proposed Cost including DOE Added Factor				$ 546,923

Fiscal Year	FY 2017 Labor Category	Labor Rate	Proposed Direct Labor Hours	Total Estimated Cost
Direct Labor	Sr. SAE [illegible]	$ [illegible]	70	$ 8,582.15
	SAE 4 [illegible]	$ [illegible]	60	$ [illegible]
	SAE 3	$ [illegible]	40	$ [illegible]
	SAE 2			
	SAE 1			
	Sr. Advance [illegible]	$ [illegible]	6	$ [illegible]
	Sr. Technician			
	Technician	$ [illegible]	220	$ [illegible]
	Crafts			
	Project coordinator	$ 75.7[illegible]	40	$ [illegible]
Total Labor Hours & Direct Labor			419	$ 31,367
Subcontracts Consultants				$ [illegible]
Overheads				$ [illegible]
Total Direct Costs				$ 170,728
General and Administrative Expense				$ 20,097
Total Proposed Cost				$ 188,428
DOE Added Factor				$ 4,753
Total Proposed Cost including DOE Added Factor				$ 193,178

Fiscal Year	FY 2018 Labor Category	Labor Rate	Proposed Direct Labor Hours	Total Estimated Cost
Direct Labor	Sr. SAE [illegible]	$ 128.14	33	$ [illegible]
	SAE 4 [illegible]	$ [illegible]	[illegible]	$ [illegible]
	SAE 3			
	SAE 2			
	SAE 1			
	Sr. Advance [illegible]			
	Sr. Technician			
	Technician	$ 54.[illegible]	[illegible]	$ [illegible]
	Crafts			
	Project coordinator	$ [illegible]	24	$ [illegible]
Total Labor Hours & Direct Labor			327	$ [illegible]
Overheads				$ [illegible]
Total Direct Costs				$ 63,638
General and Administrative Expense				$ [illegible]
Total Proposed Cost				$ [illegible]
DOE Added Factor				$ [illegible]
Total Proposed Cost including DOE Added Factor				$ [illegible]

[illegible]

PART 3: SPENDING PLAN

	NRC Agreement Number NRC-HQ-25-14-D-0001	NRC Agreement Modification Number	NRC Task Order Number NRC-HQ-20-14-T-0025

Project Title: Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC

FY 2014

	October	November	December	January	February	March	April	May	June
Estimated Cost									
Total FY Cost	**$**								

FY 2015

	October	November	December	January	February	March	April	May	June
Estimated Cost	$ 69,041	$ 89,275	$ 151,338	$ 60,434	$ 65,227	$ 54,872	$ 47,687	$ 33,125	$197,404
Total FY Cost	**$**								

FY 2016

	October	November	December	January	February	March	April	May	June
Estimated Cost	$ 95,882	$ 95,882	$ 178,472	$ 87,491	$ 87,490	$ 87,490	$ 87,490	$ 87,490	$ 87,490
Total FY Cost	**$**								

FY 2017

	October	November	December	January	February	March	April	May	June
Estimated Cost	$ 26,587	$ 26,586	$ 26,586	$ 26,586	$ 26,586	$ 26,586	$ 26,586	$ 26,586	$ 26,586
Total FY Cost	**$**								

FY 2018

	October	November	December	January	February	March	April	May	June
Estimated Cost	$ 1,150	$ 1,150	$ 1,150	$ 1,150	$ 1,150	$ 8,568	$ 8,560	$ 8,560	$ 8,550
Total FY Cost	**$**								

FY 2019

	October	November	December	January	February				
Estimated Cost	$ -	$ -	$ 12,699	$ 12,699	$ 12,699				
Total FY Cost	**$**								

NOTE spend plan represents current authorized ceiling plus mod 5 funding.

MODIFICATION #5 (additional funds necessary for revised worksope)					
TASK	FY16	FY17	FY18	FY19	Sum $'s
Task 2a Optional	(not proposed at this time)				
Task 3	$169,686				$169,686
Task 4	$59,852				$59,852
Task 5	$14,039				$14,039
Task 5C Optional	$30,644	$51,520			$82,164
Task 7	$176,030				$176,030
T7a	$60,530				$60,530
T7b	$0				$0
T7c	$84,618				$84,618
T7d	$30,882				$30,882
Task 7a Optional	$49,412				$49,412
Task 10A Optional	(Task 10 was proposed under original SOW - no new funding necessary)				
Task 11 Optional		$83,506			$83,506
Task 11a		$52,624			$52,624
Task 11b		$30,882			$30,882
12c Optional			$51,847	$38,097	$89,944
14 PM & MLSRs	$27,050	$28,152	$13,791		$68,993
Task 16 New Optional	$19,210				$19,210
SUM ALL	$545,923	$163,178	$65,638	$38,097	$812,837
SUM without Options	$446,657	$28,152	$13,791	$0	$488,600
Only Options	$99,266	$135,026	$51,847	$38,097	$324,236

COST ELEMENT INFORMATION

DIRECT LABOR

Direct labor costs are based on average charge-out rates for specific job categories. Average charge out rates are computed as follows

Average Salary x (1 + Fringe Benefit Rate)
Productive Hours

Average charge-out rates are calculated each fiscal year (FY is October 1 through September 30) as follows

FY	Salary Increase (compounding annually)	Fringe Benefit Rate	Productive Hours
2015	0.00%	32.50%	1832
2016	2.32%	32.50%	1840
2017	3.69%	32.50%	1832
2018	3.35%	32.50%	1832
2019	3.35%	32.50%	1832

The fringe benefit rate for limited term employees is 20.4% and the hourly fringe rate is 9%. Productive hours in a year exclude holidays, vacation and other absences

OVERHEAD

Organizational Overhead

Organizational Overhead represents costs for management, supervision and administration of technical departments. Organizational Overhead for each respective research organization also includes costs for building and utilities, small tools, lab supplies, laundry, maintenance, and expenses associated with equipment unless the equipment is assigned to a specific equipment center. Organizational Overhead for the Intern Fellows will be used to collect and recover Intern associated costs, such as office space, computer workstations, mandatory training requirements and other similar expenses. This overhead will only apply to exempt students. Non exempt students are short term, usually are not assigned office space and do not usually receive a new computer or amenities an exempt staff member would require. Organizational overhead rates have been submitted to the US Department of Energy, Pacific Northwest Site Office

Program Development and Management (PDM)

The Program Development and Management (PDM) pool is used to accumulate the costs associated with business development and program integration activities. PDM is allocated to objectives by applying the appropriate rate to value added (excluding PDM) costs, plus materials and subcontracts costs (excluding Science and Engineering and Education Program, Inter-entity Work Order and Inter-Laboratory Administrative costs). The PDM rates have been submitted to the US Department of Energy, Pacific Northwest Site Office. The PDM rate per fiscal year is as follows

2015	5.40%
2016	5.40%
2017	5.40%
2018	5.40%
2019	5.40%

TRAVEL

Airfare rates have been estimated utilizing non refundable quotes from Travel Management Partners (TMP). Subsistence costs (meals and lodging) have been estimated using per diem rates published in the Federal Travel Regulations. Travel rates have been escalated at the annual rates listed below

2015	0.00%
2016	2.10%
2017	2.20%
2018	2.30%
2019	2.30%

OTHER DIRECT COST

Procurement & Subcontracts Support

The support costs for acquisition of goods and services are recovered by applying the appropriate rate to all cost objectives. The acquisition service rates have been submitted to the US Department of Energy, Pacific Northwest Site Office. The rate applied per FY is as follows

2015	6.50%
2016	6.50%
2017	6.50%
2018	6.50%
2019	6.50%

Purchasing Card

The support costs for acquisition of goods and services using P-cards are recovered by applying the appropriate rate to all cost objectives. The acquisition service rates have been submitted to the US Department of Energy, Pacific Northwest Site Office. The rate applied per FY is as follows

2015	4.90%
2016	4.90%
2017	4.90%
2018	4.90%
2019	4.90%

Business to Business

The support costs for acquisition of goods and services using B2B are recovered by applying the appropriate rate to all cost objectives The acquisition service rates have been submitted to the US Department of Energy Pacific Northwest Site Office The rate applied per FY is as follows:

2015	4.90%
2016	4 90%
2017	4.90%
2018	4 90%
2019	4 90%

OTHER INDIRECT COST

Lab Directed Research and Development

LDRD is research and development work of a creative and innovative nature for the purpose of maintaining the scientific and technological vitality of the Laboratory and/or responding to new scientific or technological opportunities. Costs are pooled and then allocated to final objectives by applying the predetermined rate to the value added base. The value-added base includes labor, organizational overhead, Program Development and Management, travel, service and equipment centers, building and utility, and other direct costs. Excluded from the base costs are procurements, subcontracts, Science and Engineering and Education Program, and other Hanford contractor service costs The LDRD rates have been submitted to the US Department of Energy Pacific Northwest Site Office The LDRD rate per fiscal year is as follows·

2015	9 00%
2016	9.00%
2017	9.00%
2018	9 00%
2019	9 00%

General and Administrative Expense

G&A includes general functions such as Accounting, Legal and Personnel department costs, contract administration, replacement cost of laboratory support equipment and the purchase of general research equipment G&A is allocated to final objectives by applying the appropriate rate to the value-added base. The value-added base includes: labor, travel, service and equipment centers, organizational overhead, program development and management building and utility costs and other direct costs Excluded from the base costs: procurements, subcontracts, Science and Engineering Education (SEE), and Other Hanford Contractor (OHC) services The G&A rates have been submitted to the US Department of Energy, Pacific Northwest Site Office. The G&A rate per fiscal year is as follows

2015	34 50%
2016	34 50%
2017	34 50%
2018	34 50%
2019	34 50%

Service Assessment

Service Assessment includes the fee Department of Energy pays its Management and Operations (M&O) contractor, costs paid to DOE for plant-wide support services such as fire, library, road maintenance, and DOE Emergency Response Center Service Assessment costs are allocated at applicable rate of total estimated costs The rates have been submitted to the US Department of Energy Pacific Northwest Site Office The rates per fiscal year are as follows:

2015	2 00%
2016	2 00%
2017	2 00%
2018	2.00%
2019	2.00%

Federal Administrative Charge

The Federal Administrative Charge (FAC) includes costs for administrative effort of the Department of Energy allocable to the Work For Others (WFO) and Agreement for Commercialization of Technology Programs The Federal Administrative Charge is a percentage of total cost, including service assessment The Federal Administrative Charge per fiscal year is as follows

2015	3 00%
2016	3 00%
2017	3 00%
2018	3 00%
2019	3 00%

ATTACHMENT 2
NRC Agreement Task Order No.: NRC-HQ-20-14-T-0025 - Proposal

Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC

STATEMENT OF WORK

NRC Agreement Number NRC-HQ-25-14-D-0001	NRC Agreement Modification Number N/A	NRC Task Order Number (If Applicable) NRC-HQ-20-14-T-0025	NRC Task Order Modification Number (If Applicable)
Project Title Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC			
Job Code Number	**B&R Number**	**DOE Laboratory** Pacific Northwest National Lab	
NRC Requisitioning Office NRR			
NRC Form 187, Contract Security and Classification Requirements ☐ Applicable ☒ Not Applicable	☐ Involves Proprietary Information ☐ Involves Sensitive Unclassified		
☒ Non Fee-Recoverable	☐ Fee-Recoverable (If checked, complete all applicable sections below)		
Docket Number (If Fee-Recoverable/Applicable)	**Inspection Report Number (If Fee Recoverable/Applicable)**		
Technical Assignment Control Number (If Fee-Recoverable/Applicable)	**Technical Assignment Control Number Description (If Fee- Recoverable/Applicable)**		

1.0 BACKGROUND

Primary water stress corrosion cracking (PWSCC) of nickel-base alloy components and welds in the reactor coolant system of pressurized water reactors is a significant regulatory concern due to the potential for cracking or boric acid corrosion that could lead to a loss of coolant accident. Regulatory requirements have been established over the past 10-years to develop an inspection program that tries to proactively address this potential degradation mechanism to provide reasonable assurance of leak-tightness and structural integrity of the reactor coolant pressure boundary. Several mitigation techniques have been authorized by the NRC to allow relaxation of these inspection requirements due to the evaluated effectiveness of the mitigation to address PWSCC. Similarly these mitigation programs with the associated modified inspection program provide defense in depth to meet the NRC goals of protecting public health and safety.

The Materials Reliability Program (MRP) of Electric Power Research Institute (EPRI) submitted a topical report for review to the NRC entitled, "Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement (MRP-335, Revision I)." This report summarizes a technical basis to allow the NRC to review the effectiveness of three types of surface stress improvement; water jet peening, underwater laser peening and air laser peening. The purpose of the report is to provide a basis for licensees of pressurized water reactors to proactively mitigate their nickel-alloy components and welds and then modify their inspection programs for the mitigated components or welds.

In order to complete an effective evaluation of the peening processes identified, NRC staff requires the use of laboratory resources to perform testing on realistic plant components under as close as possible in-service operational conditions. Further, the NRC staff is focusing this testing on surfaces for which access is limited or the surface condition is rough to ensure effective application of the peening process is possible for the range of components identified in MRP-335.

In February 2015, the NRC re-evaluated the path forward for the review of MRP-335. After a series of public meetings with stakeholders, the NRC determined that the review would consist of three distinct parts. The first part would be to determine if peening for the purpose of surface stress improvement would be allowed to be implemented. The second part would be the determination of the regulatory examination frequency relief that should be provided given a certain level of stress improvement, as generically defined in MRP-335. The third part would be the verification process necessary to ensure a licensee's peening process was effective at obtaining the necessary level of stress improvement, as generically defined in MRP-335. This three-part approach significantly changed the way MRP-335 was to be reviewed for approval.

Hence the three part approach to review peening and MRP-335 has a significant impact on this task order's scope of work. This revised statement of work is provided to transition the old program into the scope of the new NRC objectives. **It should be noted that while the scope of the original work has changed, it is not envisioned that the agreement ceiling will increase as the result of this modification.**

2.0 OBJECTIVE

The objective of the new verification project is to provide the NRC staff the tools necessary to ensure the effectiveness of any peening process to meet the levels of stress improvement defined in MRP-335. The tools will be DOE findings of the tasks outlined in this statement of work that have been developed to support NRC identified limitations of peening processes. The NRC will use these tools to evaluate each licensee's specific peening process through their quality assurance programs in the third part of the review process. This work is not to be considered a comprehensive research project to evaluate the full and complete effectiveness of each peening process; it is instead a verification of known limiting cases to provide reasonable assurance that each process meets the levels of stress improvement defined in MRP-335.

3.1 SCOPE OF WORK

The DOE Laboratory must provide all resources necessary to accomplish the tasks and deliverables described in this statement of work (SOW). The following items should be considered;

1. Upper head penetration nozzles with at least three different incident angles (0-10 degrees, 15- 25 degrees, and > 30 degrees) including partial penetration weld. No grinding should be performed on the weld surfaces.

2. Alloy 182/82 butt welds representative of reactor coolant system piping butt welds with surface roughness at the limits allowed by MRP-335.

3. Alloy 600 plate
   a. Without flaws as a baseline for initiation testing
   b. Without flaws to be peened for initiation testing
   c. With surface stress corrosion cracks to be peened for crack arrest testing

4. Alloy 182 weld on plate, surface cleaned but left in the "as-welded" condition.
   a. Without flaws as a baseline for initiation testing
   b. Without flaws to be peened for initiation testing
   c. With fabrication defects both surface breaking and very near-surface (5mm to 0.2mm in depth from surface) for initiation testing
   d. With surface stress corrosion cracks to be peened for crack arrest testing

The DOE Laboratory must be able to perform eddy current and ultrasonic testing of items above. The DOE Laboratory must be able to add sufficient indications in items above to determine the surface and subsurface depth detection capability of the eddy current inspection technique. The DOE laboratory must be able to provide expert recommendations for the implementation of examination techniques to provide inspection coverage for the depth of compression identified in MRP-335.

The DOE Laboratory must be able to mathematically predict the weld residual stresses in items 1 and 2 above to identify the areas of higher weld residual surface and near surface stresses. The DOE Laboratory must be able to use multiple weld residual stress measurement techniques (including, but not limited to, surface incremental hole drilling, slotting and x-ray diffraction) to evaluate the predicted weld residual surface and near surface stress conditions up to 1 millimeter in depth of items 1 and 2 above, both pre and post peening. The DOE laboratory must provide their expert opinion on the effectiveness of this process to validate peening depth of compression in individual licensee mockups, and provide any recommendations for requirements to provide adequate assurance of an effective validation test.

The DOE Laboratory must be able to perform in-situ PWSCC initiation testing on baseline cold worked alloy 600/182/82 specimens in the pre and post peened conditions to determine if there is reasonable assurance that a minimum improvement factor of 5 is applicable to crack initiation for these materials.

The DOE Laboratory must be able to perform in-situ PWSCC crack arrest testing on peened cold worked alloy 600/182/82 specimens with pre-existing stress corrosion cracks of multiple depths to provide reasonable assurance of depth of compression required in MRP-335 is adequate to arrest flaw growth.

The DOE Laboratory will provide documentation of their results and participate in monthly status calls throughout the period of performance. Additionally, DOE Laboratory staff will support public meeting discussions with the authors of the topical report to address any needed additional information and discuss final results of the project. Finally, DOE Laboratory will provide a technical letter report summarizing the effort and providing all details of the findings for use in NRC written safety evaluations.

The DOE Laboratory may need to travel to supervise any subcontracts that are necessary such as manufacture or processing of samples or measurement of weld residual stress.

The DOE Laboratory will be responsible for shipment of all specimens to and from designated sites for the application of the peening process.

4.1 SPECIFIC TASKS

The DOE Laboratory must perform the following tasks:

Task 1 – The NRC will provide to the DOE Laboratory all submitted documentation associated with the review of MRP-335 to include the original submittal, any supporting technical document basis, and any additional documentation provided due to requests for additional information, as available. The DOE Laboratory will be familiar with the information provided and control proprietary information in accordance with standardized agreements between the NRC and DOE Laboratory.

DOE Laboratory (PNNL) Task 1 Response:

PNNL will obtain any necessary literature or pertinent documentation as reviews and technical expertise are requested from the Sponsor (NRC). PNNL will become familiar with the documents and any additional supporting technical documents provided by the NRC, and PNNL will handle the information appropriately (and in accordance with agreed protocols) with regard to any proprietary or business sensitive information contained therein. PNNL understands that the NRC may request technical support in the form of reviews or technical comments as requests for relief are submitted and as requests for additional information (RAIs) are generated. PNNL will support these requests on an as-needed basis, and understands that these requests will likely be supported via written reviews, and verbal discussions (telephone calls or teleconferences). However, some situations may develop that require PNNL travel to Rockville, MD, (or other destination) to support a discussion or request for a technical opinion, via a face-to-face meeting, and these situations will be handled on a case-by-case basis as the project evolves, directly with the NRC Contracting Officer's Representative (COR).

PNNL notes that during the last round of RAI discussions, MRP specified that ID peening was required to support their risk analysis. While PNNL does not agree with this position, if ID peening becomes an important aspect to this work, an additional modification to the workscope will become necessary, as the work defined in this SOW is solely focused on OD peening applications.

Task 2 – The DOE Laboratory must acquire the following types of samples in sufficient quantity to meet the needs of the remaining tasks of this statement of work.

1. Upper head penetration nozzles with at least three different incident angles (0-10 degrees, 15- 25 degrees, and > 30 degrees) including partial penetration weld. No grinding should be performed on the weld surfaces.

2. Alloy 182/82 butt welds representative of reactor coolant system piping butt welds with surface roughness at the limits allowed by MRP-335.

3. Alloy 600 plate
   a. Without flaws as a baseline for initiation testing
   b. Without flaws to be peened for initiation testing
   c. With surface stress corrosion cracks to be peened for crack arrest testing

4. Alloy 182 weld on plate, surface cleaned but left in the "as-welded" condition.
   a. Without flaws as a baseline for initiation testing
   b. Without flaws to be peened for initiation testing
   c. With fabrication defects both surface breaking and very near-surface (5mm to 0.2mm in depth from surface) for initiation testing
   d. With surface stress corrosion cracks to be peened for crack arrest testing

DOE Laboratory (PNNL) Task 2 Response:

PNNL will identify, locate and configure the necessary materials/samples for fabrication of the required specimens identified in Task 2 above, (1-4). Many of the specimens have already been located at PNNL and prepared for use on the project. Some specimens may need to be cut out (extracted) from larger component configurations. In addition, some specimens may require reduction in size (and weight) for more improved handling and manipulation in the Lab. This Task includes acquisition and configuration of the necessary NDE data acquisition systems and scanning setups.

Items 1 and 2 above:

For the DMW mockups, in particular the nozzles provided to PNNL by Engineering Mechanics Corporation of Columbus (EMC^2), it may be necessary to cut (reduce) the carbon steel back-end of the mockup, by cutting off some amount of the nozzle (away from the DMW of interest) to allow ease of handling, manipulation and rotation for ET scanning. The existing PNNL rotational scanner platform (for conducting outside surface ET exams on cylindrical components) has a maximum weight capacity of 500 lbs. If the owner's of

the mockups will not allow for some carbon steel nozzle material reduction, PNNL will need to obtain a rotational scanning platform (under Task 3) that has a higher weight capacity and also procure motors and motor drivers to couple the motion control to both existing PNNL data acquisition/control systems and the new WesDyne ET data acquisition system. The material costs associated with this option are approximately $15K, and will provide the capability to conduct rotational ET scans on very heavy, large components without the need to cut them down in size. There will also be some labor associated with writing up the driver code to couple the motor pulses from the DAS to the motor controller, but this is anticipated to be on the order of 40-60 hours. PNNL believes these nozzles could be reduced in size (via cutting), without significantly affecting the stresses on the targeted DMWs.

PNNL will subcontract this work out to a trusted and proven 3rd party for any required fabrication, cold spray or welding processes. These specimens will be appropriately marked and sectioned for specific activities (two stages of NDE, peening, and two stages of WRS measurements) throughout the effort. Baseline markings for development of a scanning coordinate system will be etched onto the surfaces of the mockups. Sufficient surface areas on each specimen will be made available for effective peening and for both NDE and WRS measurements. Specimens will contain areas designated for "no-peening" and "peening-only" processes. Some of this work has already been completed in numbers 1 and 2 above, however, the addition of a small (0° to 10°) incident angle upper head penetration nozzle will require some additional work. Originally, all CRDM nozzles for potential use on this project had been identified, extracted from the vessel and machined/prepared for characterization and NDE. This CRDM nozzle may need to be extracted from the remaining cluster of 3 upper head penetrations still residing in the vessel head material. If this is the case, an identical process as conducted on the other CRDM nozzles over the past many months, will be conducted to extract the one remaining nozzle from the vessel head, machine, cut and condition the mockup, for more manageable NDE, WRS and peening activities. This part of the effort will include Teamster costs associated with the use of a crane, flatbed truck and transportation costs, CRDM extraction/cutting, additional sample specimen conditioning and machining for reduction of unnecessary material and nozzle length, and associated in-lab configurations for handling and management of these large and heavy specimens. Work at PNNL to cut, machine or otherwise configure, handle and ship specimens out, will require the use of Service Requests through the Laborer's Union contract currently in operation at the Hanford Site. These requests typically take more time and can be more costly than anticipated. The schedule and costing information associated with this Task have taken this into consideration.

Item 3 above:

PNNL agrees with this, and the material for Items 3a and 3b have already been obtained as part of the originally accepted SOW. Item 3c will be obtained by starting with the same material used for Items 3a and 3b. As part of Task 5, SCC cracks will be grown into oversize specimens using SCC testing methods that have been developed at PNNL for CT specimen crack growth rate testing.

Item 4 above:

Regarding 4a and 4b, PNNL agrees with this, and the material was obtained as part of the originally accepted SOW. Regarding item 4c, this material was not in the originally accepted SOW and represents significant additional time and cost to produce. The time available to respond to this SOW was insufficient to determine a feasible means to produce such a material. An optional task (16) has been added to determine a cost to obtain this material and test it. Regarding 4d, PNNL agrees with this, and the material will be obtained by starting with the same material used for Items 4a and 4b. As part of Task 5, SCC cracks will be grown into oversize specimens using SCC testing methods that have been developed at PNNL for CT specimen crack growth rate testing.

Task 2a (optional) – The DOE Laboratory will implant flaws, stress corrosion crack like indications, in one or more of the items in Task 2, Items 1 and 2, as directed by the NRC. If Task 2a is implemented, NRC understands it may delay the completion of Task 3 by two months.

DOE Laboratory (PNNL) Task 2a Response:

As directed by the NRC COR, PNNL will support this activity to identify a suitable vendor and direct the introduction of flaws into specimens identified in Items #1 and #2 of Task 2. There are numerous ways to introduce flaws or stress corrosion crack-like indications into these specimens. These may include implantation techniques, thermally induced crack initiation, cold-spray techniques, or other methods. The cost and time to complete these various flaw introduction approaches vary as a function of the flaw-type, flaw dimensions, flaw locations, and component-material configuration and characteristics. If the NRC COR directs PNNL to investigate insertion of flaws/cracks into these mockups, a cost assessment will need to be conducted, and a determination can be made at that time, to pursue or not pursue this activity.

If this Task is initiated, PNNL recommends adding some simulated voids/inclusions for near surface flaws based on the destructive testing (DT) results from South Texas Project (STP) and the Arizona Public Service (APS) leaking bottom mounted nozzles. Even though BMIs are not components currently specified in this evaluation, it is essentially the same disease. Both the NRC and PNNL have copious amounts of information on these efforts, to support a basis for including these.

Task 3 – The DOE Laboratory will perform eddy current and ultrasonic examinations of the areas to be peened of items 1 & 2 of Task 2. The DOE Laboratory can perform eddy current examination of items 3 and 4 as necessary to evaluate the examination process on these materials. The DOE Laboratory will document, in a procedure, the steps taken to develop the most effective eddy current examination for surface and subsurface flaw of the items of Task 2.

DOE Laboratory (PNNL) Task 3 Response:

PNNL will conduct a best-effort for obtaining effective baseline NDE (including ET and PA-UT examinations) on pre-peened areas of the sample specimens identified in items #1

and #2 above in Task 2. There may exist as-welded surface conditions and geometry on some specimens that may impede access or otherwise degrade NDE data quality (for example due to liftoff of the ET probe). PNNL will conduct the most effective NDE assessments available for these measurements. In addition, all NDE approaches and scanning protocols employed in this work will be documented appropriately. A detailed procedure, defining the steps performed for an assessment of ET detection performance (to determine maximum detection capabilities for near/sub surface flaws) will also be developed. Specimens identified for these measurements may employ a well-controlled cold-spray technique, iteratively applied over the surface of the specimens to provide step-wise changes in thickness of the surface coating as a function of each ET test. This will provide an effective means to determine probe depth of penetration as a function of frequency and flaw characteristics. Additionally, PNNL suggests considering the use of time-of-flight diffraction ultrasonic testing (TOFD-UT) as a complementary technique for characterizing the J-groove welds and DMWs identified in Task 2.

The specific probes desired to conduct the NDE assessments have been obtained. The Eddy Current data acquisition and signal conditioning system will be procured as part of this activity. Once obtained, a scan plan and protocol will be developed and ET will be conducted on all J-groove welds and DMWs identified in items #1 and #2 above in Task 2. For the CRDM specimens, 0° phased array ultrasonic (PA-UT) examinations will also be conducted for detection and localization of weld fabrication defects and slag inclusions at the J-groove weld/tube-wall boundary. It is critical that PNNL assess whether or not the CRDM specimens contain this condition or not. Much of this NDE work has already been conducted on the CRDM nozzle mockups, with the exception of the small (0° to 10°) incident angle upper head penetration nozzle. For the DMW specimens, PA-UT examinations _may_ be conducted to baseline the welds prior to WRS and peening activities, but only with guidance from the NRC COR.

If the owner's of the mockups in Task 2 (item 2) will not allow for some carbon steel nozzle material reduction, PNNL will need to obtain a rotational scanning platform (under Task 3) that has a higher weight capacity and also procure motors and motor drivers to couple the motion control to both existing PNNL data acquisition/control systems and the new WesDyne ET data acquisition system. The material costs associated with this option are approximately $15K, and will provide the capability to conduct rotational ET scans on very heavy, large components without the need to cut them down in size. There will also be some labor associated with writing up the driver code to couple the motor pulses from the DAS to the motor controller, but this is anticipated to be on the order of 40-60 hours. PNNL believes these nozzles could be reduced in size (via cutting), without significantly affecting the stresses on the targeted DMWs.

PNNL will make every effort to expedite the schedule and compress the time for conducting and reporting NDE measurements. The PNNL team will encounter a time-lag between the time the ET data acquisition system is procured (immediately upon acceptance and authorization of this modified SOW by the NRC) and the time the system has been received at PNNL, and configured for laboratory data acquisition work. Current lag-time is anticipated to be approximately 10 weeks.

The NDE data obtained in Task 3 will be used as baseline data to compare/contrast with post-peened mockups. This subsequent work will be conducted under Task 10.

Task 4 – The DOE Laboratory will engineer, procure and evaluate through testing, a crack initiation testing rig and a crack arrest testing rig capable of in-situ testing of each sample under pressurized water reactor conditions with increased environmental susceptibility due to temperature only. The DOE Laboratory will provide a technical letter report (TLR) documenting the assembly, evaluation and verification of the equipment prior to use on specimens. The NRC will review and approve the TLR prior to testing.

DOE Laboratory (PNNL) Task 4 Response:

PNNL proposes to add an additional task to develop and qualify an appropriate test specimen to evaluate the effectiveness of peening on SCC crack initiation and SCC crack arrest. PNNL also proposes changes to this task description to add more detail.

Task 4a: ***Design and Evaluate a Specimen for Assessing The Effect of Peening on SCC***

A new test specimen will be designed and evaluated to establish its effectiveness to assess the effect of peening on SCC initiation and SCC crack arrest. This task will begin with finite element modeling of specimen concepts with a goal of producing a specimen that can be fitted with DCPD instrumentation to monitor for cracking and can be peened. A key aspect of specimen design will be to produce peak stresses in the region where SCC initiation is desired to occur. Several specimens will then be fabricated and tested to demonstrate initiation response using an available PNNL-owned or NRC-owned test system. In addition, both FEA and CGR testing on a relevant material will likely be conducted on cold-worked Alloy 600.

Through ongoing work started under the original SOW, a 4-point bend specimen has been selected. Specimen design is complete, and a test fixture design is nearly complete that maintains load on the specimen through the peening process and the entire test period. This ability to maintain load is vital to effectively simulate a service environment where the completed reactor structure with its residual stresses and strains is peened.

While only a few short steps are needed to produce a peened specimen for crack initiation testing, several more steps that take a substantial length of time are needed to produce a peened crack arrest specimen. The additional steps needed to prepare such a specimen are: 1) Grow an intergranular SCC crack into an oversized, notched 4-pt bend specimen. [~3.5 months] 2) Remove excess material from the specimen to produce a surface crack of desired depth. [~0.5 months] 3) Confirm SCC response of this modified specimen. [~1 month]. The total additional time is expected to be ~5 months. Due to the variability in SCC response for a given material, especially for weld metals, it is challenging to grow SCC cracks to a particular length in multiple specimens simultaneously in one autoclave. It is envisioned that this can be done with only 3 specimens at a time. These steps to produce SCC cracked specimens for peening adds

substantial time to the process and will limit the number of crack arrest specimens that can be produced during the program lifetime.

The level of effort estimated to complete this task has grown beyond expectation due to the selection of a brand new specimen concept and also due to the realization that in order to properly evaluate the effects of peening, the fixture must be able to maintain load on the specimen before, during, and after the peening process. Careful consideration was needed to determine a design that cannot only maintain load as described, but also allows the specimen surface to be peened. Effects of thermal expansion on load relaxation during fixture heating also had to be considered for the design. And at the same time, the goal of a 27-specimen fixture had to be maintained.

Task 4b: ***Fabrication of One Test System for Peening SCC Initiation Research***

An SCC initiation test system will be engineered, components will be procured, and the system operation will be validated through testing. The completed system will enable simultaneous testing of not less than 27 specimens under PWR primary water conditions at 360°C with in-situ crack detection.

Task 4c: ***Fabrication of Test System for Peening SCC Crack Arrest Study***

A test system to evaluate the effect of peening on SCC crack arrest will be engineered, parts will be procured, and the system will be constructed. The system will be capable of in-situ testing of not less than 6 specimens simultaneously under 360°C PWR primary water conditions, and it will have the capability to easily be later retrofitted with a 27-36 specimen SCC initiation load train.

Task 4d: ***Technical Letter Report on Specimen Design and System Construction***

A technical letter report (TLR) will be provided documenting peening specimen design and validation, and the assembly, evaluation and verification of the equipment prior to use for evaluating the effect of peening on SCC initiation and SCC crack arrest. The NRC will review and approve the TLR prior to testing to evaluate the effectiveness of peening.

Task 5 – The DOE Laboratory will produce specimens for the crack initiation and crack arrest testing rigs from items 3 and 4 of Task 2. The samples will include the following at a minimum,

1. 15% cold worked alloy 600,
2. Item 1 with stress corrosion cracks with depths between 0.005 to 0.01 inches,
3. Item 1 with stress corrosion cracks with depths between 0.02 to 0.05 inches,
4. 15% cold worked alloy 182 with dendrites in line with the cracking plane,
5. Item 4 with fabrication defects as much as possible in line with the cracking plane,
6. Item 4 with stress corrosion cracks with depths between 0.02 to 0.04 inches,
7. Item 4 with stress corrosion cracks with depths between 0.05 to 0.08 inches,

The total number of specimens will be determined by the size of the testing rigs. Items 1, 4 and 5 are provided for the crack initiation testing rig. Items 2, 3, 6 and 7 are provided for the crack arrest testing rig. An even distribution of each item for each rig should be produced. Variation in crack depth can be allowed provided it is approved by NRC staff.

DOE Laboratory (PNNL) Task 5 Response:

PNNL concurs with obtaining 15% cold worked alloy 600 and alloy 182 for this program. As part of the original SOW, appropriate material in the non-CW condition has already been obtained but still needs to be 15% cold worked. In order to provide better detail of the proposed work, this task is being broken into two different sections, one for initiation specimens and one for crack arrest specimens.

Item 5.5 (alloy 182 specimens with built-in defects) is outside of the originally accepted scope and will require extended investigation to determine how the material could be produced. An optional task (16) has been added to determine a cost to obtain this material and test it.

Task 5a: ***Production of Specimens for Evaluating Effect of Peening on Crack Initiation***

4-point bend SCC initiation test specimens will be produced to fill the initiation test system and, as possible, enable a statistical evaluation of time for crack nucleation. Assuming a 27-specimen test system, it is proposed to test 9 alloy 600 specimens and 18 alloy 182 specimens. Two rounds of testing will be required - one for baseline response of unpeened specimens and one to evaluate peening. Six extra specimens each of alloy 600 and alloy 182 will be produced. This leads to the following specimen quantities:

- **Twenty-four (9+9+6=24) 15% cold worked alloy 600 specimens**
- **Forty-two (18+18+6=42) 15% cold worked alloy 182 specimens with the weld aligned in the most susceptible orientation**

Task 5b: ***Production of Specimens for Evaluating The Effect of Peening on SCC Crack Arrest***

The originally accepted SOW only provided time and funding to produce three 15% CF alloy 600 specimens and three 15% CF alloy 182 specimens for crack arrest testing. To adhere to the originally accepted SOW time and cost structure, either Items 5.2 and 5.6 (specimens with shorter SCC cracks) or Items 5.3 and 5.7 (specimens with longer SCC cracks) can be produced and evaluated. PNNL proposes that the NRC choose which of these two sets of specimens are to be produced and evaluated.

Task 5c (Optional): ***Additional Production of Specimens with SCC Cracks for Evaluating The Effect of Peening on SCC Crack Arrest***

PNNL will produce an additional 3 specimens each of 15% CF alloy 600 and 15% CF alloy 182 with either short SCC cracks or long SCC cracks. This will require additional funding,

and completion of testing of these specimens would require extending the project end date to April 30, 2019.

While it is highly desirable to produce extra crack arrest specimens of each type to be evaluated, the balance between available time and the desire to test as many different conditions as possible precludes this. If any specimens become damaged during the production process or do not turn out as intended, the number of specimens for crack arrest testing will be reduced by that amount.

<u>**Task 6**</u> – The DOE Laboratory will perform baseline crack initiation testing of samples from Items 1, 4 and 5 of Task 5.

<u>**DOE Laboratory (PNNL) Task 6 Response:**</u>

Nine 15% CF alloy 600 and eighteen 15% CF alloy 182 specimens will be tested in the unpeened condition. All will be instrumented for SCC initiation. These specimens will be loaded such that the outer surface will be at or above the yield strength of the 15% CF material. While it is likely that all specimens will initiation within four months, six months are being set aside for the testing and another month is set aside for startup and shutdown activities.

As discussed in the PNNL response to Tasks 2, 4, and 5, materials with built-in defects are outside of the originally accepted SOW and represent significant additional effort to procure and test. An optional task (16) has been added to determine a cost to obtain this material and test it.

<u>**Task 7**</u> – The DOE laboratory will provide an assessment on the effectiveness of the licensee's proposed process to validate peening depth of compression in individual licensee mockups. The DOE laboratory will use a section of weld from Item 4 of Task 2. The DOE laboratory will take surface residual stress measurements (including, but not limited to, surface incremental hole drilling, slotting and x-ray diffraction) of the weld and near plate material surfaces. Each measurement type should be performed three times. The DOE laboratory will then provide the data with any notes to the NRC.

The DOE laboratory will also provide any recommendations for requirements to provide adequate assurance of an effective validation test through the following steps.

> <u>**Task 7a**</u> - The DOE Laboratory will mathematically predict the weld residual surface and near surface stresses in items 1 and 2 of Task 2. The DOE Laboratory will then submit these analyses for NRC review.
>
> <u>**Task 7b**</u> – The NRC will identify up to 3 areas of high tensile stress to be evaluated by the DOE Laboratory.
>
> <u>**Task 7c**</u> - The DOE Laboratory will use weld residual stress measurement techniques (including, but not limited to, surface incremental hole drilling, slotting and x-ray diffraction) to evaluate the predicted weld residual surface and near surface stress conditions up to 1 millimeter in depth of the locations identified in Task 7b.

Task 7d – The DOE Laboratory will provide a technical letter report documenting this task and providing assessment of this technique to choose locations to validate the effectiveness of peening.

DOE Laboratory (PNNL) Task 7 Response:

PNNL will manage this effort via a modified subcontract to EMC^2 for all weld residual stress measurements and analysis. With input from the subcontractor, PNNL will generate a TLR documenting the locations and values of the stress profiles for each specimen. EMC^2 and its senior staff have conducted extensive analytical, computation, experimental and confirmatory research work for the US NRC for several decades. These efforts recently have included weld modeling, weld residual stress mitigation and fracture mechanics of surface and through wall flaws in Class 1, 2 and 3 safety-related components in nuclear power plants – which are directly related to the proposed efforts in this modified SOW. EMC^2 will conduct the research on this Task and will engage subcontractors of their own on an as-needed basis, to include (but not limited to) companies that have unique and significant expertise in the area of residual stress measurement such as, Hill Engineering, Rancho Cordova, CA.

The goal of the weld-on-plate WRSM task is to validate the accuracy of the various residual stress measurement techniques using a simple specimen such as a stainless steel plate with a weld. Emc2 will first work with PNNL to determine the size of the stainless steel plate as well as the number of weld passes needed to prepare this sample plate specimen. Three areas on this specimen in the parent (plate) material and three areas in the weld region will then be selected for measuring residual stresses using at least three techniques including: hole-drilling, slotting and x-ray diffraction. These plate specimens shall then be fabricated by PNNL and shipped to Emc2 or its subcontractor to make these WRSM measurements.

Upon receiving the results from the residual stress measurements, Emc2 will compile the results for comparison and then make recommendations to PNNL and NRC about effective validation methods for the CRDM specimens in the subsequent Tasks below.

Emc2 will, in accordance with the RFP, provide monthly letter summary reports, coordinate meetings and conference calls with all participating entities as necessary and provide technical assistance and support, including participating in meetings at NRC, vendors, or PNNL as required to successfully complete these efforts. Two "optional" trips to NRC for 2 staff members for 2 days per trip will be scheduled for progress meetings and reviews as described in the specific task discussions. We have also budgeted for "optional" trips to the vendors and to PNNL for face-to-face meetings with technical personnel, where needed.

In addition, and if needed, Emc2 will provide any technical support for public meetings, such as ACRS hearings related to these efforts. The required resources for this support has been identified as "optional".

DOE Laboratory (PNNL) Task 7a Response:

With regard to FE Analyses of CRDMs, the work proposed in this task was not in the original scope of the on-going project at Emc2. This additional scope described below is deemed necessary based on the progress to date and will therefore increase the cost ceiling of the existing effort.

Emc2 will support PNNL in its efforts to predict weld residual surface and near surface stresses along with full field stresses identified in Items 1 and 2 of Task 2 via computational methods supported by physical data developed for both the upper head penetration nozzles and the Alloy 182/82 butt welds of interest. Task 7 will focus on characterizing these properties in the 'as received' samples, prior to any optional 'peening' processing that may be selected during this project (See Optional Task 11 later in this document for Post-Peening discussions). Emc2 will use the VFT© code along with ABAQUS for these solutions. Specifically related to these efforts:

Emc2, in consultation with PNNL, will select three (3) representative Control Rod Drive Mechanism (CRDM's) specimens with upper head penetration nozzle geometries in the ranges of:

- 0-10 Degree
- 15-25 Degree
- > 30 Degree

PNNL will measure the geometry of each of the CRDM specimens adequately and provide the input needed to Emc2 to develop a full 3-dimensional finite element model for each of the CRDM specimens above. Once the 3D FE Model has been constructed and appropriately checked for completeness, Emc2 will conduct a full scale 3D FE Analysis of each of the models to determine stress profiles across the CRDMs. The FEA results will be used to identify critical areas of high tensile residual stresses for each model. These results will be submitted to PNNL for forwarding to NRC-NRR in conjunction with parallel efforts at PNNL.

The "Optional" portion of this subtask encompasses work associated with FEA of dissimilar metal butt welds (item #2 of Task 2). In addition to the WRSM on the CRDM specimens, a similar methodology will be used to evaluate WRS on an Alloy 182/82 butt weld that is representative of reactor coolant system butt welds. The weld evaluated will be selected and generated by PNNL and delivered to Emc2 or its subcontractor for inclusion in the various studies with the CRDM samples.

This task is currently optional and will only be undertaken if deemed necessary by the NRC and PNNL in consultation with Emc2 staff.

DOE Laboratory (PNNL) Task 7b Response:

Upon review of the results from Task 7a, NRC-NRR will, in consultation with appropriate PNNL and Emc2 technical staff, identify up to three (3) areas of high tensile residual stress

determined through the FE Analysis (FEA) to be experimentally confirmed by the PNNL/Emc2 team. This work will require a conference call with PNNL, NRC and Emc2 staff in order to critically review the FEA results of Task 7a to insure that sufficient detail was available in the initial analyses to be able to select appropriate high stress areas. If necessary, after this initial review and with direction and approval from PNNL, Emc2 will conduct additional scoping FEA to provide more fidelity in the models to provide greater clarity in defining the three (3) best areas for Weld Residual Stress Measurement (WRSM) in each CRDM.

DOE Laboratory (PNNL) Task 7c Response:

The work proposed in this task was not in the original scope of the on-going project at Emc2. This additional scope described below is deemed necessary based on the progress to date and will therefore increase the cost ceiling of the existing effort.

Currently, a 'practice' CRDM resides at Hill Engineering in Sacramento, CA which conducted deep hole drilling (DHD) WRSMs in earlier tasks on this effort to determine comparability of experimentally determined WRS with those predicted using FEA. An objective of Task 7c is to develop complementary experimental techniques to DHD as a quality assurance (QA) check of the primary analysis and test methodologies.

For Task 7c, Emc2 has identified two (2) potential vendors of X-ray diffraction analyses that have the capabilities to evaluate WRS in both the CRDM and butt weld sample specimens. These vendors, Lambda Technologies of Cincinnati, OH and America Stress Technologies of Pittsburgh, PA, will be asked to analyze the 'practice' CRDM in similar locations as Hill Engineering has to confirm Hill's WRSM findings using the complementary x-ray diffraction technology. Based on discussions with Hill Engineering, Lambda Technologies has developed their own proprietary process for mitigating weld residual stresses. During discussions with Lambda staff, additional information will be obtained about their process and provided to PNNL and NRC for further consideration as part of this task.

Thus, Emc2 will arrange to have the 'practice' CRDM returned from Hill to Emc2 laboratories. Upon return of this specimen, Emc2 will inspect visually to make sure no evident damage occurred during shipment. Following this internal inspection, Emc2 will then ship the sample to Lambda for WRSM via x-ray diffraction. Following Lambda's testing, the specimen will be returned to Emc2 for forwarding to American Stress Technologies (AST) for similar x-ray diffraction WRSM testing.

After both Lambda and AST have completed their measurements and provided a report on their findings, Emc2, PNNL and NRC-NRR staff will review the results and select one vendor for conducting additional x-ray diffraction work on the three (3) CRDMs selected in Task 7a along with the butt weld specimen prepared for these exercises. Once the CRDMs selected in Task 7a and the butt weld have been received by the selected x–ray diffraction vendor, they will be asked to conduct analyses at three locations on each CRDM that was identified from the Task 7b effort along with the location(s) identified for the butt weld sample.

Once the x-ray diffraction measurements on these CRDMs and the butt weld have been completed the samples will be shipped to Hill Engineering for DHD analyses using both hole and slotting techniques that have been conducted on the 'practice' CRDM previously. The x-ray diffraction vendor will supply a report of their results on each of the separate CRDMs and the butt welded specimen to forward to Emc2 for comparison the DHD results of Hill. Likewise, Hill will provide a report of results of their WRSM.

Based on discussions between NRC and PNNL, there may be another vendor available to conduct X-ray diffraction measurements that is currently used by the industry (Westinghouse). If a third vendor is available, they will be engaged for this effort after approval by NRC staff.

DOE Laboratory (PNNL) Task 7d Response:

Some of the work proposed in this task was not in the original scope of the on-going project at Emc2. This additional scope described below is deemed necessary based on the progress to date and will therefore increase the cost ceiling of the existing effort.

Task 7d will focus on preparing a technical letter report comparing the results of the computational FEA with those of the experimental methods, x-ray diffraction, hole drilling and slotting efforts. The report will provide recommendations and conclusions regarding the confidence levels when comparing computational WRS prediction results with those determined experimentally and will identify the preferred experimental technique for efforts of this type.

Emc2 will prepare draft technical reports for PNNL to review and forward to NRC-NRR for review and comments.

Task 8 - The DOE Laboratory will provide a TLR documenting each sample. The TLR will clearly identify the surfaces of each sample that can be peened. The NRC will review this document and provide comments to the DOE Laboratory. The DOE Laboratory will address any comments in a reasonable time period to support schedule. The NRC will use this document to have each sample peened as necessary to support the review process.

DOE Laboratory (PNNL) Task 8 Response:

PNNL will provide detailed specimen information including photographs and specimen maps defining specific areas for peening, and outlining these areas where NDE baseline and post-peening measurements, WRS baseline and post-peening measurements and any other measurements or processes are to be applied. This TLR will be written and submitted to the NRC for use in vendor discussions and guidance for peening. This effort will focus on the specimens identified for peening in Task 2. This work includes writing the TLR, performing PNNL's internal ERICA review processes and iterating with the client and subcontractors on TLR content/modifications. The TLR will clearly identify the three regions for each sample type for items 1-4 of Task 2 that can be peened. The NRC will use this document to have each sample peened using the appropriate techniques identified in MRP-335 R1. Therefore, the NRC will review this document and

provide comments to the DOE Laboratory. The DOE Laboratory will address any comments in a reasonable time period to support schedule.

<u>Task 9</u> – The DOE Laboratory will ship the specimens as described by written letter from the NRC. The NRC will provide shipping order letters based on the NRC relief request evaluation schedule and vendor ability to peen items. The shipping orders will be based on information provided by the Task 8 TLR. The NRC will be responsible to ensure that each sample is peened in accordance with the Task 8 TLR. Once a specimen is peened, the DOE Laboratory will be responsible to ship it back to the DOE Laboratory facilities. NRC understands that a cost estimate of this shipping task is highly variable, as all specimens many not be required to be peened or peened at the same location. NRC requests a cost estimate of shipping all specimens, in shipments to contain all specimens of the same type, to the AREVA facilities in Lynchburg, VA.

<u>DOE Laboratory (PNNL) Task 9 Response:</u>

PNNL concurs with the NRC guidance defined in Task 9. Since some specimens to be peened are linked to crack arrest and crack initiation activities while others are associated with the NDE/WRS activities, PNNL acknowledges that specimen shipments may not be coordinated in time (scheduling) as these two sets of specimens are programmatically decoupled. PNNL will coordinate logistics and ship the specimens to the vendor(s) of choice, as per guidance from the NRC COR. Shipping/freight costs will be attributed to this Task for this activity. The DOE Laboratory will ship the Task 2 specimens as directed, to the AREVA facilities in Lynchburg, VA, as described by written letter from the NRC. The NRC shipping order letter will be based (in part) on information provided by the Task 8 TLR. The NRC will be responsible to ensure that each sample is peened in accordance with the Task 8 TLR. Once peened, the DOE Laboratory will be responsible for shipping all of the peened specimens back to the DOE Laboratory facilities for additional NDE and WRS assessments, to be conducted in Tasks 10 and 11.

<u>Task 10 (optional)</u>– If any Task 2, Item 1 or 2 specimen is peened and returned to the DOE Laboratory, the DOE Laboratory will perform ultrasonic and eddy current examinations of each specimen. The DOE Laboratory will compare the results of the examinations from Task 3 to those of Task 10. If there are any discrepancies or difficulties in performing an effective examination, they should be identified and an expert opinion for the cause documented in a TLR to the NRC. The NRC will review this document and provide comments to the DOE Laboratory. The DOE Laboratory will address any comments in a reasonable time period to support schedule.

<u>DOE Laboratory (PNNL) Task 10 Response:</u>

PNNL will conduct a best-effort for obtaining effective post-peening NDE (including ET and PA-UT examinations) on all post-peened areas of the sample specimens identified in items #1 and #2 above in Task 2, and baselined in Task 3. Again, there may exist as-welded surface conditions and geometry on some specimens that may impede access or otherwise degrade NDE data quality (for example due to liftoff of the ET probe). PNNL

will conduct the same NDE assessments as those conducted in Task 3 prior to peening. All NDE approaches and scanning protocols employed in this Task will be identical to those employed earlier in Task 3. The same probes will be used to conduct the NDE assessments. PNNL will make every effort to expedite the schedule and compress the time for conducting and reporting these post-peening NDE measurements. The NDE data obtained in Task 3 will be used as baseline data to compare/contrast with the post-peened data acquired on these mockups. If any differences or notable changes are identified via the post-peening NDE assessments, these results will be documented in a TLR and a technical analysis will be conducted to determine the source(s) of these differences.

Task 11 (optional)– If any Task 2, Item 1 or 2 specimen is peened and returned to the DOE Laboratory, the DOE Laboratory will measure the surface and near subsurface stress as in Task 7, to evaluate stress conditions of each specimen in the locations identified in Task 7b. The DOE Laboratory will document the location and values of these stress profiles and compare the measurements to the values provided in Task 7 for each specimen in a revision/continuation of the Task 7 TLR. The NRC will review this document and provide comments to the DOE Laboratory. The DOE Laboratory will address any comments in a reasonable time period to support schedule.

DOE Laboratory (PNNL) Task 11a Response:

Subtask 11a is deemed "optional". Depending on decisions made in Task 2 regarding potential peening of any of the specimens, Emc2 will support PNNL in developing stress profiles of the peened specimens. Similar to the Task 7 efforts, Emc2 will ship for analysis up to three (3) CRDMs and one butt welded specimen post-peening to the selected x-ray diffraction vendor chosen in Task 7. This vendor will then develop WRSM at the locations determined from Task 7b. Following these measurements, the same CRDM and butt weld specimens will be shipped to Hill Engineering for WRSM using hole drilling and slotting techniques in a manner similar to Task 7c.

DOE Laboratory (PNNL) Task 11b Response:

This subtask is deemed "optional", and will also focus on preparing a draft technical report for PNNL to forward to NRC-NRR which will compare the results from all above tasks, i.e., FEA vs x-ray vs hole drilling and slotting techniques. Results from both pre- and post-peening measurements will be analyzed separately to determine if the peening process creates any different relationships amongst the analysis methods. Results, recommendations and conclusions from these evaluations will be incorporated in to the volume to be delivered to PNNL for review and forwarding to NRC-NRR for review and comments.

Emc2 will, in accordance with the RFP, provide monthly letter summary reports, coordinate meetings and conference calls with all participating entities as necessary and provide technical assistance and support, including participating in meetings at NRC, vendors, or PNNL as required to successfully complete these efforts. Two "optional"

trips to NRC for 2 staff members for 2 days per trip will be scheduled for progress meetings and reviews as described in the specific task discussions. We have also budgeted for "optional" trips to the vendors and to PNNL for face-to-face meetings with technical personnel, where needed.

In addition, and if needed, Emc2 will provide any technical support for public meetings, such as ACRS hearings related to these efforts. The required resources for this support has been identified as "optional".

Task 12 – The DOE Laboratory will perform crack initiation and crack arrest testing of the peened specimens of Task 5. The DOE Laboratory may interrupt the crack initiation test to monitor and maintain the test specimens, but the full test length shall continue until either all specimens have initiated cracks or until five times the time required for the 75th percentile of the crack initiation time of the specimens in Task 6. If any peened specimens develop indications of cracking, the DOE Laboratory will be expected to perform additional metallurgical analysis as authorized by the NRC.

DOE Laboratory (PNNL) Task 12 Response:

Item 5.5 (alloy 182 specimens with built-in defects) is outside of the originally accepted scope and will require some investigation to determine how it could be produced. Therefore, it is not under consideration for testing in this revised SOW.

Task 12a: ***Crack Initiation Testing of Peened Materials***

Nine 15% CF alloy 600 specimens (Item 5.1) and eighteen 15% CF alloy 182 specimens (Item 5.4) will be tested in the peened condition. All will be instrumented for SCC initiation. These specimens will be loaded such that the outer surface will be at or above the yield strength of the 15% CF material. 12 months are being set aside for testing and another 1 month has been set aside for startup and shutdown activities.

Task 12b: ***Crack Arrest Testing of Peened Specimens with SCC Cracks***

Three 15% CF alloy 600 crack arrest specimens of Item 5.2 or Item 5.3 and three 15% CF alloy 182 crack arrest specimens of Item 5.6 or Item 5.7 will be SCC tested in the peened condition. Specimens will be loaded to a stress intensity roughly equivalent to that used to confirm SCC crack growth before peening. All six specimens will be instrumented to observe SCC crack growth of the small crack. Testing is expected to last 6 months.

Task 12c (Optional): ***Additional Crack Arrest Testing of Peened Specimens with SCC Cracks***

A second evaluation of SCC cracked specimens is outside the original scope, and therefore is being offered as an optional task. Three 15% CF alloy 600 crack arrest specimens of Item 5.2 or Item 5.3 and three 15% CF alloy 182 crack arrest specimens of Item 5.6 or Item 5.7 will be SCC tested in the peened condition. Testing would take up to

8 months. Because it takes considerable time to prepare these specimens, not only is additional funding required, but the project end date must also be extended. This optional additional work can be completed by April 30, 2019.

<u>**Task 13**</u> – At the conclusion of the crack initiation testing, the DOE Laboratory will develop a TLR documenting all testing results. The NRC will review this document and provide comments to the DOE Laboratory. The DOE Laboratory will address any comments in a reasonable time period.

<u>DOE Laboratory (PNNL) Task 13 Response:</u>

PNNL concurs with this Task. It is suggested that this TLR be completed within 2 months of the completion of all tests and specimen examinations.

<u>**Task 14**</u> – DOE Laboratory will provide monthly letter status reports (MLSRs) to the contracting officer's representative (COR), alternate COR, and the Division of Contracts at <u>ContractsPOT.Resource@nrc.gov</u>. The MLSRs will be reviewed by the NRC and DOE Laboratory during monthly phone calls.

<u>DOE Laboratory (PNNL) Task 14 Response:</u>

PNNL identifies this Task as the Management Task for this project. PNNL concurs with the NRC guidance for monthly letter reporting. The Task manager will be responsible for overseeing the work being performed, including developing detailed project plans, tracking all project deliverables, ensuring they are delivered on time and within planned budgets, and coordinating weekly or monthly teleconference calls with the NRC. In addition, this Task includes preparing integrated monthly business letter reports and semi-annual reports (as needed), organizing and conducting any project reviews as directed by NRC, coordinating and supporting project modifications and re-direction based on emergent issues, and supporting other NRC requests. PNNL will conduct the work defined in the NRC SOW guidance and provide specified deliverables within the time and budget provided. Due to the number and complexity of deliverables defined here, and based on discussions with the NRC COR, this task has been determined to be important and necessary for PNNL project task coordination. The costs/level-of-effort defined in Task 14 cover much more than writing of MLSRs. These costs cover all other PM functions as well, including PNNL required Project Management Office and Sector reviews, monthly teleconferences, and all other required PM activities over the life of the project.

This task is also focused on providing support to activities where PNNL's expertise is required through consultation or engagement. On an as-needed basis, PNNL will provide NRC with technical assistance in resolving high priority, fast track issues related to NDE to support the NRC-NRR program offices related to peening. The NRC COR must approve technical assistance to the program offices prior to initiation of any effort. This task includes the monitoring of technologies being developed and applied in the field for specific NDE inspection problems related to mitigation/peening techniques, support for

public meetings, video teleconferences, consultation-focused phone calls, and other support activities related to this Task. This Task does not require the performance of specific research but involves tracking relevant publications and possibly attending important meetings and/or conferences. PNNL should identify any meetings deemed to be important and discuss them with the NRC COR, who will grant formal approval before PNNL staff attend any meeting/conference or activity. PNNL will provide letter reports on this task as requested by the NRC COR. PNNL will provide technical assistance and consultation as directed by NRC guidance and complete specified deliverables within the time and budget provided. Since consulting is on an as-needed basis and driven by unplanned and unexpected events, it is not possible to assess these activities in advance; thus, each request made by the NRC will be addressed by defining the scope of work, time frame to accomplish the work, level of effort required, and deliverables. This information will be provided in the monthly report to document the activities on this Task.

In addition, it is necessary for PNNL to capture efforts conducted by EMC^2, in accordance with PNNL's subcontract with EMC^2, and define PM activities conducted by the EMC^2. It is expected that EMC^2 will provide PNNL with monthly letter summary reports, coordinate meetings and conference calls with all participating entities as necessary and provide technical assistance and support, including participating in meetings at NRC, vendors, or PNNL as required to successfully complete these efforts. For EMC^2, a minimum of two trips to NRC for 2 staff members for 2 days per trip will be scheduled for progress meetings and reviews as described in the specific task discussions. It is also necessary to engage EMC^2 at various stages of the project, and therefore travel to the vendors and to PNNL for face-to-face meetings with technical personnel have been captured here for eventual inclusion in the subcontract to EMC^2. Finally, it is expected that EMC^2 will provide all technical support along with attendance and testimony at public meetings such as ACRS hearings related to these efforts.

Task 15 (optional) – Should concerns be raised about the adequacy of the peening process, NRC reserves the option to discuss additional scope of testing with the mutual agreement of the DOE Laboratory and modifications to the SOW, as necessary.

DOE Laboratory (PNNL) Task 15 Response:

PNNL concurs with the NRC guidance in Optional Task 15. Note: this optional task is not included as part of this cost proposal. If this task is authorized, a revised cost proposal will need to be generated.

Task 16 (Optional): Determine Time and Cost to Produce and Test Alloy 182 with Built-in Defects

Methods to produce alloy 182 with surface-breaking and subsurface defects will be investigated. Associated costs and time to obtain such a material will be reported along with the cost to perform initiation testing on unpeened and peened material.

5.0 DELIVERABLES AND/OR MILESTONES SCHEDULE

The following table provides NRC concept on the timeline goals to meet milestone completion dates, which are the ***bold italic*** listings in the table. With the multiple numbers of tasks in this SOW, some must be completed in series, while others can be done in parallel. This table is provided as a tool for communication with only the ***bold italic*** line items to be considered contract requested requirements.

Potential Timeline With Recommended ***Milestones in Bold Italic***		
Task Number(s)	Task Description or ***Deliverable/Milestone Description***	Goal Completion or ***Milestone Completion***
1a	NRC provide MRP-335 and initial supporting documentation to DOE Laboratory	Completed
1b	NRC provide additional resources to support the peening review	Within 5 working days of receipt at the NRC
2	DOE acquires all samples	1 month after modification of contract
2a	Optional, DOE shall implant flaws in specimens as directed by NRC	2 months after completion of Task 2
3	DOE completes NDE on Task 2 samples	3 months after completion of Task 2 or 2a if implemented
4a	DOE crack arrest and initiation testing rigs completed	3 months after modification of contract
4b	Final TLR on testing rig verification	30 days after Task 4a completed
5	DOE acquires all crack arrest specimens	4 months after Task 4 completed
6	DOE completes crack initiation testing of non-peened mini-tensile specimens	4 months after Task 4 completed
7	DOE completes surface stress measurement technique evaluation	1 month after the completion of Task 2.
7a	DOE completes all stress profiles on non-peened specimens	2 months after completion of Task 2 or 2a if implemented
7b	NRC and DOE agree on testing locations	10 days after Task 7a completed
7c	DOE completes stress measurements	2 months after Task 7b completed
7d	Final TLR on stress analysis	30 days after Task 7c completed
8	**Final TLR documenting specimens and areas to be peened**	**8 months after modification of contract**

Potential Timeline With Recommended ***Milestones in Bold Italic***		
Task Number(s)	Task Description or ***Deliverable/Milestone Description***	Goal Completion or ***Milestone Completion***
9	DOE Ship/ NRC Peen/DOE Ship	As required by NRC
10a	Optional, DOE completes NDE on peened specimens	1 month after completion of Task 9
10b	Optional, DOE completes final TLR on NDE	30 days after Task 10a completed
11a	Optional, DOE completes stress profiles on peened specimens	2 months after completion of Task 10a
11b	Optional, DOE completes final TLR on peening stress profile improvement	30 days after Task 11a
12	DOE completes crack arrest and initiation testing on peened specimens	15 months after the completion of Task 9
13	**DOE completes final TLR on crack arrest and initiation**	**30 days after completion of Task 12**
14	***Monthly MLSRs***	***Every month***

<u>**DOE Laboratory (PNNL) Deliverables and/or Milestones Schedule Response:**</u>

It is unclear as to why there is a milestone 1b. This appears to be an NRC action and not a PNNL milestone or deliverable. From a review of this Milestones/Deliverables Table, PNNL understands that there exist six (6) tangible deliverables for this project (excluding MLSRs) including:

1. **Final TLR on Testing Rig Verification (Task 4)**
2. **Final TLR on Stress Analysis (Task 7)**
3. **Final TLR on Specimen Documentation and Peening Areas (Task 8)**
4. **Final TLR on Post-Peening NDE Assessments (Task 10)**
5. **Final TLR on Peening Stress Profile Improvement (Task 11)**
6. **Final TLR on Crack Arrest And Initiation (Task 13)**

PNNL concurs with these tangible deliverables. It is acknowledged, that the NDE and WRS measurement activities that focus on Task 2 (items #1 and #2) sample specimens are essentially decoupled from the materials crack initiation and crack arrest Task activities. However, in order to expedite schedule and minimize the level of duplicate efforts, PNNL will make every attempt to coordinate and synchronize activities that can leverage each other between NDE/WRS activities and crack initiation/arrest activities.

An updated version of the activity/milestone table is provided here to match the DOE (PNNL) laboratory outlook on timing for the activities and milestones.

Potential Timeline With Recommended ***Milestones in Bold Italic***		
Task Number(s)	Task Description or ***Deliverable/Milestone Description***	Goal Completion or ***Milestone Completion***
1a	NRC provide MRP-335 and initial supporting documentation to DOE Laboratory	Completed
1b	NRC provide additional resources to support the peening review	Within 5 working days of receipt at the NRC
2	DOE acquires all materials	1 month after modification of contract
2a	Optional, DOE shall implant flaws in specimens as directed by NRC	2 months after completion of Task 2
3	DOE completes NDE on Task 2 samples	3 months after completion of Task 2 or 2a if implemented
4a,b,c	DOE crack arrest and initiation testing rigs completed	8 months after modification of contract
4d	Final TLR on testing rig verification	30 days after Task 4a,b,c completed
5a	DOE acquires all crack initiation specimens	5 months after modification of contract
5b	DOE acquires crack arrest specimens	11 months after completion of Task 4c
5c (optional)	DOE acquires additional crack arrest specimens	11 month after completion of Task 5b
6	DOE completes crack initiation testing of non-peened specimens	9 months after Task 4b completed
7	DOE completes surface stress measurement technique evaluation	1 month after the completion of Task 2.
7a	DOE completes all stress profiles on non-peened specimens	2 months after completion of Task 2 or 2a if implemented
7b	NRC and DOE agree on testing locations	10 days after Task 7a completed
7c	DOE completes stress measurements	2 months after Task 7b completed
7d	Final TLR on stress analysis	30 days after Task 7c completed
8	**Final TLR documenting specimens and areas to be peened**	**8 months after modification of contract**
9	DOE Ship/ NRC Peen/DOE Ship	As required by NRC
10a	Optional, DOE completes NDE on peened specimens	1 month after completion of Task 9

Potential Timeline With Recommended *Milestones in Bold Italic*		
Task Number(s)	Task Description or ***Deliverable/Milestone Description***	Goal Completion or ***Milestone Completion***
10b	Optional, DOE completes final TLR on NDE	30 days after Task 10a completed
11a	Optional, DOE completes stress profiles on peened specimens	2 months after completion of Task 10a
11b	Optional, DOE completes final TLR on peening stress profile improvement	30 days after Task 11a
12a	DOE completes initiation testing on peened specimens	16 months after the completion of Task 9
12b	DOE completes crack arrest testing of peened specimens with SCC cracks	8 months after completion of Task 9, or if Task 5c is accepted, 8 months after that
12c (optional)	DOE completes crack arrest testing of additional peened specimens with SCC cracks	11 months after completion of Task 12b
13	**DOE completes final TLR on crack arrest and initiation**	**30 days after completion of Task 12**
14	***Monthly MLSRs***	***Every month***
Task 16 (optional)	Develop cost and timeline to fabricate and assess welds with defects	3 months after modification of contract

6.0 TECHNICAL AND OTHER SPECIAL QUALIFICATIONS REQUIRED

Specialized experience must include expertise in such areas as (1) ultrasonic inspection, (2) eddy current inspection, (3) surface and near surface stress profile measurement, (4) material sample manufacturing and processing, (5) material sample testing, and (6) metallurgical analysis. Additional expertise is desired regarding American Society of Mechanical Engineer's Boiler and Pressure Vessel Code activities regarding the construction and inspection of upper and lower reactor pressure vessel heads and various sized dissimilar metal butt welds. Specialized expertise is requested in addressing each of these areas with the application of alloy 600/182/82 materials.

7.0 MEETINGS AND TRAVEL

All travel requires written Government approval from the CO, unless otherwise delegated to the COR.

Foreign travel for the DOE laboratory personnel requires a 60-day lead time for NRC approval. For prior approval of foreign travel, the DOE laboratory shall submit an NRC Form 445, "Request for Approval of Official Foreign Travel." NRC Form 445 is available in the MD 11.7 Documents library and on the NRC Web site at: http://www.nrc.gov/reading-rm/doc-collections/forms/. Foreign travel is approved by the NRC Executive Director for Operations (EDO).

<u>DOE Laboratory (PNNL) Meetings and Travel Response:</u>

Travel, to support technical activities defined in this SOW, to support public meetings, engage in face-to-face discussions or conduct technical reviews of subcontractor work, are anticipated and required. The information in Table 7.1 defines (at a minimum) the proposed travel by PNNL staff in the conduct of work defined in this SOW.

Task	Description of Travel	Staff/Duration	Destination	FY
3	Technical Data Acquisition Planning and ET System Configuration	Two trips, 1 person, 5 days	Hartford, CT to Richland, WA	16

8.0 REPORTING REQUIREMENTS

The DOE Laboratory is responsible for structuring the deliverable to follow agency standards. The current agency standard is Microsoft Office Suite 2010. The current agency Portable Document Format (PDF) standard is Adobe Acrobat 9 Professional. Deliverables must be submitted free of spelling and grammatical errors and conform to requirements stated in this section.

Technical Letter Reports

DOE Laboratory shall provide technical letter reports (TLR) as described in the SOW. TLRs are expected to be concise reports that provide data results and additional analysis as required. Additional analysis is defined in the SOW above, but could consist of procedure to perform eddy current to achieve maximum detection of sub-surface defects or additional metallurgical analysis of indications of cracking in crack initiation test specimens. Each TLR is expected to have a short introduction including the requested information, a short discussion on the data collection process and finally the results. One expectation is the TLR for Task 8. The Task 8 TLR will list all samples and identify areas of peening for each sample.

Monthly Letter Status Reports

In accordance with Management Directive 11.7, NRC Procedures for Placement and Monitoring of Work with the U.S. Department of Energy, the DOE Laboratory must electronically submit a Monthly Letter Status Report (MLSR) by the 20th day of each month to the Contracting Officer Representative (COR) with copies to the Contracting Officer (CO) and the Office Administration/Division of Contracts to <u>ContractsPOT.Resource@nrc.gov</u>. If a project is a task ordering agreement, a separate MLSR must be submitted for each task order with a summary project MLSR, even if no work has been performed during a reporting period. Once NRC has determined that all work on a task order is completed and that final costs are acceptable, a task order may be omitted from the MLSR.

The MLSR must include the following: agreement number; task order number, if applicable; job code number; title of the project; project period of performance; task order period of performance, if applicable; COR's name, telephone number, and e-mail address; full name and address of the performing organization; principal investigator's name, telephone number, and e-mail address; and reporting period. At a minimum, the MLSR must include the information discussed in Attachment 1. The preferred format can also be found in Attachment 1.

9.0 PERIOD OF PERFORMANCE

The estimated period of performance for this agreement is August 11, 2014 through February, 2019.

10.0 CONTRACTING OFFICER'S REPRESENTATIVE

The COR monitors all technical aspects of the agreement/task order and assists in its administration. The COR is authorized to perform the following functions: assure that the DOE Laboratory performs the technical requirements of the agreement/task order; perform inspections necessary in connection with agreement/task order performance; maintain written and oral communications with the DOE Laboratory concerning technical aspects of the agreement/task order; issue written interpretations of technical requirements, including Government drawings, designs, specifications; monitor the DOE Laboratory's performance and notify the DOE Laboratory of any deficiencies; coordinate availability of NRC-furnished material and/or GFP; and provide site entry of DOE Laboratory personnel.

Contracting Officer's Representative

Name:	Jay Collins
Agency:	U.S. Nuclear Regulatory Commission
Office:	Office of Nuclear Reactor Regulation
Mail Stop:	OWFN-9H4
	Washington, DC 20555-0001
E-Mail:	jay.collins@nrc.gov
Phone:	301-415-4038

Alternate Contracting Officer's Representative

Name:	Stephen Cumblidge
Agency:	U.S. Nuclear Regulatory Commission
Office:	Office of Nuclear Reactor Regulation
Mail Stop:	OWFN-9H4
	Washington, DC 20555-0001
E-Mail:	stephen.cumblidge@nrc.gov
Phone:	301-415-2823

11.0 MATERIALS REQUIRED

Materials Property/Material	Quantity	Associated Task	Estimated Cost
Alloy 600 plate	1	Task 2	$ 10,000 Material
Rotational Bore Scanning Tool for UT Scans	1	Task 3/10	$ 35,000 Material
ET and UT Probes	6	Task 3/10	$166,000 Material
Crack initiation test rig	1	Task 4	$220,000 Material
Crack arrest test rig	1	Task 4	$175,000 Material
TOTAL ITEMS/COST:	12	n/a	$606,000 TOTAL COST

DOE Laboratory (PNNL) Materials Required Response:

See revised material required:

Materials Property/Material	Quantity	Associated Task	Estimated Cost
Alloy 600 plate	1	Task 2	$ 10,000 Material
Rotational Bore Scanning Tool for UT Scans	1	Task 3/10	$ 35,000 Material
ET and UT Probes	6	Task 3/10	$3,000 Material
Crack initiation test rig	1	Task 4	$220,000 Material
Crack arrest test rig	1	Task 4	$175,000 Material
ECT Equipment	1	Task 3	$100,000 Material
Rotating Table and motor drives/controls	1	Task 3	$15,009 Material
Test System overhaul parts	1	Task 12C	$1,500 Material
TOTAL ITEMS/COST:			$559,009 TOTAL COST

PNNL concurs with the materials required list in Section 11.0 with a few additions. If however, the NRC COR requests that PNNL employ a complementary NDE technique other than PA-UT or ET for evaluation of the J-groove welds and DMWs identified in Task 2, procurement of additional probes may be required. In particular, if TOFD-UT is requested, probe-wedge combinations may need to be procured for this application. This revised list includes a rotational scanning platform that has a higher weight capacity than the existing PNNL platform, and motors and motor drivers to couple the motion control of this platform to both existing PNNL data acquisition/control systems estimated at $15K and the new WesDyne ET data acquisition system estimated at $100K. (See discussion under Tasks 2 and 3).

12.0 SUBCONTRACTOR/CONSULTANT INFORMATION

Task 2a: Some specimens may require fabrication, welding and/or introduction of flaws. PNNL will subcontract this work out to a trusted and proven 3rd party for any required fabrication processes. See Task Section above for more detail. Estimated cost is $24.7K. FlawTech is the likely vendor to conduct this work based upon their past performance and experience in providing these types of services to PNNL on other NRC JCNs.

In addition, the extraction (cutting) of the three (13) CRDMs from the vessel head cannot be performed by PNNL crafts services, and this will require a subcontract. This subcontract will include transportation of the vessel head from PNNL to the subcontractor (metal fabricator/machining organization) and back, as well as cutting of the CRDM nozzles from the head and any conditioning/machining for reduction of unnecessary material from the 4 or 5 CRDMs to be identified for this work. Estimated cost is $37K

Task 7: PNNL will manage these efforts via a subcontract to EMC^2 for all weld residual stress measurements and analysis. See Task Section above for more detail. Estimated cost is $175.4K.

<u>DOE Laboratory (PNNL) Response:</u>

As a result of the increased scope in Task 7, additional support is required from EMC2 (see Task 7 of SOW. Increased subcontracting value is estimated at $142,500.

As part of Task 5 and Optional Task 5c additional material forging services will be necessary. Estimated cost is $20K.

13.0 NRC-FURNISHED PROPERTY/MATERIALS

NRC-Furnished Property/Material	Quantity	Date provided to DOE Laboratory	Method of Shipment
Upper head penetration nozzle and associated J-groove weld	4-5	On site	On site
Dissimilar Metal Butt Weld	1	On site	On site
Alloy 600/182/82 materials for testing	As needed	On site	On site

14.0 RESEARCH QUALITY

The quality of NRC research programs are assessed each year by the Advisory Committee on Reactor Safeguards. Within the context of their reviews of RES programs, the definition of quality research is based upon several major characteristics:

Results meet the objectives (75% of overall score)

Justification of major assumptions (12%)

Soundness of technical approach and results (52%)

Uncertainties and sensitivities addressed (11%)

Documentation of research results and methods is adequate (25% of overall score)

Clarity of presentation (16%)

Identification of major assumptions (9%)

It is the responsibility of the DOE Laboratory to ensure that these quality criteria are adequately addressed throughout the course of the research that is performed. The NRC COR will review all research products with these criteria in mind.

15.0 STANDARDS FOR CONTRACTORS WHO PREPARE NUREG-SERIES MANUSCRIPTS (TYPE N/A IF NOT APPLICABLE)

The U.S. Nuclear Regulatory Commission (NRC) began to capture most of its official records electronically on January 1, 2000. The NRC will capture each final NUREG-series publication in its native application. Therefore, please submit your final manuscript that has been approved by your NRC Project Manager in both electronic and camera-ready copy.

The final manuscript shall be of archival quality and comply with the requirements of NRC Management Directive 3.7 "NUREG-Series Publications." The document shall be technically edited consistent with NUREG–1379, Rev. 2 (May 2009) "NRC Editorial Style Guide." The goals of the "NRC Editorial Style Guide" are readability and consistency for all agency documents.

All format guidance, as specified in NUREG-0650, "Preparing NUREG-Series Publications," Rev. 2 (January 1999), will remain the same with one exception. You will no longer be required to include the NUREG-series designator on the bottom of each page of the manuscript. The NRC will assign this designator when we send the camera-ready copy to the printer and will place the designator on the cover, title page, and spine. The designator for each report will no longer be assigned when the decision to prepare a publication is made. The NRC's Publishing Services Branch will inform the NRC Project Manager for the publication of the assigned designator when the final manuscript is sent to the printer.

For the electronic manuscript, the Contractor shall prepare the text in Microsoft Word, and use any of the following file types for charts, spreadsheets, and the like.

File Types to be Used for NUREG-Series Publications	
File Type	File Extension
Microsoft®Word®	.doc
Microsoft® PowerPoint®	.ppt
Microsoft®Excel	.xls

Microsoft®Access	.mdb
Portable Document Format	.pdf

This list is subject to change if new software packages come into common use at NRC or by our licensees or other stakeholders that participate in the electronic submission process. If a portion of your manuscript is from another source and you cannot obtain an acceptable electronic file type for this portion (e.g., an appendix from an old publication), the NRC can, if necessary, create a tagged image file format (file extension.tif) for that portion of your report. Note that you should continue to submit original photographs, which will be scanned, since digitized photographs do not print well.

If you choose to publish a compact disk (CD) of your publication, place on the CD copies of the manuscript in both (1) a portable document format (PDF); (2) a Microsoft Word file format, and (3) an Adobe Acrobat Reader, or, alternatively, print instructions for obtaining a free copy of Adobe Acrobat Reader on the back cover insert of the jewel box.

16.0 ORGANIZATIONAL CONFLICT OF INTEREST

Upon submitting a proposal to the NRC, each DOE Laboratory would continue to acknowledge the disclosure requirements of: 1) the NRC Clause, the NRC Conflict of Interest, Management Directive 11.7, Section 2.3.2.12 and Section 2.33; and 2) the provisions of the Memorandum of Understanding (MOU) between DOE and NRC, dated 1998 (which states, in part, that DOE recognizes that Section 170A of the Atomic Energy Act of 1954, as amended, requires that NRC be provided with disclosures on potential conflicts when NRC obtains technical, consulting, research and other supporting services). DOE further recognizes that the assignment of NRC work to DOE laboratories must satisfy NRC's organizational conflict of interest (OCOI) standards.

Therefore, each DOE Laboratory, in its proposal to NRC (which will be incorporated into an interagency agreement between NRC and DOE), is required to make an assertion per #1 or #2 of Part A below. If the DOE Laboratory selects #1, then, it must also fill out the accompanying Part B; whereby the DOE Laboratory must, again, make an assertion by answering each of the five (5) NRC OCOI provisions per the NRC Acquisition Regulation (NRCAR).

PART A:

"In accordance with PNNL's role in, and responsibility for, disclosing its relationships with organizations which conduct business in the same and/or similar technical area as described by the present and/or ongoing NRC project's scope of work, and in accordance with the NRC clause as stated herein, PNNL hereby asserts that it has examined its relationships with all such organizations, and has also examined its current and future/planned work, and where appropriate, its past work (generally for the previous five years), for DOE and other organizations, and PNNL states the following:

1) PNNL hereby discloses the following relationships _______ [state the name of persons, organizations, and business relationships, etc. **] _______ that may give rise to a potential OCOI. (DOE Laboratory must answer the questions in Part B below);

Or

2) PNNL to the best of its knowledge and belief, asserts that it has no current work, planned work, and where appropriate, past work for DOE and others (to mean - organizations in the same and/or similar technical area as the present and/or ongoing NRC project scope of work); and PNNL hereby asserts that it is not aware of any same/similar technical work that would give rise to any potential OCOI as defined in the Atomic Energy Act of 1954, as amended, and in the NRC/DOE MOU.

Signed: ______________________

PART B:

In accordance with PNNL role/responsibility regarding OCOI disclosure, as stated in Part A, above PNNL further discloses, to the best of its knowledge and belief, that:

1) PNNL and/or any of its organizational affiliates* as defined in Part A above [does/does not] provide advice and recommendations to the NRC in the same technical area (e.g., fire protection, probable risk assessment, seismic, vulnerability analysis, fracture mechanics) where it is also providing consulting assistance to any organization regulated by NRC. If PNNL "does" - the PNNL hereby discloses such organization(s) in Part A above;

2) PNNL and/or any of its organizational affiliates as defined in Part A above [does/does not] provide advice and recommendations to the NRC on the same or similar matter (e.g., particular licensing amendment, particular EIS, particular high level waste repository site) on which it is also providing assistance to any organization regulated by NRC. If PNNL "does" - the PNNL hereby discloses such organization(s) in Part A above;

3) PNNL and/or any of its organizational affiliates as defined in Part A above [will/will not] be required to evaluate its own products or services, or has been substantially involved in the development or marketing of the products or services of another entity. If PNNL "does" - the PNNL hereby discloses such organization(s) in Part A above;

4) PNNL and/or any of its organizational affiliates as defined in Part A above [does/does not] have a conflicting role, given the award of the present and/or ongoing NRC project, in which its judgment or the judgment of any of its organizations may be biased in relation to its work for NRC. If PNNL "does" – the PNNL hereby discloses such conflicting role(s) with organization(s) in Part A above;

5) PNNL and/or any of its organizational affiliates as defined in Part A above [are/are not] soliciting or performing concurrent work at an applicant or licensee site, while performing work in the same/similar technical area for NRC at the same site. If PNNL "does" – then the PNNL hereby discloses such organization(s) in Part A above."

Signed: ______________________________

*Organization affiliate – Business concerns which are affiliates (related) to each other when either directly or indirectly, one concern or individual controls or has the power to control another, or when a third party (i.e., parent firm) has the power to control both.

** The Atomic Energy Act of 1952 uses the term "person" to mean any entity – e.g., sole proprietorship, partnership, joint venture, corporation; university; limited partnership, subchapter S corporation; limited liability company, etc.

The OCOI disclosure requirement extends to any subcontractors the DOE laboratory intends to use under the agreement.

ATTACHMENT 3 – STAFFING PLAN

Key Personnel

Technical Assistance for Topical Report Review of MRP-335, Peening Mitigation of PWSCC, Task Order NRC-HQ-20-14-T-0025, Modification No. 5

NAME	DISCIPLINE	TIME AVAILABLE
Eva Eckert Hickey	Program Manager	TBD
Aaron Diaz	Task Project Manager/Principal Investigator/ NDE, ASME Code Expert	TBD
Michael T. Anderson	NDE, AMSE Code Expert (resume already on file with EWA)	TBD
Stephen B. Bruemmer	Material Science Expert	TBD
Mychailo B. Toloczko	Material Science Expert	TBD
Jack Lareau	NDE and Nuclear ISI expert.	TBD
Lori Bisping	Project Support	TBD

Staffing Plan: Eva Eckert Hickey is the Program Manager (PM) for the Enterprise Wide Agreement (EWA). Aaron Diaz as the Task Project Manager/Principal Investigator/Sr. Scientist/Engineer for this effort, and will provide technical input, guidance, and review of all products.

Eva Eckert Hickey has previously been a NRC employee. Ms. Hickey was an environmental engineer (co-op) in Region II in 1979.

Resumes for Jack Lareau is attached. Resumes for other Key Personnal are already on file with the NRC for this Task Order.

ATTACHMENT 4 – RESUME

JOHN P. LAREAU
Principal Technical Advisor
Applied Physics Group - National Security Directorate
Pacific Northwest National Laboratory

EDUCATION

University of Massachusetts, 1972 (Cum Laude), B.S. Physics
Bettis Reactor Engineering School (Advanced Mathematics, Metallurgy, Nuclear Materials, Statistics), 1973-1976
University of Pittsburgh, Graduate Studies in Electrical Engineering, 1973-1975
Rensselaer Polytechnic Institute, 1984, M.S. Engineering Science

EXPERIENCE

2014–Present, Principal Technical Advisor, Pacific Northwest National Laboratory, Richland, WA.

After retiring from 40+ years in private industry, Mr. Lareau joined the PNNL Applied Physics Laboratory on a part time basis working in the field on nondestructive testing development and qualification. In this capacity, he primarily supports the research efforts of various branches of the NRC, primarily Research, Nuclear Reactor Regulation and Nuclear Material Safety.

2003-2014, Chief Engineer: Westinghouse Electric Company: Nuclear Services
WesDyne International.

In this role, Mr. Lareau's responsibilities included oversight of NDE development and application for the WesDyne offices in the US, Sweden and Germany. Among the technical inspection issues addressed have been reactor vessel head nozzles, dissimilar metal welds, pressurized thermal shock reactor vessel belt line regions and reactor vessel internals. One key area has been the resolution and explanation of false positive indications in dissimilar metal welds and CRDM nozzle inspections.

This activity has included extensive interaction with several regulatory bodies (USNRC, China Nuclear National Safety Agency, Korea Institute for Nuclear Safety). In addition, activities included participation in the Materials Reliability Program Inspection Subcommittee and the PWR Materials Subcommittee. Within Westinghouse, activities included participation in the Technology and Engineering Forum overseeing global R&D activities, the patent committee, George Westinghouse Signature Award selection committee and the NEI Top Industry Practices award selection committee. Interactions with various national laboratories (PNNL and ORNL) on numerous NDE related activities have been an ongoing activity for several years.

2000-2003, Chief Engineer: Westinghouse Electric Company: Nuclear Services
Mr. Lareau was the Chief Engineer, reporting to the Vice-President of Westinghouse Electric Company Nuclear Services, Field Services. In this role, Mr. Lareau advised on R&D matters as

well as the more immediate field application issues of nondestructive testing. Also, in this capacity, Mr. Lareau coordinated all the Field Services R&D programs and interacted with outside research agencies, universities and government agencies.

1988-2000, Principal Consulting Engineer: ABB Combustion Engineering Nuclear Power (ABB CENP)

Mr. Lareau reported to the Vice-President of Field Services of ABB CENP as an advisor on technical issues regarding nondestructive evaluation systems and applications. In this capacity, he authorized and reviewed the internal R&D programs for ABB CENP, which specializes in providing fully integrated and qualified inspection systems and services. Predominantly, his activities are in the technologies of Ultrasonic and Eddy Current testing, Data Acquisition, Imaging and Analysis.

He worked extensively in applying technology originally developed for nuclear plant applications to other fields; specifically aerospace, aircraft and oil industry components, as well as continuing the traditional uses in nuclear power plants. Mr. Lareau was the technology lead for the development of the inspection process for solid rocket motors for both the NASA Space Shuttle and USAF Titan III Launch Vehicle as well as automated inspections of off shore oil well rigs. He was also responsible for coordinating R&D activities among the several international ABB Nuclear Power companies.

1976-1988, Combustion Engineering, Inc. Power Systems, Nuclear Power Systems

1987 to 1988	Principal Consulting Engineer, Engineering & Technology Department
1985 to 1987	Senior Consulting Engineer, Examination Services and Products
1979 to 1985	Supervisor, Inspection Services Development
1978 to 1979	Principal Engineer, Inspection Services Department
1976 to 1978	Senior Engineer, Inspection Services Department

Mr. Lareau served in a variety of technical positions in the field of NDE development and services. During this period, he acted as a Level III in eddy current, ultrasonic and visual testing for ASME Boiler and Pressure Vessel Code inspections. He was responsible for the operation of the NDE Development Laboratory which developed inspection techniques and systems for nuclear plant components and fuel. The laboratory work was a combination of internally funded and contract R&D programs. He acted as Program Manager on a variety of EPRI funded contracts. He also organized and instructed in-house courses in Eddy Current and Ultrasonic Testing.

1972-1976, Engineer: Westinghouse Electric Company, Bettis Atomic Power Laboratory

As an engineer at Westinghouse-Bettis, Mr. Lareau's responsibilities included development of nondestructive testing techniques for the inspection of various nuclear plant components employing Ultrasonic, Eddy Current and Acoustic Emission testing. His responsibilities included analysis of data, writing and evaluating procedures, designing special purpose tests and writing a text on Eddy Current testing for steam generator tubes. Other responsibilities included evaluation of ASME Code requirements for In-Service Ultrasonic inspection of plant components and evaluation of Acoustic Emission testing as an In-Service inspection technique.

PROFESSIONAL HONORS

- George Westinghouse Lifetime Achievement Award for Technology Development (2011).
- Connecticut Academy of Sciences and Engineering (elected in 2012).
- Combustion Engineering, Nuclear Power Outstanding Achievement Award, 1980, for Nondestructive Testing Technology Development.
- Principal Consulting Engineer appointment, 1987, from the Technical Appointment Committee, Nuclear Power Systems.

PATENTS ISSUED / PATENTS PENDING / COPYRIGHT / TRADEMARKS:

- Method for Effecting a Surface Examination of Coated Components
  #4,418,315, May 1981 (with L. J. Edwards)
- Apparatus for Remotely Indicating Angular Position
  #4,493,155, September 1982 (with J. H. Comeau and H. A. Runde)
- Near Surface Inspection System
  #4,509,369, August 1983 (with Z. Kuljis and M. V. Brook)
- System for a Fiber Optic Cable for Remote Inspection of Internal Structure of a Nuclear Steam Generator
  #4,575,185, August 1983 (with T. H. Wentzel and C. B. Innes, Jr.)
- Eddy Current Testing Imaging System, #5,311,128, June 1992 (with D. Leonard)
- Lamb Wave Ultrasonic Probe for Crack Detection and Measurement in Thin Wall Tubing, #5,767,410, June 1998 (with M. Brook)
- Steam Generator Nondestructive Examination Method
  #7,647,829 B2, January 2010 (with W. Junker)
- Method for Applying Burnable Poison onto the Exterior of Nuclear Rod Cladding
  #7,815,964 B2, October 2010 (with E. Lahoda, W. Junker and T. Congedo)
- Steam Generator nondestructive Examination Method
  #8,011,249 B2, September 2011 (with Warren Junker)

PUBLICATIONS, ARTICLES, PROCEEDINGS AND TECHNICAL REPORTS

"Eddy Current Test Manual", J. P. Lareau et al, Bettis Atomic Power Laboratory, TM-123, 1973.

"Nondestructive Measurements of Zirconium Oxide Corrosion Films on Irradiated Zircaloy Clad Fuel Rods", H. D. Goddard, J. P. Lareau et al, NPSD-102, 1980.

"Implementation of USNRC Regulatory Guide 1.150", J. P. Lareau, ANS Transactions, Volume 41, 1982.

"Advanced NDE Techniques", J. P. Lareau, Corporate Technology Conference Transactions, 1983.

"Reliable IGSCC Detection with Automated Ultrasonic Imaging System", A.A. Bhave, J. P. Lareau, R. P. Simpson, Nuclear Plant Safety, November-December, 1986.
"Eddy Current Imaging of Aircraft Using Real Time Image Signal Processing", J. P. Lareau and M. W. Kirby, Quantitative Nondestructive Testing Transactions, 1989.

"Review of Pulse/Echo Ultrasonic Methods for Inspecting Bondlines", J. P. Lareau and R. S. Devlin, NDE of Adhesive Bonds and Bondlines, ASNT Fall Conference Proceedings, 1989.

"Boiling Water Reactor Feedwater Nozzle Inner Radius Inspection Using Ultrasonic Phased Array Methods", J. P. Lareau and D. King, EPRI Phased Array Technology Conference, August, 2001.

Numerous Westinghouse technical reports (WCAPs) e.g. embedded flaw repair for CRDM nozzles, evaluation of shop UT practices in response to findings at the Doel 3 plant, and false positive evaluations for CRDM nozzles.

Emc² Response to PNNL Request for Quote for Additional Emc² Scope for NRC-HQ-20-14-T-0025 On Emc² Project 14-G61-01 PNNL Subcontract # 244644

The US NRC-NRR has provided PNNL with additional scope requirements for their current task (NRC-HQ-20-14-T0025) dealing with **"Verification of Residual Stress Measurements in Reactor Coolant System Components and Welds."** As a subcontractor to this contract, Emc² has been tasked with supporting and helping to address the first two major items identified in the NRC-NRR SOW indicated below:

"The DOE Laboratory (PNNL) must provide all resources necessary to accomplish the tasks and deliverables described in this statement of work (SOW). The following items should be considered;

1. *Upper head penetration nozzles with at least three different incident angles (0-10 degrees, 15- 25 degrees, and > 30 degrees) including partial penetration weld. No grinding should be performed on the weld surfaces.*

2. *Alloy 182/82 butt welds representative of reactor coolant system piping butt welds with surface roughness at the limits allowed by MRP-335.....*

...The DOE Laboratory must be able to mathematically predict the weld residual stresses in items 1 and 2 above to identify the areas of higher weld residual surface and near surface stresses. The DOE Laboratory must be able to use multiple weld residual stress measurement techniques (including, but not limited to, surface incremental hole drilling, slotting and x-ray diffraction) to evaluate the predicted weld residual surface and near surface stress conditions up to 1 millimeter in depth of items 1 and 2 above, both pre and post peening. The DOE laboratory must provide their expert opinion on the effectiveness of this process to validate peening depth of compression in individual licensee mockups, and provide any recommendations for requirements to provide adequate assurance of an effective validation test.

The DOE Laboratory will provide documentation of their results and participate in monthly status calls throughout the period of performance. Additionally, DOE Laboratory staff will support public meeting discussions with the authors of the topical report to address any needed additional information and discuss final results of the project. Finally, DOE Laboratory will provide a technical letter report summarizing the effort and providing all details of the findings for use in NRC written safety evaluations.

The DOE Laboratory may need to travel to supervise any subcontracts that are necessary such as manufacture or processing of samples or measurement of weld residual stress."

4.1 SPECIFIC TASKS

Based on the specifications laid out in the SOW, Emc² will support PNNL on the following tasks and subtasks.

Statements from the SOW are quoted in italics in the following sections.

Task 7 – Weld Residual Stress Measurements of Upper Head Penetration Nozzles and Reactor Coolant System Butt Welded Piping

"...The DOE laboratory will provide an assessment on the effectiveness of the licensee's proposed process to validate peening depth of compression in individual licensee mockups. The DOE laboratory will use a section of weld from Item 4 of Task 2. The DOE laboratory will take surface residual stress measurements (including, but not limited to, surface incremental hole drilling, slotting and x-ray diffraction) of the weld and near plate material surfaces. Each measurement type should be performed three times. The DOE laboratory will then provide the data with any notes to the NRC.

The DOE laboratory will also provide any recommendations for requirements to provide adequate assurance of an effective validation test through the following steps.

> ***Task 7a -*** *The DOE Laboratory will mathematically predict the weld residual surface and near surface stresses in items 1 and 2 of Task 2. The DOE Laboratory will then submit these analyses for NRC review..."*
>
> Engineering Mechanics Corporation of Columbus (Emc²) will support PNNL in its efforts to predict weld residual surface and near surface stresses along with full field stresses identified in Items 1 and 2 of Task 2 via computational methods supported by physical data developed for both the upper head penetration nozzles and the Alloy 182/82 butt welds of interest. Task 7 will focus on characterizing these properties in the as received samples, prior to any optional 'peening' processing that may be selected during this project (See Optional Task 11 discussion later in this document for Post-Peening discussions). Emc² will use the VFT© code along with ABAQUS for these solutions. Specifically related to these efforts:

1. Emc², in consultation with PNNL, will select three (3) representative Control Rod Drive Mechanism (CRDM's) specimens with upper head penetration nozzle geometries in the ranges of:
   a. 0-10 Degree
   b. 15-25 Degree
   c. > 30 Degree
2. These CRDMs will be delivered to Emc² so that Emc² can build 3D Finite Element (FE) models of the systems based on the actual dimensions determined or Emc² staff will travel to the location of the nozzles to obtain the

correct geometry if desired.

3. Once the 3D FE Model has been constructed and appropriately QA'd for completeness, Emc² will conduct a full scale 3D FE Analysis of each of the models to determine stress profiles across the CRDMs
4. The FEA results will be used to identify critical areas of high tensile residual stresses for each model
5. These results will be submitted to PNNL for forwarding to NRC-NRR in conjunction with parallel efforts at PNNL
6. In addition to the WRSM on the CRDM specimens, a similar methodology will be used to evaluate WRS on an Alloy 182/82 butt weld that is representative of reactor coolant system butt welds. The weld evaluated will be selected and generated by PNNL and delivered to Emc² for inclusion in the various studies with the CRDM samples.

Emc²'s estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is $95,000 which includes labor, materials, shipping and other ODC's associated with the work.

Task 7b –"*...The NRC will identify up to 3 areas of high tensile stress to be evaluated by the DOE Laboratory...*"

Upon review of the results from Task 7a, NRC-NRR will, in consultation with appropriate PNNL and Emc² technical staff, identify up to three (3) areas of high tensile residual stress determined through the FE Analysis (FEA) to be experimentally confirmed by the PNNL/Emc² team. This work will require a meeting with PNNL, NRC and Emc² staff in order to critically review the FEA results of Task 7a to insure that sufficient detail was available in the initial analyses to be able to select appropriate high stress areas. If necessary, after this initial review and with direction and approval from PNNL, Emc² will conduct additional scoping FEA to provide more fidelity in the models to provide greater clarity in defining the three (3) best areas for Weld Residual Stress Measurement (WRSM) in each CRDM.

Emc²'s estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is $20,000 which includes labor, materials, shipping and other ODC's associated with the work.

Task 7c – "*...The DOE Laboratory will use weld residual stress measurement techniques (including, but not limited to, surface incremental hole drilling, slotting and x-ray diffraction) to evaluate the predicted weld residual surface and near surface stress conditions up to 1 millimeter in depth of the locations identified in Task 7b...*"

Currently, a 'practice' CRDM resides at Hill Engineering in Sacramento, CA which conducted deep hole drilling (DHD) WRSMs in earlier tasks on this effort to determine comparability of experimentally determined WRS with those predicted using FEA. An objective of Task 7c is to develop complementary experimental techniques to DHD as a quality assurance (QA) check of the primary analysis and test methodologies.

For Task 7c, Emc² has identified two (2) potential vendors of X-ray diffraction analyses that have the capabilities to evaluate WRS in both the CRDM and butt weld sample specimens. These vendors, Lambda Technologies of Cincinnati, OH and America Stress Technologies of Pittsburgh, PA, will be asked to analyze the 'practice' CRDM in

similar locations as Hill Engineering has to confirm Hill's WRSM findings using the complementary x-ray diffraction technology.

Thus, Emc^2 will arrange to have the 'practice' CRDM returned from Hill to Emc^2 laboratories. Upon return of this specimen, Emc^2 will inspect visually to make sure no evident damage occurred during shipment. Following this internal inspection, Emc^2 will then ship the sample to Lambda for WRSM via x-ray diffraction. Following Lambda's testing, the specimen will be returned to Emc^2 for forwarding to American Stress Technologies (AST) for similar x-ray diffraction WRSM testing.

After both Lambda and AST have completed their measurements and provided a report on their findings, Emc^2, PNNL and NRC-NRR staff will review the results and select one vendor for conducting additional x-ray diffraction work on the three (3) CRDMs selected in Task 7a along with the butt weld specimen prepared for these exercises. Once the CRDMs selected in Task 7a and the butt weld have been received by the selected x–ray diffraction vendor, they will be asked to conduct analyses at three locations on each CRMD that were identified from the Task 7b effort along with the location(s) identified for the butt weld sample.

Once the x-ray diffractions measurements on these CRDMs and the butt weld have been completed the samples will be shipped to Hill Engineering for DHD analyses using both hole and slotting techniques that have been conducted on the 'practice' CRDM previously. The x-ray diffraction vendor will supply a report of their results on each of the separate CRDMs and the butt welded specimen to forward to Emc^2 for comparison the DHD results of Hill. Likewise, Hill will provide a report of results of their WRSM.

Emc^2's estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is $68,000 which includes labor, materials, shipping and other ODC's associated with the work.

<u>Task 7d</u> – *"...The DOE Laboratory will provide a technical letter report documenting this task and providing assessment of this technique to choose locations to validate the effectiveness of peening..."*

Task 7d will focus on preparing a technical letter report comparing the results of the computational FEA with those of the experimental methods, x-ray diffraction, hole drilling and slotting efforts. The report will provide recommendations and conclusions regarding the confidence levels when comparing computational WRS prediction results with those determined experimentally and will identify the preferred experimental technique for efforts of this type.

Emc^2 will prepare draft technical reports for PNNL to review and forward to NRC-NRR for review and comments.

Emc^2's estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is $25,000 which includes labor, materials, shipping and other ODC's associated with the work.

Task 11 (optional)–"*...If any Task 2, Item 1 or 2 specimen is peened and returned to the DOE Laboratory, the DOE Laboratory will measure the surface and near subsurface stress as in Task 7, to evaluate stress conditions of each specimen in the locations identified in Task 7b. The DOE Laboratory will document the location and values of these stress profiles and compare the measurements to the values provided in Task 7 for each specimen in a revision/continuation of the Task 7 TLR. The NRC will review this document and provide comments to the DOE Laboratory. The DOE Laboratory will address any comments in a reasonable time period to support schedule...*"

Task 11a Optional, DOE completes stress profiles on peened specimens

Depending on decisions made in Task 2 regarding potential peening of any of the specimens, Emc^2 will support PNNL in develop stress profiles of the peened specimens. Similar to the Task 7 efforts, Emc^2 will ship for analysis up to three (3) CRDMs and one butt welded specimen post-peening to the selected x-ray diffraction vendor chosen in Task 7. This vendor will then develop WRSM at the locations determined from Task 7b. Following these measurements, the same CRDM and butt weld specimens will be shipped to Hill Engineering for WRSM using hole drilling and slotting techniques in a manner similar to Task 7c.

Emc^2's estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is $43,000 which includes labor, materials, shipping and other ODC's associated with the work.

Task 11b - Optional, DOE completes final TLR on peening stress profile improvement

Task 11b will focus on preparing a draft technical report for PNNL to forward to NRC-NRR which will compare the results from all above tasks, i.e., FEA vs x-ray vs hole drilling and slotting techniques. Results from both pre- and post-peening measurements will be analyzed separately to determine if the peening process creates any different relationships amongst the analysis methods. Results, recommendations and conclusions from these evaluations will be incorporated in to the volume to be delivered to PNNL for review and forwarding to NRC-NRR for review and comments.

Emc^2's estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is $30,000 which includes labor, materials, shipping and other ODC's associated with the work.

Task – Emc^2 Coordination & Tech Support

Emc^2 will, in accordance with the RFP, provide monthly letter summary reports, coordinate meetings and conference calls with all participating entities as necessary and provide technical assistance and support, including participating in meetings at NRC, vendors, or PNNL as required to successfully complete these efforts. A minimum of two trips to NRC for

2 staff members for 2 days per trip will be scheduled for progress meetings and reviews as described in the specific task discussions. We have also budgeted for trips to the vendors and to PNNL for face-to-face meetings with technical personnel.

In addition, Emc[2] will provide all technical support along with attendance and testimony at public meetings such as ACRS hearings related to these efforts.

Emc[2]'s estimated cost for these efforts, based on our understanding of the scope and requirements at this time, is broken down by subject as:

- Travel $12,500
- MLSRs, Coordination, Conference Calls $24,000
- Technical Support & Public Meeting $35,000

TOTAL budget $352,500
Estimated Remaining balance in project - $60,000 after 8/31/15
Additional funds needed – $292,500

7	DOE completes surface stress measurement technique evaluation	1 month after the completion of Task 2.
7a	DOE completes all stress profiles on non-peened specimens	2 months after completion of Task 2 or 2a if implemented
7b	NRC and DOE agree on testing locations	10 days after Task 7a completed
7c	DOE completes stress measurements	2 months after Task 7b completed
7d	Final TLR on stress analysis	30 days after Task 7c completed
8	**Final TLR documenting specimens and areas to be peened**	**8 months after modification of contract**
9	DOE Ship/ NRC Peen/DOE Ship	As required by NRC
10a	Optional, DOE completes NDE on peened specimens	1 month after completion of Task 9
10b	Optional, DOE completes final TLR on NDE	30 days after Task 10a completed
11a	Optional, DOE completes stress profiles on peened specimens	2 months after completion of Task 10a
11b	Optional, DOE completes final TLR on peening stress profile improvement	30 days after Task 11a

MEMORANDUM

Pacific Northwest
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Date:	**April 13, 2015**	Project No.:	**TO25 - 66419**
To:	**Jay Collins and Carol Nove**	Internal Distribution:	**File/LB**
From:	**Aaron Diaz**		
Subject:	**Expert Opinion – ET Detection Capability Questions**		

Hello Jay and Carol,

In an email last month (March), you requested some technical feedback regarding various issues and questions associated with Eddy Current Testing (ET) detection capabilities. Here are some thoughts that have been assembled (via Jack Lareau). I wanted to make sure you had them captured somewhere for future reference and discussions you may be holding at NRC with regard to the peening issues.

In particular, you requested that PNNL provide an expert opinion on eddy current minimum size indication detection capability to support the MRP-335 R1 review. Additionally, you asked about the minimum flaw size that is qualified for detection with eddy current and you requested this information as a function of various surfaces to be addressed. Below in bold **Blue** are the responses from Jack Lareau for many of the surfaces/configurations you asked about.

<u>Surfaces to be addressed:</u>

1. **Nozzle inside surface**

PNNL Response:

ID surface flaws as small as a few mils deep are detectable, but not necessarily reported. With TOFD probes, there is a momentary interruption of the lateral wave when either the transmitter or receiver crystal is over something as small as a scratch. In France, these were categorized as Class 0 indications (no depth). WesDyne routinely reported these types of signals. No growth has ever been found with these types of indications. In fact, real ID flaws in CRDMs have not been seen in fifteen years. They were mostly limited to a few heats of rotary straightened B&W Tubular Products heats. (Note that there were a number of RPVHs that were started by B&W but finished by others (North Anna 1, 2 went to Rotterdam, Beaver Valley 1 went to CE, and these had ID cracking. The Oconee plants all had ID cracking.) Also, the growth rate of ID base metal flaws is fairly low and well

bounded by ASME Appendix C calculations. If ID flaws were a concern, then the inspection interval could easily be doubled from the existing rules.

2. Nozzle outside surface

PNNL Response:

In the few cases where OD ET has been done, the detection is about 5 mils. With ID TOFD, the N-729 demonstrations started at about 10% (~0.060"), but flaws are routinely reported at 0.030". The problem area is the toe of the weld where grinding can create phantom signals up to 0.060" just from the grinding process. Several such signals have been catalogued over the years and have shown no growth. In the early inspections, it was not clear whether these signals were flaws or weld artifacts. Extensive ET scans of the J-groove welds were performed to confirm that there was no surface breaking indication and none of them confirmed any cracking. There is a report written for PWROG on these false positives created by welding and grinding.

3. J-groove weld surface

PNNL Response:

This gets a little complicated to describe. The primary issue is coverage. Automated ET has been offered by WesDyne since 2000, but it has been limited to confirmatory inspections for UT results or the last several years. MRP-089 Sections 5.7 and 5.9 discuss the results of ET on ground and as-welded surfaces. This report showed that flaws 8 mm long for an as welded surface were detectable and 4 mm for the ground surface. (These were the minimum length flaws in the mockups.) For the removed CRDMs from North Anna 2, ET of the j weld found flaws 4.5 mm long in the butter layer, which was ground. ET is typically performed with a 1 mm step and calls are made with three successive hits. One and two hits were often false positives in other experiences on butt welds. The mockups had CIP EDM notches and actual SCC.

The false positives were related to abnormal weld conditions that would not exist in the real world since these conditions would have failed the final PT. Beaver Valley 2 reported two missed flaws by ET. Jack Lareau was on the Root Cause Team for FENOC and concluded that one flaw miss was operator error by setting the spatial derivative parameters incorrectly during analysis and the second miss was due to lack of coverage at the toe of the weld. In order to cover the toe of the weld, the orbital scan has to be done in quadrants trying to maximize the coverage of a circular scan onto segments of an oval.

The PINC report also looked at ET of J-groove welds and indicated that the X Probe (cross-point probe) had the best results and that the available array probes had the worst. This report should be evaluated in more detail and referenced in any response, especially since it is a joint NRC/EPRI undertaking.

a. High angle nozzles (30-50 degrees)

i. As welded surfaces

PNNL Response:

The issue is coverage rather than sensitivity. Even with quadrant scans, approximately 45 degrees on the uphill and downhill side miss about a ¼" strip.

4. Weld filet to nozzle interface

PNNL Response:

The OD ET scanner has two separate mechanisms, one for the nozzle OD and one for the J weld surface (these have been named "tube" and "roof" scanners). OD nozzle scans were very successful in tracking right up to the weld fillet and several flaws were reported at Beaver Valley 1. However, there is still about 45 degrees on the downhill side where the physical size of the probe hits the RPVH surface and misses about ¼". On the other hand, the UT from the ID can be used to determine if any subsurface inclusions exist in this region ad augments the ET coverage nicely. This UT review is strongly recommended since this is also the most likely location for any such inclusions.

5. Weld filet to J-groove weld

PNNL Response:

The current X point probe does not have the conformance to the filet geometry to provide coverage. Several flexible array probes have been tried with minimal improvement. The array probes also have a much lower data density than a single scanning probe, although the EddyFi array has performed quite well. (Unfortunately, EddyFi will not sell this probe without purchasing their instrument as well, so it is hard to evaluate independently). The PINC report has data on array probes for BMI J welds,

which I will review and summarize separately. PNNL will be trying a ribbon probe concept that has been successfully used in aerospace applications.

6. J-groove weld butter to stainless steel cladding

   i. Machined welds

PNNL Response:

No issues with an X Point probe, pancakes have interference from the conductivity change. In fact, X Point probes are not effective in finding the weld to clad interface and pancake coils are needed. (An X point in absolute mode would also work.)

b. Low angle nozzles (0-30 degrees)

   ii. As welded surfaces

PNNL Response:

Everything is the same as above with somewhat better coverage. For high angle nozzles the total area coverage is ~90%, for low angles it improves to about ~95%. In either case, the UT review for inclusions augments assessment at the weld fillet, especially on the downhill side.

What are PNNL thoughts on Figure 5-4 for the probability of detection for ET exams in MRP-335 R1?

PNNL Response:

The MRP-335 Figure 5.4 is a complete fabrication and has no bearing on reality. ET can easily detect real flaws at 0.25-0.5 mm depth. I (Jack Lareau) cannot imagine ET missing a flaw 1 mm deep. The length is the bigger issue. There was extensive work done on the VC Summer butt weld that was removed after leaking. ET and DT were compared. All ET calls with three or more detections at 1 mm steps were confirmed. By the way, the destructive testing showed aspect ratios (length/depth) ranging from 1.1:1 to 3:1. MRP 335-1 uses a half-length/depth descriptor and states that this cannot be <1:1, however the VC Summer flaws mostly are, in fact, in that lower range. The MRP-335-R1 evaluation is probably correct for circumferential flaws, but totally incorrect for axial flaws.

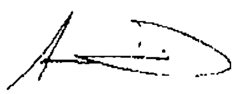
For ET studies, the CIP process produces misleading results for two reasons. First, the square corners of the original EDM notch tend to crack outward at a 45 degree angle while the faces of the EDM in the middle of

the notch close almost to fusing together. SO the strongest response comes at the two ends and the middle tends to disappear a bit. Neither is representative of real cracks. For real SCC, the crack faces are converted to an insulating layer (either an oxide or a salt) and this remains as a current block even with tight contact. Again, at VC Summer, the non-leaking nozzles had shallow PWSCC that were recorded by ET. These had MSIP applied at the next outage. One was no longer detected by UT, but both were essentially unchanged in ET response.

In summary, ET of the wetted surface does work well, but J-groove weld ET inspections would add about a week to the schedule. ET of the nozzle ID has been performed on thousands of nozzles, but dropped for plants with thermal sleeves once the EPRI qualifications required TOFD in two directions and the ET coil was replaced by an additional TOFD-UT pair. The existing ID TOFD can find very shallow flaws in any orientation by reporting interference in the lateral wave. WesDyne reports these conditions, but there are no requirements to do so.

A limited amount of ET on the nozzle OD has been performed. The only instances of OD cracking separated from toe of the weld occurred in plants with cold worked, rotary straightened B&W tubing nozzles. These heads have all been retired. UT detection for OD flaws, given that there is now prior data for comparison that can be used to eliminate false positives from welding phantoms, is realistically 5%T, including in the weld region. The biggest concern, is the possible existence of near subsurface flaws at the toe of the weld. A UT review of existing data would detect this condition. This actually is a requirement for inspections in Europe.

Sincerely Submitted,



Aaron Diaz
Senior Staff Scientist – Acoustics & Ultrasonics
Pacific Northwest National Laboratory (PNNL)

AAD/AAD/aad (*Signer/originator/typist initials*)

Enclosures/Attachments (none)

MEMORANDUM

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Date:	**April 13, 2015**	Project No.:	**TO25 - 66419**
To:	**Jay Collins and Carol Nove**	Internal Distribution:	**File/LB**
From:	**Aaron Diaz**		
Subject:	**Comments on MRP-335 R1, Appendix A – PNNL Perspective**		

Hello Jay and Carol,

A couple weeks ago you requested PNNL comments and technical feedback regarding a review of Appendix A in MRP 335, R1. PNNL conducted a review of this Appendix and expert opinions and thoughts have been documented here for your consideration as you both continue to engage in discussions about Peening at the NRC. These thoughts and perspectives were generated by Jack Lareau and are summarized here for your future reference and consideration. Below in bold **Blue** are the responses from Jack Lareau from his recent review of Appendix A.

PNNL Comments:

Of primary concern with this report is the very nature of, and selective use of the data which are available to MRP/EPRI. There are a number of documents that contain data that contradicts many of the assumptions. All the mathematical analytical conclusions are sound, but one has to question the initial assumptions, which use selective data.

Section A.5 assumes a semi-elliptical model for crack growth, which has NEVER been the case for actual flaws in welds. It also only analyzes for a circumferential flaw, which has never been confirmed. All confirmed flaws have been axial (which makes sense since the hoop stress is about double the axial stress). Also note that this report uses a c/a value (crack half-length/depth) while the ASME Code uses a/l (depth/length), which can confuse reviewers. The report states that c/a will be >1 and the model cannot deal with lower values. However, Table A.6 switches to a listing of 2c/a. Converting the values for axial flaws, the c/a value becomes <1.

On page A.29 there is a statement that flaw growth behind a compressive layer is unlikely, or at least slow. At VC Summer, the surface grinding of the weld created a shallow compressive layer (~5 mils). Nearby flaws that started on the surface did indeed grow beneath that layer. An example image of this type of flaw is available showing subsurface crack propagation.

The flaws found at the VC Summer outlet nozzle had a c/a value ranging from 0.55 to 1.5. That report is selectively not referenced. The report assumes that only circumferential flaws are of interest. The actual flaws that have been missed by PDI techniques have been axial (VC Summer, North Anna). The report (A.8.4.2) downgrades the POD for axial flaws by 20%, with no technical basis. Field data contradicts this assumption. Using circumferential flaws (which have limited beam transmission through the weld metal) to axial flaws (with total sound transmission through weld metal), has no basis.

Section A.8.2.8 extrapolates POD for 5% flaws at 50% from the 90% value for 10% flaws (PDI limit). There is no basis for this and there is contradictory data. For the infamous FP&L pressurizer welds that were initially called with very deep and long circumferential cracks and later changed to all subsurface manufacturing flaws, there actually were circumferential flaws that were found by ET. By destructive testing, these were shown to be hot tears, but at least one of these flaws was >15%. This is documented in an MRP report written by BWXT, but not referenced. It was dismissed since it was not PWSCC, but neither are the PDI qualification samples. The UT was automated, encoded conventional and phased array. Images in the final EPRI report do show these indications, but they are not called out. There were so many subsurface indications that had been miscalled as PWSCC earlier, everybody wanted this fiasco to go away. But, this was a real DM weld with real circumferential flaws and should not be dismissed.

There is a typo in A.6.1 with a 7 year inspection interval for "hot leg cold leg" nozzles. And finally, The ET evaluations are based on a depth value, rather than a length value, which is much more important. In A.8.4.3, there is an assumption of flaw detection when l>2 mm in the weld, however, MRP-089 and the PNNL work on the removed North Anna nozzles showed a detection limit of ~4 mm. The EPRI ET SS examples are based on steam generator tubes, which have no correlation to weld metal. For the base metal, the detection is actually better than stated, <5 mil deep flaws have been routinely reported on nozzle IDs, which have been scratches.

Sincerely Submitted,

Aaron Diaz
Senior Staff Scientist – Acoustics & Ultrasonics
Pacific Northwest National Laboratory (PNNL)

AAD/AAD/aad (*Signer/originator/typist initials*)

Enclosures/Attachments (none)

MEMORANDUM

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Date:	**April 13, 2015**	Project No.:	**TO25 - 66419**
To:	**Jay Collins and Carol Nove**	Internal Distribution:	**File/LB**
From:	**Aaron Diaz**		
Subject:	**Comments on MRP-335 R1, Appendix B – PNNL Perspective**		

Hello Jay and Carol,

Recently you requested PNNL comments and technical feedback regarding a review of Appendix B in MRP 335, R1. PNNL conducted a review of this Appendix and expert opinions and thoughts have been documented here for your consideration as you both continue to engage in discussions about Peening at the NRC. These thoughts and perspectives were generated by Jack Lareau and are summarized here for your future reference and consideration. Below in bold **Blue** are the responses from Jack Lareau from his recent review of Appendix B, regarding some very important issues concerning RPVH J-groove welds.

PNNL Comments:

The prevalent issues are:

1) The ALP vendor has backed off this claim for these materials and geometries.

2) The two currently planned mitigations are at Exelon and Beaver Valley plants. ALP is not planned for any of these sites.

Exelon plans on using a modified water jet peening process which was previously used by AREVA for the half nozzle repairs (Davis-Besse, Oconnee plants, Millstone 2, ST Lucie and others). This process, which has evolved over the years, has been docketed by the licensees). They also plan on peening the CRDM ID without removing the thermal sleeve, which greatly limits the peening depth since the annulus is only about 0.1", so any peening depth is questionable (and certainly not verified).

Beaver Valley plans on laser peening, with 1 mm penetration.

I (Jack Lareau) personally think ID peening is unnecessary since we have not seen any ID flaws in 15 years. Even if they occur, the growth is slow and can be

repaired by milling the ID to remove the flaw or by a weld inlay. (A dozen such repairs have been performed at DC Cook (2), Millstone (1) and Doel (9)).

3) Fundamentally, the probabilistic assessment for welds ignores the possibility of manufacturing flaws, which have been a major contributing factor for both butt welds and J-groove welds.

I am not concerned about butt welds since the Sect III RT, Sect XI surface inspection and the committed surface exams before peening are sufficient to find any problems.

The J-groove weld is an entirely different issue. Since there was no volumetric inspection during construction, the ASME III Code degrades the joint efficiency by 30%. (I remember this, but do not have chapter and verse reference, so the code experts can weigh in on this.) In the actual failures of J-groove welds (combining BMIs and CRDMs), near subsurface inclusions (or voids, per EPRI) were found in most cases, always at the toe of the weld. For the two BMI leaks that had destructive testing done, the remaining ligaments above the manufacturing flaws were 0.02" and 0". Peening to a depth of 0.04" could break or weaken such a ligament.

For J-groove welds, there is an incremental PT about every half inch of weld deposition performed during welding. Then one can assume 3 PT's through the depth. Probablistically, one can argue, given a Code assumption that each weld has an aggregate of 30% weld flaws, distributing this over the three separate PT zones, 10% reside in the outer 0.5" of weld. Take the Appendix B assumption of 0.03" (0.8 mm flaws) equally distributed through this thickness, then about 0.6% of welds have a condition with a near subsurface flaw that peening could open to the primary water. A UT data review using the leak path detection technique would identify the potential for flaws that could be opened up by peening. (I had recommended this to utilities before I retired and I think some utilities did this.)

To generally summarize, many of the probablistic arguments are based on an assumed head temperature. It is important to understand that there is no defined way to actually measure this value and some plants use the outlet temperature. This is a problem with B&W plants since the core design shunts about 10% of the control rod column flow directly to the center of the head resulting in temperatures in the center region that are about 10-15°F higher than the outlet. (That is why Davis-Besse had the biggest issues with the lowest residual stress penetrations, and they leaked earlier than the MRP EDY model would suggest because they used the wrong temperature for the calculation). Also, the shape of the head is important because it contributes to the operational stress. WEC RPVHs are hemispherical and deform into an ellipse at pressure, CE heads are elliptical and elongate vertically at pressure, B&W plants have a truncated chord of a sphere and are comparatively flat, which produces the most distortion at

pressure. The CE elliptical design is a contributing factor for no leakage in the peripheral ICI nozzles.

The biggest issue is that all the crack initiation and growth models ignore manufacturing flaws, which have been a major source of cracking. For J-groove welds, since there is no volumetric inspection of the weld, the ASME assigns a "joint efficiency factor" of 70%. This means there is an inherent Code assumption that 30% of the weld thickness is flawed.

The second major stumbling block is an assumption of a 3 mm compressive layer. Note: B-XX denotes page number, B.X.Y denotes section numbering.

B-5: There is an apparent typo in first full paragraph saying Appendix B explanations overlap Appendix B explanations (should be Appendix A).

B-16: On page B-16 there is a statement that the analysis assumes a 3 mm compressive layer on the nozzle OD and J-groove weld. If that is really an underlying assumption, then no one can peen a RPVH. I thought they had changed that, especially since even the assumed vendor backed down on that claim.

B-19: There is a statement of "no clear stress dependent location". I do not understand this since the residual stresses are entirely location dependent around the RPVH and around any given weld.

B.4.2: This model is the same one that DID not predict any of the early leaks.

B.4.4: This states an assumption that weld cracks would start at the centerline. That is not true.

B.5: Concerning crack growth rate, these assumptions are backed up. I (Jack Lareau) conducted an evaluation of crack growth for around 20 flaws that were missed in one and detected the next inspection in WEC plants. The results came in at about the 50th percentile of the rate shown in MRP-55. As a matter of note, it came out to be 0.045"/RIY.

B.8.2.8: There is no basis for extrapolating a median POD for a 5% flaw in the weld region. Weld repairs without documentation can be up to 10%T and are frequently detected.

B8.4.1: I believe they transposed hot and cold heads stating that a hot head would be inspected after the 12th cycle and a cold head after the 6th.

B.8.4.2: These POD curves are very conservative, but if the analysis works with these values, so much the better for the real world.

B-66: On page B-66 it also assumes a 3 mm compressive layer and that ALP (Air Laser Peening) will be used for this situation.

These perspectives and opinions are not made with the intent or suggestion to kill peening, but are offered to help identify key issues that could have unintended consequences if they are not suitably evaluated. If a new crack were to be caused by this method, there would be time to repair it before a real problem occurred, but if one of the first peening plants subsequently found a new crack during the next outage, the peening process would come into question. Acknowledging this low probability and preparing for it, would create a better overall strategy.

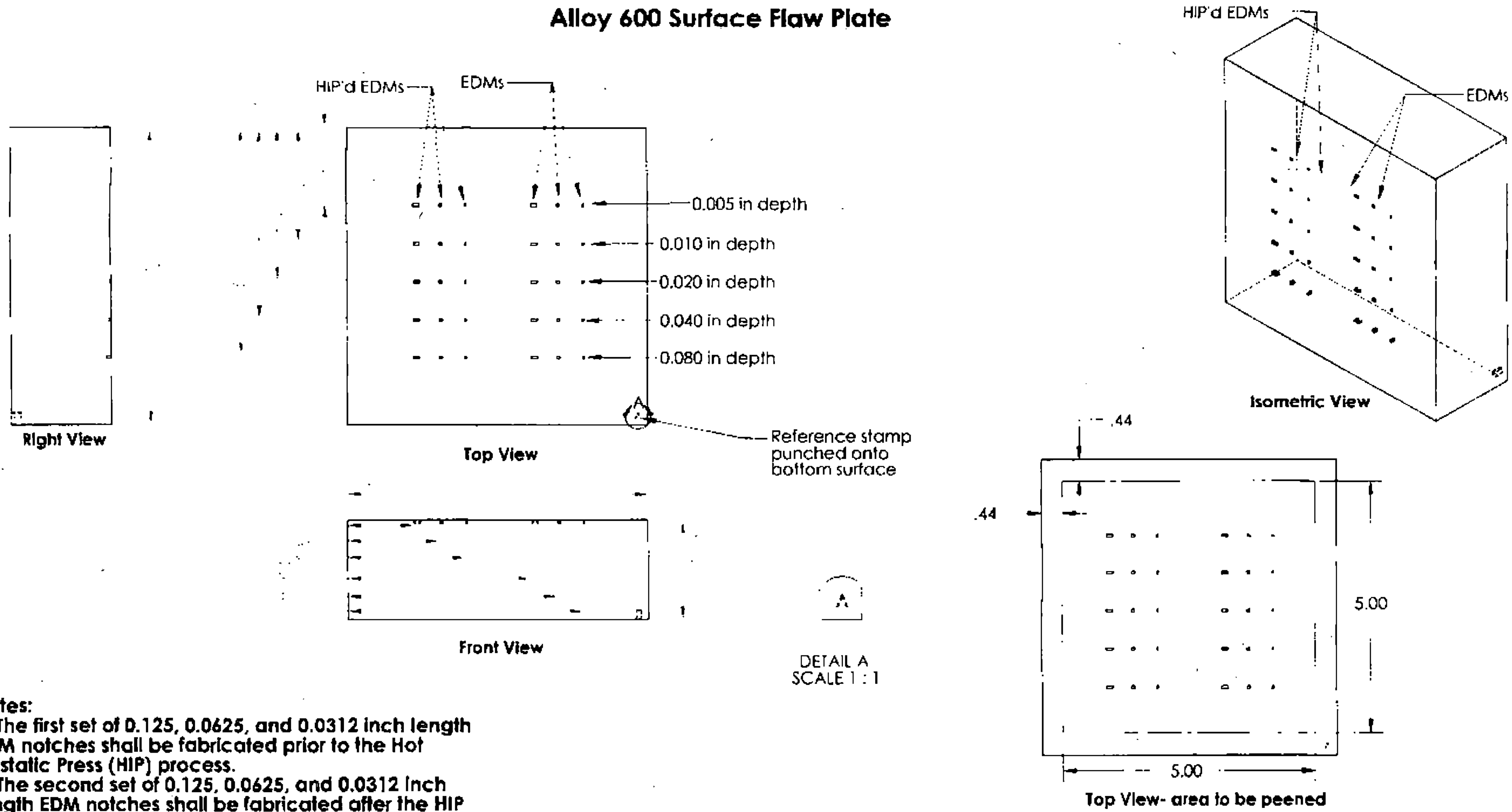
Sincerely Submitted,

Aaron Diaz
Senior Staff Scientist – Acoustics & Ultrasonics
Pacific Northwest National Laboratory (PNNL)

AAD/AAD/aad (*Signer/originator/typist initials*)

Enclosures/Attachments (none)

Alloy 600 Surface Flaw Plate

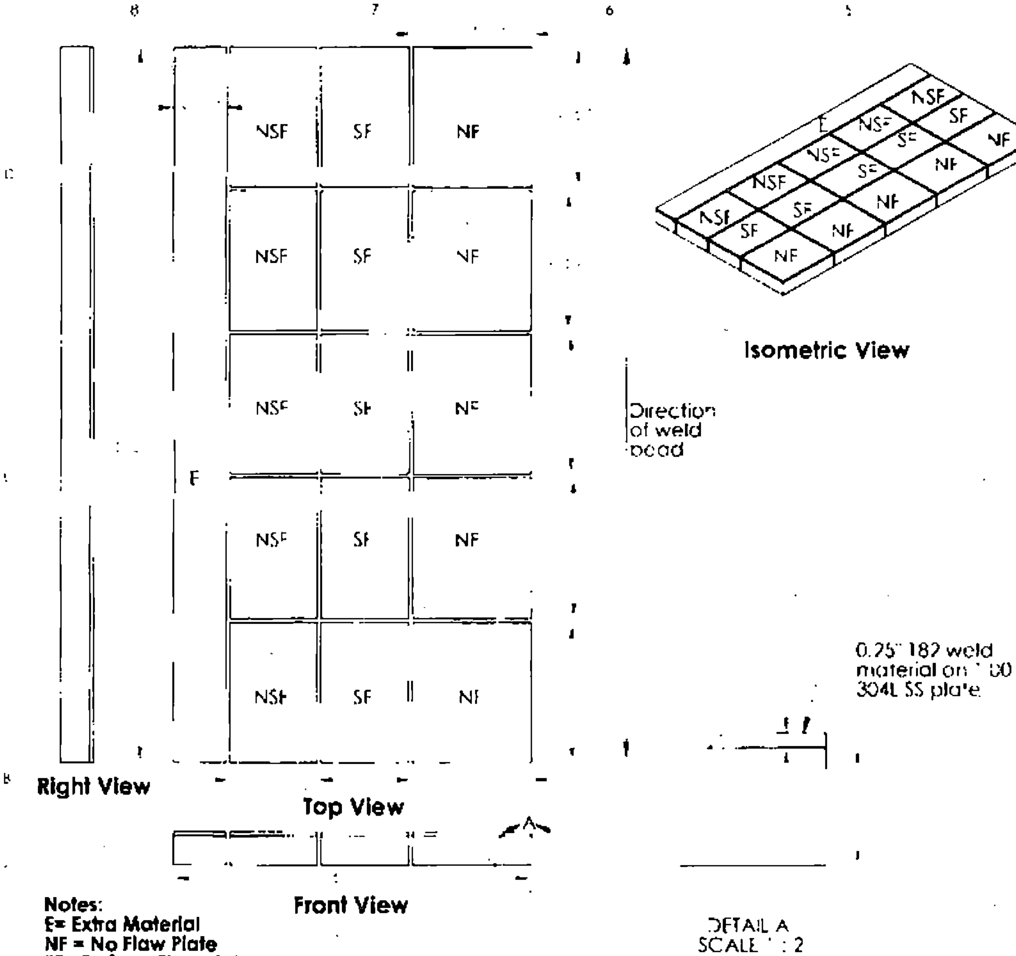


Notes:
1. The first set of 0.125, 0.0625, and 0.0312 inch length EDM notches shall be fabricated prior to the Hot Isostatic Press (HIP) process.
2. The second set of 0.125, 0.0625, and 0.0312 inch length EDM notches shall be fabricated after the HIP process is complete.
3. All EDM notches shall be fabricated such that the notches have 0.050 inch width and the specfied depth. The depth shown in the Top View is applicable to every notch in that row.
4. Peening shall be peromed on the face of the plate containing the EDM notches. The peened area shall be 5.0"x5.0" and centered on the plate as shown in the additional top view.

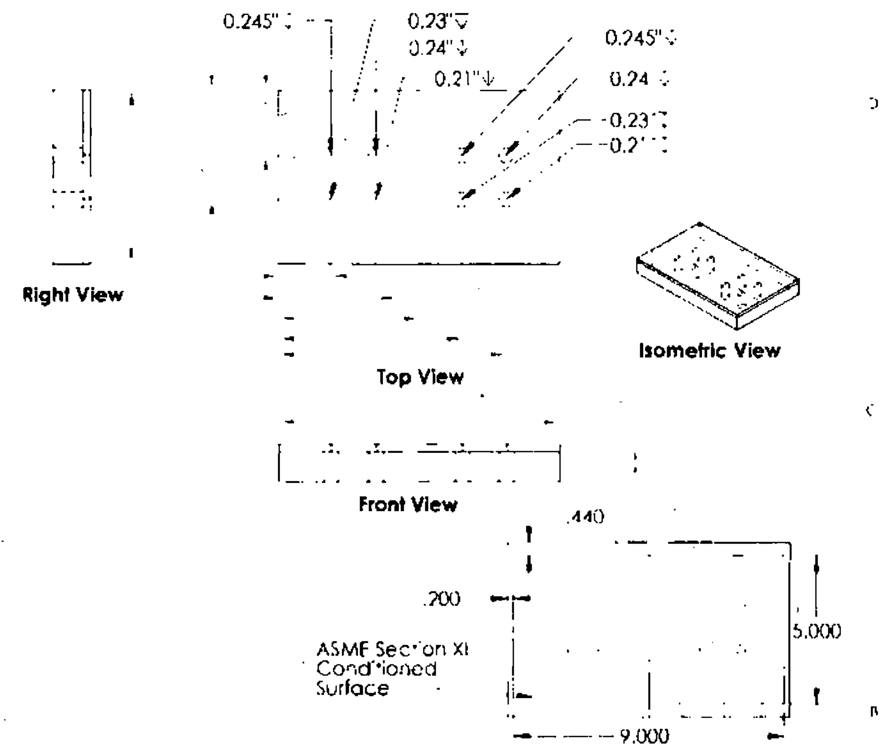
TITLE:

SIZE DWG. NO REV
B Surface Flaw Plate

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



Near Surface Flaw Plate



Notes:
E= Extra Material
NF = No Flaw Plate
SF= Surface Flaw Plate
NSF = Near Surface Flaw Plate
The 2"x24"x48" 304L SS plate shall have a 0.25" cladding layer of 182 welded onto the top surface with the weld bead in the direction specified in the Top View. The cladding layer shall be 0.25" thick after surface prep is performed. The surface shall be prepared such that surface roughness is reduced so eddy current and ultrasonic exams can be performed. After the 0.25" cladding layer is complete the plate shall be cut in 16 pieces as specified below:
5- 2.25"x7.875"x9.400" (5 NF)
5- 1.25"x5.875"x9.400" (5 SF)
5- 1.25"x5.875"x9.400" (5 NSF)
1- 1.25"x3.625"x48.0" (E)
The desired plate dimensions have been reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

Near Surface Flaw Plate Notes:

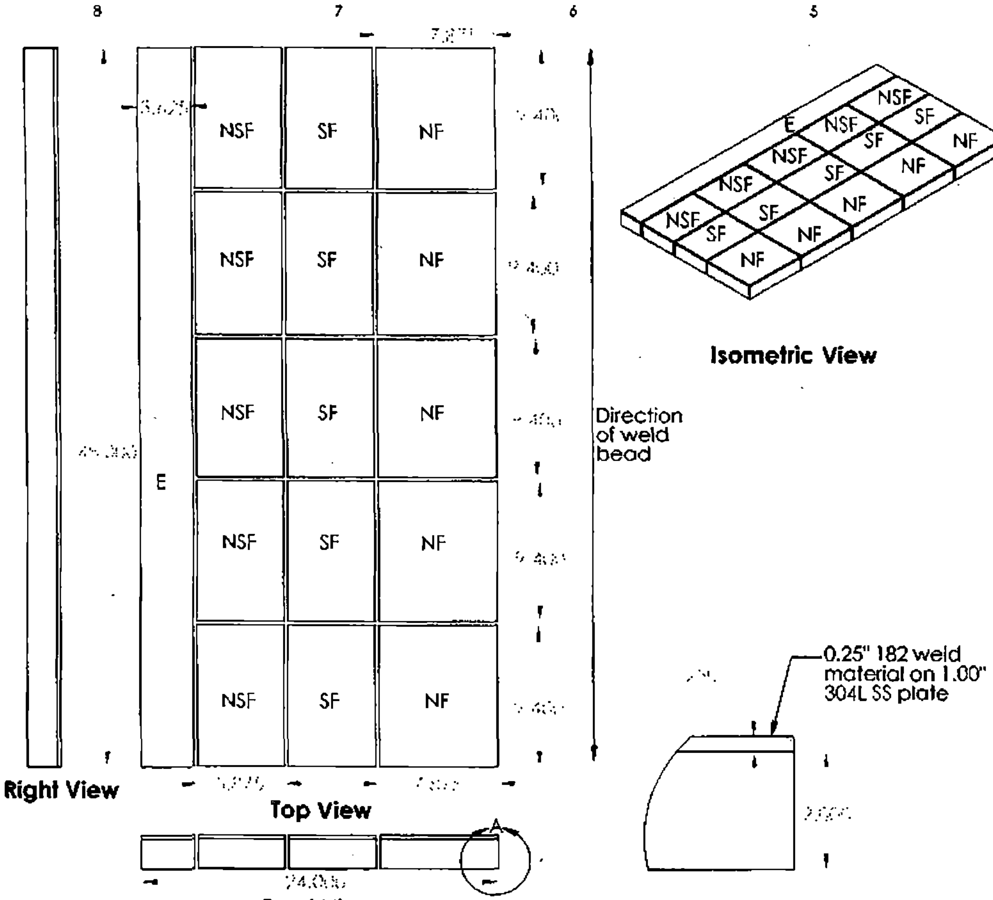
The 2.25"x5.875"x9.4" plate shall have 0.5" diameter flat bottom holes drilled from the 304L SS side that are 0.90" in depth. Then a 0.04" diameter bit shall be used to drill 4 holes to the specified depths that are concentric with the 0.5" holes. The holes depths shall be 0.345", 0.34", 0.33", and 0.31" (leaving a ligament of 182 weld material that is 0.005", 0.01", 0.02", and 0.04" respectively). The left half of the plate, as viewed from the top view, shall have the surface conditioned to the specification in nonmandatory appendix D of the ASME section XI code.

PROPRIETARY AND CONFIDENTIAL

TITLE:

SIZE DWG. NO. REV
B 182Weld Specimen

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

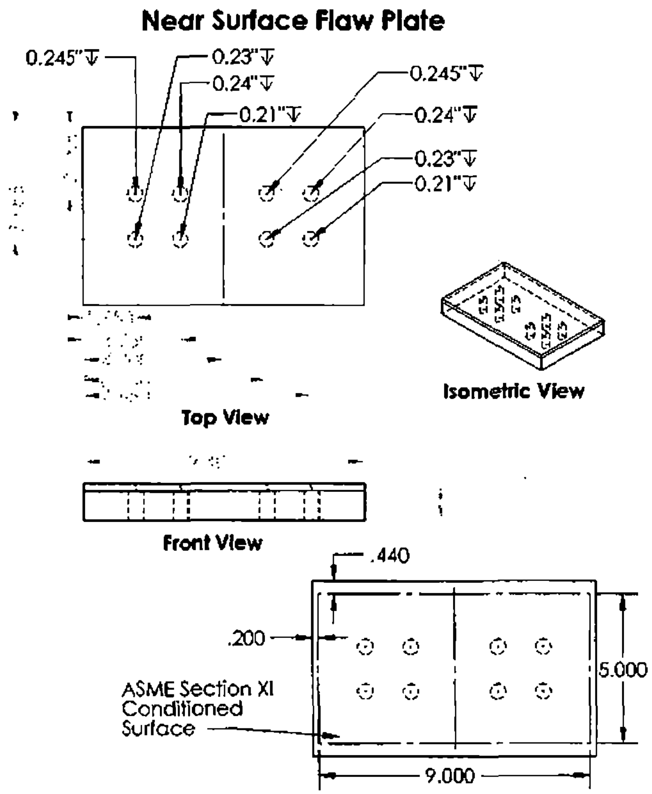


Front View

DETAIL A
SCALE 1 : 2

Notes:
E= Extra Material
NF = No Flaw Plate
SF= Surface Flaw Plate
NSF = Near Surface Flaw Plate
The 2"x24"x48" 304L SS plate shall have a 0.25" cladding layer of 182 welded onto the top surface with the weld bead in the direction specified in the Top View. The cladding layer shall be 0.25" thick after surface prep is performed. The surface shall be prepared such that surface roughness is reduced so eddy current and ultrasonic exams can be performed. After the 0.25" cladding layer is complete the plate shall be cut in 16 pieces as specified below;
5- 2.25"x7.875"x9.400" (5 NF)
5- 1.25"x5.875"x9.400" (5 SF)
5- 1.25"x5.875"x9.400" (5 NSF)
1- 1.25"x3.625"x48.0" (E)
The desired plate dimensions have been reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

Near Surface Flaw Plate



Top View- area to be peened

Near Surface Flaw Plate Notes:

The 2.25"x5.875"x9.4" plate shall have 0.5" diameter flat bottom holes drilled from the 304L SS side that are 0.90" in depth. Then a 0.04" diameter bit shall be used to drill 4 holes to the specified depths that are concentric with the 0.5" holes. The holes depths shall be 0.345", 0.34", 0.33", and 0.31" (leaving a ligament of 182 weld material that is 0.005", 0.01", 0.02", and 0.04" respectively). The left half of the plate, as viewed from the top view, shall have the surface conditioned to the specification in nonmandatory appendix D of the ASME section XI code.

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES; TOLERANCES: FRACTIONAL ±; ANGULAR: MACH ± BEND ±; TWO PLACE DECIMAL ±; THREE PLACE DECIMAL ±; INTERPRET GEOMETRIC TOLERANCING PER:; MATERIAL; FINISH

NAME | DATE — DRAWN; CHECKED; ENG APPR.; MFG APPR.; Q.A.; COMMENTS:

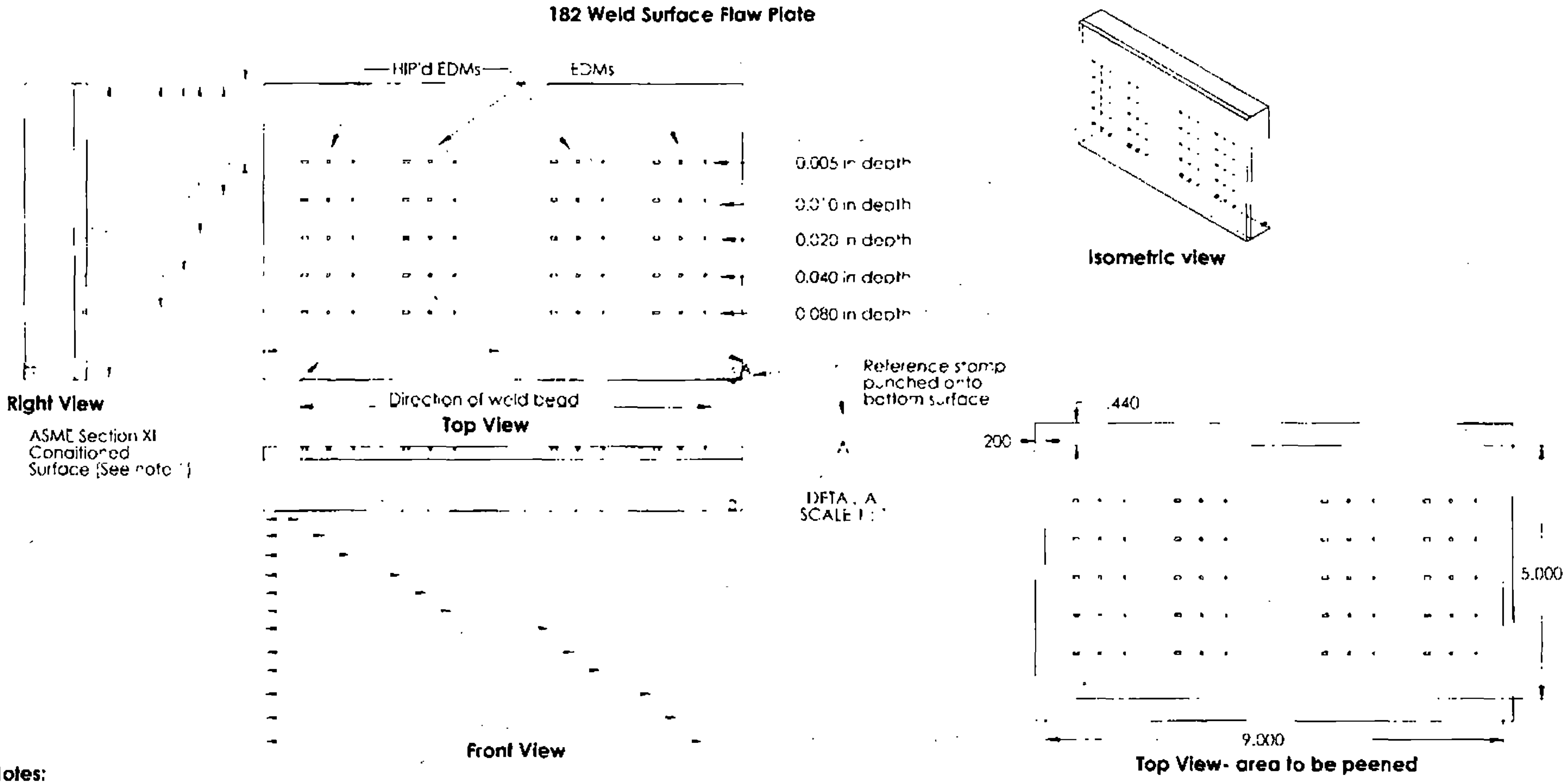
TITLE:

SIZE: B | DWG. NO. 182Weld Specimen | REV

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

DO NOT SCALE DRAWING

182 Weld Surface Flaw Plate



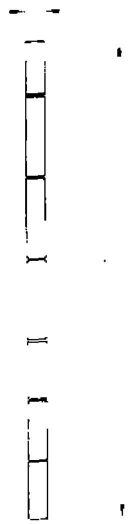
Notes:
1. The plate shall be welded as specified in the 182 Weld Specimens drawing. After welding and cutting, the left half of the top surface,as viewed from the top view, shall have the surface conditioned to the specifcation in nonmandatory appendix D of AMSE Section XI. The right half of the plate shall have the surface left as-welded.
2. The HIP'd EDMS shall be fabricated and put through the HIP process before fabrication of the standard EDM notches. All notches shall be fabricated such that the notches are orieted parallel to the weld bead, have a 0.050 inch width, and the specified depth stated in the Top View. The notch depths listed in the Top View are applicable to every notch in that row.
3. Peening shall be performed on the face of the plate containing the EDM notches. The peened area shall be 5.0"x9.0" as shown in the additional Top View.

Rexolite

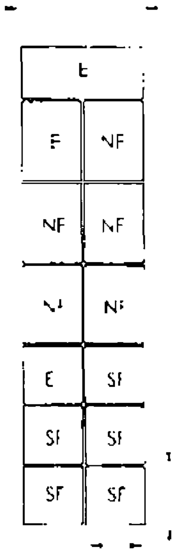
SIZE B DWG. NO. 182 Surface Flaw Plate REV

SCALE 1:2 WEIGHT: SHEET 1 OF 1

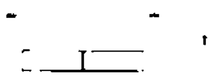
~~PREDECISIONAL~~



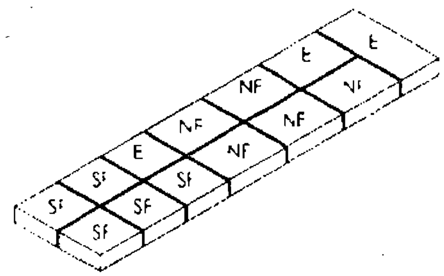
Right View



Top View



Front View



Isometric View

Notes:
The Alloy 600 Plate to be cut is nominally 2"x12"x48".

E – Extra Material
NF – No Flaw Plate
SF – Surface Flaw Plate

The 2"x12"x48" plate shall be cut into smaller plates such that 6- 2"x 5.875"x5.875", 6- 2"x5.875"x7.875", and 1- 2"x5.25"x12" plates are fabricated. The desired plate dimensions are reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

PROPRIETARY AND CONFIDENTIAL

TITLE

DWG. NO. REV

B Alloy 600 Plate with No Weld

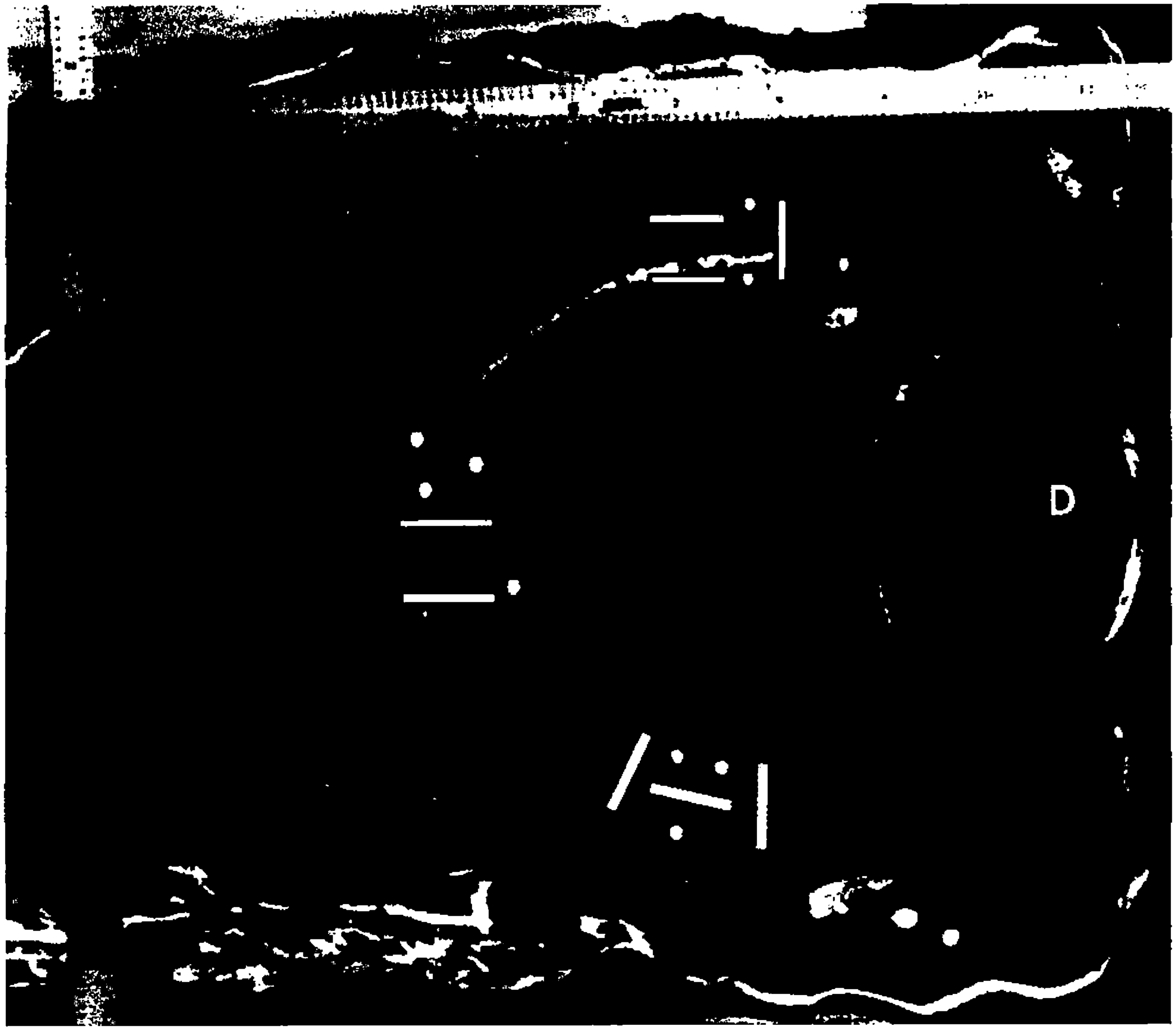
SCALE: 1:2 WEIGHT SHEET 1 OF 1

~~PREDECISIONAL~~

~~PREDECISIONAL~~

Proposed Slot and Hole Measurements for Weld Residual Stress

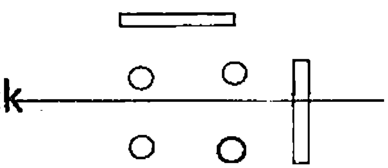
All measurements (except for D) should be in the J-groove weld, associated filet weld, or weld butter region.



E

A (uphill) (6 o'clock) – as shown
B (sidehill) (9 o'clock) – as shown
C (sidehill) (3 o'clock) – as shown
D (nozzle inside diameter)
 one slot and hole at 6 o'clock position ½-inch and 1-inch below the weld toe
E (downhill) (12 o'clock)
 in the pattern shown below centered on 12 o'clock position.

12 o'clock



~~PREDECISIONAL~~

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December 16, 2014

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C. (b)(6)
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Scope: Quote for Peened Surface Indications and Remaining Ligament Indications in Alloy 600 Plates and 182 Clad Plates

1. **Quote is based on PNNL provides drawings and notes acquired during PNNL visit to FlawTech.**
    - 1.1. Total of 4 drawings
        - 1.1.1. DWG. NO. Alloy 600 Plate with No Weld (aka Sheet 1)
        - 1.1.2. DWG. NO. Surface Flaw Plate (aka Sheet 2)
        - 1.1.3. DWG. NO. 182 Weld Specimen (aka Sheet 3)
        - 1.1.4. DWG. NO. 182 Surface Flaw Plate (aka Sheet 4)
    - 1.2. Material:
    - 1.3. PNNL will provide the material (CFM) for the Alloy 600 plate.
        - 1.3.1. Ref. in Sheet 1 & 2
    - 1.4. FlawTech will provide the carbon steel base plate and 182 cladding.
        - 1.4.1. Ref. in Sheet 3 & 4
    - 1.5. Manufacturing:
        - 1.5.1. FlawTech will perform all machining and welding as required in this scope of work.
            - 1.5.1.1. The exception would be any contract services that might expedite delivery. This possible contract service may also directly affect the quoted price.
            - 1.5.1.2. FlawTech will subcontract the HIP service.
2. **Specifications for Alloy 600 Plates:**
    - 2.1. FlawTech will water jet CFM Alloy 600 plates to the dimensions specified on Sheets 1 & 2. Leaving "extra" material as a continuous drop piece.
    - 2.2. FlawTech will Pad, Machine and EDM the 30 notches (per plate) as specified on Sheet 2 with the noted exception below.
        - 2.2.1. **Exception Notes:** PNNL has requested that the non-HIP notches be 0.005" in width. This width is not repeatable at the various depths and lengths requested. FlawTech will use a 0.004" wide electrode as much possible and step up the electrode width only as needed in order to keep notch width as tight as possible. Our test runs have resulted in a consistent 0.008" wide notch at 0.080" depth. The initial notch width employed for the HIP'ed notches will be ~0.014" to ~0.020" wide prior to HIP. The purpose of the HIP process is to close the notch tight. Most notch widths after HIP can only be measured via magnification or destructive analysis.
    - 2.3. FlawTech will apply a Weld Pad for the HIP EDM notches.
        - 2.3.1. FlawTech will make sure there is a minimum of 0.5" between the notch edge and pad edge.
        - 2.3.2. Once HIP is complete FlawTech will machine away the Weld Pad.
            - 2.3.2.1. **Please Note:** The Weld Pad application will cause the Alloy 600 plate to distort slightly. Therefore when FlawTech machines away the Weld Pad there will be areas of the Weld Pad projecting or proud of the actual plate surface. This prominent material will vary in spots (greater towards the center of the plate) and there may be

visible signs of the Weld Pad edge after machining. The goal is not to machine or cut into the Alloy 600 base plate. This extra thickness will cause the EDM notch depth to vary. FlawTech will document this variance in the final documentation.

2.3.2.1.1. **Please Note**: The documentation/recording process used by FlawTech for the final notch depth for the HIP'ed notches will be a best effort using methods proven satisfactory for previous scopes of work. If PNNL has any specific requirements regarding this process please share with FlawTech prior to contract issuance.

2.4. FlawTech will stamp plates with unique reference number.

3. Specifications for 182 Weld Specimens:

3.1. FlawTech will apply 182 cladding and machine clad thickness to a nominal 0.25" thickness.

3.1.1. **Please Note:** The weld clad application will cause the base plate to distort. Thus causing the clad thickness to vary after machining.

3.2. Near Surface Flaw Plate – Sheet 3

3.2.1. It is FlawTech understanding that the clad thickness dimension is not as critical for the remaining ligament dimension.

3.2.2. Therefore after cladding has been applied FlawTech will water jet the welded specimen plates to the dimensions specified on Sheets 3. Leaving "extra" material as a continuous drop piece.

3.2.3. FlawTech will machine the clad surface and the unclad base metal surface parallel to a nominal thickness.

3.2.4. FlawTech will then mill (machine) the 4 holes (per plate) as requested in Sheet 3

3.2.4.1. The pilot hole diameter is not critical

3.2.4.2. The Remaining Ligaments are to be 0.005", 0.01", 0.02" and 0.04" and the target diameter is 0.04".

3.2.4.3. Ligament tolerance is -0/+0.003"

3.3. Surface Flaw Plate – Sheet 4

3.3.1. It is FlawTech understanding that the distortion caused by the cladding for these Surface Flaws is not as critical as is the surface condition.

3.3.2. As per client specification FlawTech will machine or grind flush the left half of each plate. As for the right half of each plate FlawTech will leave in an as welded condition.

3.3.2.1. **Exception Note:** FlawTech will have to recondition the as welded right side surface after the HIP process in order to blend the HIP'ed side (with pad) with the non-HIP'ed as welded side. This will be a manual process and there will be some light grinding evidence upon completion. FlawTech has provided PNNL a test piece illustrating the difference between a blended crown vs. an as welded crown.

3.3.2.2. **Terms Definitions:**

3.3.2.2.1. **"Flush Crown"** means the weld crown has been removed either by grinding or machining. Leaving no visible bead pattern.

3.3.2.2.2. **"As Welded"** means the weld has not been dressed or conditioned other than that of a wire brush or chipping hammer to remove weld spatter.

3.3.2.2.3. **"Blended Crown"** means the weld crown has been dressed or condition to a point using a grinding tool. Normally the convexity of the crown has not been changed to any significant degree however some of if not all of the bead weave pattern (crescent shape on top of crown) may be removed or reduced.

3.4. FlawTech will Pad, Machine and EDM the 60 notches (per plate) as specified on Sheet 4 with the noted exception below.

3.4.1. **Exception Notes:** PNNL has requested that the non-HIP notches be 0.005" in width. This width is not repeatable at the various depths and lengths requested. FlawTech will use a 0.004" wide electrode as much possible and step up the electrode width only as needed in order to keep notch width as tight as possible. Our test runs have resulted in a consistent 0.008" wide notch at 0.080" depth. The initial notch width employed for the HIP'ed notches will be ~0.014" to ~0.020" wide prior to HIP. The purpose of the HIP process is to close the notch tight. Most notch widths after HIP can only be measured via magnification or destructive analysis.

3.5. FlawTech will apply a Weld Pad for the HIP EDM notches.

3.5.1. FlawTech will make sure there is a minimum of 0.5" between the notch edge and pad edge.

3.5.2. Once HIP is complete FlawTech will machine away the Weld Pad.

3.5.2.1. **Please Note:** The Weld Pad application will cause the Weld Clad Plate to distort slightly. Therefore when FlawTech machines away the Weld Pad there will be areas of the Weld Pad projecting or proud of the actual clad surface. This prominent material will vary in spots (greater towards the center of the plate) and there may be visible signs of the Weld Pad edge after machining. The goal is not to machine or cut into the Weld Clad. This extra thickness will cause the EDM notch depth to vary. FlawTech will document this variance in the final documentation.

3.5.2.1.1. **Please Note**: The documentation/recording process used by FlawTech for the final notch depth for the HIP'ed notches will be a best effort using methods proven satisfactory for previous scopes of work. If PNNL has any specific requirements regarding this process please share with FlawTech prior to contract issuance.

3.6. The as built or finished depth tolerance for the notches is -0"/+0.003".

3.7. FlawTech will stamp plates with unique reference number.

4. Price:

4.1. Alloy 600 Plates

4.1.1. Quantity 5 @ $107,946.00 Lot

4.1.2. Quantity 3 @ $72,888.00 Lot

4.2. 182 Weld Specimens

4.2.1. Quantity 5 Near Surface and 5 Surface Plates @ $305,425.00 Lot

4.2.2. Quantity 3 Near Surface and 3 Surface Plates @ $197,945.00 Lot

4.3. Please note price is based on FlawTech understanding of the scope of work and the aforementioned. This price is also based on FlawTech performing all the work in house.

5. Delivery and Terms:

5.1. Will need to be discussed again in detail.

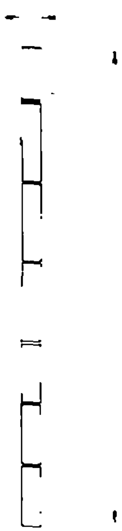
Best Regards:

John Turner
President / CEO

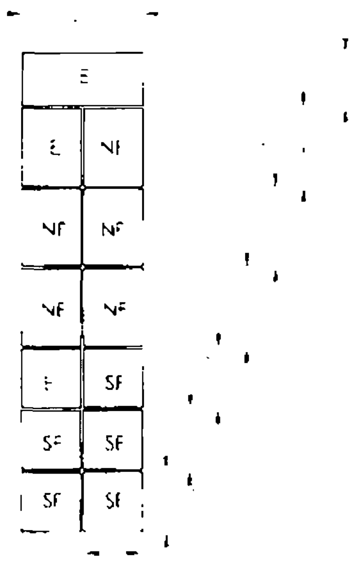
FlawTech

Celebrating 32 Years of Excellence
www.flawtech.com
jturner@flawtech.com
704-795-4401 Tel.
704-795-4403 Fax

PNNL 812-17-14 05

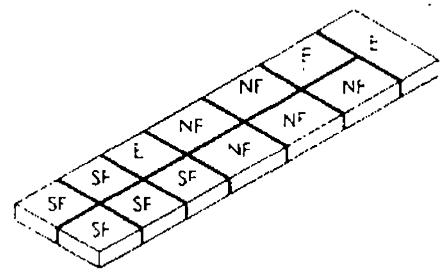


Right View



Top View

Front View



Isometric View

Notes:
The Alloy 600 Plate to be cut is nominally 2"x12"x48".

E – Extra Material
NF = No Flaw Plate
SF – Surface Flaw Plate

The 2"x12"x48" plate shall be cut into smaller plates such that 6- 2"x 5.875"x5.875", 6- 2"x5.875"x7.875", and 1- 2"x5.25"x12" plates are fabricated. The desired plate dimensions are reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

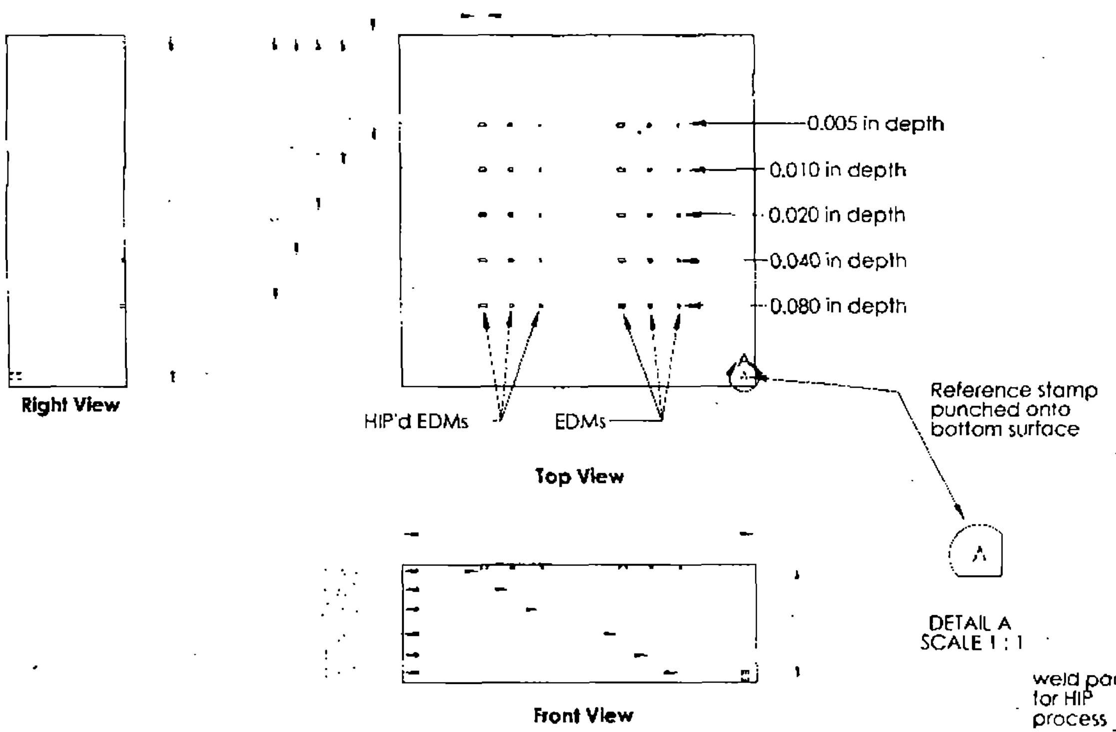
PROPRIETARY AND CONFIDENTIAL

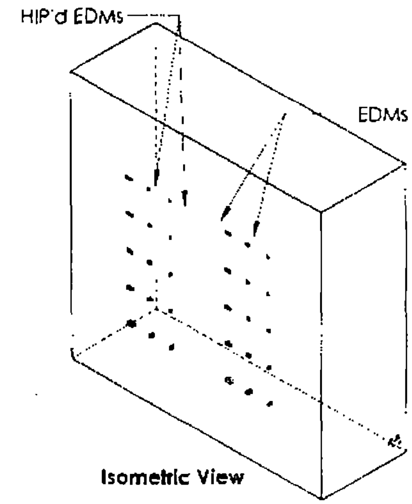
TITLE:

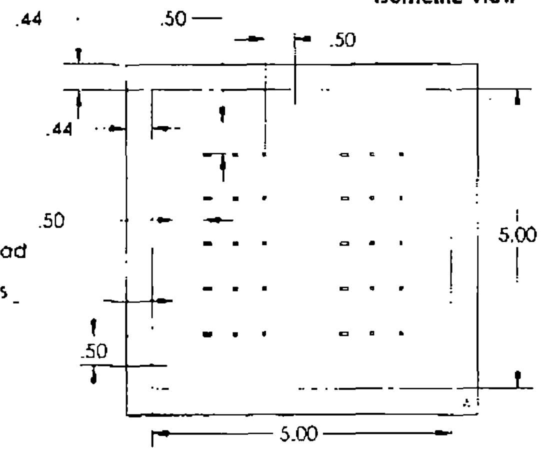
SIZE DWG. NO. REV
B Alloy 600 Plate with No Welds
SCALE: 1:12 WEIGHT: SHEET 1 OF 1

PREDECISIONAL

Alloy 600 Surface Flaw Plate







Top View- area to be peened

Notes:

1. All EDM notches shall be fabricated as specified in the Top View. All notches within a column have the same length (1/8, 1/16, or 1/32") and all notches in a row have the same depth (shown in Top View). All notches shall have a width of 0.005".
2. After all EDM notches have been fabricated, the notches to be HIP'd shall have a weld pad put over the notch opening to facilitate the HIP process. This pad shall extend 0.5" away from the notches all the way around, as shown in the additional Top View. After the HIP process is complete, the cover pad shall be machined away and blended with the original Alloy 600 surface. The EDM depth tolerance from this final surface shall be -0/+0.003".
3. Peening shall be perormed on the face of the plate containing the EDM notches. The peened area shall be 5.0"x5.0" and centered on the plate as shown in the additional top view.

PROPRIETARY AND CONFIDENTIAL

TITLE:

SIZE B DWG. NO. Surface Flaw Plate REV

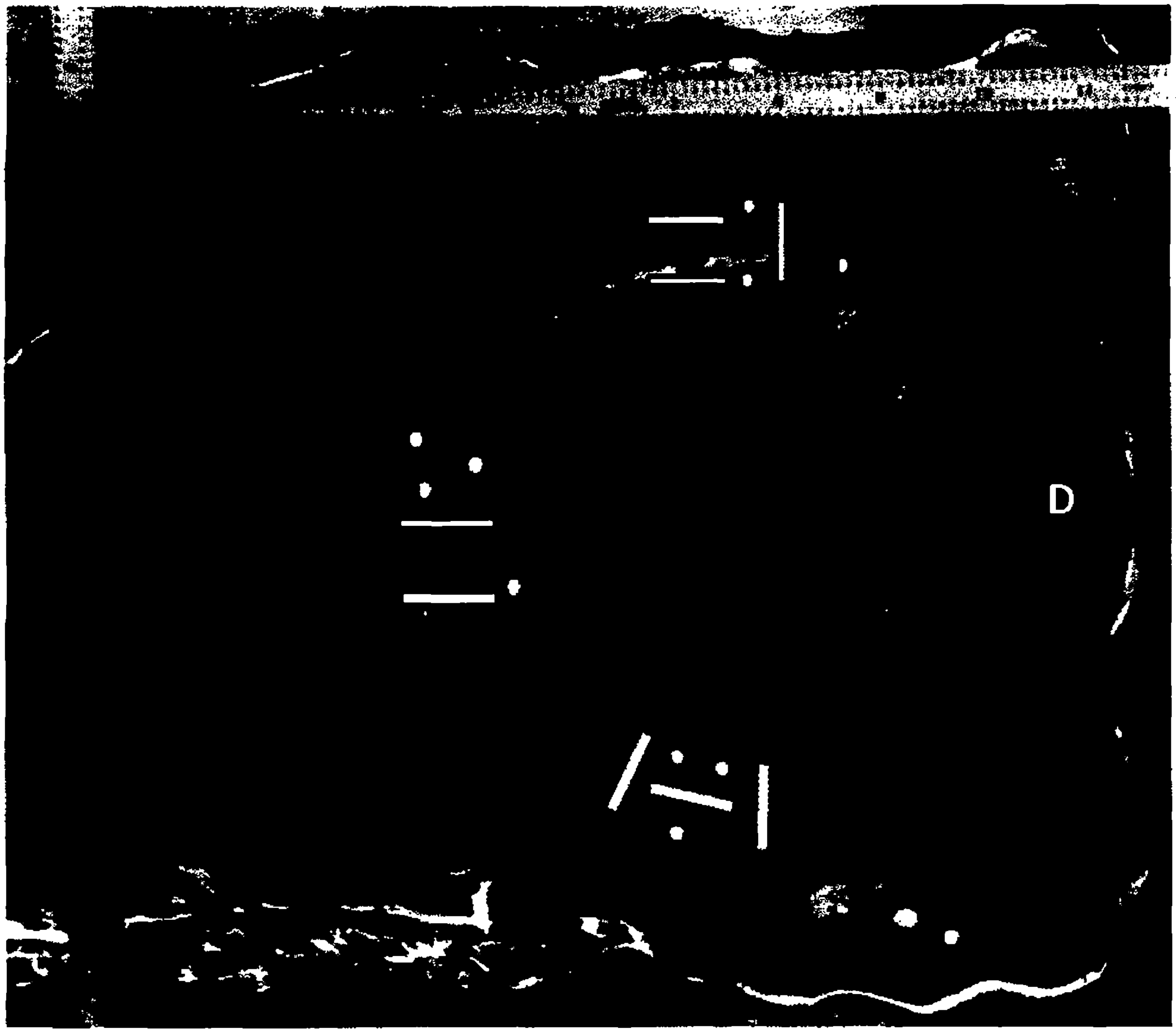
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

PREDECISIONAL

~~PREDECISIONAL~~

Proposed Slot and Hole Measurements for Weld Residual Stress

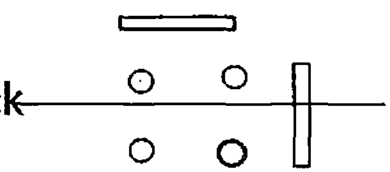
All measurements (except for D) should be in the J-groove weld, associated filet weld, or weld butter region.



E

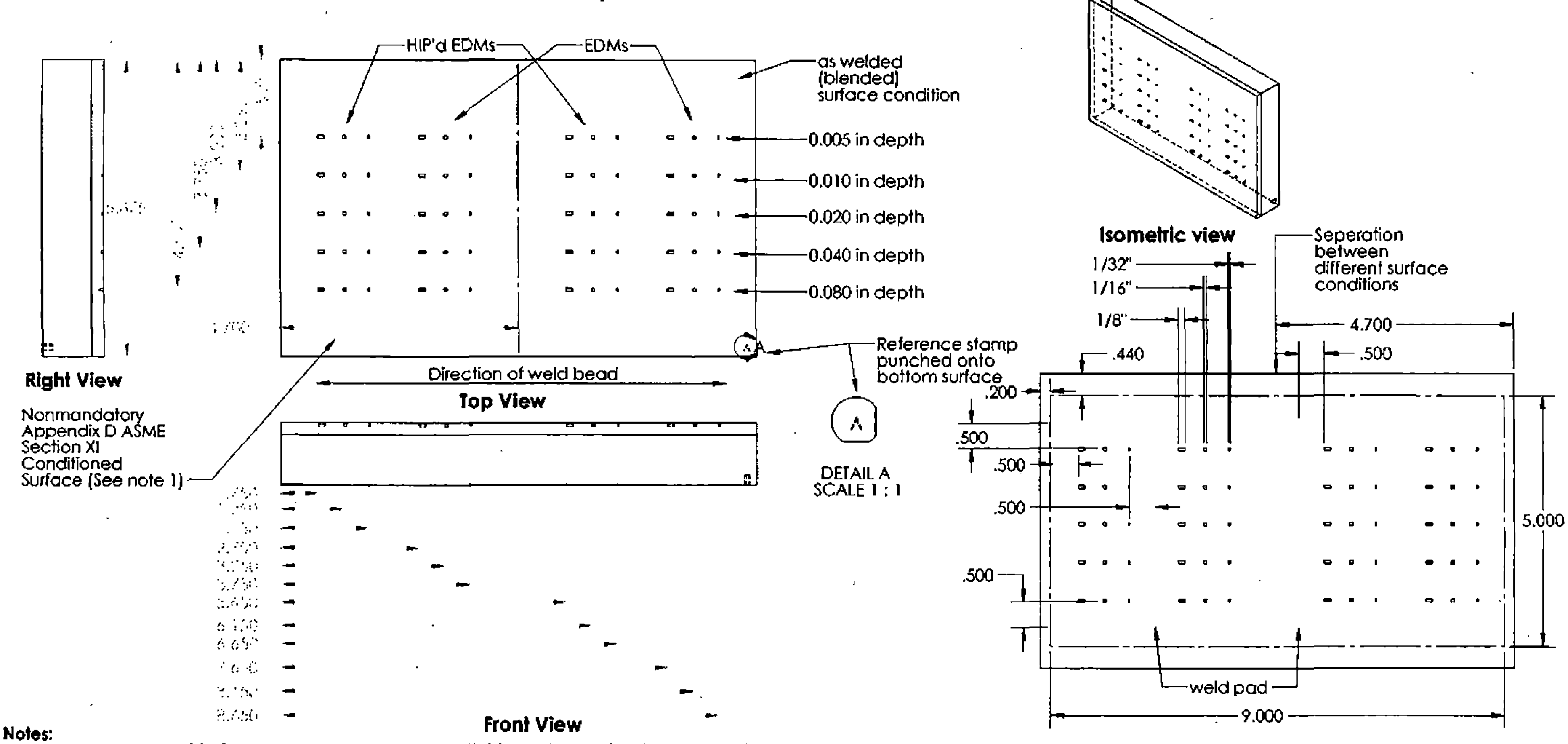
A (uphill) (6 o'clock) – as shown
B (sidehill) (9 o'clock) – as shown
C (sidehill) (3 o'clock) – as shown
D (nozzle inside diameter)
one slot and hole at 6 o'clock position ½-inch and 1-inch below the weld toe
E (downhill) (12 o'clock)
in the pattern shown below centered on 12 o'clock position.

12 o'clock



~~PREDECISIONAL~~

Alloy 182 Weld Surface Flaw Plate



Top View- area to be peened

Notes:

1. The plate shall be welded as specified in the Alloy 182 Weld Specimens drawing. After welding and cutting, the left half of the top surface,as viewed from the top view, shall have the surface conditioned to the specification in Nonmandatory Appendix D of ASME Section XI. The right half of the plate shall have the surface left as-welded (blended).

2. All EDM notches shall be fabricated as specified in the Top Views and oriented parallel to the weld bead. Each notch shall be 0.005" wide. The pattern showing the length of the notches can be seen in the additional Top View (1/8, 1/16, 1/32"). The depths shown in the Top View are applicable to every notch in that row. Notches to be HIP'd shall have a weld pad put over them as outlined in the additional Top View. This pad shall extend 0.5" away from the edge of every notch all the way around. After the HIP process is complete this pad shall be removed and the surface shall be blended with the Alloy 182 weld surface. The depth tolerance for each EDM notch from the final surface shall be -0/+0.003".

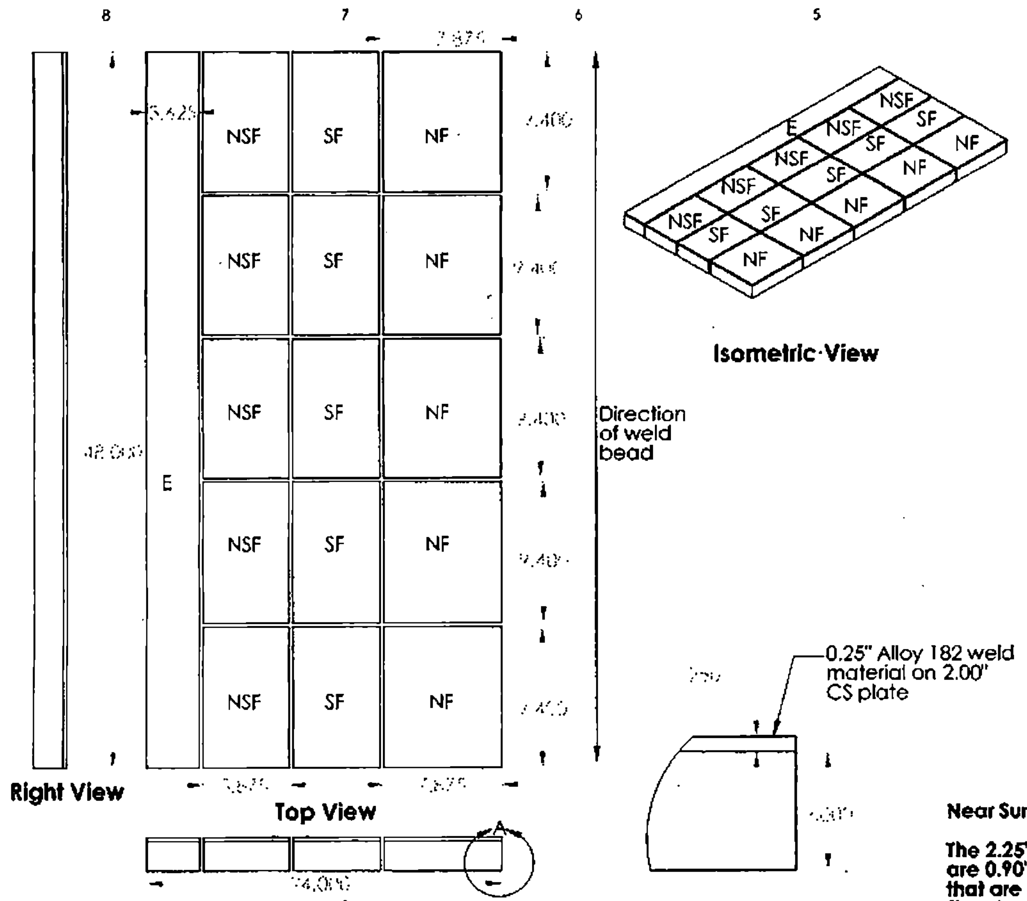
3. Peening shall be performed on the face of the plate containing the EDM notches. The peened area shall be 5.0"x9.0" as shown in the additional Top View.

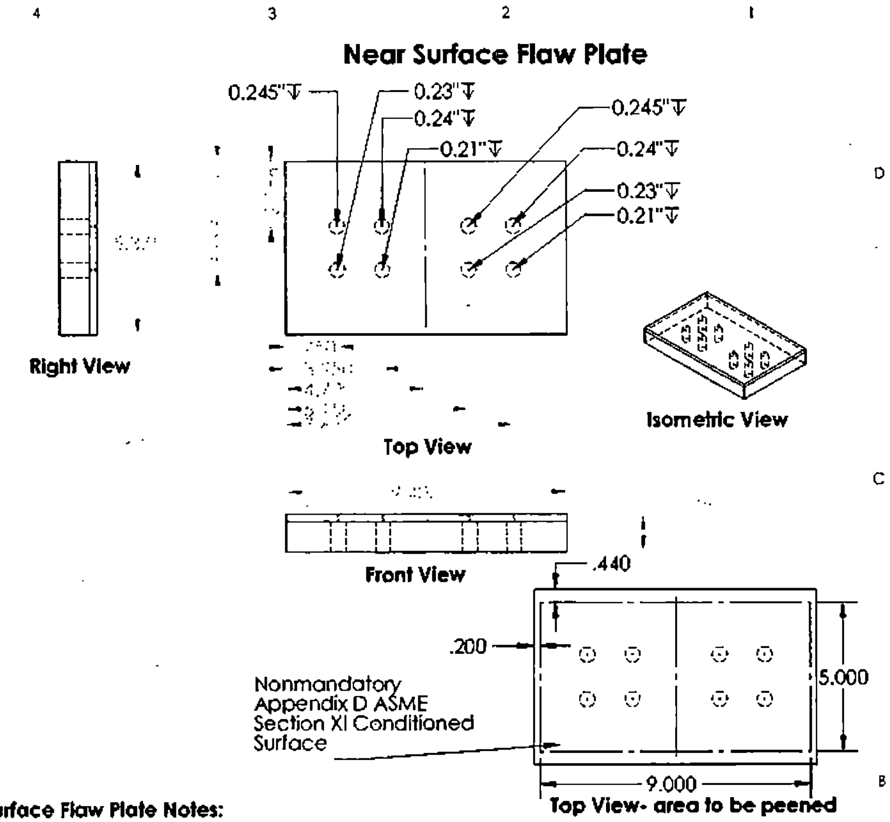
UNLESS OTHERWISE SPECIFIED		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Rexolite	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

TITLE:

SIZE B DWG. NO. 182 Surface Flaw Plate REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1





Near Surface Flaw Plate Notes:

The 2.25"x5.875"x9.4" plate shall have 0.5" diameter flat bottom holes drilled from the CS side that are 0.90" in depth. Then a 0.04" diameter bit shall be used to drill 4 holes to the specified depths that are concentric with the 0.5" holes. The holes depths shall be 0.345", 0.34", 0.33", and 0.31" (leaving a ligament of Alloy 182 weld material that is 0.005", 0.01", 0.02", and 0.04" respectively). The tolerance for the ligament shall be -0/+0.003". Additional maching of the top and bottom surfaces may be required to get them flat and parallel for hole depth measurements and calculation. The left half of the plate, as viewed from the top view, shall have the surface conditioned to the specification in Nonmandatory Appendix D of the ASME Section XI code. The other half of the plate shall have the surface left as welded (blended)

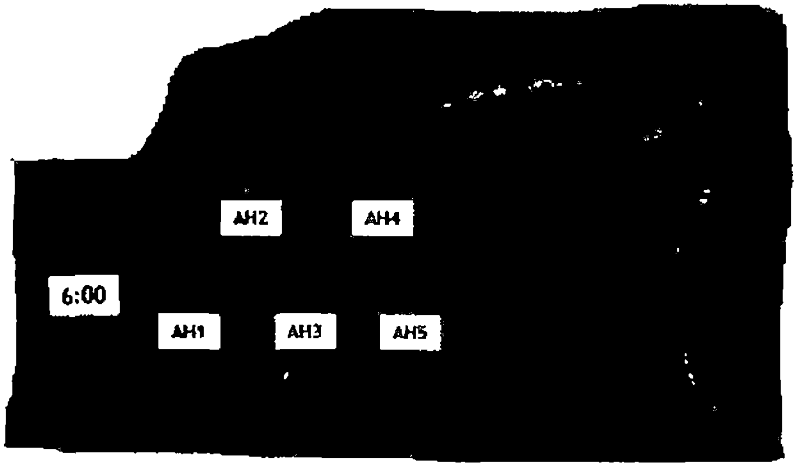
Notes:
E= Extra Material
NF = No Flaw Plate
SF= Surface Flaw Plate
NSF = Near Surface Flaw Plate
The 2"x24"x48" carbon steel (CS) plate shall have a 0.25" cladding layer of Alloy 182 welded onto the top surface with the weld bead in the direction specified in the Top View. The cladding layer shall be 0.25" thick after surface prep is performed. The surface shall be prepared such that surface roughness is reduced so eddy current and ultrasonic exams can be performed. After the 0.25" cladding layer is complete the plate shall be cut in 16 pieces as specified below:
5- 2.25"x7.875"x9.400" (5 NF)
5- 1.25"x5.875"x9.400" (5 SF)
5- 1.25"x5.875"x9.400" (5 NSF)
1- 1.25"x3.625"x48.0" (E)
The desired plate dimensions have been reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

UNLESS OTHERWISE SPECIFIED | NAME | DATE
DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER
MATERIAL
FINISH
DO NOT SCALE DRAWING

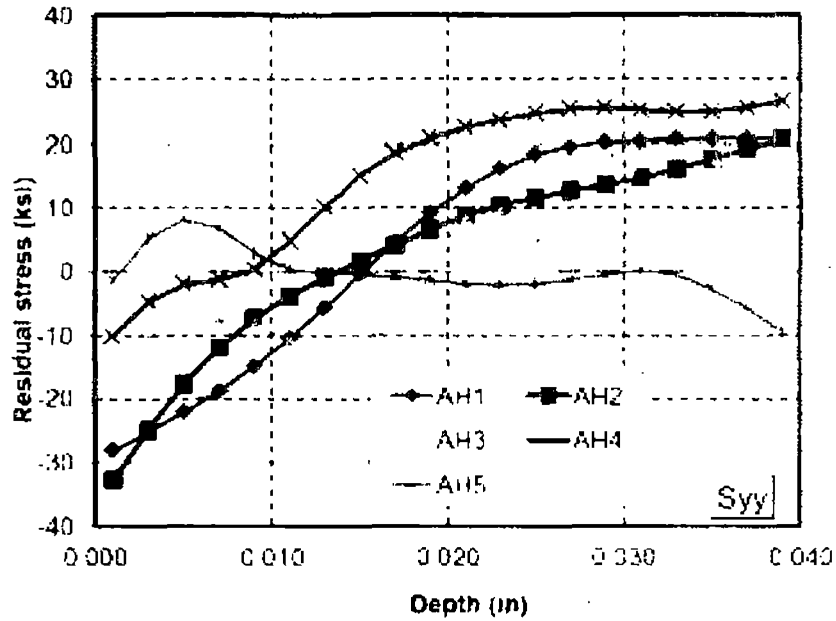
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

TITLE:

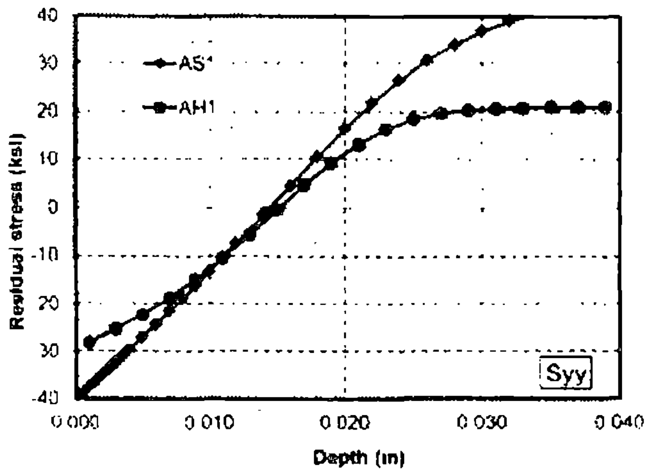
SIZE B | DWG. NO. 182Weld Specimen | REV
SCALE: 1:8 WEIGHT: SHEET 1 OF 1



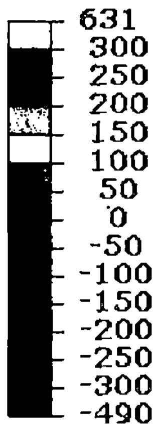
Y-Stress (~Hoop Stress)

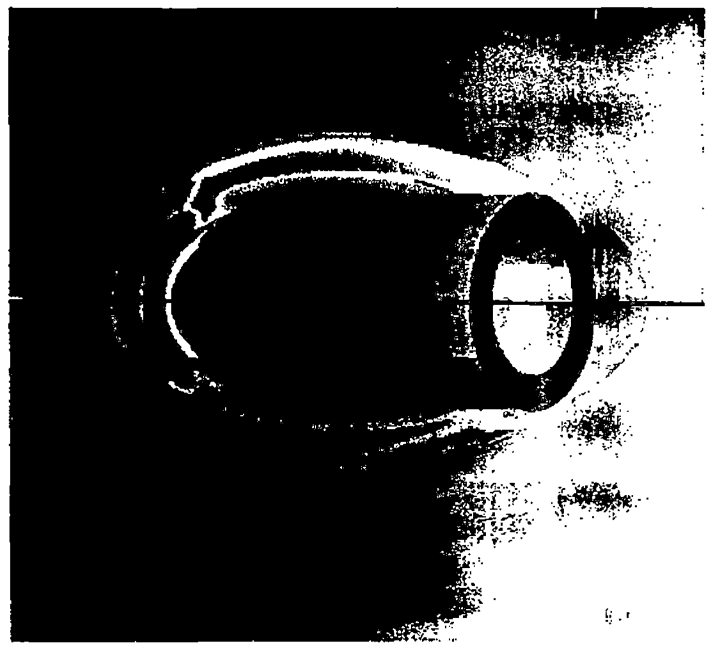


40 ksi ~ 275 MPa

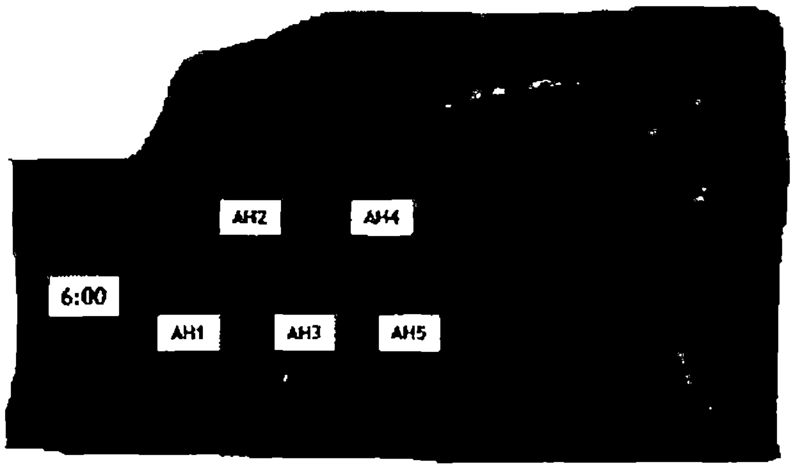


Hoop Stress
MPa

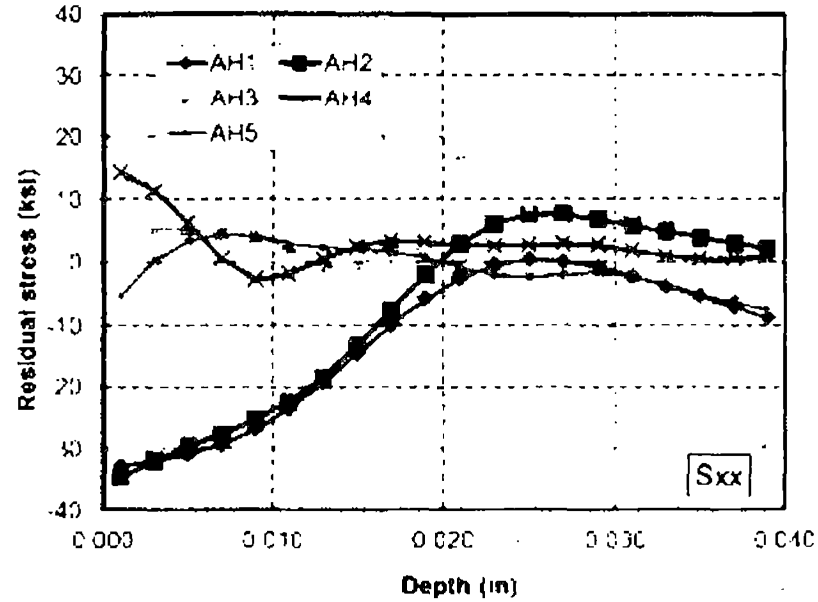




Hoop Stress comparison reasonable between prediction and slot measurement



X-Stress (~Radial Stress)



Radial stresses are measured low and predicted to be low at 6 O'clock.

The next few slides discuss possible measurement locations

Suggestions are based on model results (isotropic hardening)

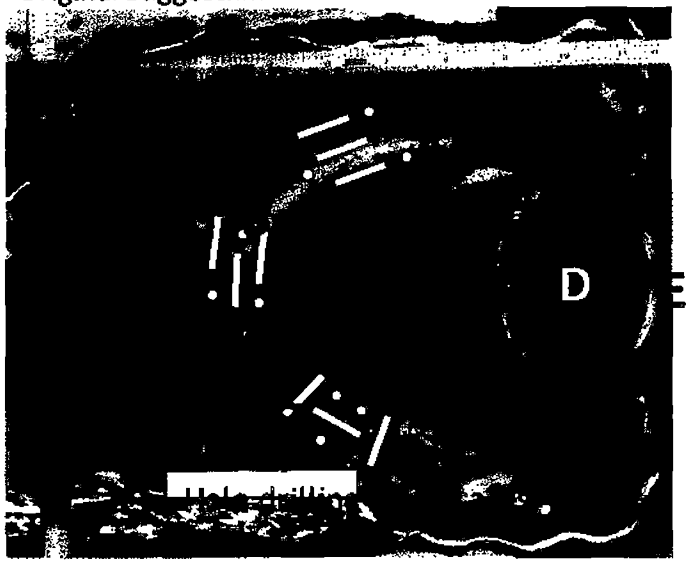
Measurements (53-degree)

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

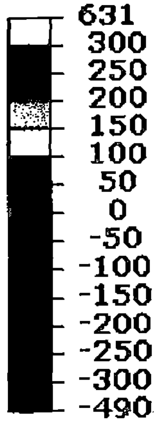
Locations A, B, C

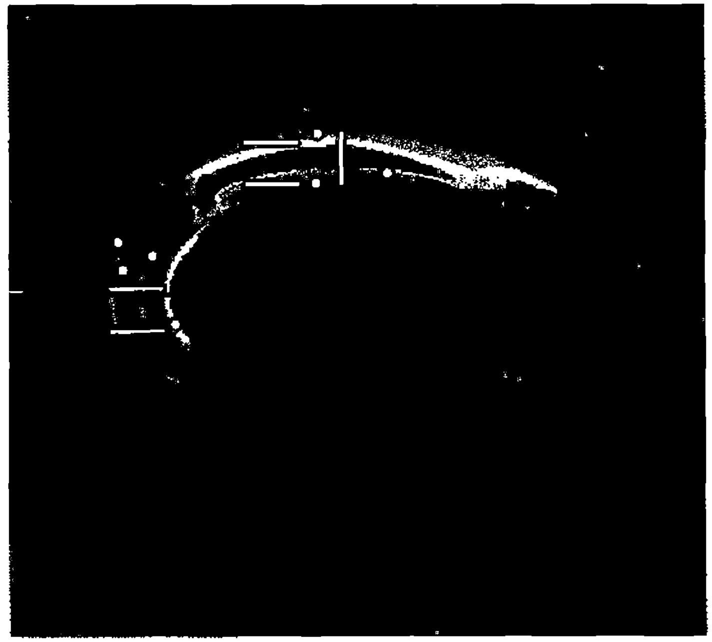
Model rotated on symmetry plane added for clarity

Original Suggestion



Hoop Stress
MPa

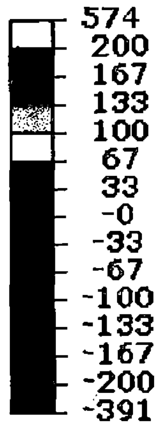




Notes:

- *Measurement locations at B arranged for hoop stress measurements using slots and both hoop and radial with holes*
- *Measurements at A and C same. Look for radial stress with two slots, hoop stress with one slot, and both with two holes*
- *For lower angle nozzles (25-degree and less) suggest same arrangement (see next slide)*

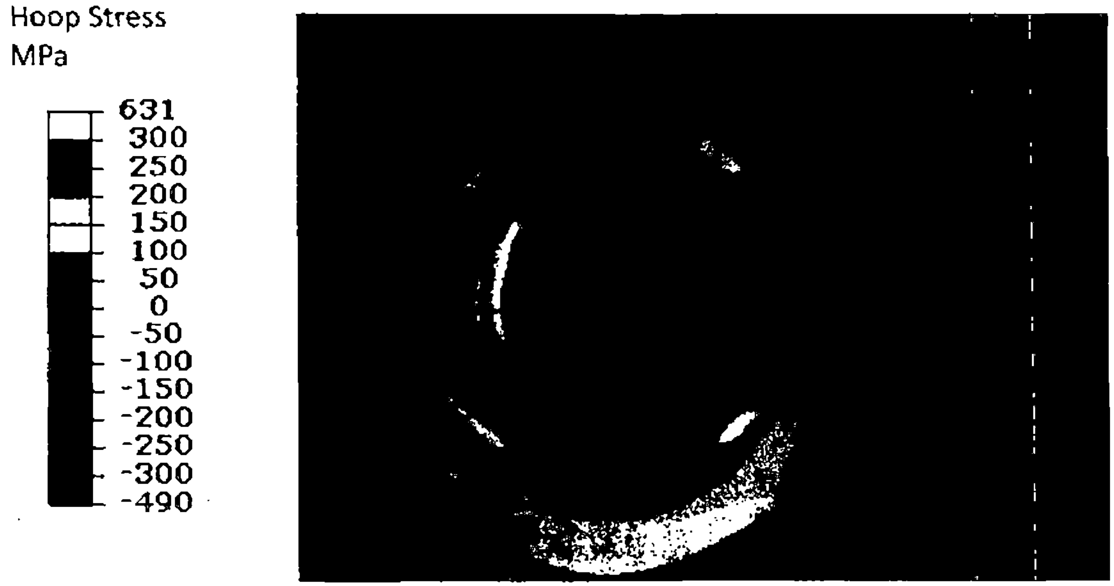
Radial Stress
MPa



Measurements (25-degree)

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

Model rotated on symmetry plane added for clarity



Measurements (53-degree)

Location E

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

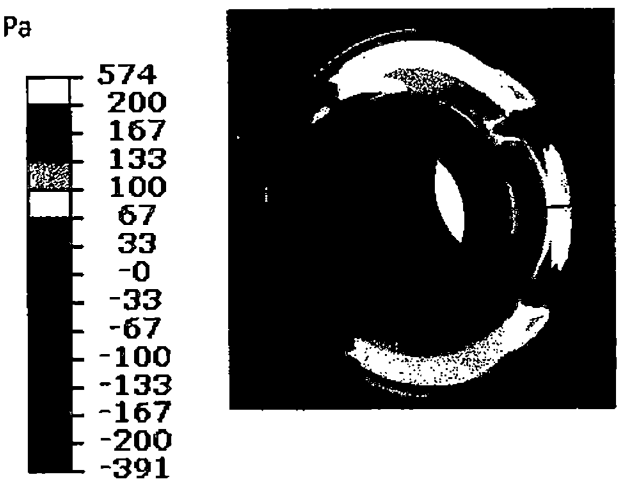
Model rotated on symmetry plane added for clarity

Notes:

- *Measurement locations at E arranged to obtain hoop stresses.*
- *Could include a slot to obtain radial stress also as per bottom right illustration*
- *For lower angle nozzles (25-degree and less) suggest same arrangement (see next slide)*

Hoop Stress MPa

Radial Stress MPa

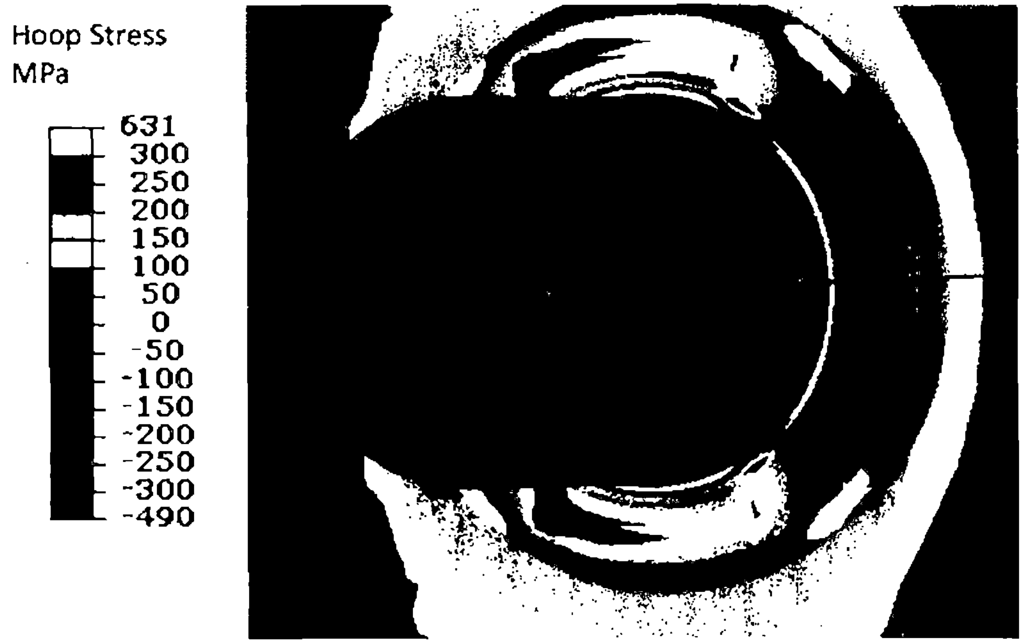


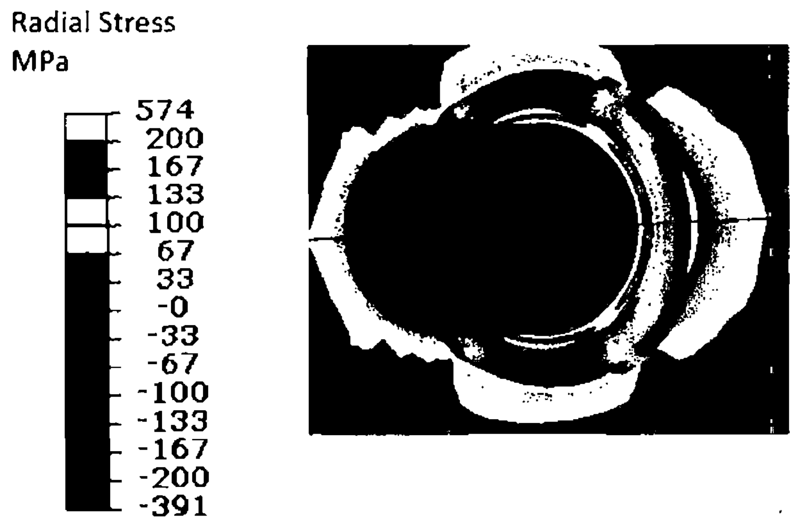
Measurements (25-degree)

Location E

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

Model rotated on symmetry plane added for clarity





Measurements (53-degree)

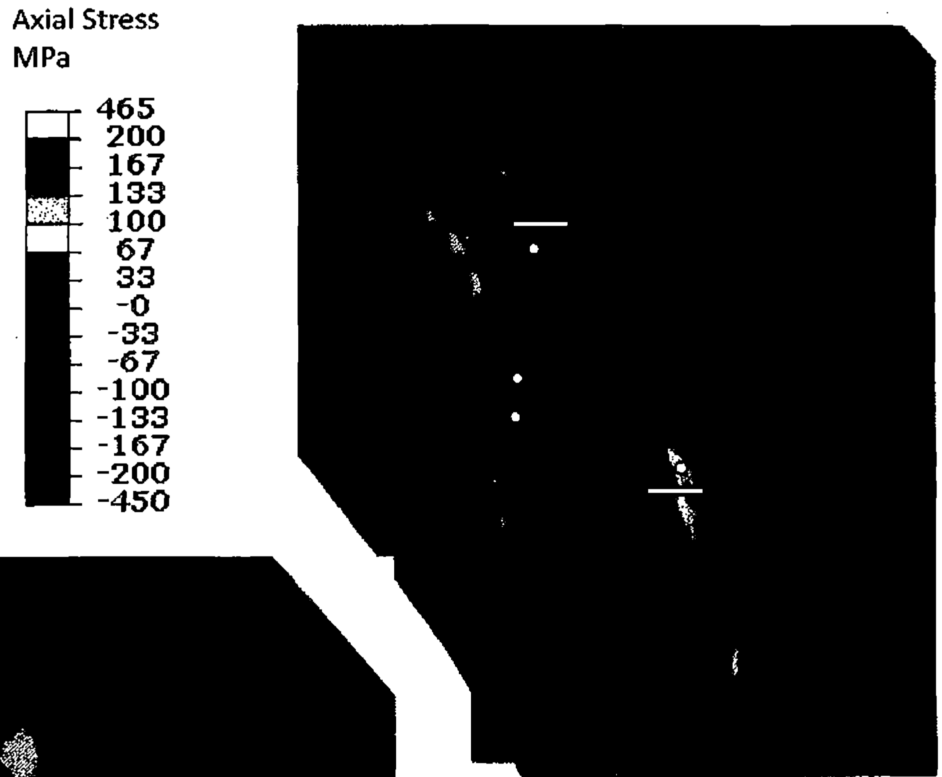
Location D

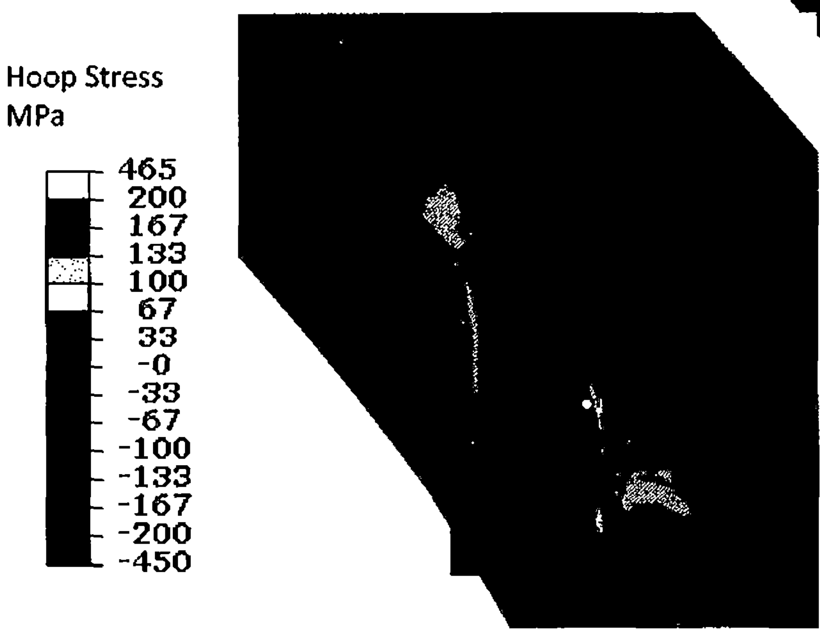
Hoop is in tube 'hoop' direction and 'axial' is in the tube axis direction

Model rotated on symmetry plane added for clarity

Notes:

- ***Measurement locations at D arranged to obtain axial stresses at location 6 O'clock (or location B) in tube above weld location***
- ***Might also try hoop stresses at location near 12 O'clock location (below). Hoop stresses can be obtained with hole drilling. Hoop stresses appear low though in tube ID.***
- ***For lower angle tubes (next slide) it appears that tube axial stresses are larger***





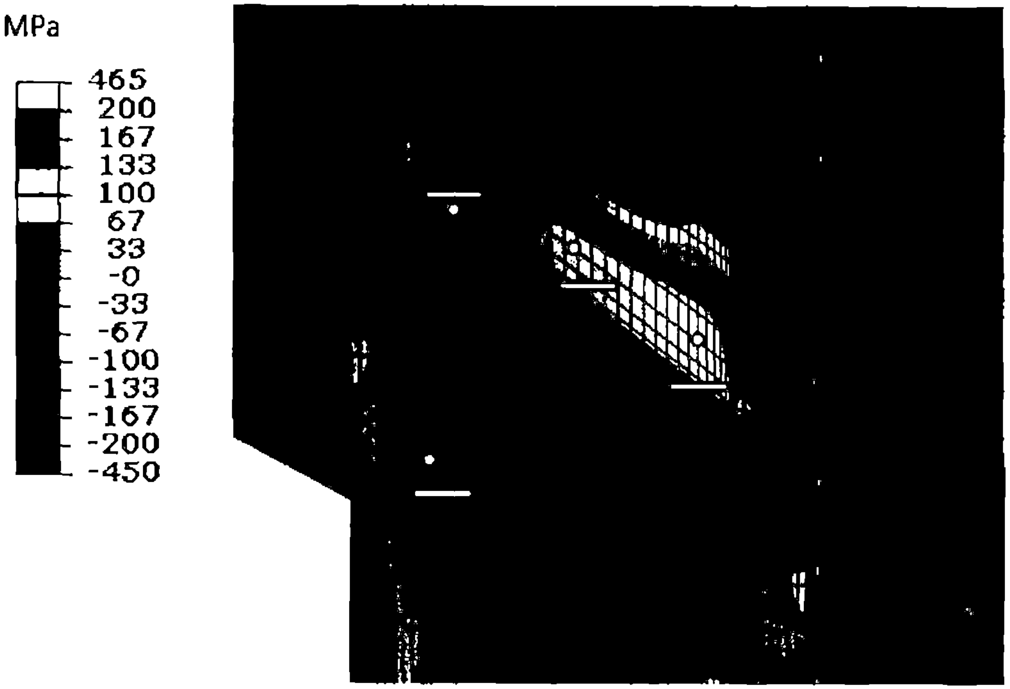
Measurements (25-degree)

Location D

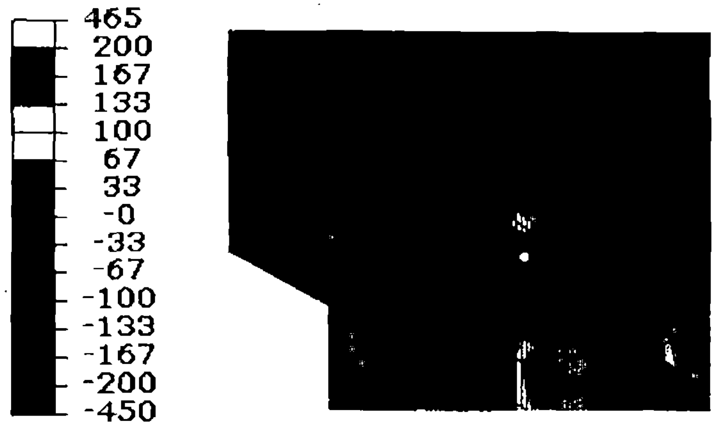
Hoop is in tube 'hoop' direction and 'axial' is in the tube axis direction

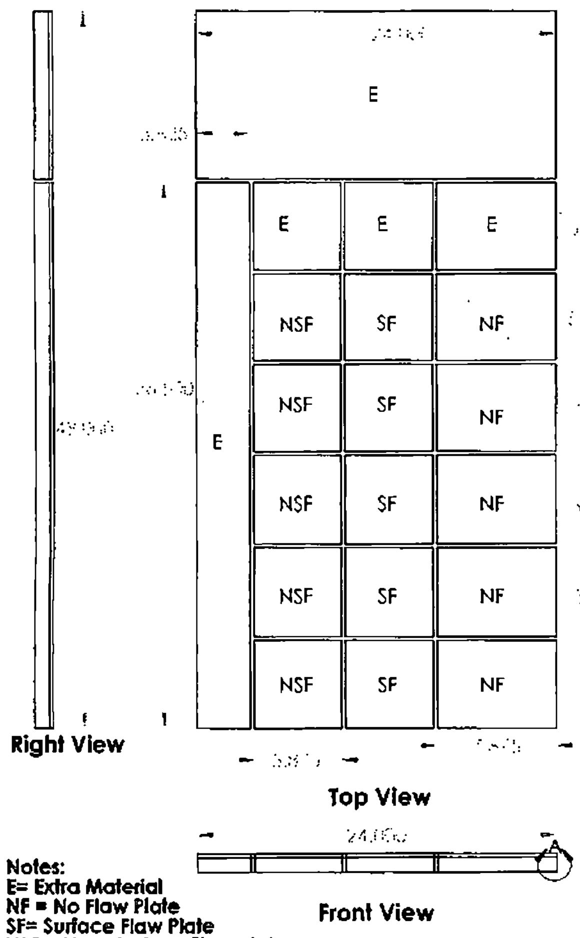
Model rotated on symmetry plane added for clarity

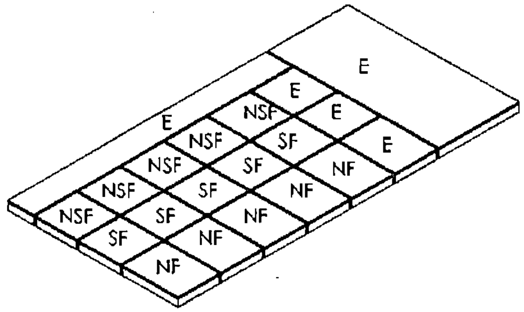
Axial Stress
MPa



Hoop Stress
MPa

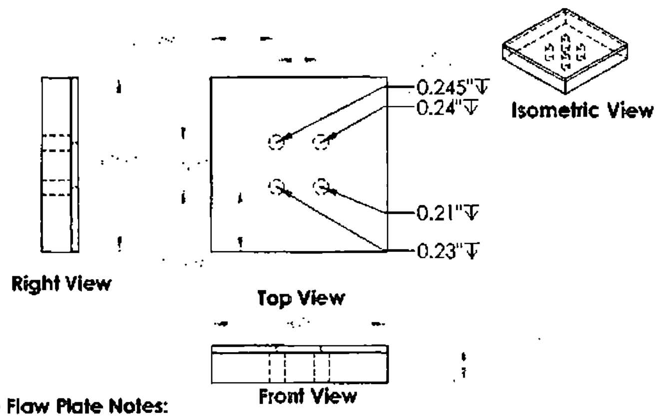






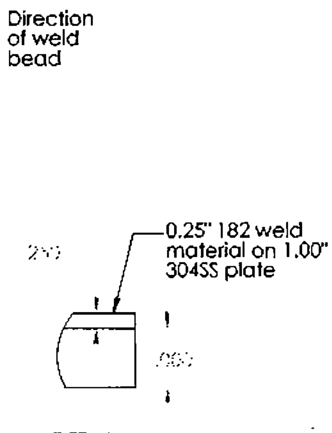
Isometric View

Near Surface Flaw Plate



Near Surface Flaw Plate Notes:

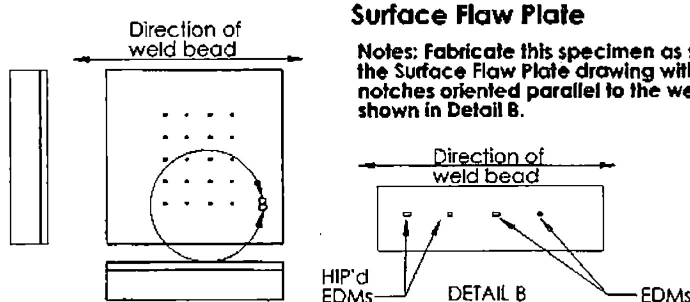
The 1.25"x5.875"x7.875" plate shall have 0.5" diameter flat bottom holes drilled from the 304L SS side that are 0.90" in depth. Then a 0.04" diameter bit shall be used to drill 4 holes to the specified depths that are concentric with the 0.5" holes. The holes depths shall be 0.345", 0.34", 0.33", and 0.31" (leaving a ligament of 182 weld material that is 0.005", 0.01", 0.02", and 0.04" respectively).



DETAIL A
SCALE 1 : 2

Surface Flaw Plate

Notes: Fabricate this specimen as specified in the Surface Flaw Plate drawing with the notches oriented parallel to the weld bead as shown in Detail B.



DETAIL B
SCALE 1 : 2

Notes:
E= Extra Material
NF = No Flaw Plate
SF= Surface Flaw Plate
NSF = Near Surface Flaw Plate
The 1"x24"x48" 304L SS plate shall have a 0.25" cladding layer of 182 welded onto the top surface with the weld bead in the direction specified in the Top View. The cladding layer shall be 0.25" thick after surface prep is performed. The surface shall be prepared such that surface roughness is reduced so eddy current and ultrasonic exams can be performed. After the 0.25" cladding layer is complete the plate shall be cut in 20 pieces as specified below:
6- 1.25"x5.875"x7.875" (5 NF & 1E)
6- 1.25"x5.875"x5.875" (5 SF & 1 E)
6- 1.25"x5.875"x5.875" (5 NSF & 1E)
1- 1.25"x3.625"x36.5" (E)
1- 1.25"x11.25"x24.0" (E)
The desired plate dimensions of 6"x8", and 6"x6" are reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER
MATERIAL
FINISH
DO NOT SCALE DRAWING

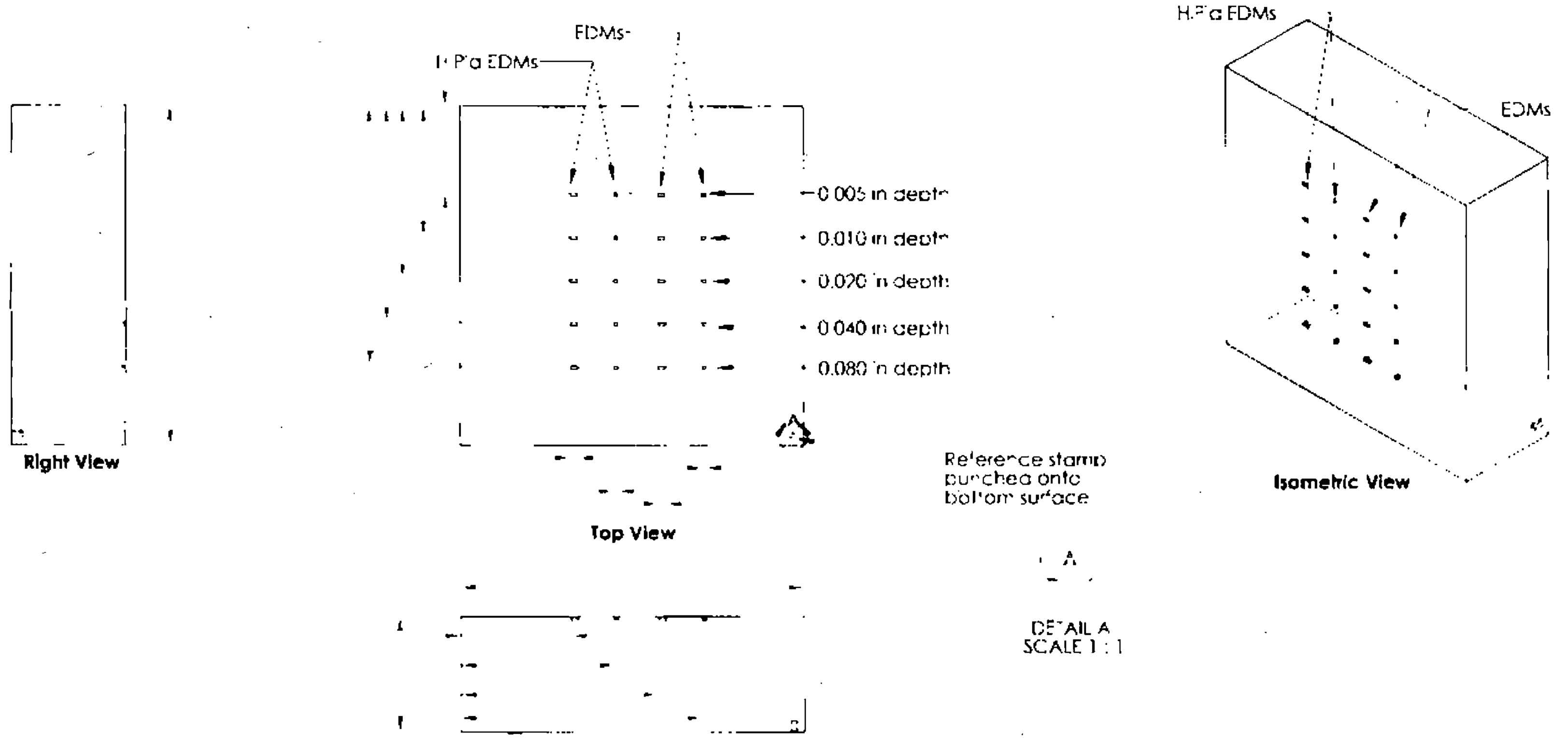
NAME DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

TITLE:

SIZE **B** DWG. NO. 182Weld Specimen REV

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

PREDECISIONAL

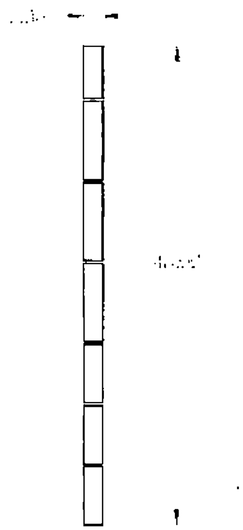


Notes:
1. The first set of 0.125 inch and 0.0625 inch length EDM notches shall be fabricated prior to the Hot Isostatic Press (HIP) process.
2. The second set of 0.125 inch and 0.0625 inch length EDM notches shall be fabricated after the HIP process is complete.
3. All EDM notches shall be fabricated such that the notches have 0.050 inch width and the specfied depth. The depth shown in the Top View is applicable to every notch in that row.

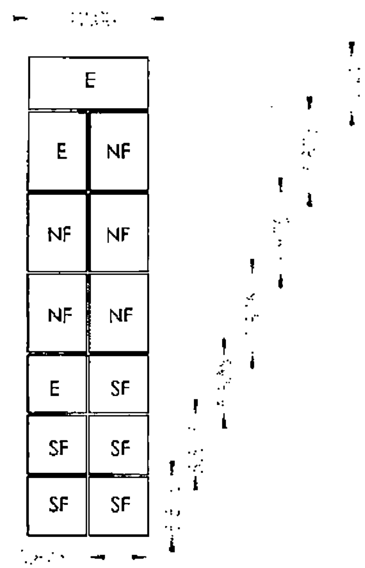
SIZE DWG NO REV
B Surface Flaw Plate
SCALE 1:2 WEIGHT: SHEET 1 OF 1

8 7 6 5 4 3 2 1

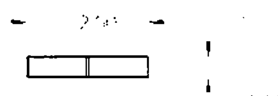
D D



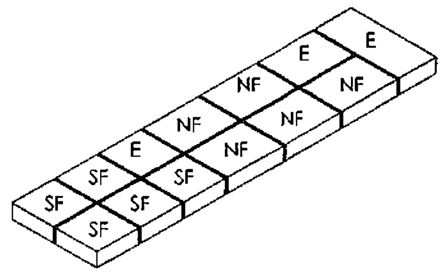
Right View



Top View



Front View



Isometric View

C C

B B

Notes:
The Alloy 600 Plate to be cut is nominally 2"x12"x48".

E = Extra Material
NF = No Flaw Plate
SF = Surface Flaw Plate

The 2"x12"x48" plate shall be cut into smaller plates such that 6- 2"x 5.875"x5.875" . 6- 2"x5.875"x7.875", and 1- 2"x5.25"x12" plates are fabricated. The desired plate dimensions are reduced in anticipation of material loss due to the cutting process. This loss is expected to be 0.25" per cut.

A A

UNLESS OTHERWISE SPECIFIED

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER
MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR		
MFG APPR		
Q.A.		
COMMENTS:		

TITLE:

SIZE B DWG. NO. Alloy 600 Plate with No Weld REV

SCALE: 1:12 WEIGHT: SHEET 1 OF 1

8 7 6 5 4 3 2 1

PNNL Samples* for Peening Work

NRC Task Order Number: NRC-HQ-20-14-T-0025
PNNL Project No. 66419

October 8, 2014

* Samples to be used for pre- and post-NDE and pre- and post-WRS measurements before and after application of various peening processes.

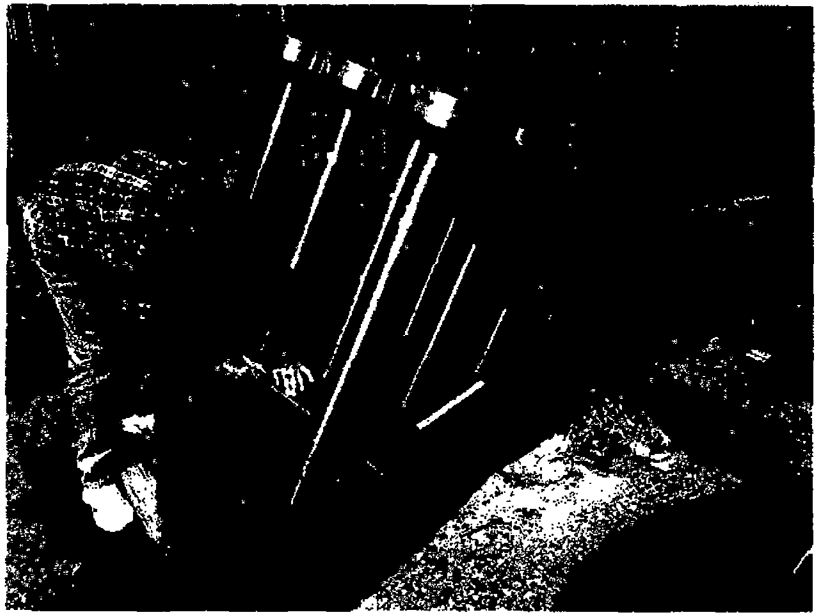
Table 1. List of PNNL Specimens to be Identified and Fabricated by PNNL for Pre- and Post-NDE and Weld Residual Stress Measurements, before and after peening.

# of Specimens	Specimen Type	Weld/Flaw Configuration	Mitigation* (3 Peening Methods)
3	Upper Head Penetration Nozzle Weld	As welded; incident angle > 30°	Peening - A Peening - B Peening - C
3(1)	Alloy 182-82 with Welds	RCS DM Butt Weld (1) small machined segment of DMW for initial WRS assessment in Optional Task 2a.	Peening - A Peening - B Peening - C
3	Alloy 600 Plate with NO Weld	Without flaws (NF)	Peening - A Peening - B Peening - C
3		With surface flaws (SF)	Peening - A Peening - B Peening - C
3		With very near subsurface flaws (NSF)	Peening - A Peening - B Peening - C
3	Alloy 600 Plate with Alloy 182 Weld	Without flaws	Peening - A Peening - B Peening - C
3		With very near subsurface flaws	Peening - A Peening - B Peening - C

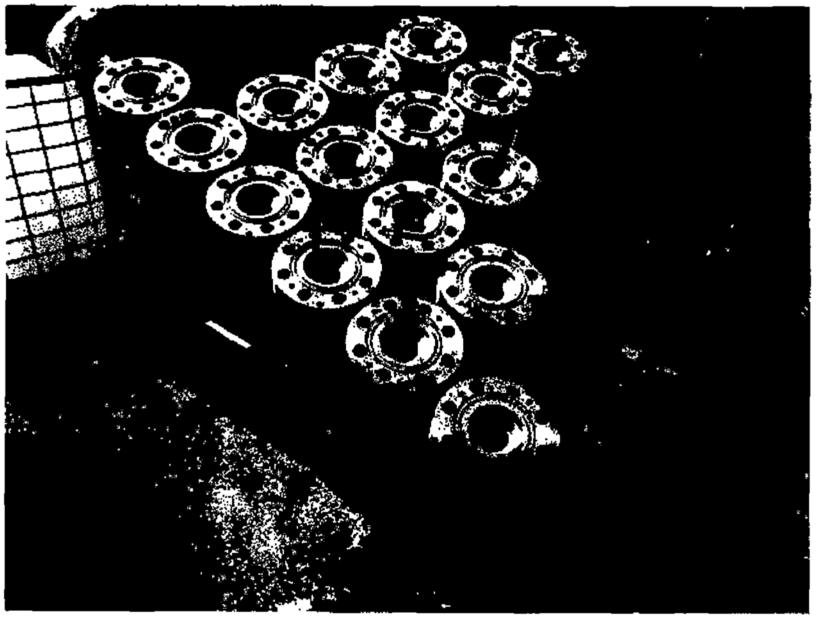
*** Three Peening Processes Include: Underwater Laser Peening, Water Jet Peening, and Air Laser Peening.**

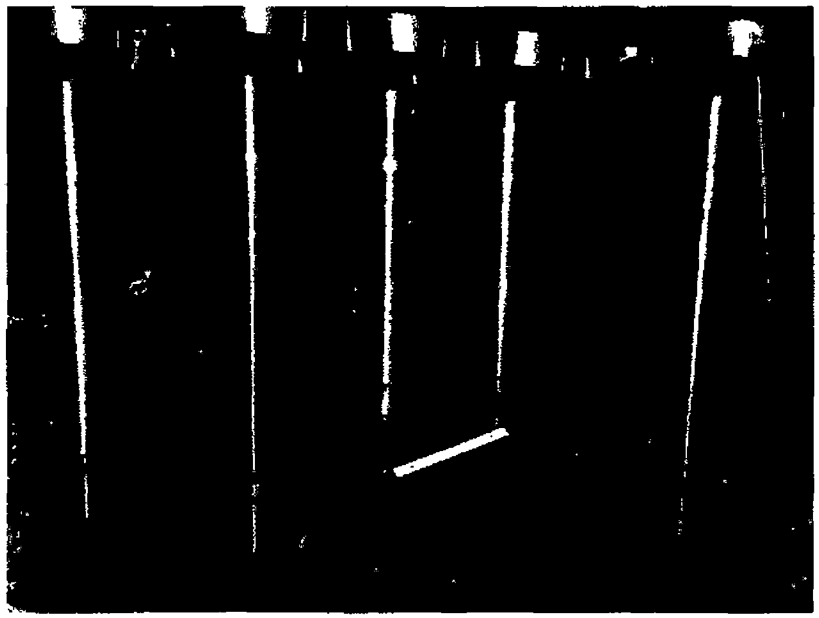
CRDMs – Upper Head Penetration Nozzle Welds

CRDM Specimens



PNNL has a section of vessel head with 16 CRDMs. 13 of these are being individually cut out of the vessel head. A group of 3 have been left uncut. The Peening project has cost shared the effort to extract CRDMs with NRC RES Project V6323. 5 CRDMs have been identified, cut, and set aside for Peening work. (Process currently underway)

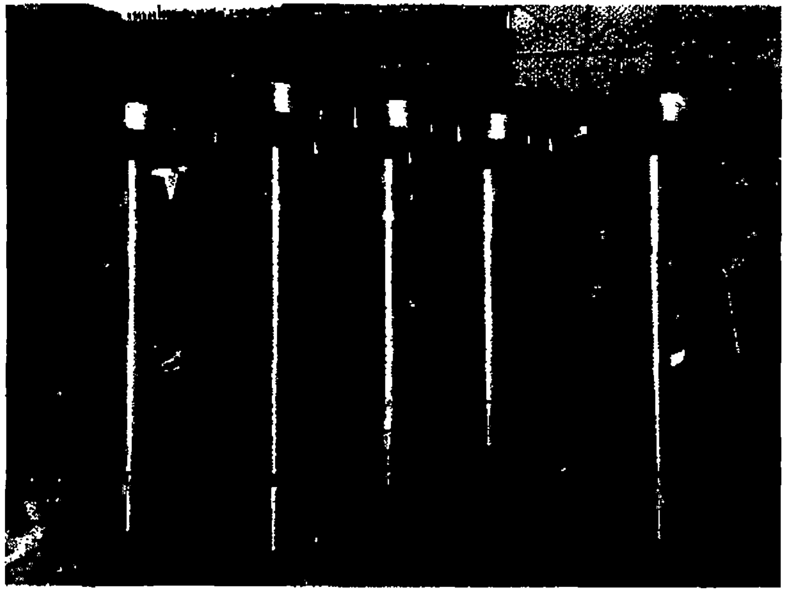




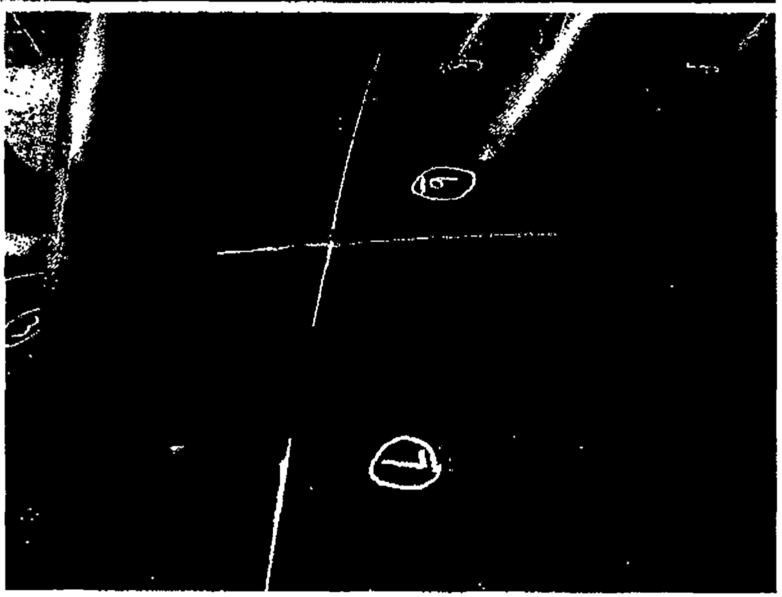
CRDM Specimens

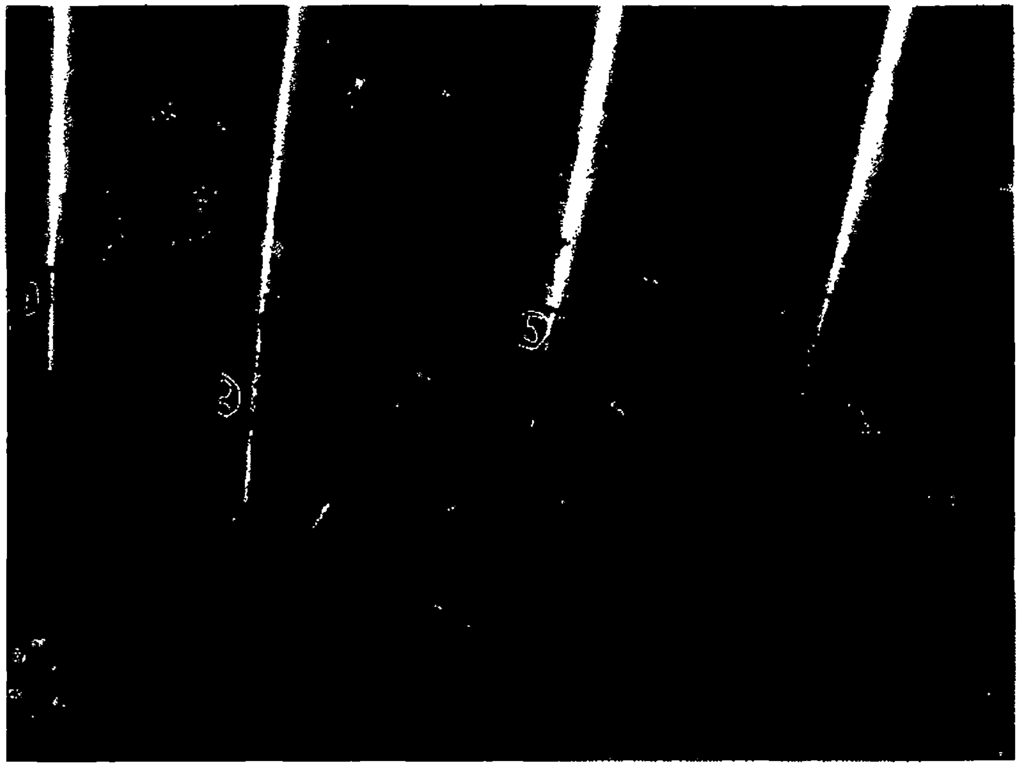
Handling, transport and extraction of these CRDMs is non-trivial, costly and time-consuming . For the Peening work we want CRDMs with large (>30°) nozzle penetration incident angles into the vessel head surface, requiring penetrations situated away from the "top" of the vessel head.

CRDM Specimens

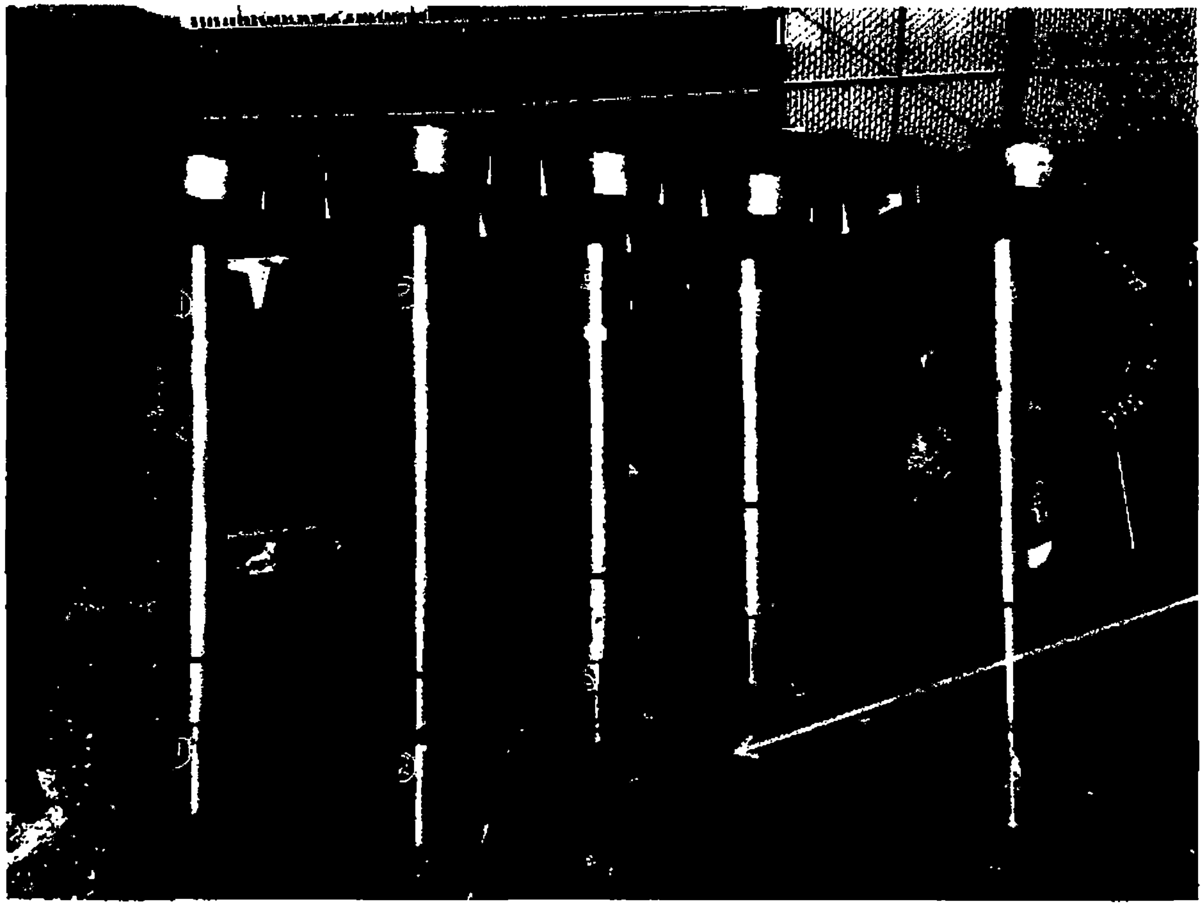


PNNL marked each CRDM and identified #'s 3, 4, 5, 6 and 7 for use on the Peening work, for NDE and WRS measurements (pre- and post-peening). Only 3 of these will be used for the current scope of work, 2 will be set aside. CRDMs #1 and #2 will be given to Mychailo for his work on materials evaluation.





CRDM Specimens

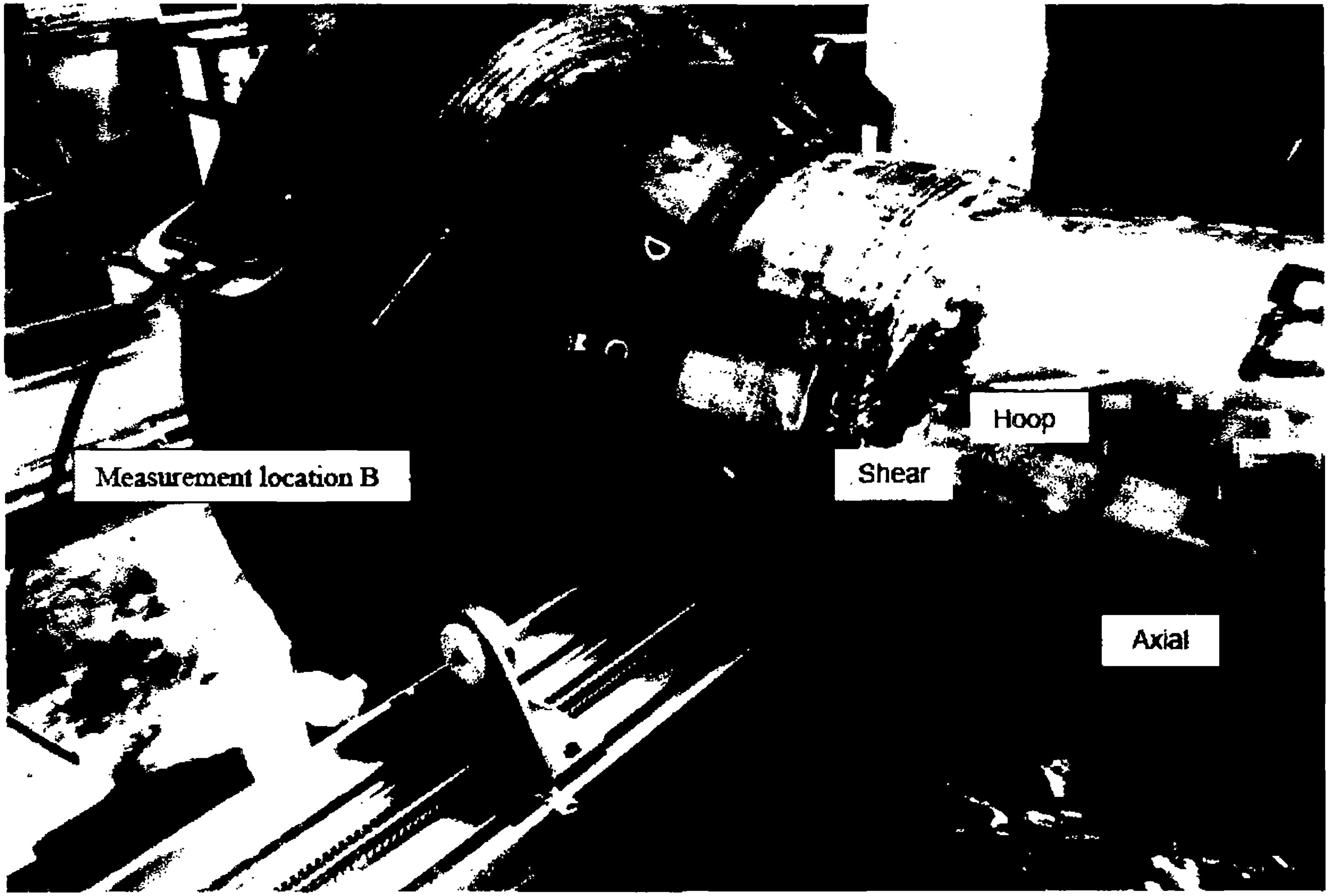


Vessel head (and CRDMs) should ship out from PNNL the week of Oct. 20th for cutting and preparation, if all goes as anticipated (keeping my fingers crossed).

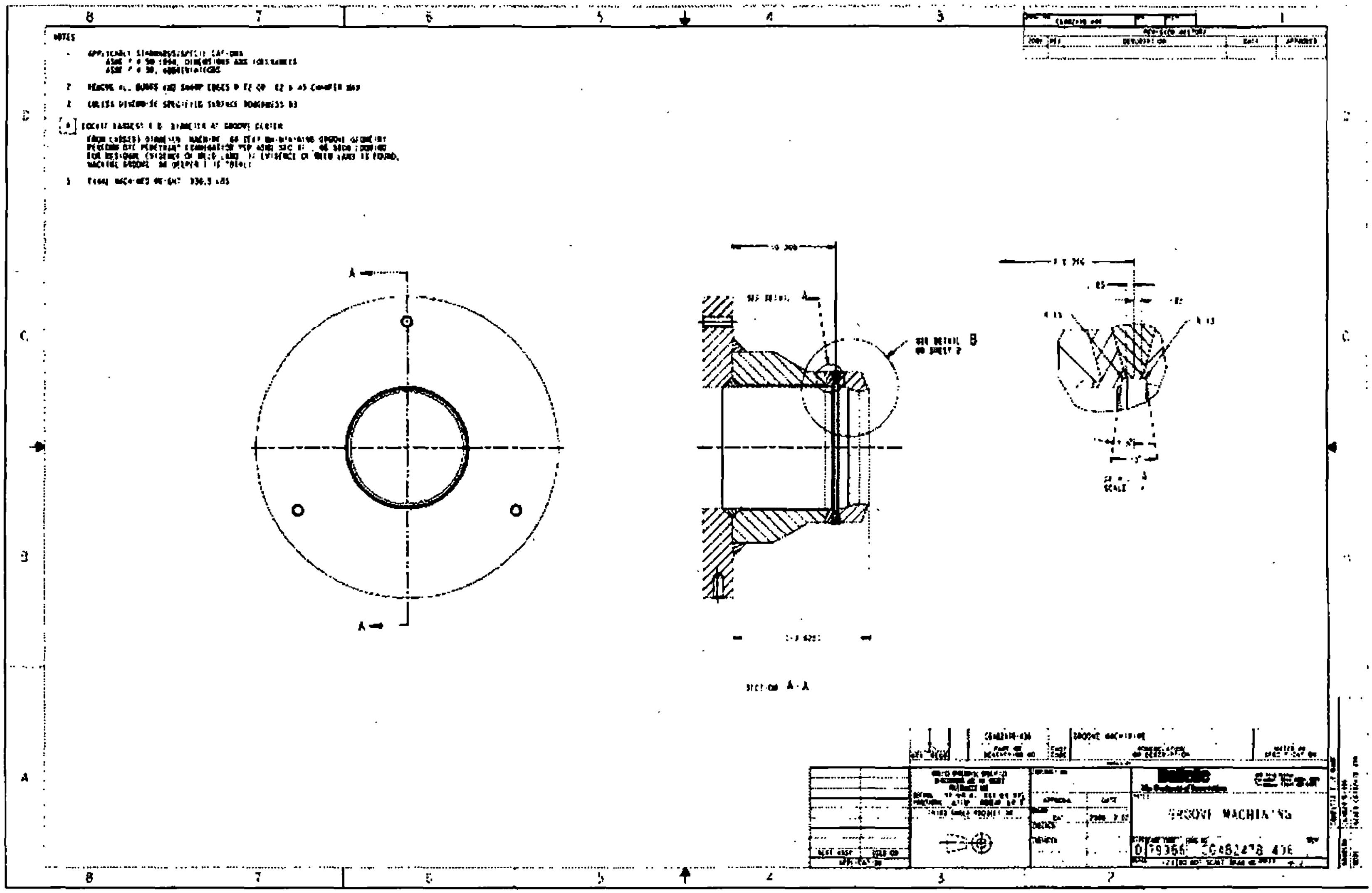
For ease of handling, reduced weight and better manipulation in the laboratory for measurement purposes, the CRDM nozzles will be cut off (see red lines for approximate cuts). The marked on the vessel head surface indicate the surrounding areas to be cut, allowing for the retention of some carbon steel head material.

Phase 2B – Alloy 182/82
RCS DM Butt Weld

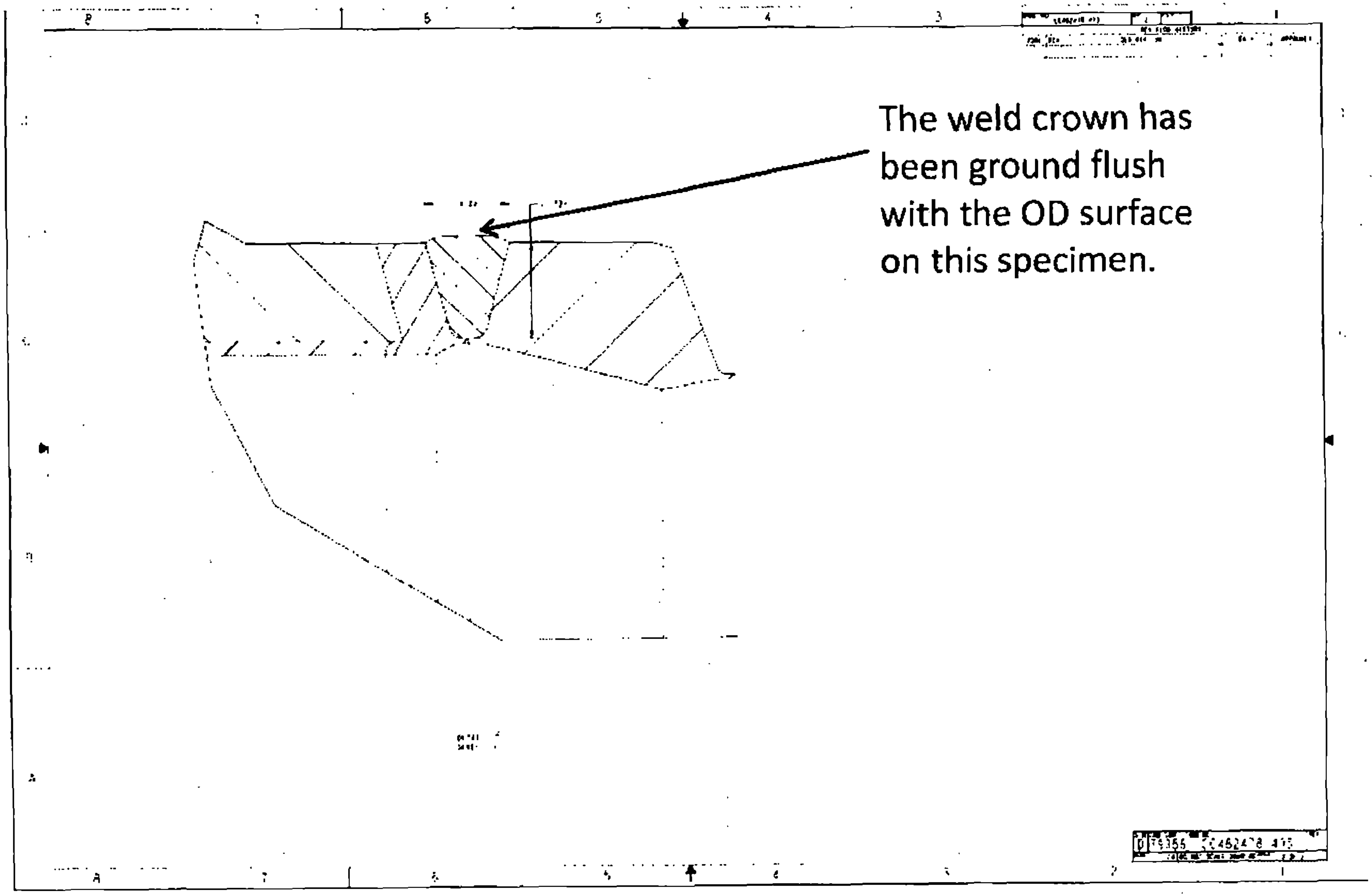
Phase 2B Alloy 182 Welded Specimen (RCS DM Butt Weld) Pictures. Weld Overlay Mockup (WOM). (Photo taken prior to sectioning)



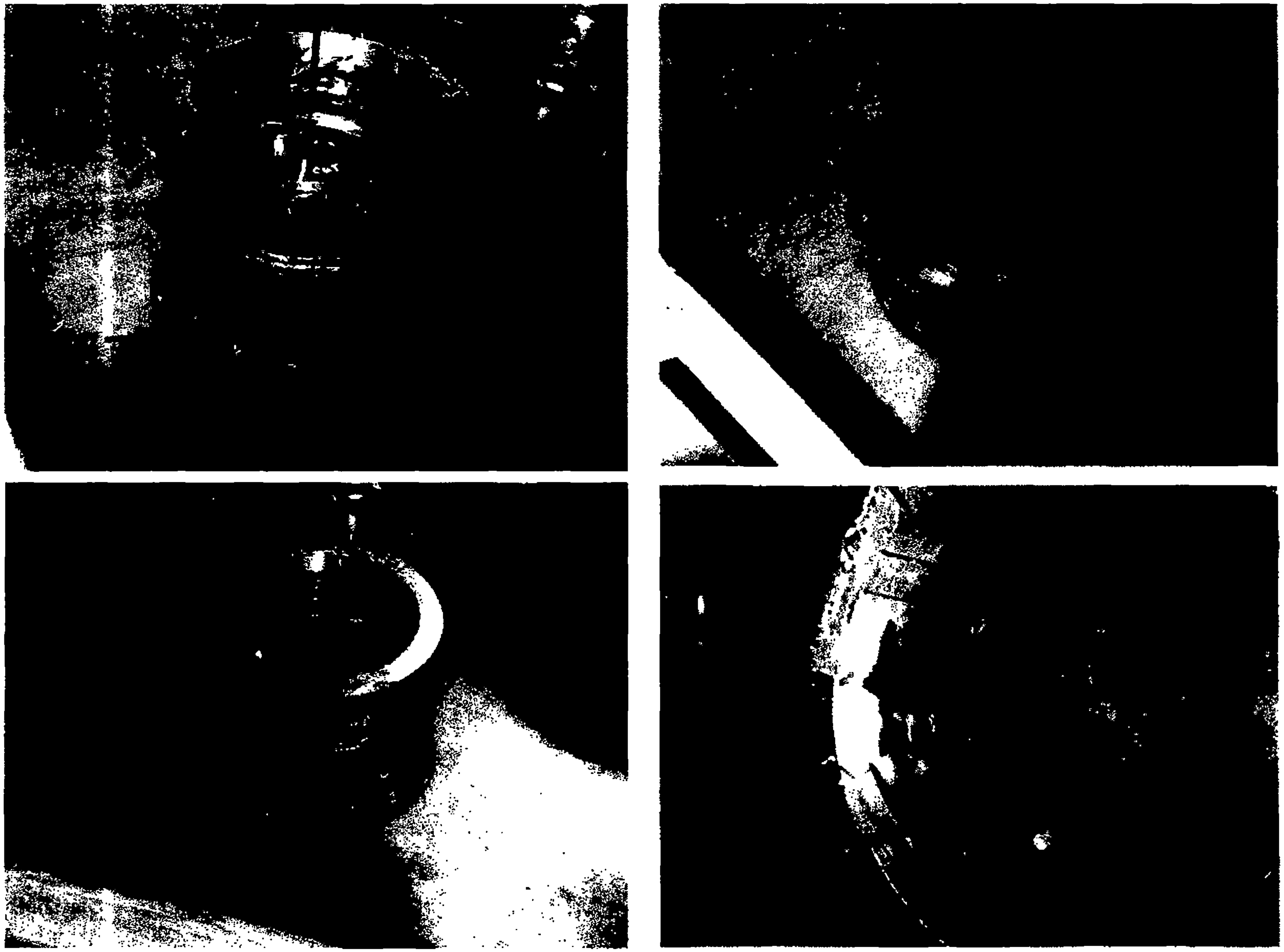
Phase 2B Alloy 182 Welded Specimen (RCS DM Butt Weld) Drawing. Weld Overlay Mockup (WOM).



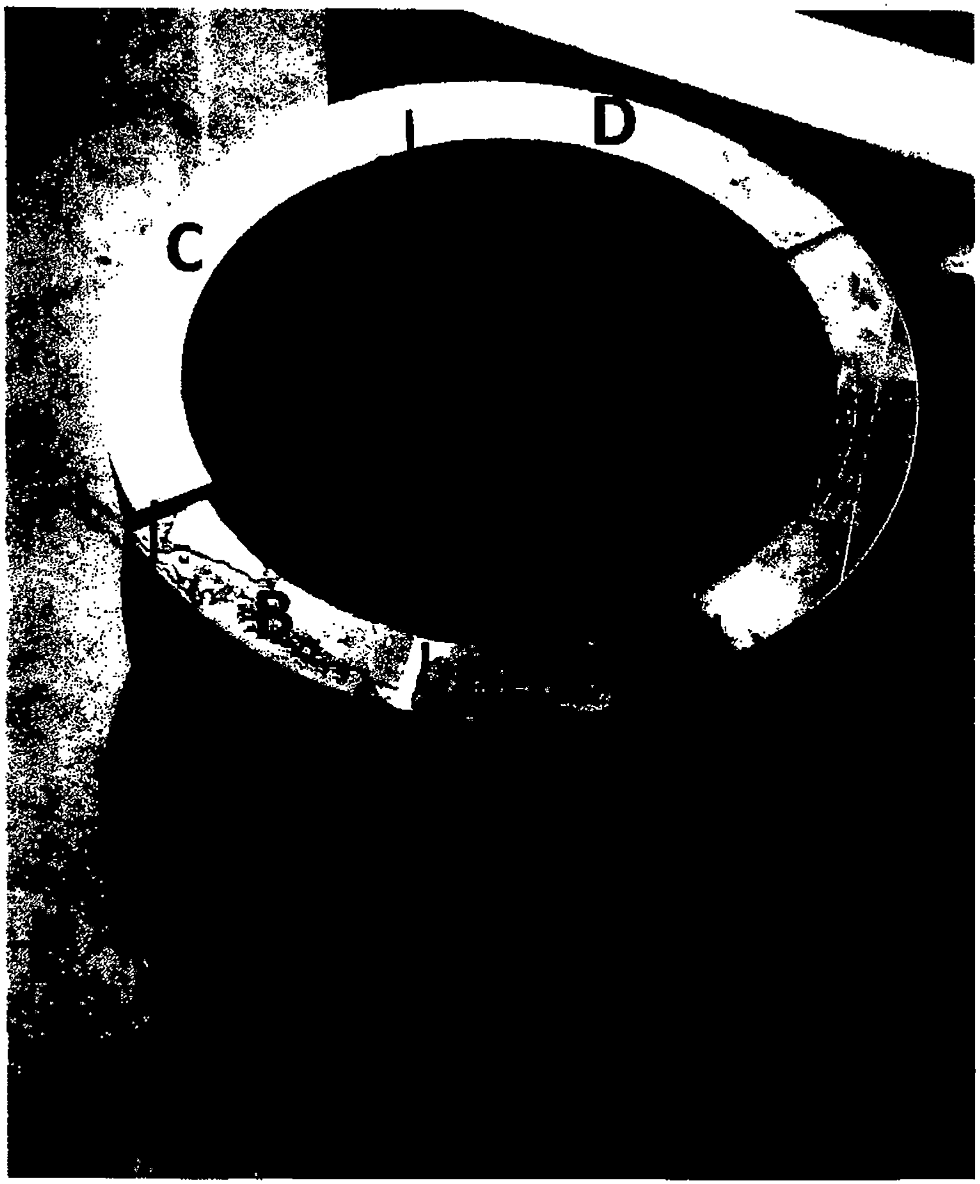
Magnified View of Phase 2B Alloy 182 DMW in WOM specimen



Recent Photos of Phase 2B Alloy 182 Welded Specimen (RCS DM Butt Weld). Weld Overlay Mockup (WOM). (Photos taken after sectioning as they currently exist at PNNL)

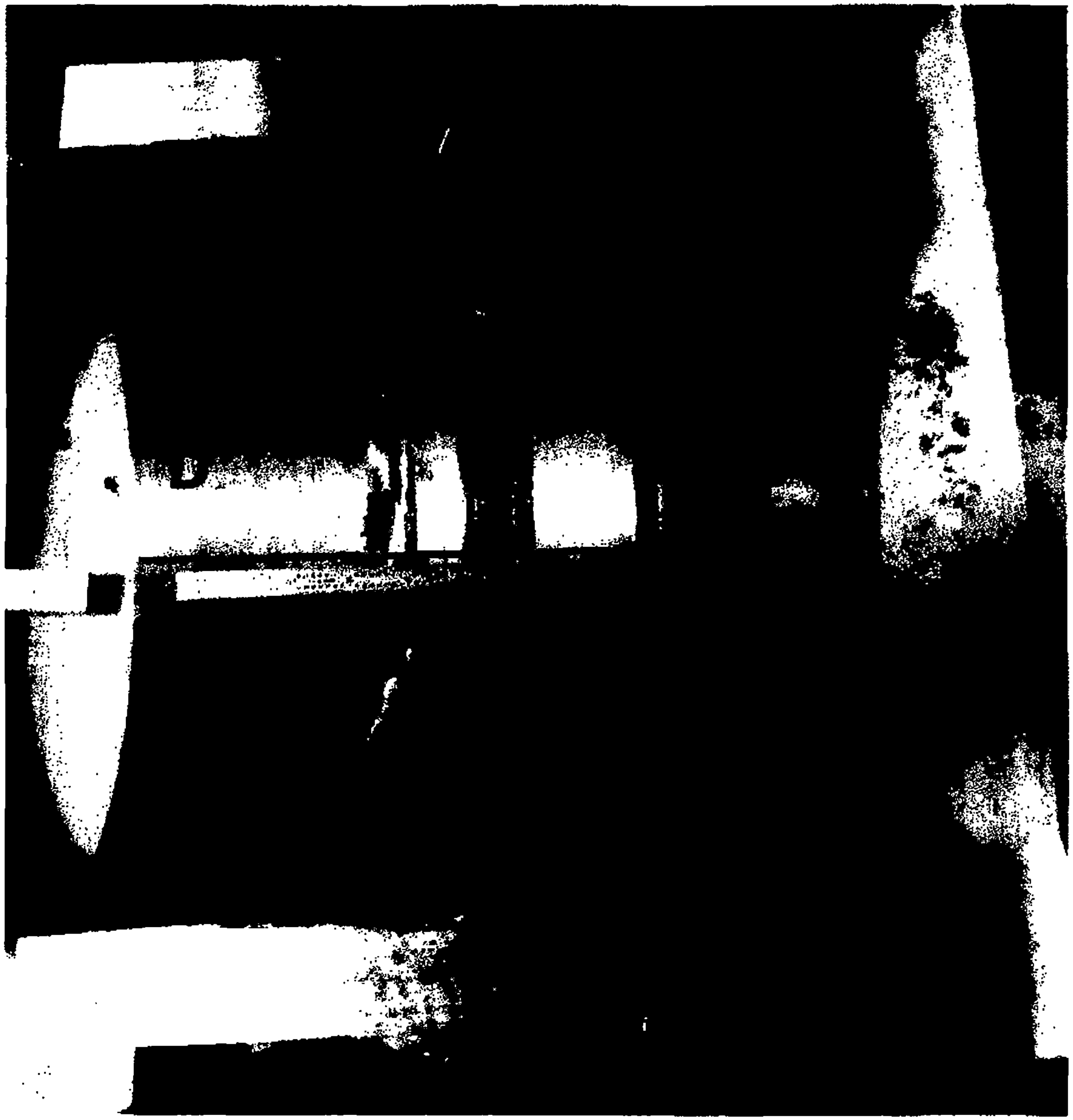


Recent Photos of Phase 2B Alloy 182 Welded Specimen (RCS DM Butt Weld). Weld Overlay Mockup (WOM). (Photos taken after sectioning as they currently at PNNL)



The two sectioned parts highlighted with **red lines (Sections A and B)** will be provided to Mychailo Toloczko and Steve Bruemmer for materials evaluation tasks, while the three larger remaining sections highlighted with **blue lines (Sections C, D and E)** will be used for NDE and WRS measurements, for both pre- and post-peening assessments. The current 180 degree segment of this mockup will be cut in half to comprise Sections **C** and **D**. This cutting will be conducted in-house at PNNL, and should be completed by Oct. 17. Sections **C, D** and **E** will essentially be 90 degree segments.

Recent ID Photos of Phase 2B Alloy 182 Welded Specimen (RCS DM Butt Weld). Weld Overlay Mockup (WOM). (Photos taken after sectioning as they currently exist at PNNL)



180 degree segment of Phase 2B RCS DM Butt Weld Mockup. This will be cut approximately where the red line is, to make two individual 90 degree specimens. Sections **C** and **D** are marked, correlating to the marked sections on the previous slide.

Recent ID Photos of Phase 2B Alloy 182 Welded Specimen (RCS DM Butt Weld). Weld Overlay Mockup (WOM). (Photos taken after sectioning as they currently exist at PNNL)

90 degree segment of Phase 2B RCS DM Butt Weld Mockup. This is Section **E**, correlating to the marked section on the previous slide.

Alloy 600 Plate (with and without Alloy 182 welds)

Alloy 600 Plate with NO Weld, and WITH Alloy 182 Weld

A **12" x 48" x 2" (thick)** Alloy 600 plate was procured from SandMeyer Steel Company via Special Metals of California. The plate was compared to other available Alloy 600 plate material, and the 46.6 ksi yield strength was chosen over others since high yield strength usually correlates to higher SCC susceptibility. The plate should arrive at PNNL on Oct. 17th. At that time, PNNL will section the plate according to one of two scenarios (defined in subsequent slides), in order to allow for the fabrication of **15** total specimens.

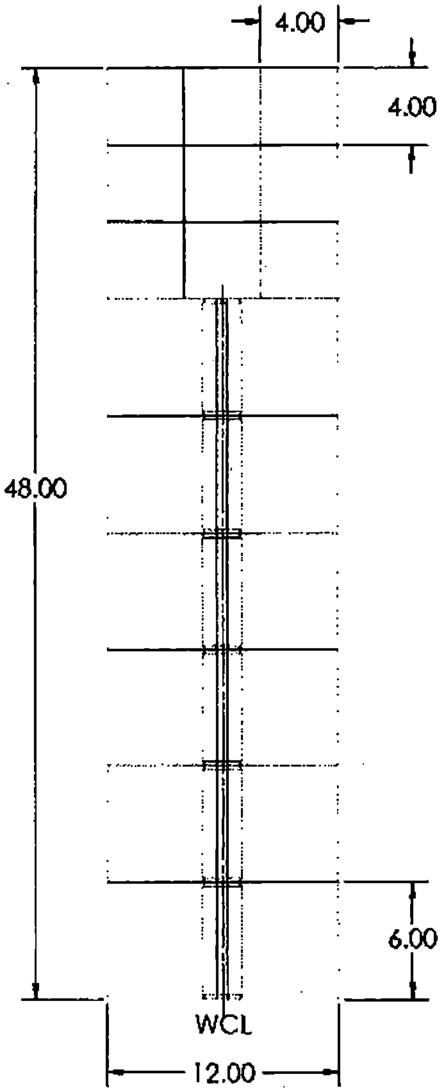
These specimens are:

- 3 Alloy 600 plate specimens with no weld and with no flaws
- 3 Alloy 600 plate specimens with no weld and with surface flaws
- 3 Alloy 600 plate specimens with no weld and with very near subsurface flaws
- 3 Alloy 600 plate specimens with Alloy 182 weld with no flaws
- 3 Alloy 600 plate specimens with Alloy 182 weld with very near subsurface flaws

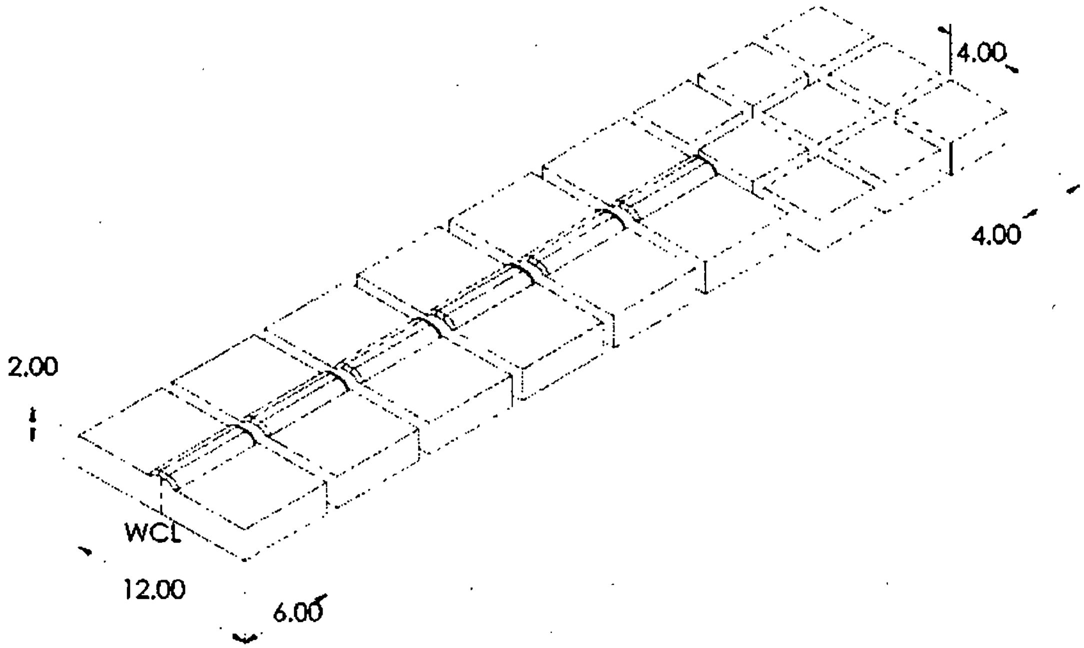
A portion of the plate will be cut and then welded with an Alloy 182 weld. This portion of the mockup will be left in the "as-welded" condition. After this process is complete, the welded section will be segmented into 6 individual specimens (for last 2 bullets above).

Alloy 600 Plate with NO Weld, and WITH Alloy 182 Weld (units in inches)

Scenario 1:

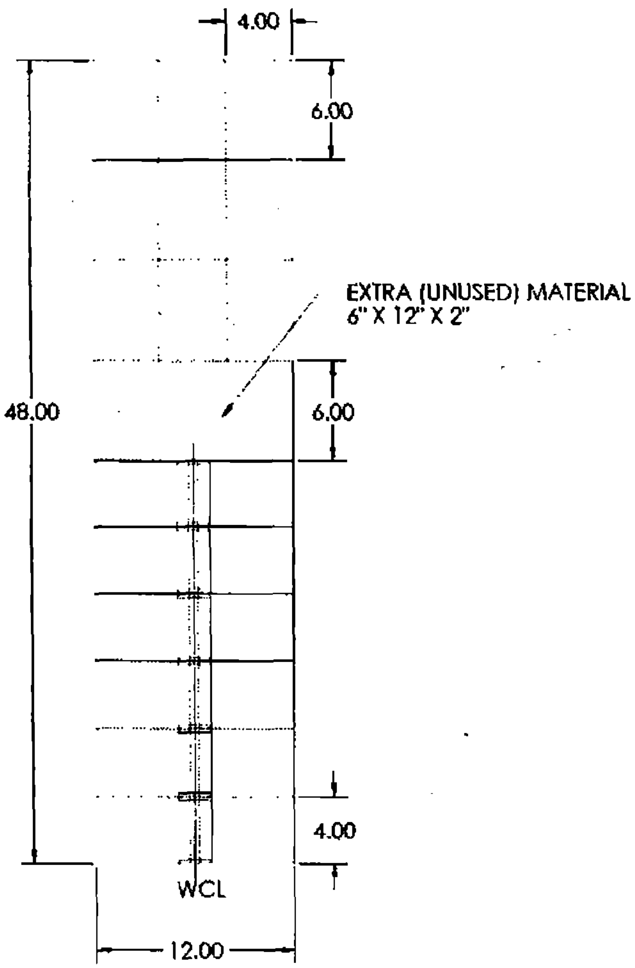


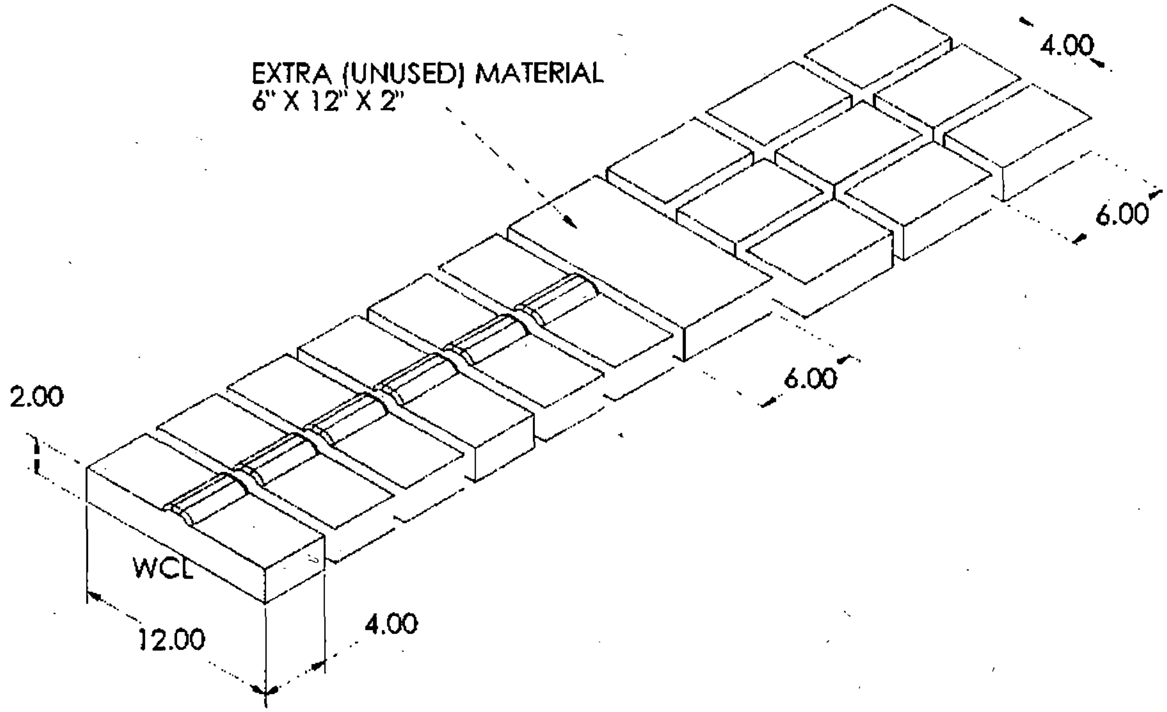
PNNL Recommends Scenario 1
This utilizes 100% of the material procured.



Alloy 600 Plate with NO Weld, and WITH Alloy 182 Weld (units in inches)

Scenario 2:





Alloy 600 Plate with NO Weld, and WITH Alloy 182 Weld (units in inches)

<u>Scenario 1 provides:</u>

- Nine (9) 4" x 4" no-weld samples (2" wall thickness).
    - ❑ 3 with no flaws
    - ❑ 3 with surface flaws
    - ❑ 3 with very near subsurface flaws
- Six (6) 6" x 12" Alloy 182 welded samples (2" wall thickness).
    - ❑ 3 with no flaws
    - ❑ 3 with very near subsurface flaws

<u>Scenario 2: provides:</u>

- Nine (9) 4" x 4" no-weld samples (2" wall thickness).
    - ❑ 3 with no flaws
    - ❑ 3 with surface flaws
    - ❑ 3 with very near subsurface flaws
- Six (6) 6" x 12" Alloy 182 welded samples (2" wall thickness).
    - ❑ 3 with no flaws
    - ❑ 3 with very near subsurface flaws
- One (1) 6" x 12" unwelded blank block of material (2" wall thickness)

Pages 205-264

Withheld in their Entirety

Exemption 4

(Confidential Commercial or Financial Information)

Hill Engineering, LLC

Engineering structural integrity

3035 Prospect Park Drive, Suite 180
Rancho Cordova, CA 95670
Ph: (916) 635-5706
www.hill-engineering.com

~~PREDECISIONAL~~ ~~PREDE~~ ~~PREDECISIONAL~~

MEASUREMENT REPORT

Report Title:	**Residual stress measurements on CRDM alloy 600 nozzle**
Report Number:	HE-R-052915
Date:	May 29, 2015
Contract Number:	14-14
HE Job Number:	HE111214a

~~PREDECISIONAL~~

Background

Hill Engineering was contracted by EMC[2] to perform hole drilling method and slotting method residual stress measurements on one CRDM nozzle. This report summarizes the results of these measurements. Results are displayed in the form of line plots of stress versus depth.

Specimen geometry

Measurements were performed one CRDM nozzle specimen (Figure 1). The specimen was comprised of a large plate (approximately 15" long x 9" wide x 8" thick) with a pipe (approximately 2.76" ID x 4.00" OD x 27.625" long) welded into it (Figure 1).

The nozzle was made from Alloy 600, assumed to have the following elastic material properties: E = 31,000 ksi, $v = 0.30$. For reference, the stated yield strength of the material is 44.5 ksi, and the stated ultimate strength is 91.4 ksi. The yield and ultimate strength values do not affect the residual stress results computed herein.

Experimental details

Residual stress measurements were performed using two measurement techniques: hole drilling and micro-slotting. The residual stress measurements were performed in four areas of the nozzle (Figure 2), in the following order: Group B, Group D, Group E, and then Group A.

Group B residual stress measurements, near the 6:00 location on the nozzle, included measurements BH1, BH2, BH3, BH4, BH5, and BS1 (Figure 3). Group D residual stress measurements, on the inner diameter of the pipe, included DH1 and DH2 (Figure 4). Group E residual stress measurements, near the 12:00 location on the nozzle, included measurements EH1 and EH2 (Figure 5). Group A residual stress measurements, near the 9:00 location on the nozzle, included measurements AH1, AH2, AH3, and AS1 (Figure 6).

Hole drilling measurements

Each hole was drilled in 0.002 inch increments to a final depth of 0.040 inches. The following is a summary of the hole drilling method measurement as it was applied here. For additional background information please consult the reference [1].

1. Install strain gage rosette on hole drilling site.
2. Incrementally drill hole through center of strain gage and record strain release for each incremental depth.
3. Compute residual stress from measured strain data.

Slotting measurements

The slotting method was used to measure the residual stress in locations AS1 and BS1. The following is a summary of the slotting measurements as they were performed here.

1. Install strain gage adjacent to slotting site.
2. Incrementally remove a slot of material adjacent to the strain gage and record the strain release for each incremental depth.

Results

Line plots of the measured residual stress for the hole drilling measurements are shown in Figure 7 through Figure 10.

Line plots of the measured residual stress for the slotting measurements are shown in Figure 11.

References

[1] ASTM Standard E837-08, "Standard Test Method for Determining Residual Stresses by the Hole-Drilling Strain-Gage Method," ASTM International, West Conshohocken, PA, 2008, DOI: 10.1520/E0837-08, www.astm.org.

Figures

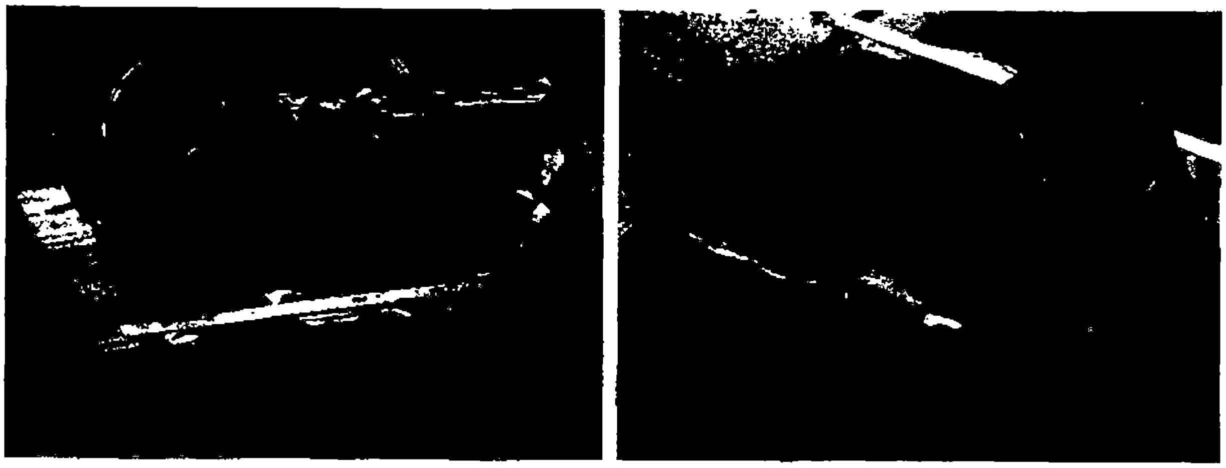


Figure 1 Photographs of CRDM nozzle specimen

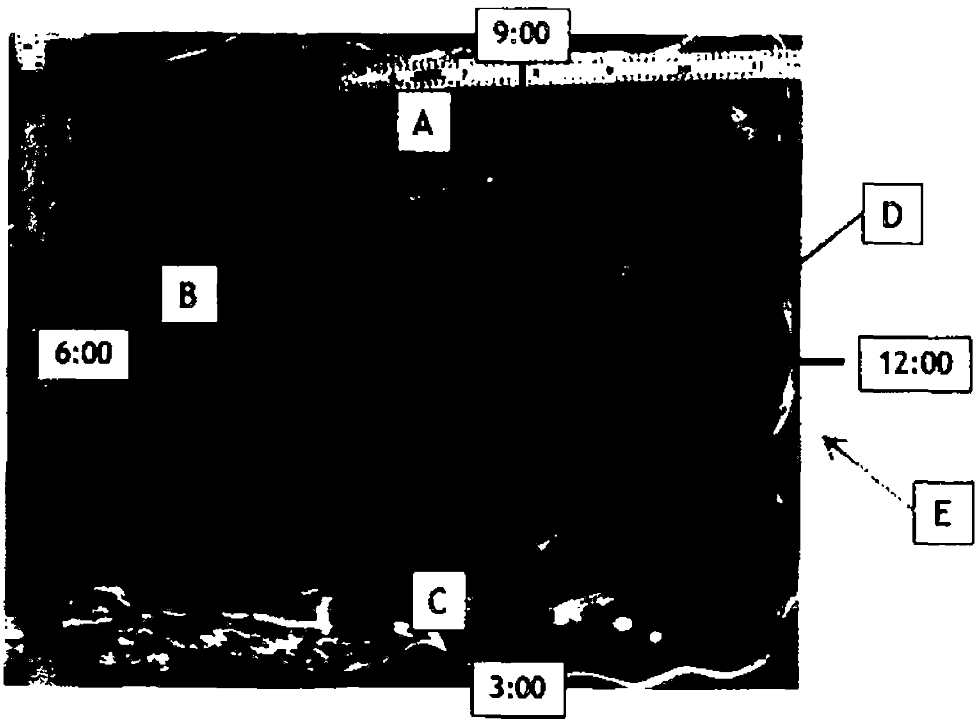


Figure 2 - Illustration of the measurement regions of the CRDM nozzle specimen

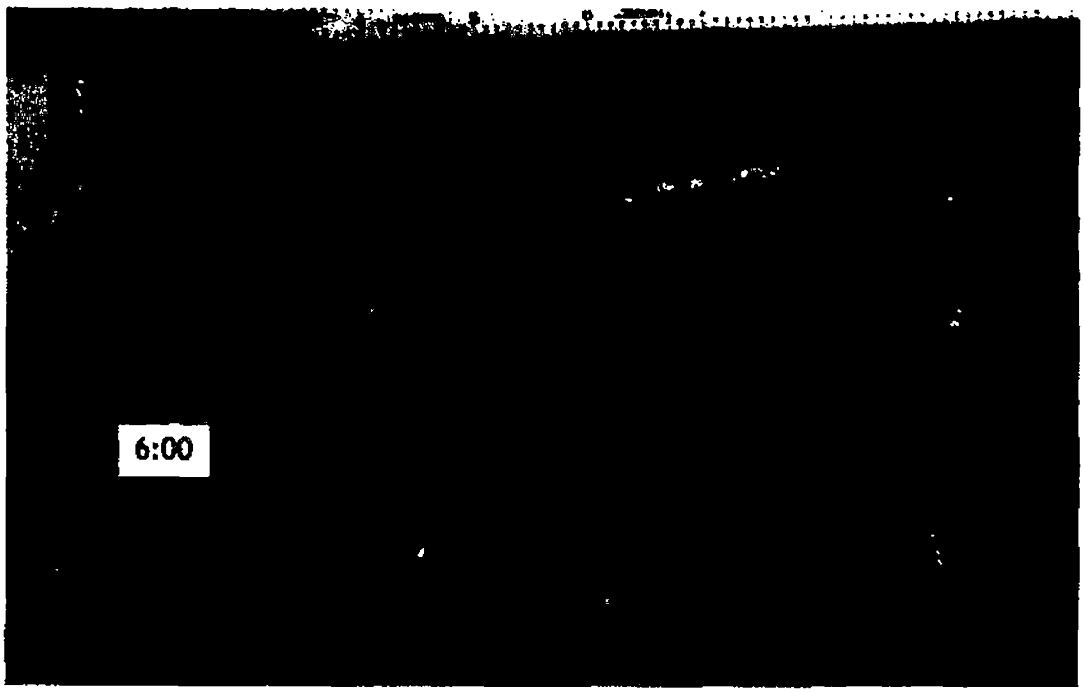


Figure 3 – Illustration of the measurement locations in region B of the CRDM nozzle specimen

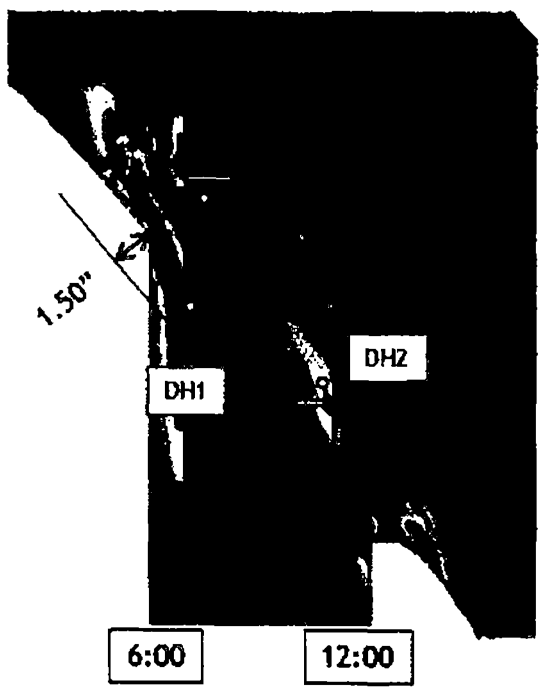


Figure 4 – Illustration of the measurement locations in region D of the CRDM nozzle specimen.

Figure 5 – Illustration of the measurement locations in region E of the CRDM nozzle specimen.

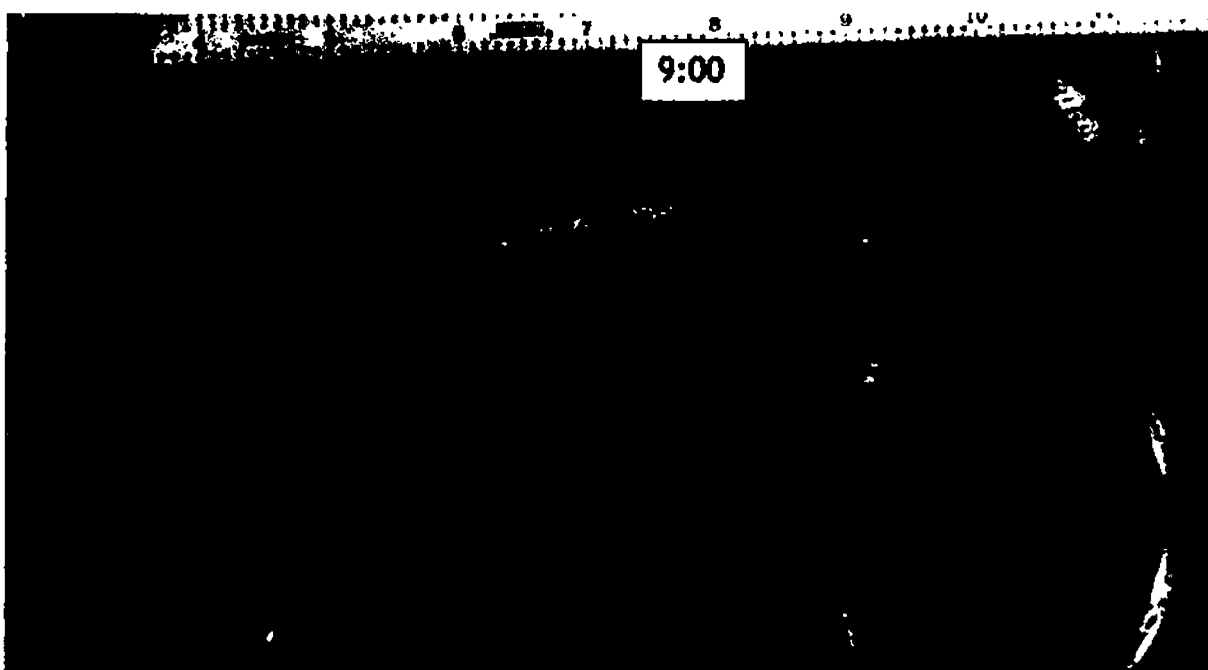
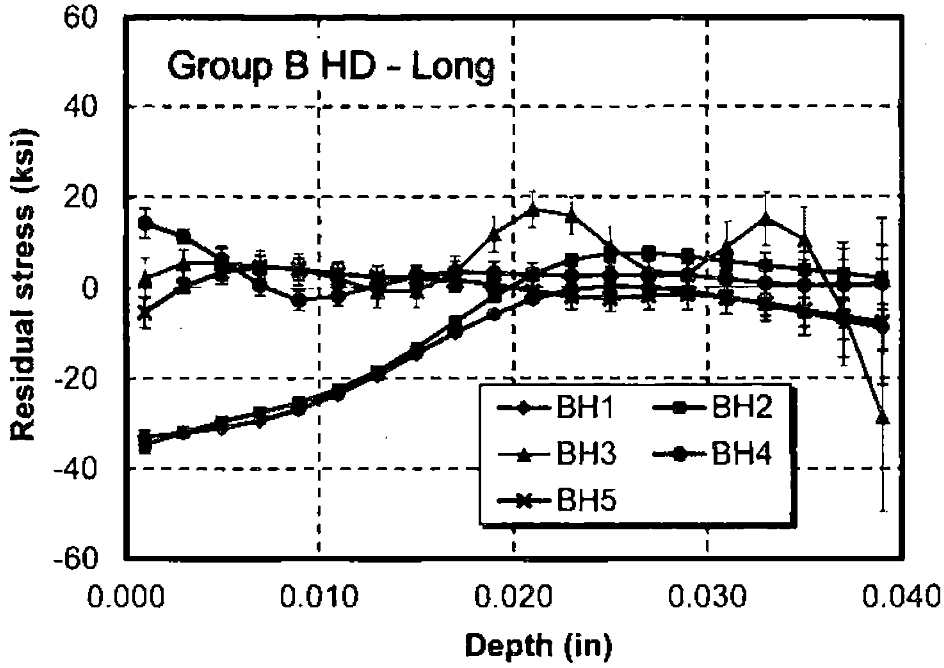


Figure 6 – Illustration of the measurement locations in region A of the CRDM nozzle specimen.



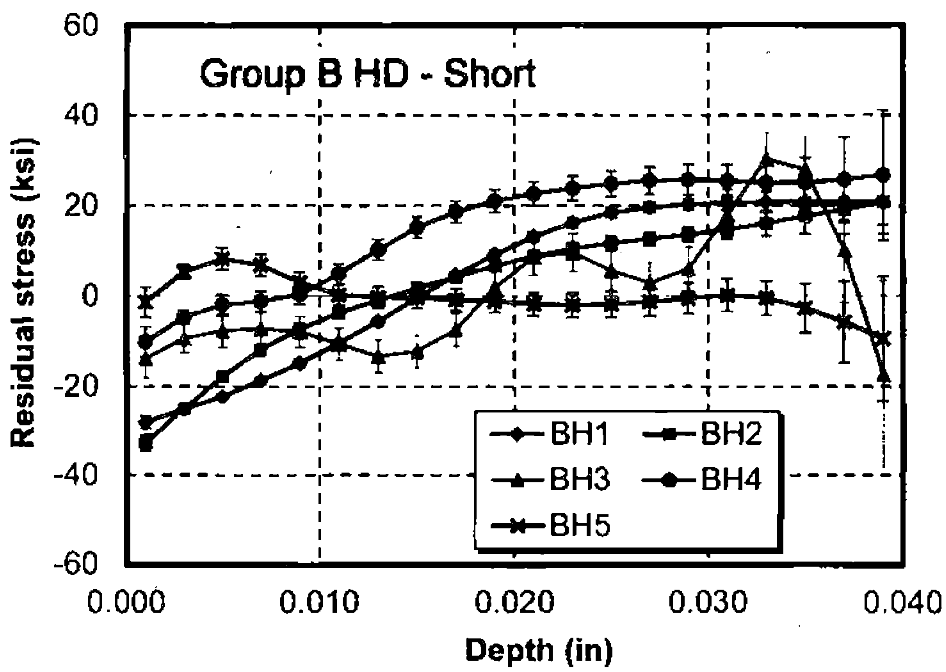


Figure 7   Line plots of the measured residual stress vs. depth for the Group B hole drilling method measurements

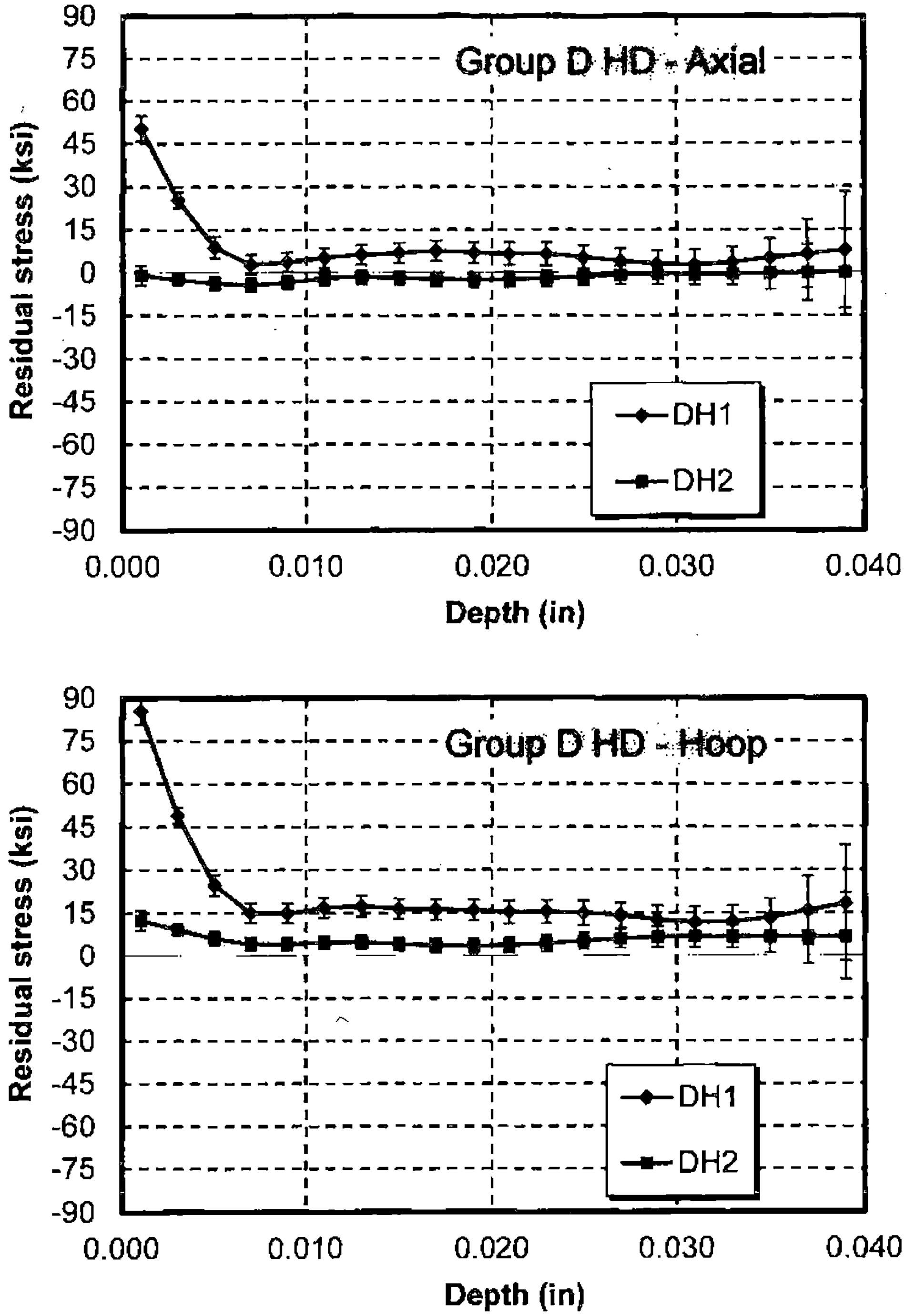


Figure 8 – Line plots of the measured residual stress vs. depth for the Group D hole drilling method measurements.

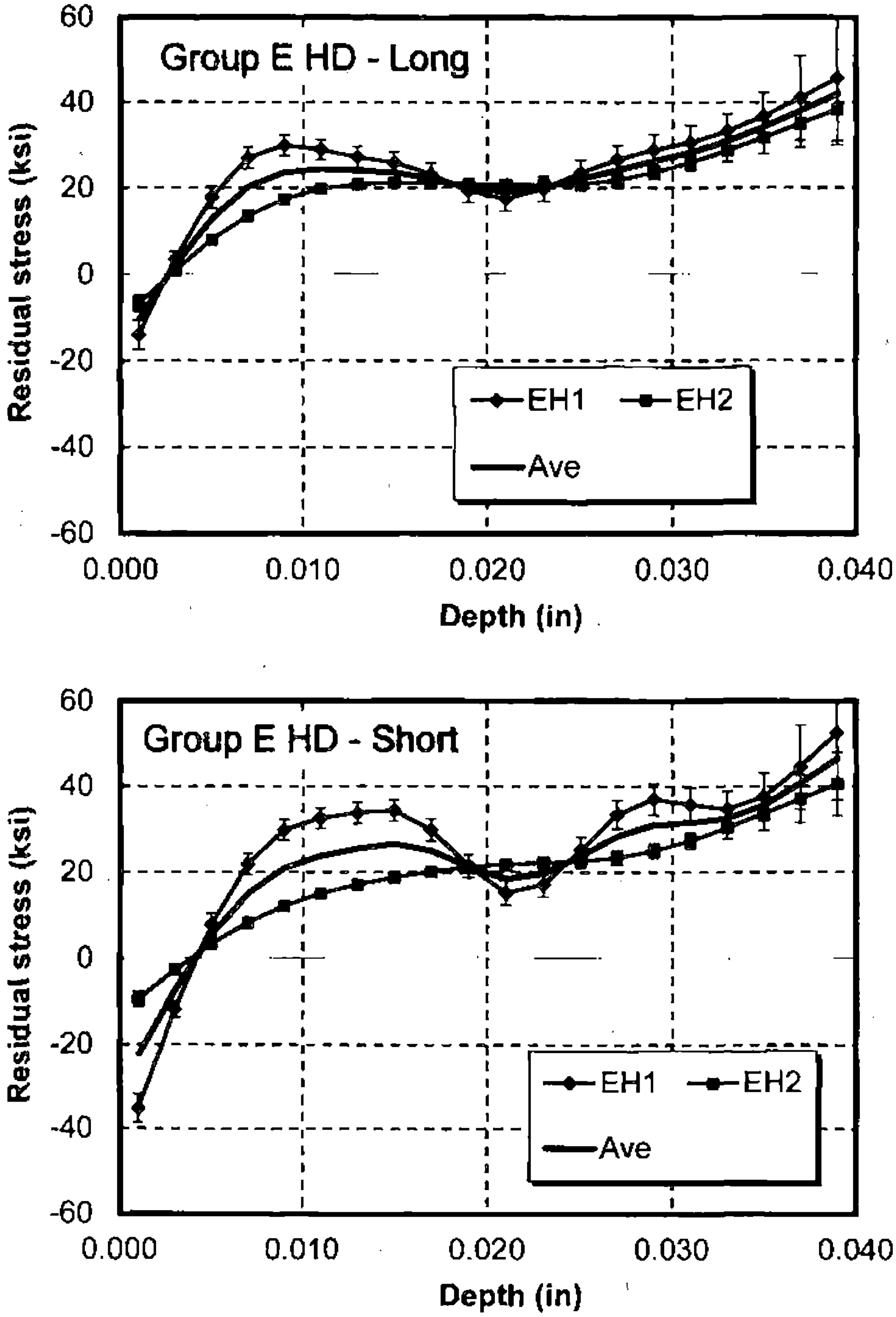
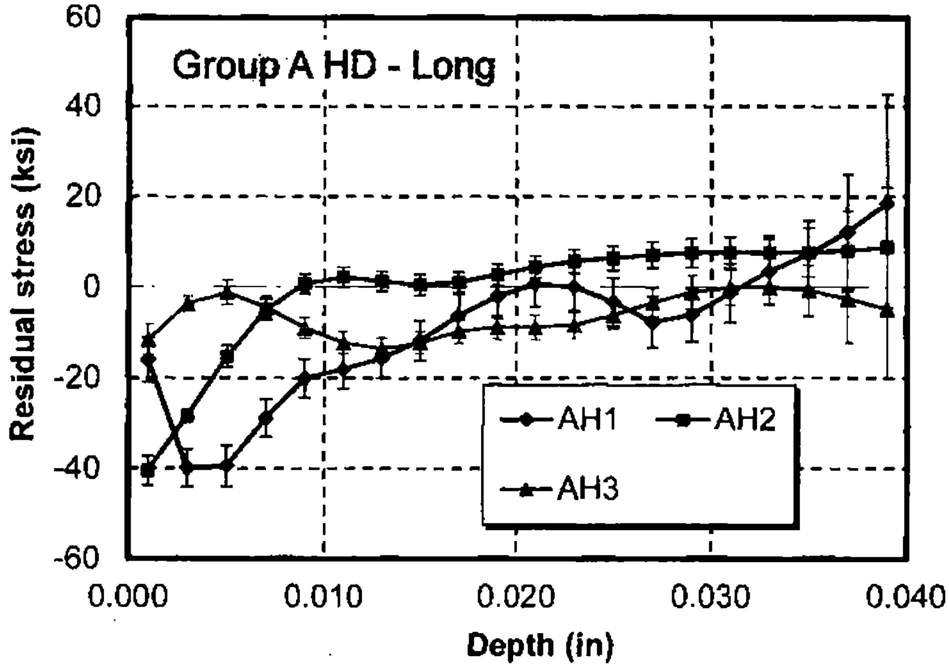


Figure 9 - Line plots of the measured residual stress vs. depth for the Group E hole drilling method measurements.



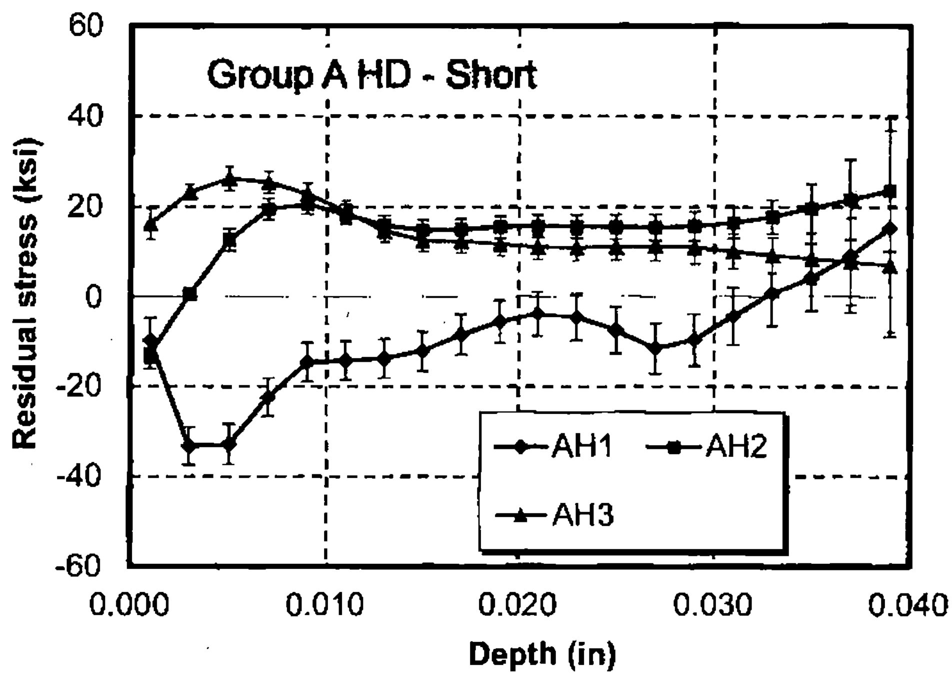


Figure 10 – Line plots of the measured residual stress vs. depth for the Group A hole drilling method measurements. For AH3, the long direction is closer to the axial direction on the pipe and the short direction is closer to the hoop direction on the pipe.

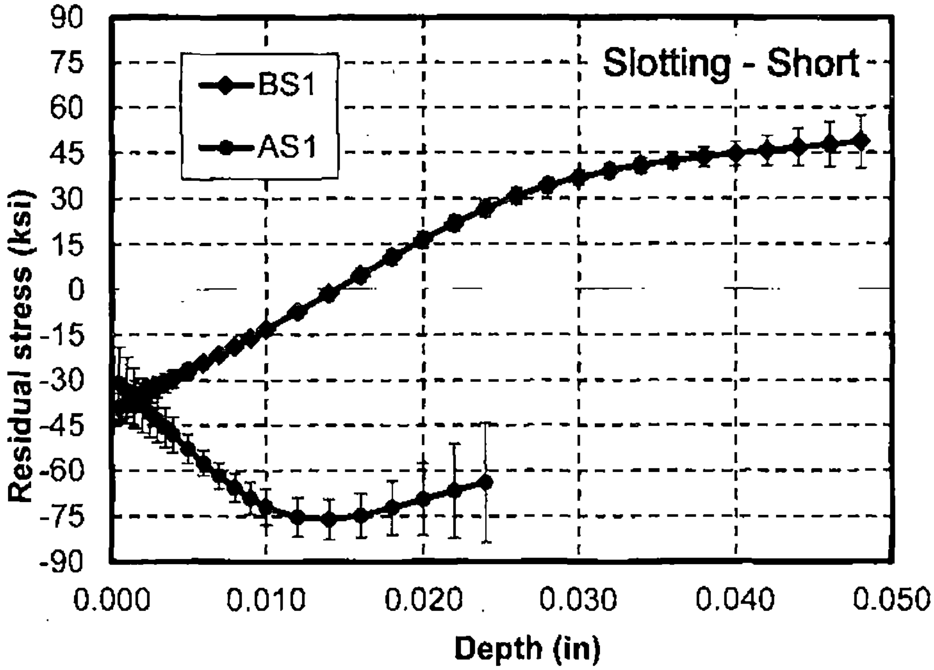


Figure 11 – Line plot of the measured residual stress vs. depth for the micro-slotting method measurements.

Emc²

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DRAFT
CONFIDENTIAL AND BUSINESS SENSITIVE
MONTHLY PROGRESS REPORT

January 11, 2015

Mr. Aaron Diaz
Senior Staff Scientist & Team Leader
Acoustics & Ultrasonics
Applied Physics Group
Pacific Northwest National Laboratory (PNNL)
902 Battelle Boulevard
Richland, WA 99352

Sent via Email: aaron.diaz@pnnl.gov

Dear Aaron:

Subject: December 2014 Monthly Progress Report on PNNL Subcontract Number: 244664 for Project "Verification of Residual Stress Measurements in Reactor Coolant System Components and Welds," Emc² Project No. 14-G61-01

This project was initiated on October 13, 2014 and ends on September 30, 2016. This is a summary progress report on the above project for December 2014.

Work Conducted During the Reporting Period

Emc² staff participated in meeting and conference calls with PNNL, NRC staff, as well as Hill Engineering (Emc² subcontractor) and other potential vendors of ultrasonic residual stress measurement (RS) during the reporting period. In addition, F. W. Brust attended a meeting in Washington with NRC staff (led by Jay Collins) and Mike Hill (of Hill Engineering) to discuss aspects of the program.

The two major activities during this period consisted of conducting RS measurements using traditional hole drilling and slotting methods at Hill Engineering (HE), and, reviewing ultrasonic RS measurement technologies that are available for commercial use.

Practice CRDM Specimen RS Measurement at HE:

There were several iterations on the exact locations on the practice CRDM specimen and the technique to be used to measure both the hoop and radial residual stresses. Attachment 1 shows the recommended locations and the technique (hole drilling and slotting) for the measurements to be conducted by HE ahead of the meeting between Emc², HE and NRC staff on December 15,

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As reported previously, SINTEC, which had been originally issued a PO to conduct ultrasonic residual stress measurements on the practice CRDM specimen on-site at HE, was unable to do so due to both administrative and technical reasons.

Ultrasonic Technologies for RS Measurements:
As reported previously, after discussions with NRC staff, it is evident that one of the major objectives of this entire project is to establish that commercially available non-destructive ultrasonic measurement (UM) technology can be used to support NRC's RS confirmatory work in the future. Given both the technical and administrative issues with SINTEC, and per discussions with both NRC and PNNL staff Emc^2 has been investigating several other possible vendors both in North America and elsewhere as summarized below:

i. *Prof. Don Bray, Consultant:* Professor Emeritus Don Bray from Texas A&M University is a recognized expert in ultrasonic NDE and RS measurement. Emc^2 had several discussions with Prof Bray regarding his current capabilities in this area. He did have a consulting company previously but he has apparently sold it and has no equipment to work on this project, though he was willing to work as a technical advisor. Emc^2 has obtained both his bio-sketch as well as his consulting rate, should he be needed.

ii. *Dr. Ted Salamanca, President, Reinhart Associates, TX:* Dr. Salamanca, a graduate student of Prof Bray in the 1980s and was highly recommended. They still have all the UM equipment but has not been used and will need to be updated and integrated with later generation electronics per Emc^2's discussion with him. Dr. Salamanca was out of the country for several weeks in late December and will provide a quote for refurbishing and calibrating the equipment for use in this project.

iii. Dr. Auteliano Santos, Univ. of MI, Ann Arbor, MI: Dr. Santos is also a former graduate student of Prof Bray who was recommended as a possible vendor. He is currently a visiting professor and does not have access to any of his UM equipment, which is located at his university in Brazil. Dr. Santos offered to purchase, assemble and make available the UM system. We are reviewing this as a back-up option to Reinhart (above).

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Based on the discussions to date reported above, UM appears to be still in the research and developmental stages and only a few unique applications (i.e. rail) are commercially available. However, we may consider sending one of the plate specimens to SINTEC's Dr. Yuri Kudryavtsev in Canada to compare measurements on a simple specimen to the corresponding hole drilling and slitting measurements. He has offered to do some preliminary demonstration of his technology at no cost to this project, if the sample specimen is shipped and made available at his laboratory.

Problems Encountered
No significant problems were encountered during the reporting period.

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Emc^2 will review the above UM RS measurement techniques and provide recommendations to PNNL and NRC staff on the path forward for a non-destructive RS measurement technique that can be readily adopted for CRDM applications.

Please feel free to call me if you have any questions, or need further information. For contractual and administrative issues please contact Mr. Gary Hattery, Director of Operations at 614-4159-3200 x224 (ghattery@emc-sq.com).

Very truly yours,

Kswamy

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DRAFT
CONFIDENTIAL AND BUSINESS SENSITIVE
MONTHLY PROGRESS REPORT

January 11, 2015

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Very truly yours,

Kswamy

Prabhat Krishnaswamy
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kswamy@emc-sq.com

Review Summary of Older CRDM Weld Analyses

and

Discussion of Peening Specimen Measurement Locations

Structural Integrity Solutions / Innovative Integrity

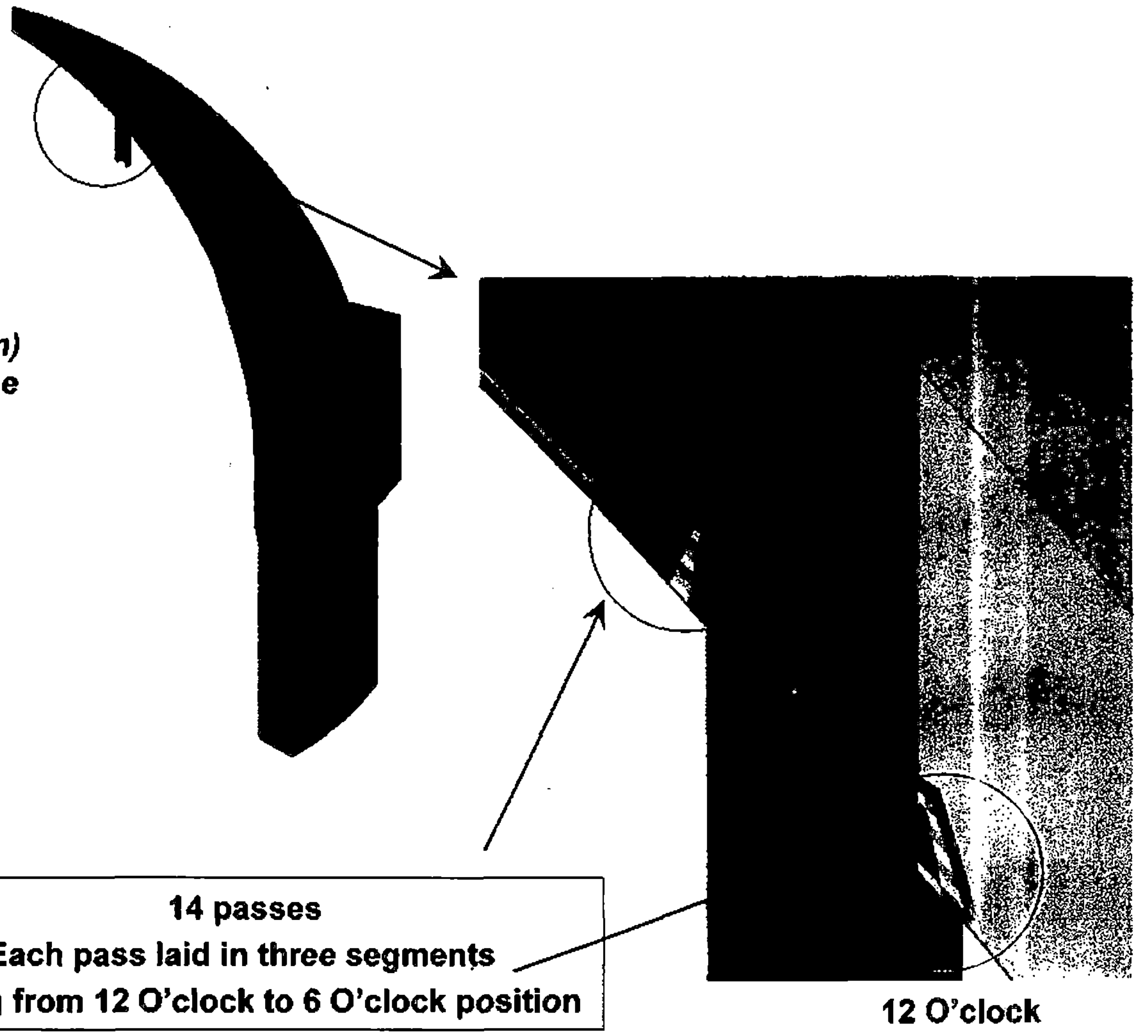
Summary

- *First we summarize older WRS results for CRDM nozzles (53-degree high angle and 25-degree intermediate nozzle)*
- *Next we propose WRS measurement locations (latter slides)*
- *We propose fewer measurements than originally proposed*
- *Suggestions assume model results are correct (at least qualitatively)*

Emc²
Innovative Integrity
Structural Solutions

Summary of CRDM Analyses (25-degree)

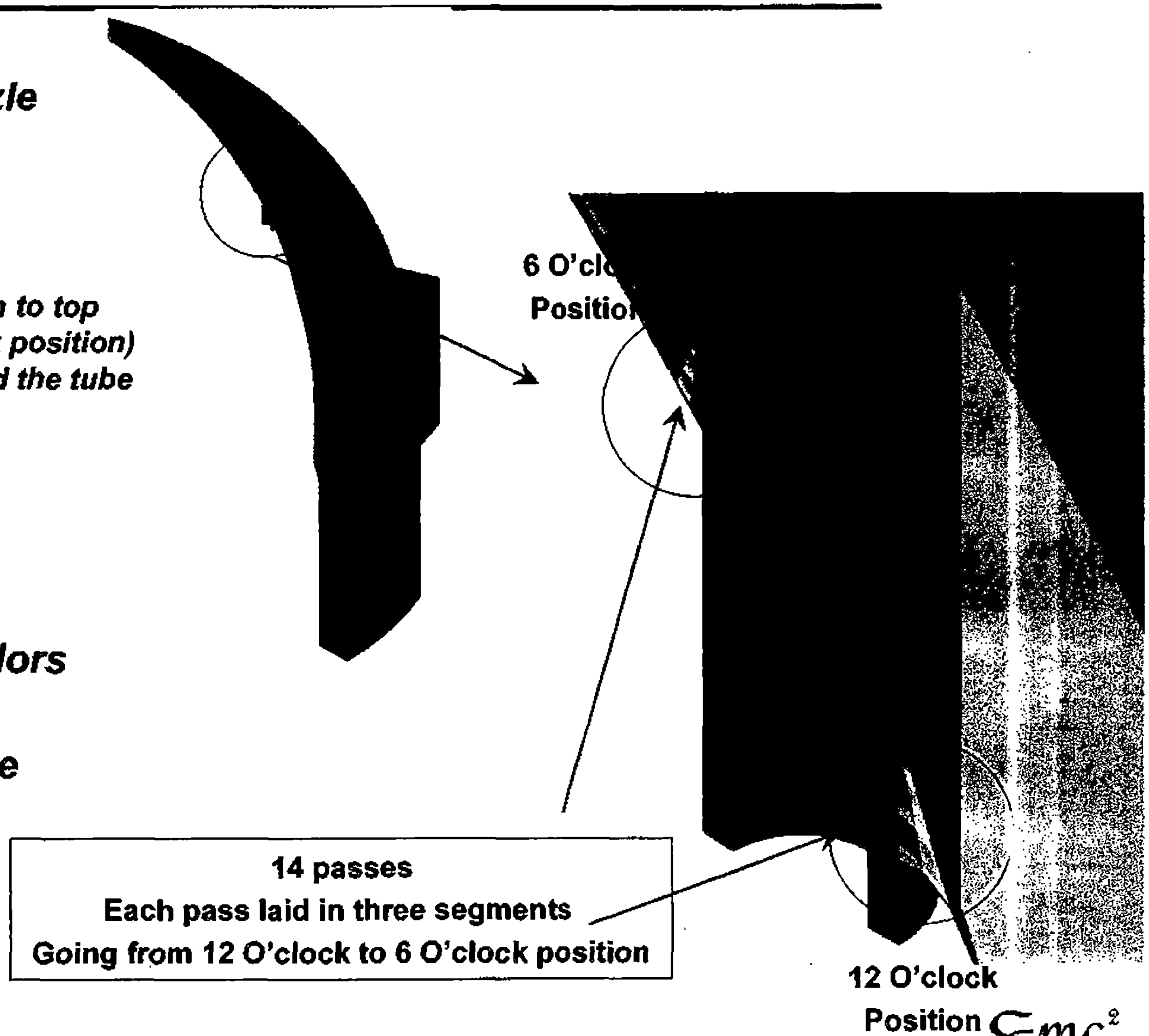
- *25-degree CRDM Nozzle Angle*
- *14 passes*
- *Quasi-moving arc*
  - *Passes laid from bottom to top (12-O'clock to 6-O'clock position) in three 'chunks' around the tube*
- *Head (tan)*
- *Clad (green)*
- *Tube (blue)*
- *Butter (red)*
- *Passes in different colors*



Emc² Structural Integrity Innovative Solutions

Summary of CRDM Analyses (53-degree)

- *53-degree CRDM Nozzle Angle*
- *14 passes*
- *Quasi-moving arc*
  - *Passes laid from bottom to top (12-O'clock to 6-O'clock position) in three 'chunks' around the tube*
- *Head (tan)*
- *Clad (green)*
- *Tube (blue)*
- *Butter (red)*
- *Passes in different colors*
- *All weld passes were assumed to start at the*

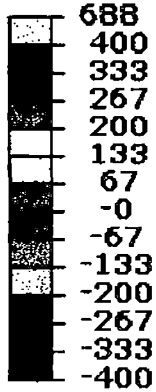


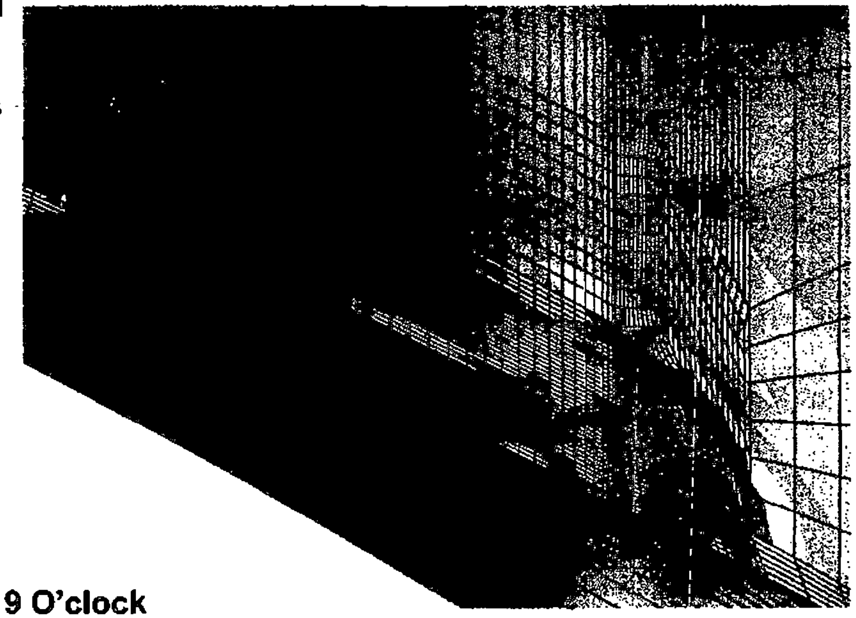
Hoop Stresses in Weld (25-degree)

6 O'clock Position

Note: Stresses at room temperature. Hoop is in tube 'hoop' direction

Tube Removed

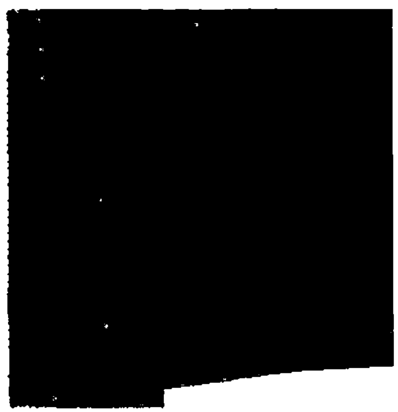




With Tube

12 O'clock Position

9 O'clock Position



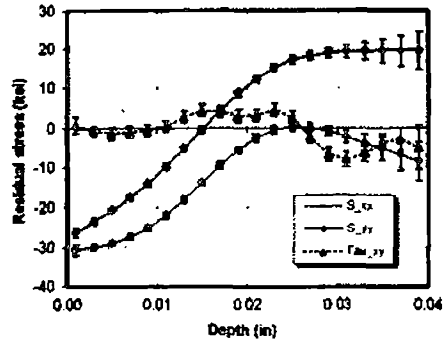
- ***Highest Hoop Stress Predicted at 12 and 6 O'clock positions***

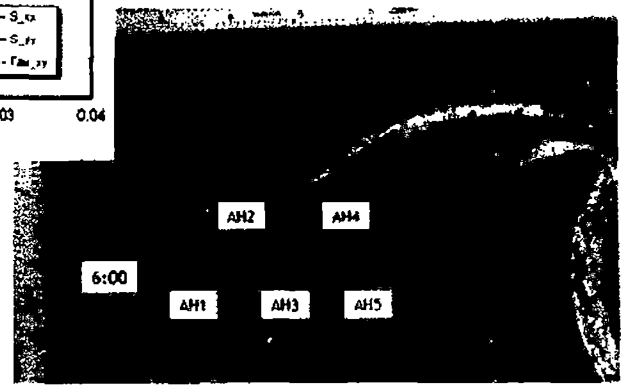
Emc² Structural Solutions Innovative Integrity

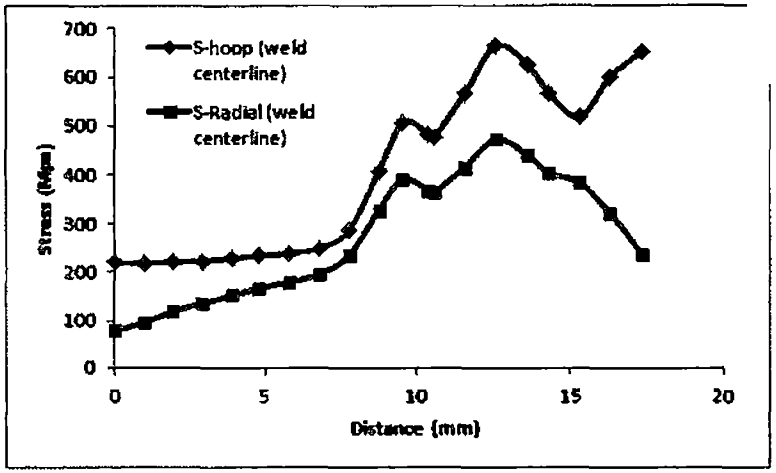
Hoop Stresses in Weld (25-degree)

[redacted]

- Hole drilling at Location AH1





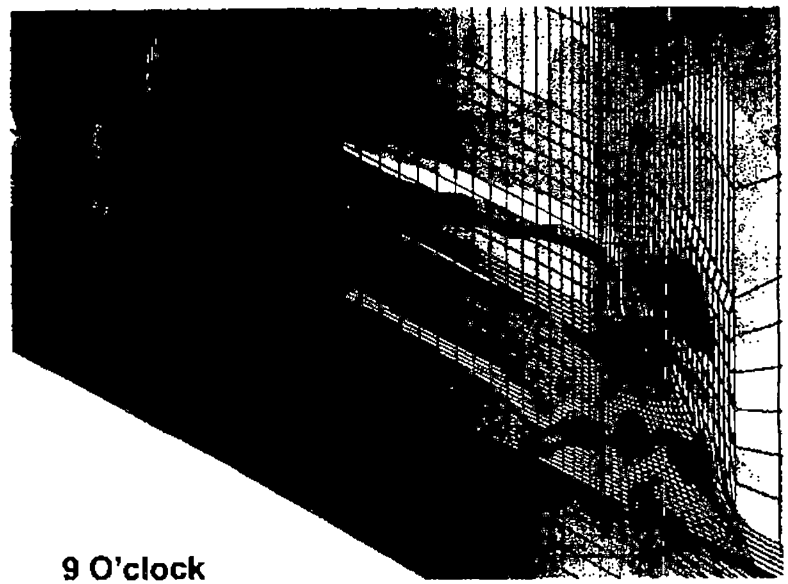


Axial Stresses in Weld (25-degree)

6 O'clock
Position

Note: Stresses at room temperature.
Axial is in tube 'axial' direction

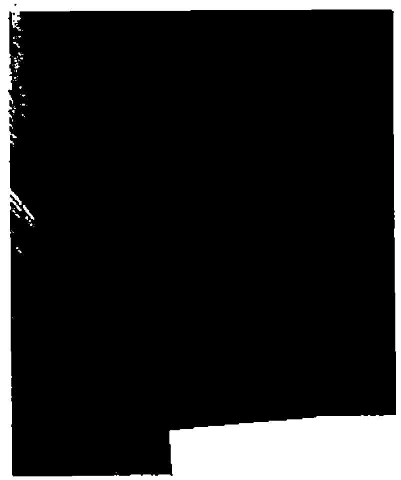
Tube Removed



9 O'clock
Position

With Tube

12 O'clock
Position



- *Highest Axial Stress in weld Predicted at 9 O'clock position*

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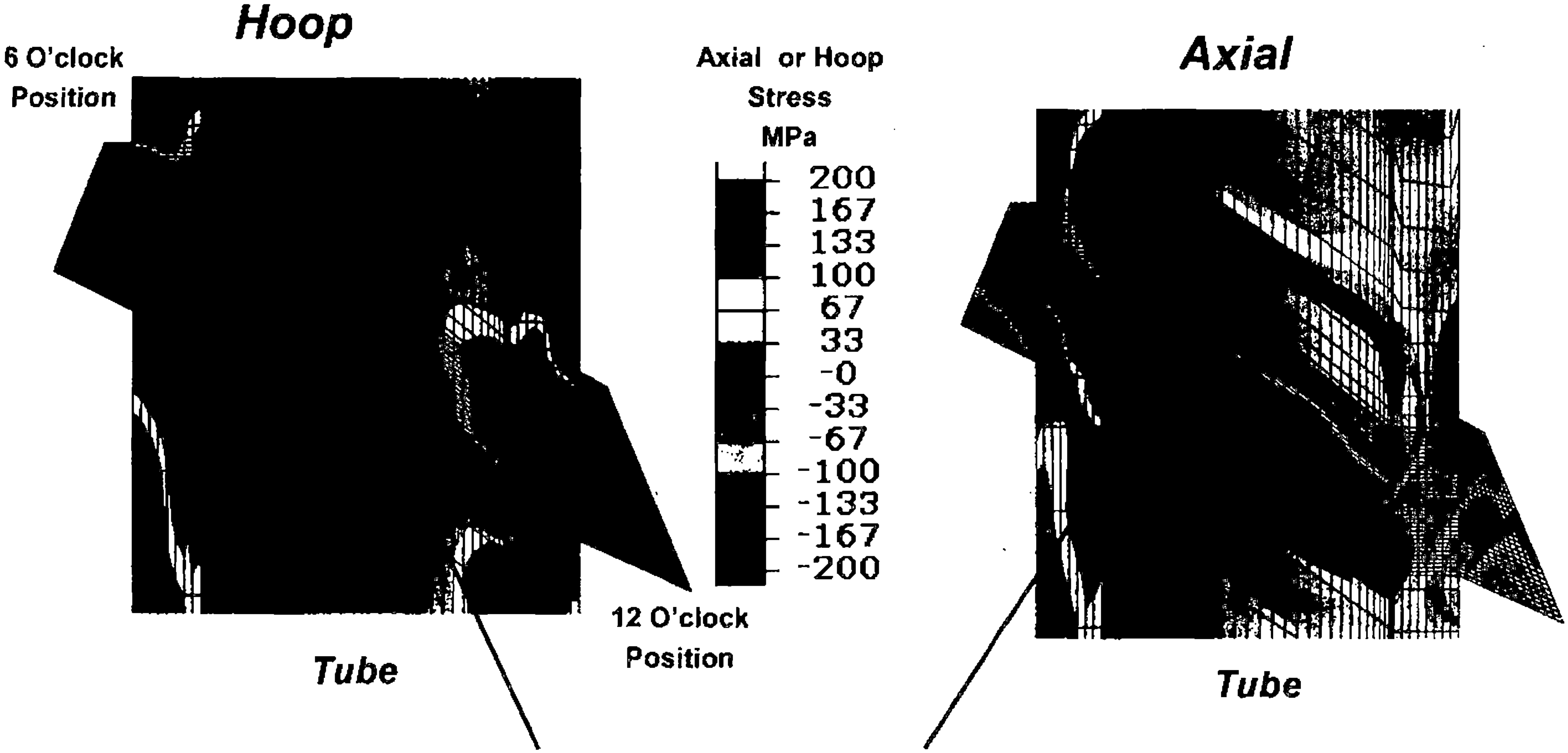
Stresses in Tube (25-degree)



- ***Highest stresses in tube appear to be in upper part of weld to above the weld in the tube. Axial stresses are tensile and hoop are small except near the 6 and 12 O'clock locations.***

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Hoop Stresses in Weld (53-degree)

6 O'clock Position

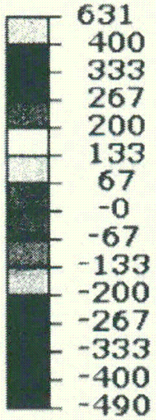
Note: Stresses at room temperature.
Hoop is in tube 'hoop' direction

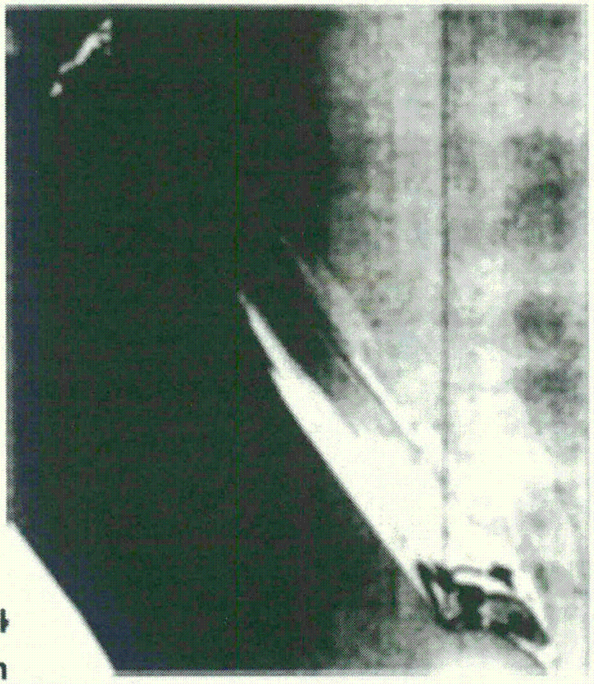
Tube Removed

With Tube

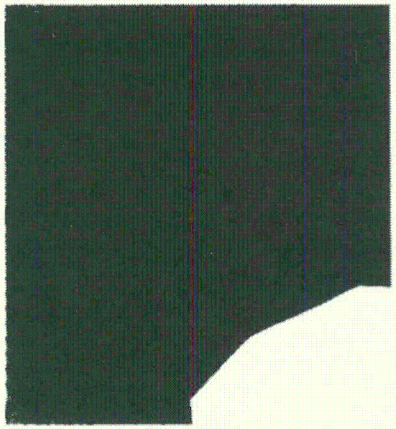
12 O'clock Position

Hoop Stress MPa





9 O'clock Position



- *Highest Hoop Stress Predicted at 12 and 6 O'clock positions as with 25-degree*

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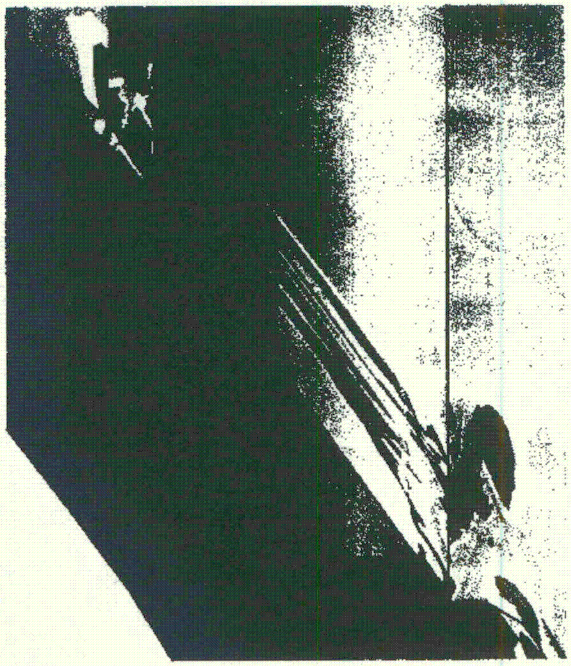
Axial Stresses in Weld (53-degree)

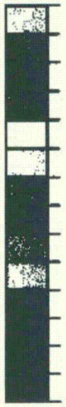
6 O'clock Position

Note: Stresses at room temperature.
Axial is in tube 'axial' direction

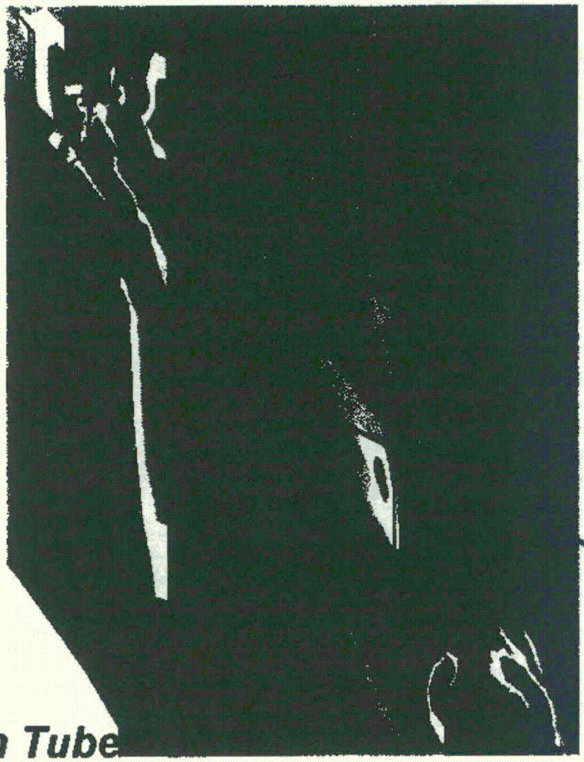
Tube Removed



Axial Stress MPa

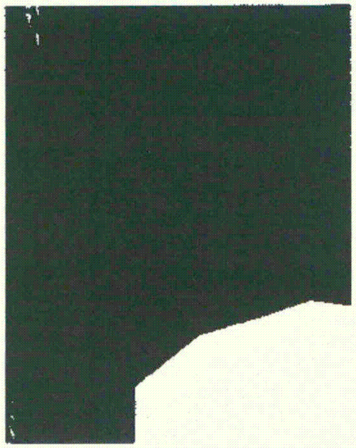


9 O'clock Position



With Tube

12 O'clock Position



- ***Highest Axial Stress in weld Predicted at 9 O'clock position***

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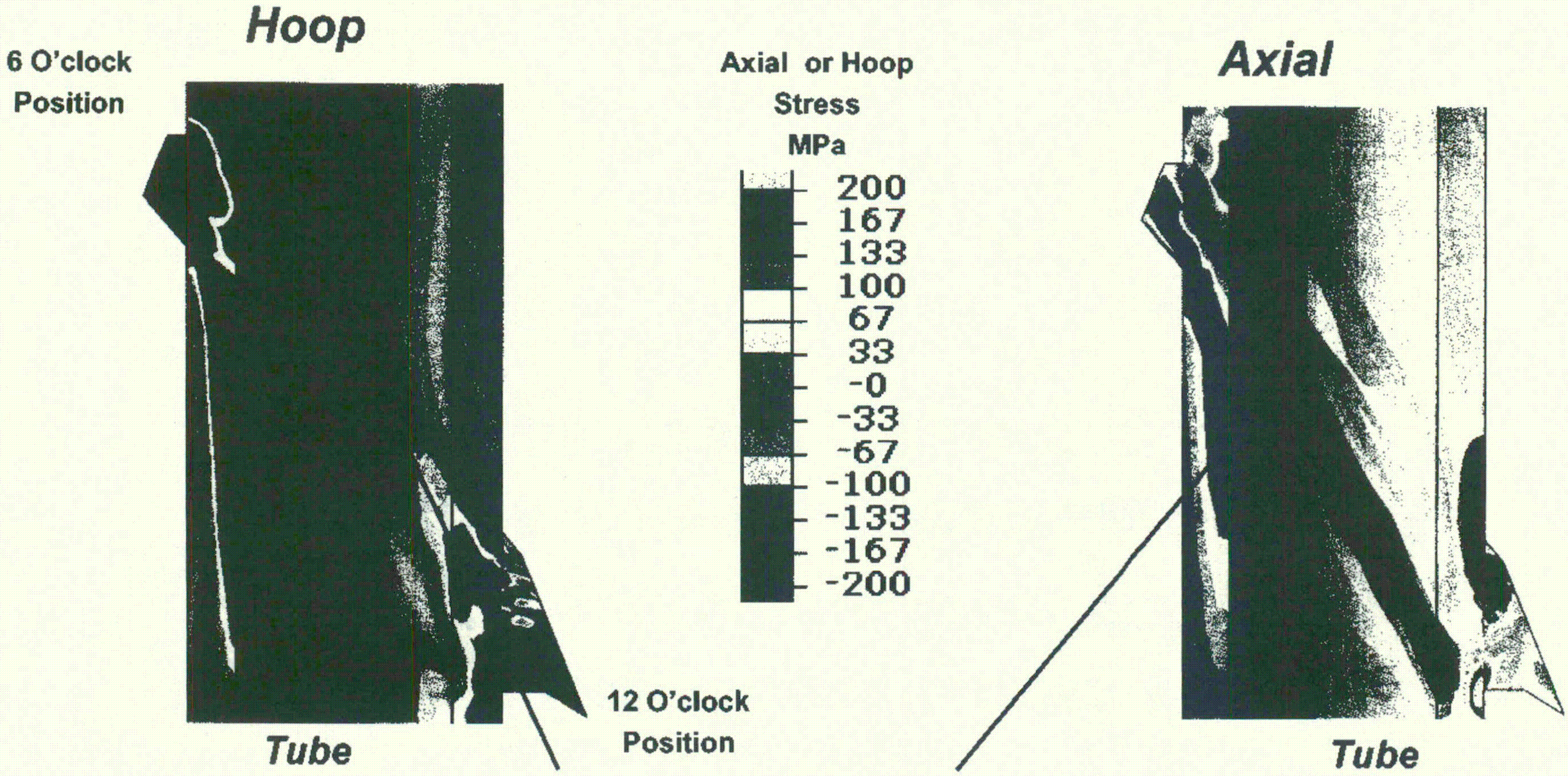
Stresses in Tube (53-degree)



- ***Highest stresses in tube appear to be in upper part of weld to above the weld in the tube. Axial stresses are tensile and hoop are small except near the 6 and 12 O'clock locations.***

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The next few slides discuss possible measurement locations

Suggestions are based on model results (isotropic hardening)

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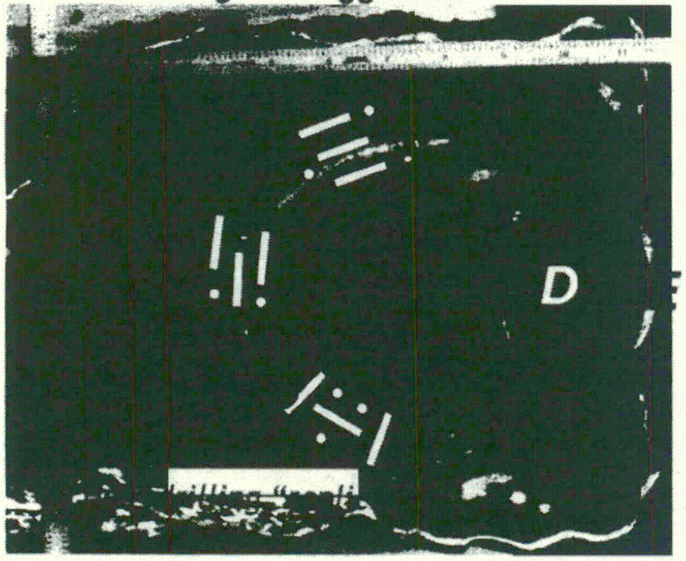
Measurements (53-degree)

Locations A, B, C

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

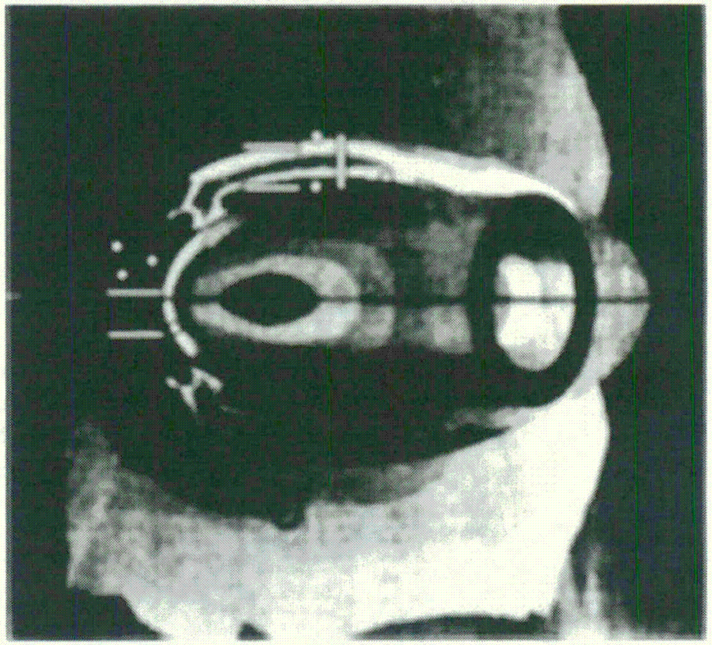
Model rotated on symmetry plane added for clarity

Original Suggestion



Hoop Stress
MPa

631
300
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
-490

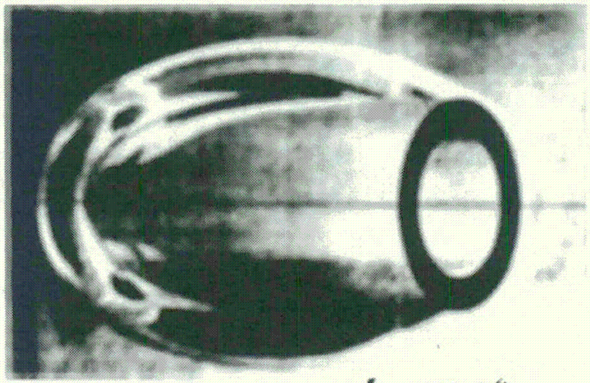


Notes:

- *Measurement locations at B arranged for hoop stress measurements using slots and both hoop and radial with holes*
- *Measurements at A and C same. Look for radial stress with two slots, hoop stress with one slot, and both with two holes*
- *For lower angle nozzles (25-degree and less) suggest same arrangement (see next slide)*

Radial Stress
MPa

574
200
167
133
100
67
33
-0
-33
-67
-100
-133
-167
-200
-391

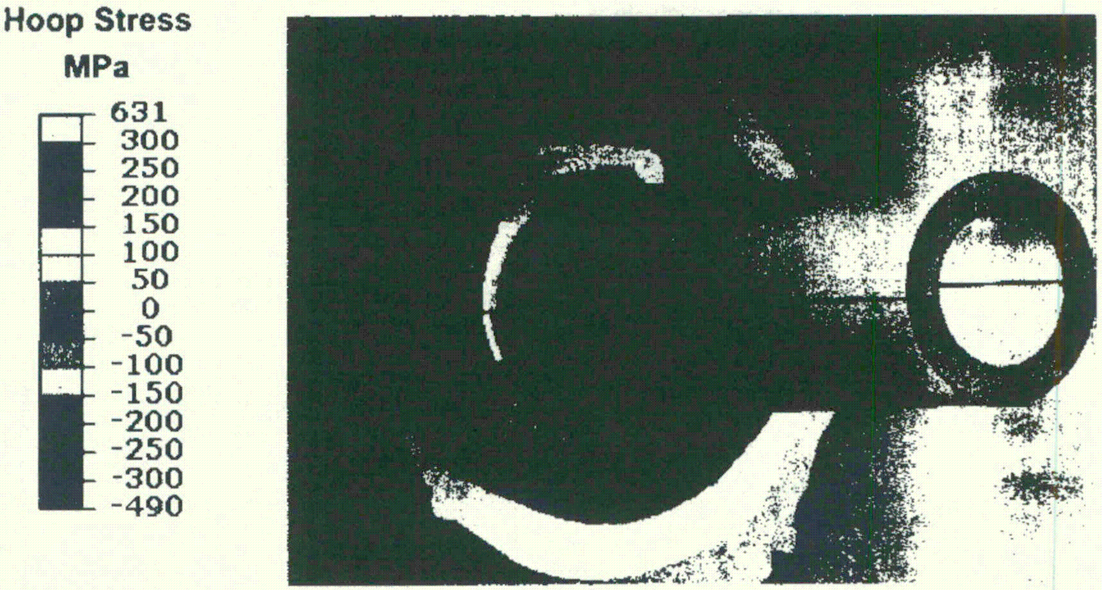


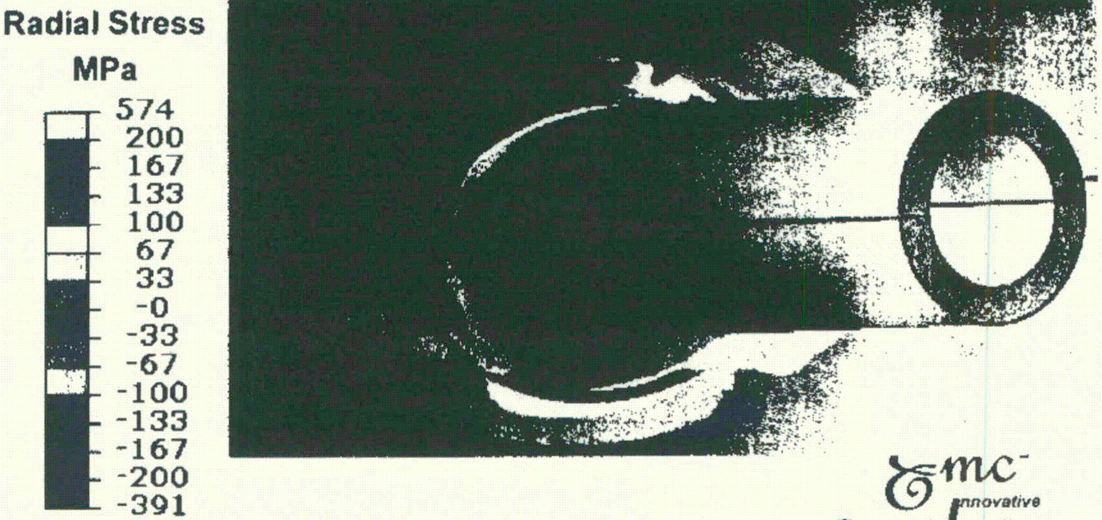
Structural Integrity Solutions

Measurements (25-degree)

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

Model rotated on symmetry plane added for clarity





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Measurements (53-degree)
Location E

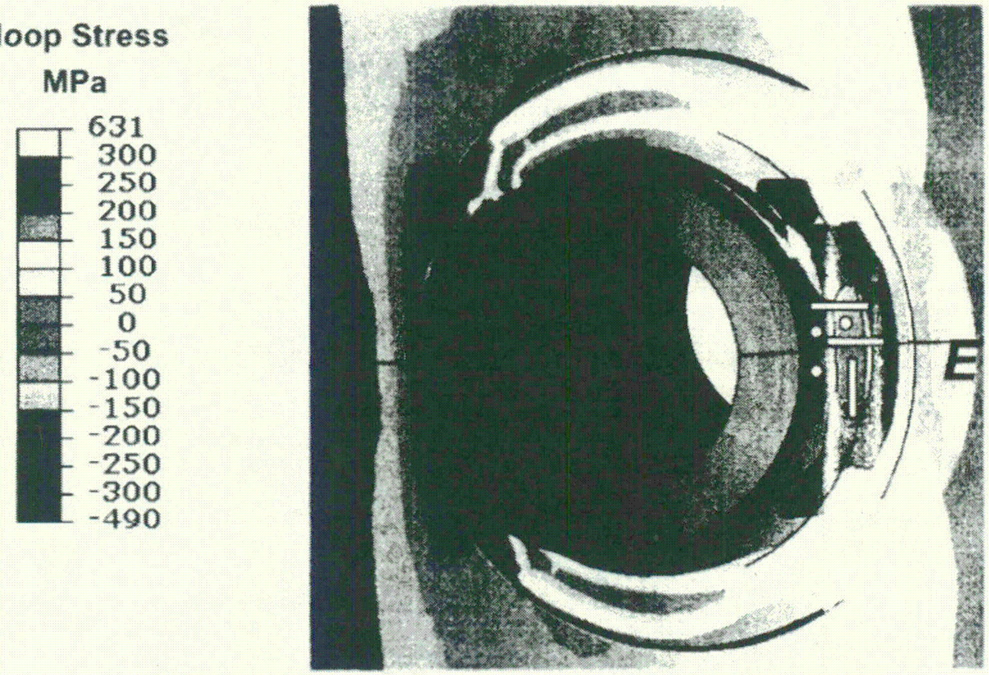
Hoop is in tube ‘hoop’ direction and ‘radial’ is in the tube radial direction

Model rotated on symmetry plane added for clarity

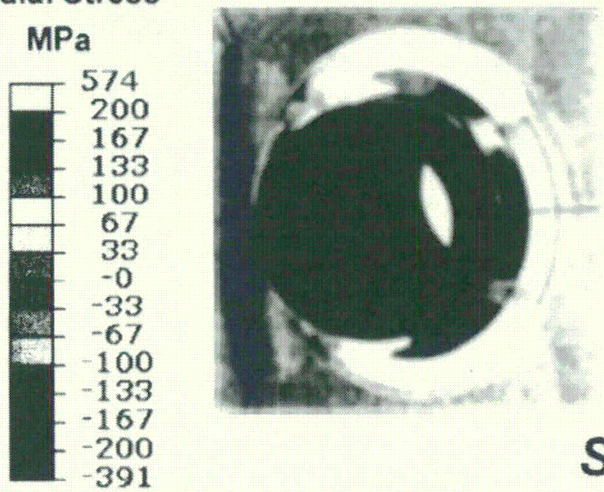
Notes:

- *Measurement locations at E arranged to obtain hoop stresses.*
- *Could include a slot to obtain radial stress also as per bottom right illustration*
- *For lower angle nozzles (25-degree and less) suggest same arrangement (see next slide)*

Hoop Stress
MPa



Radial Stress
MPa



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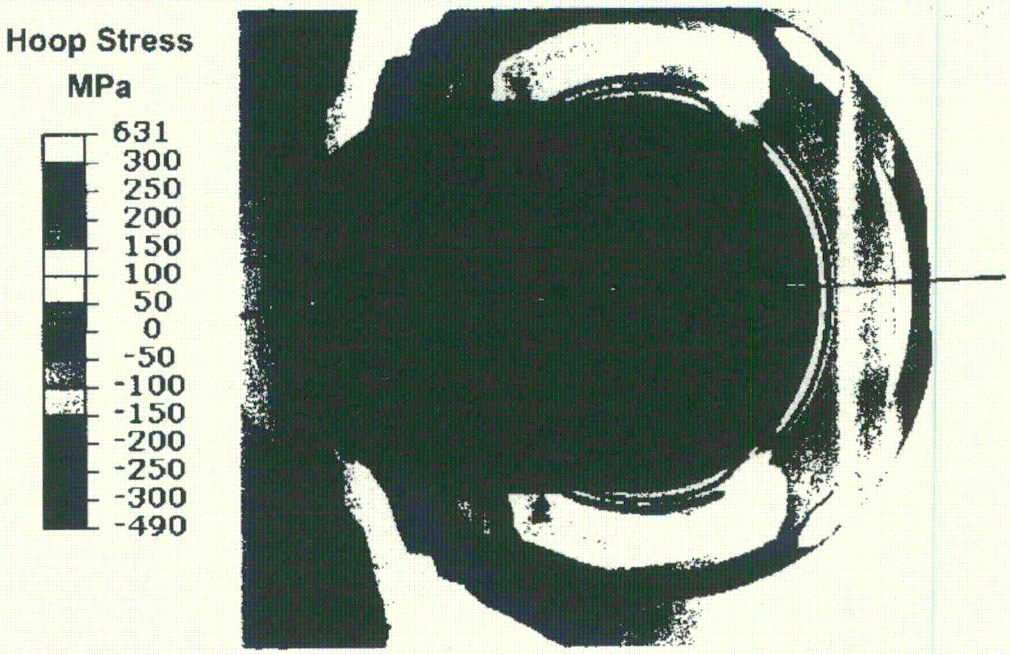
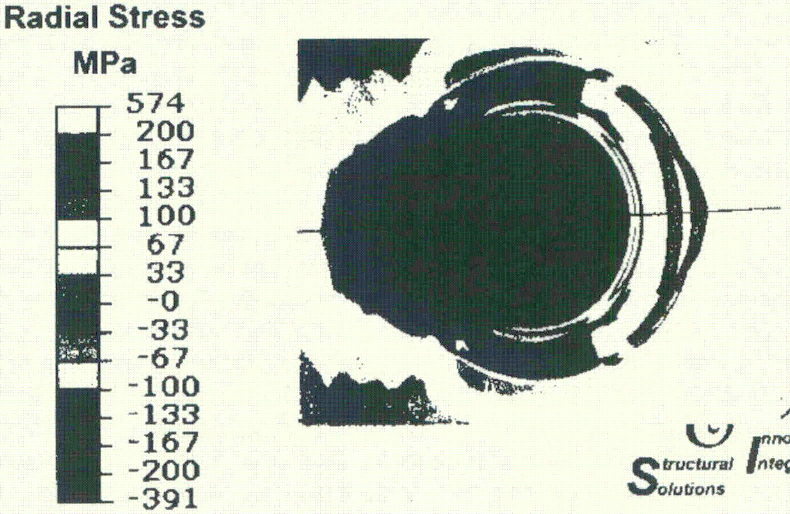
Measurements (25-degree)

Location E

Hoop is in tube 'hoop' direction and 'radial' is in the tube radial direction

Model rotated on symmetry plane added for clarity





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Measurements (53-degree)

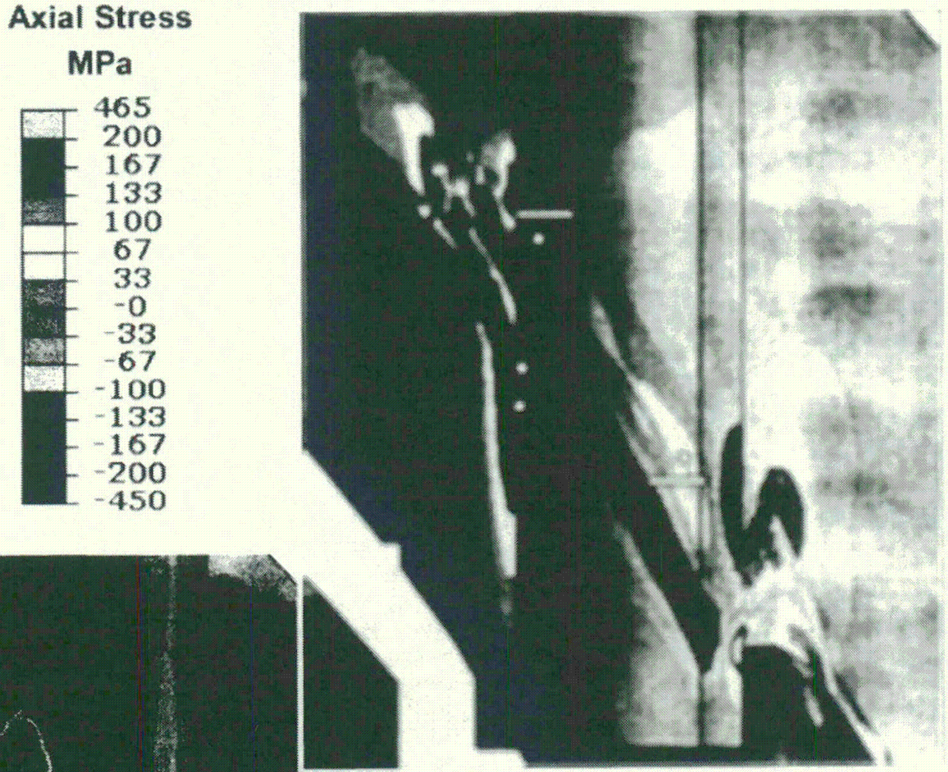
Location D

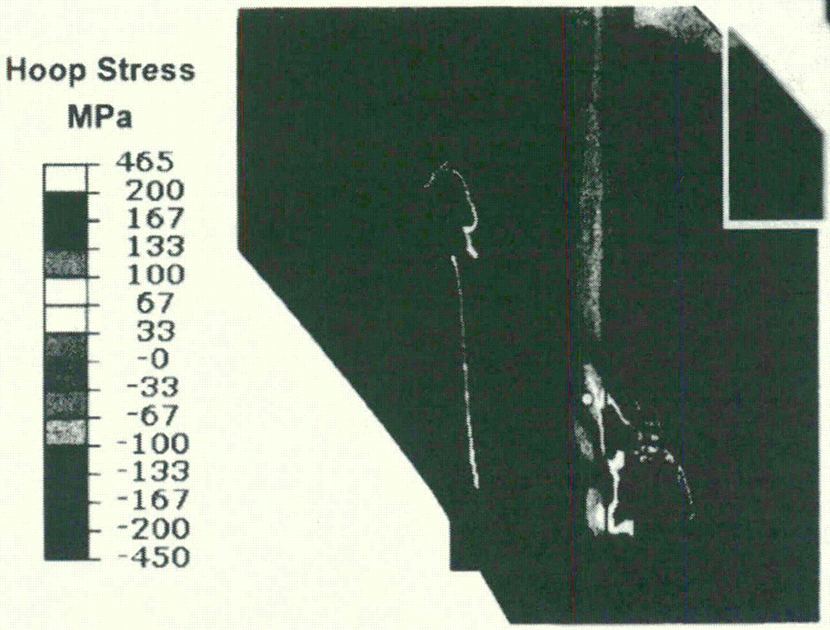
Hoop is in tube 'hoop' direction and 'axial' is in the tube axis direction

Model rotated on symmetry plane added for clarity

Notes:

- *Measurement locations at D arranged to obtain axial stresses at location 6 O'clock (or location B) in tube above weld location*
- *Might also try hoop stresses at location near 12 O'clock location (below). Hoop stresses can be obtained with hole drilling. Hoop stresses appear low though in tube ID.*
- *For lower angle tubes (next slide) it appears that tube axial stresses are larger*





Measurements (25-degree)

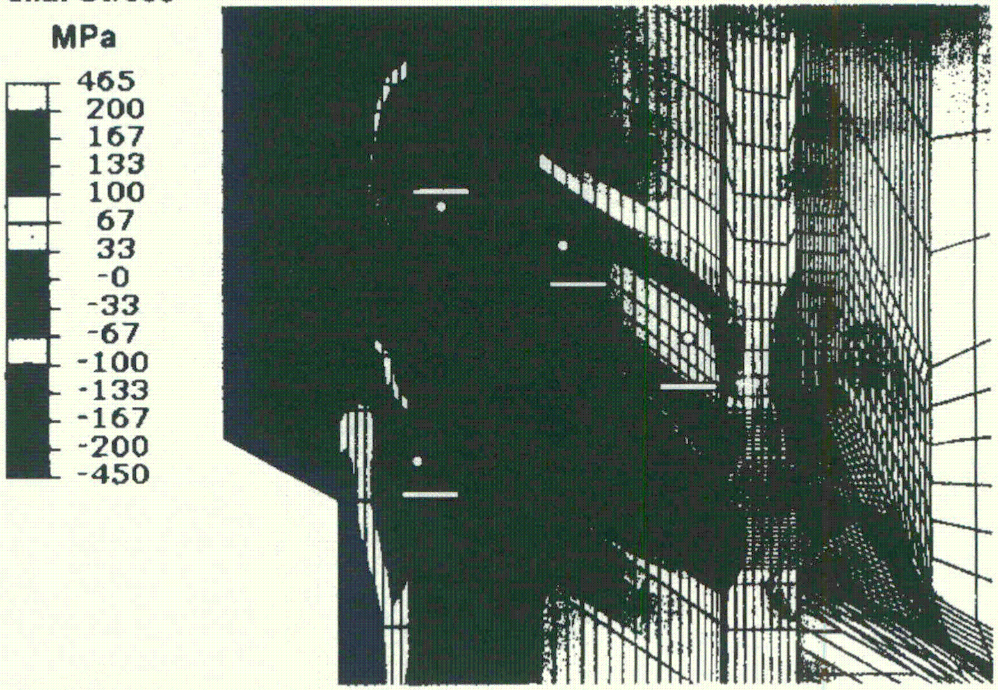
Location D

Hoop is in tube 'hoop' direction and 'axial' is in the tube axis direction

Model rotated on symmetry plane added for clarity

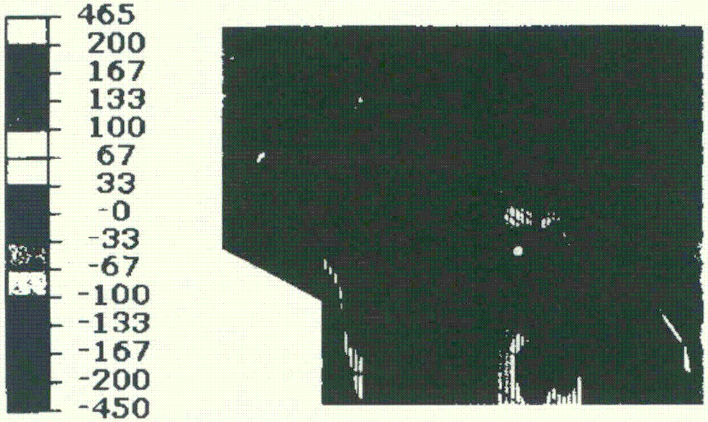
Axial Stress

MPa



Hoop Stress

MPa



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Summary of Older CRDM Weld Finite Element Analyses & Comparison with Weld Residual Stress Measurements

by

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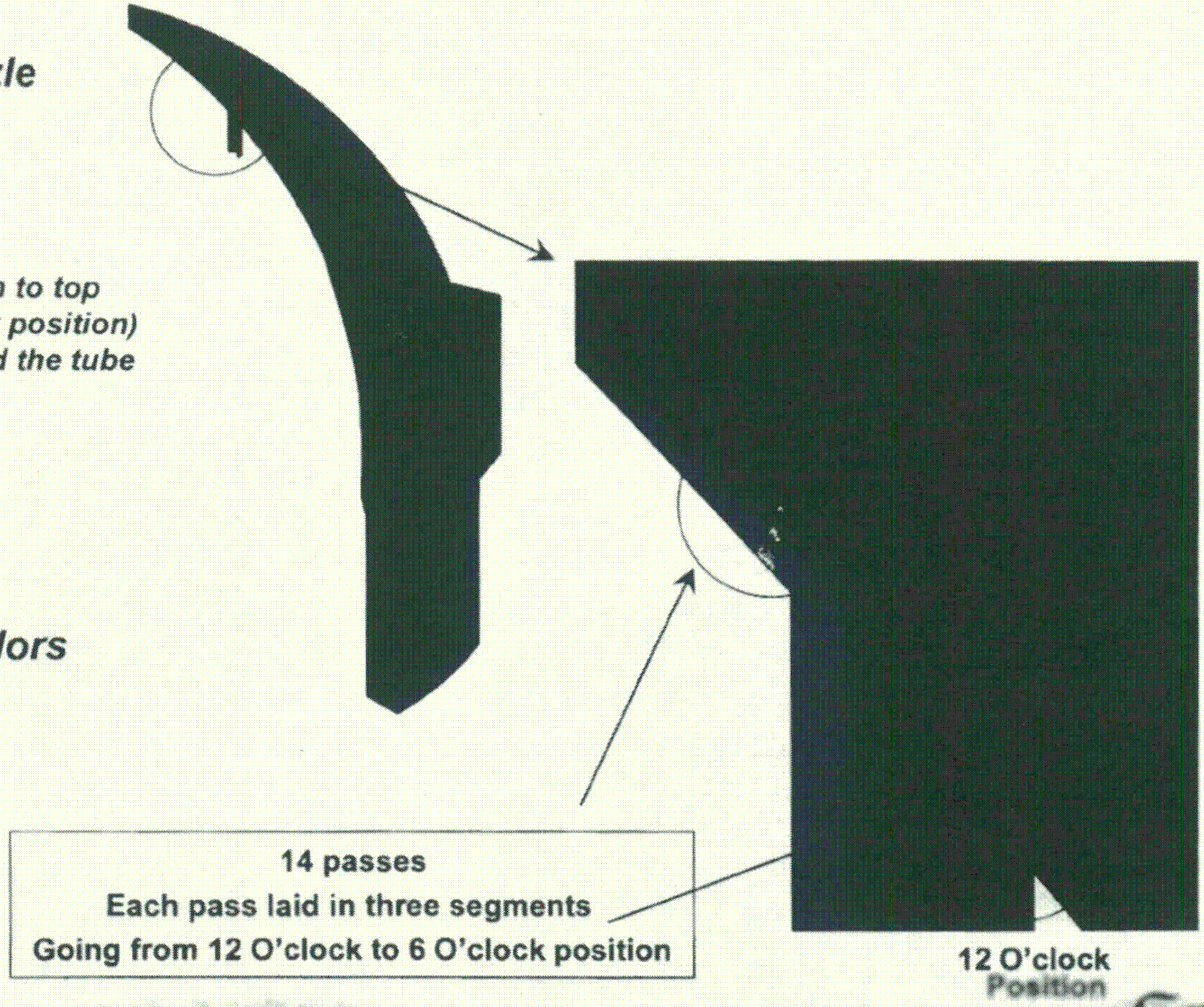
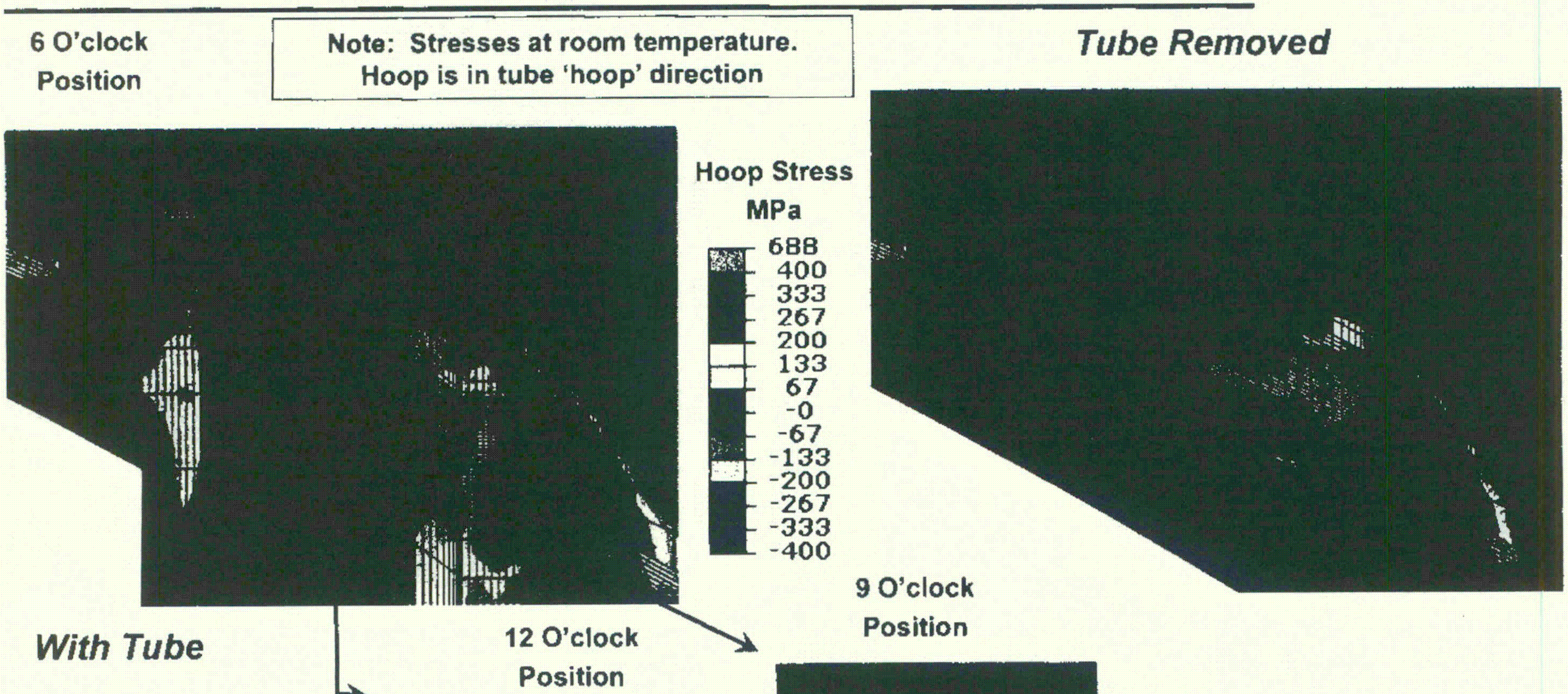
Summary of Older Finite Element Analyses of CRDM Welds
(25-degree and 53-degree)

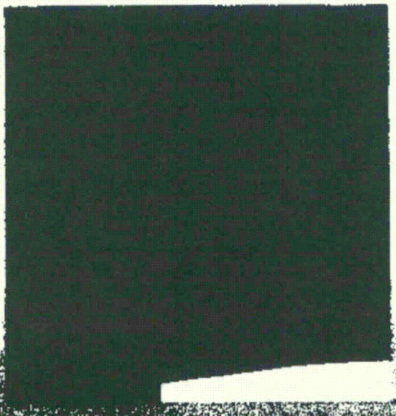
Summary of CRDM Analyses (25-degree)

- *25-degree CRDM Nozzle Angle*
- *14 passes*
- *Quasi-moving arc*
  - *Passes laid from bottom to top (12-O'clock to 6-O'clock position) in three 'chunks' around the tube*
- *Head (tan)*
- *Clad (green)*
- *Tube (blue)*
- *Butter (red)*
- *Passes in different colors*



Hoop Stresses in Weld (25-degree)

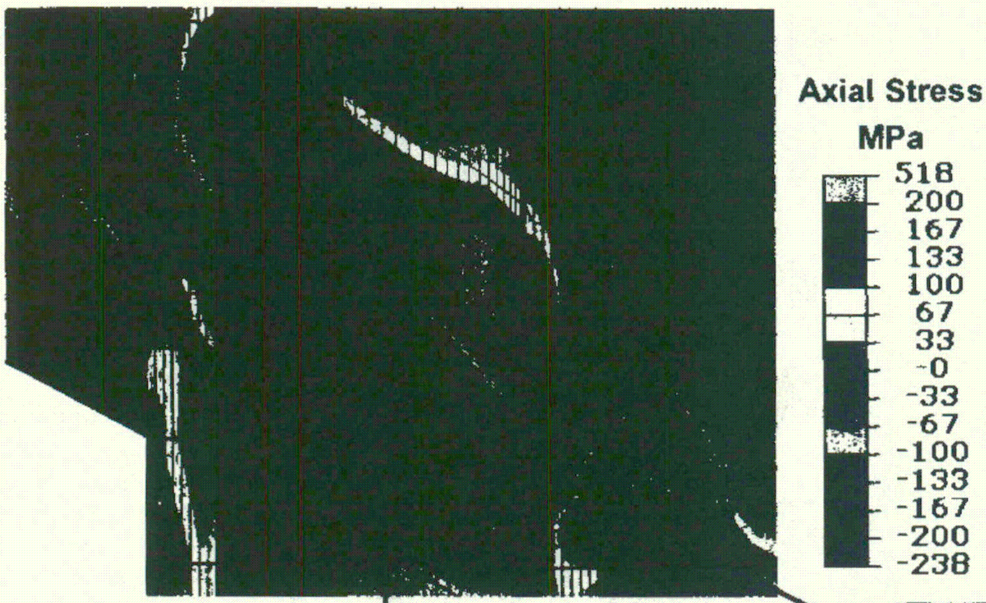


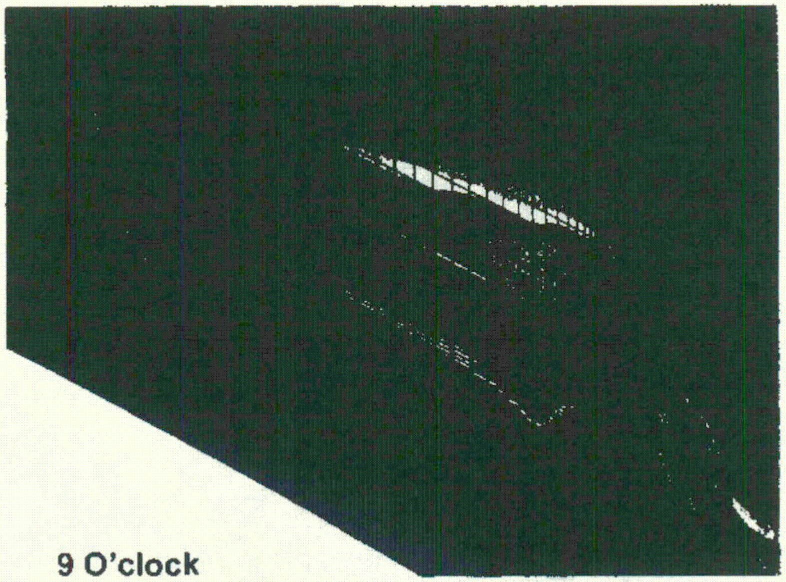


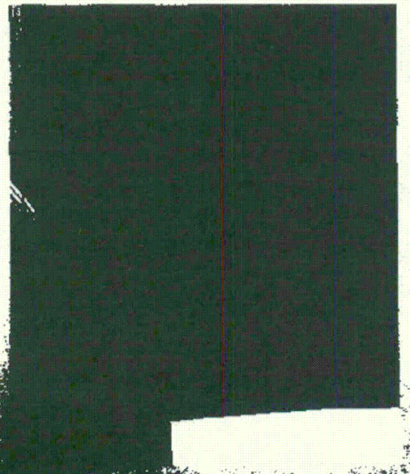
- ***Highest Hoop Stress Predicted at 12 and 6 O'clock positions***

Axial Stresses in Weld (25-degree)

Note: Stresses at room temperature.
Axial is in tube 'axial' direction

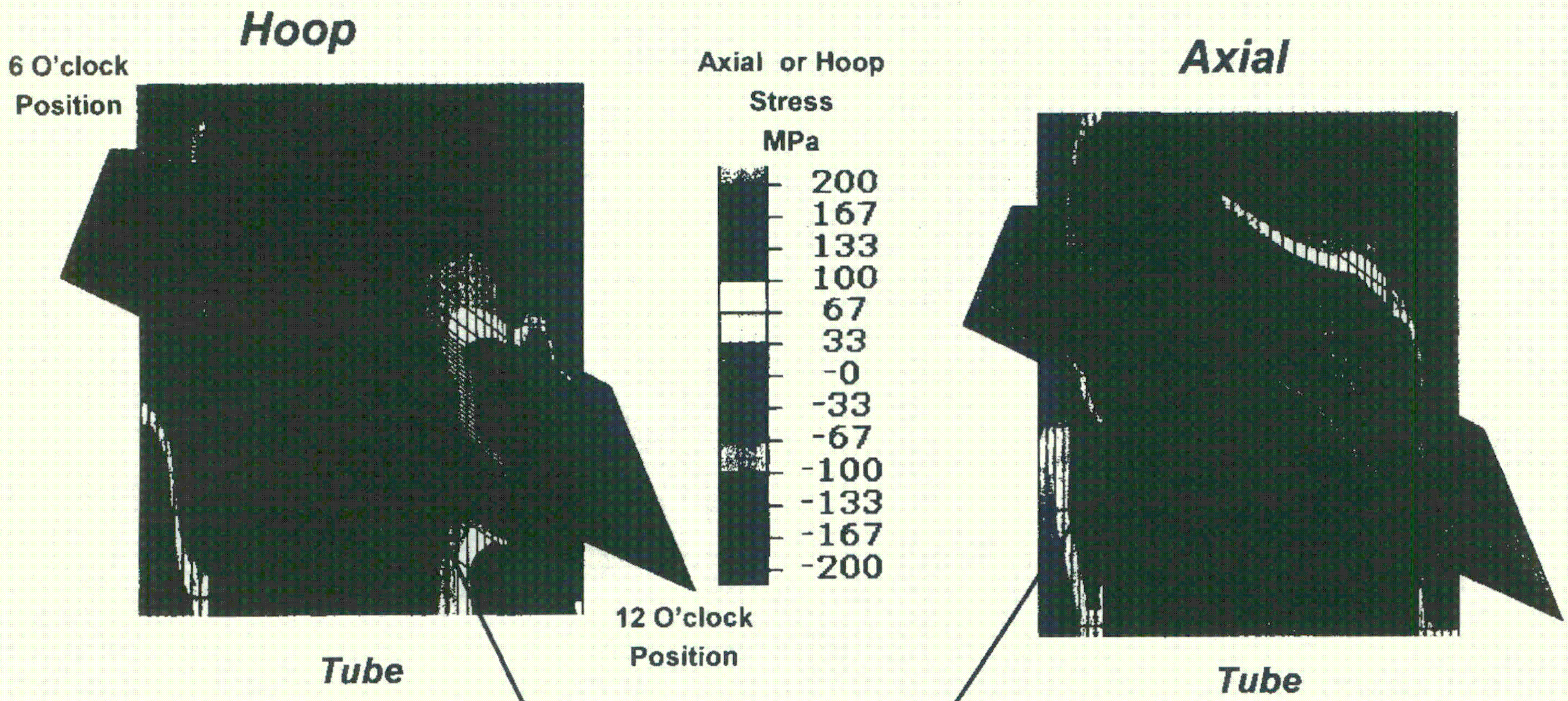






- ***Highest Axial Stress in weld Predicted at 9 O'clock position***

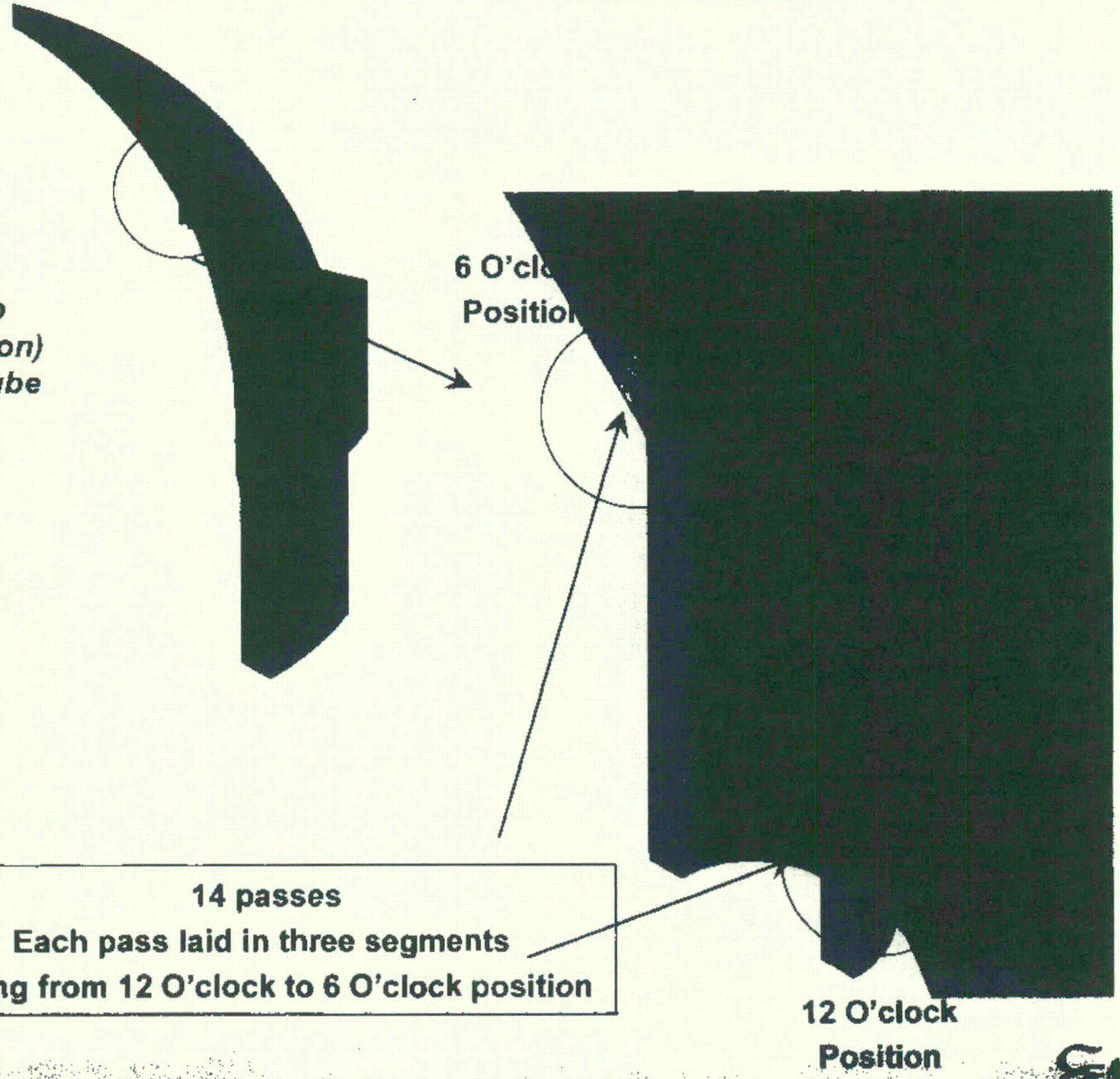
Stresses in Tube (25-degree)



- *Highest stresses in tube appear to be in upper part of weld to above the weld in the tube. Axial stresses are tensile and hoop are small except near the 6 and 12 O'clock locations.*

Summary of CRDM Analyses (53-degree)

- *53-degree CRDM Nozzle Angle*
- *14 passes*
- *Quasi-moving arc*
    - *Passes laid from bottom to top (12-O'clock to 6-O'clock position) in three 'chunks' around the tube*
- *Head (tan)*
- *Clad (green)*
- *Tube (blue)*
- *Butter (red)*
- *Passes in different colors*
- *All weld passes were assumed to start at the*



Hoop Stresses in Weld (53-degree)

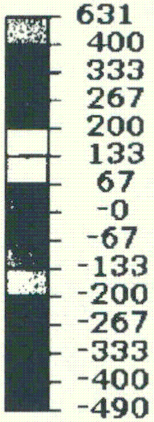
6 O'clock Position

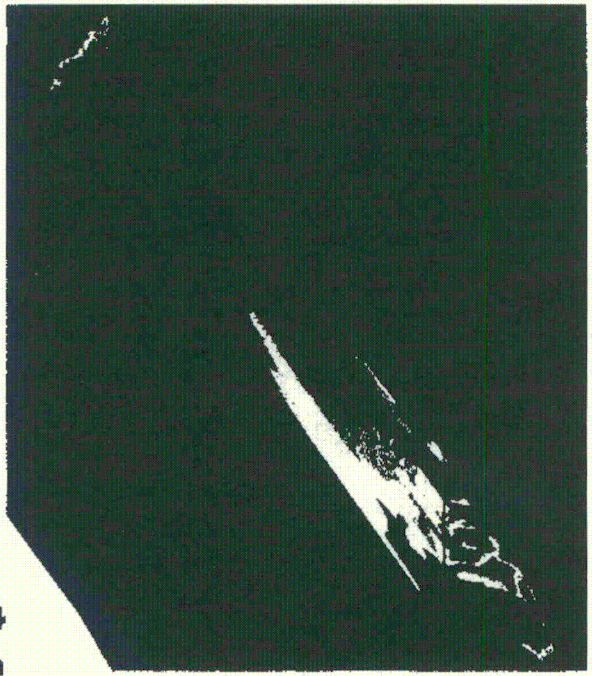
Note: Stresses at room temperature.
Hoop is in tube 'hoop' direction

Tube Removed

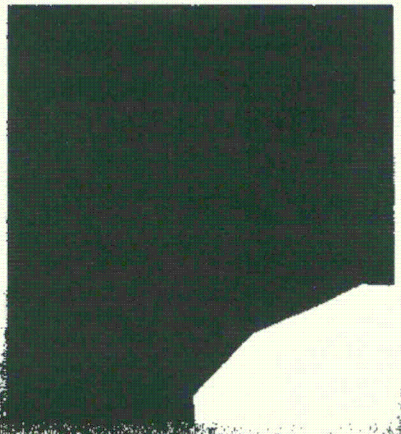
With Tube

12 O'clock Position





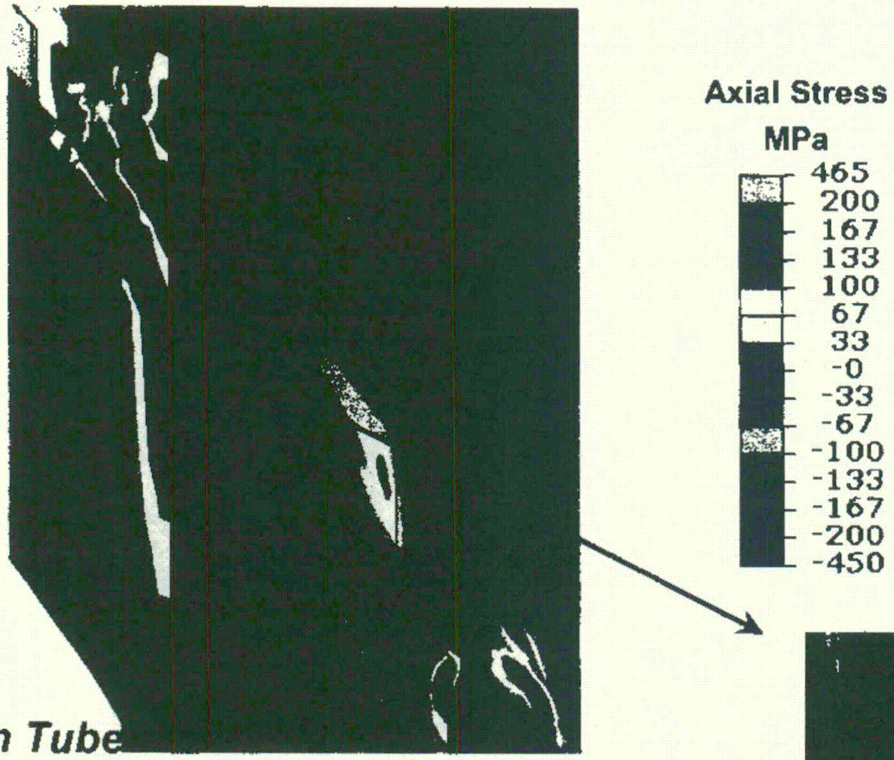
9 O'clock Position

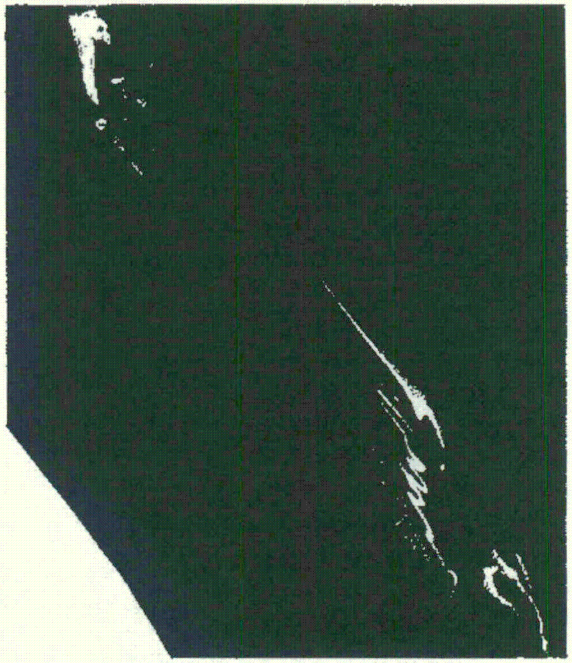


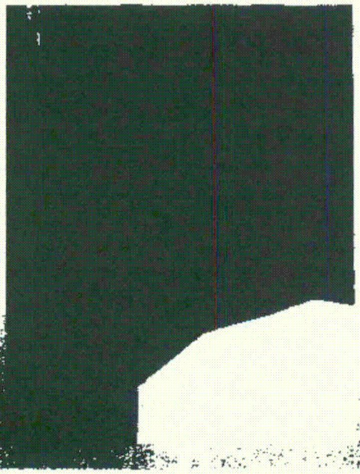
- ***Highest Hoop Stress Predicted at 12 and 6 O'clock positions as with 25-degree***

Axial Stresses in Weld (53-degree)

Note: Stresses at room temperature.
Axial is in tube 'axial' direction

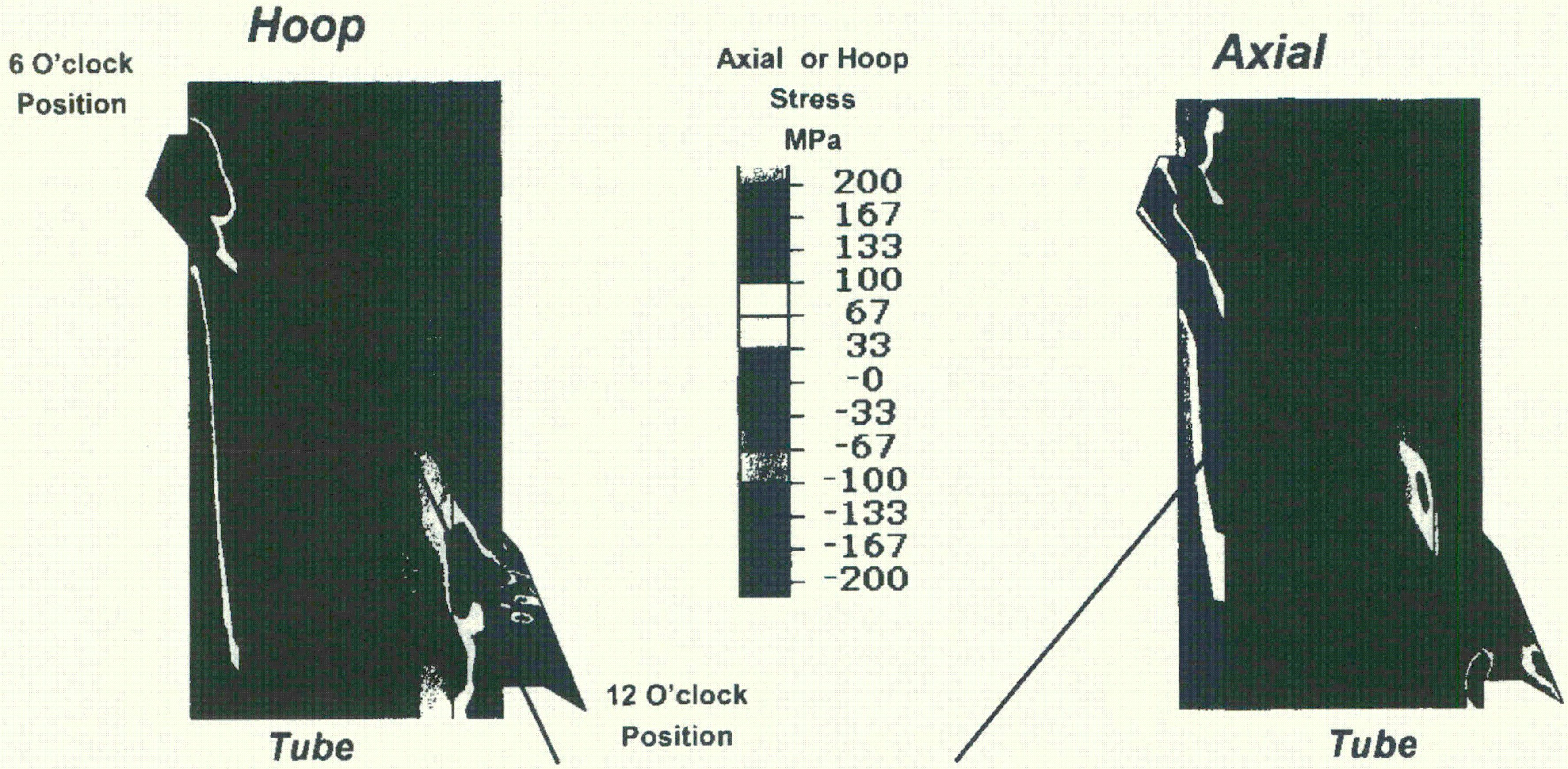






- ***Highest Axial Stress in weld Predicted at 9 O'clock position***

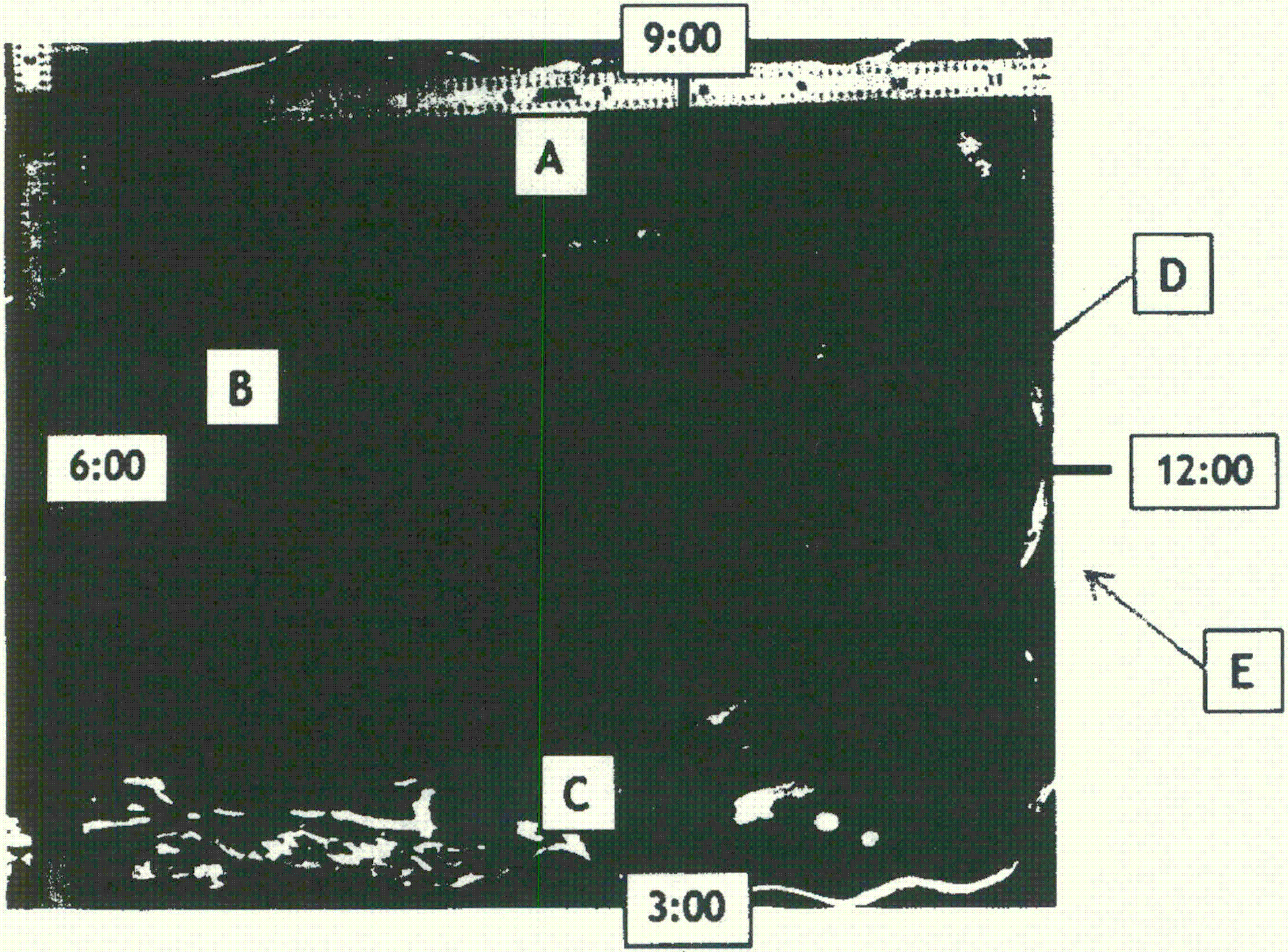
Stresses in Tube (53-degree)



- ***Highest stresses in tube appear to be in upper part of weld to above the weld in the tube. Axial stresses are tensile and hoop are small except near the 6 and 12 O'clock locations.***

Comparison of Older FE Results with WRS Measurements on Practice CRDM by Hill Engineering

Location of WRS Measurements



WRS Measured at

Location – B

Location – D

Location – E

Location – A

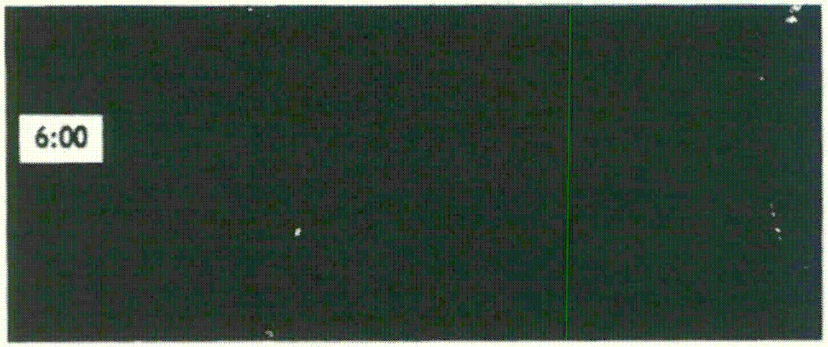
Location B

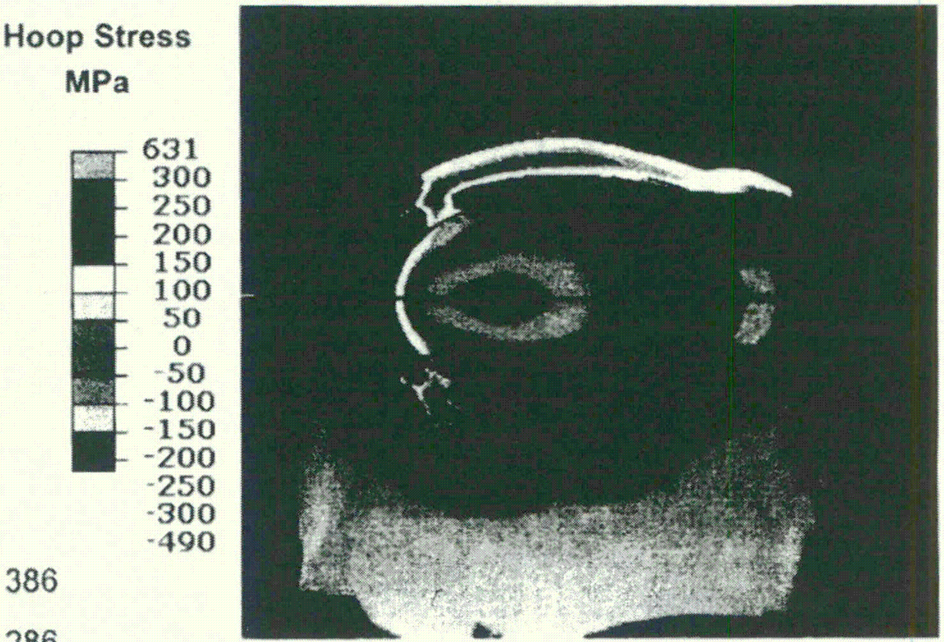
Comparison 53-degree

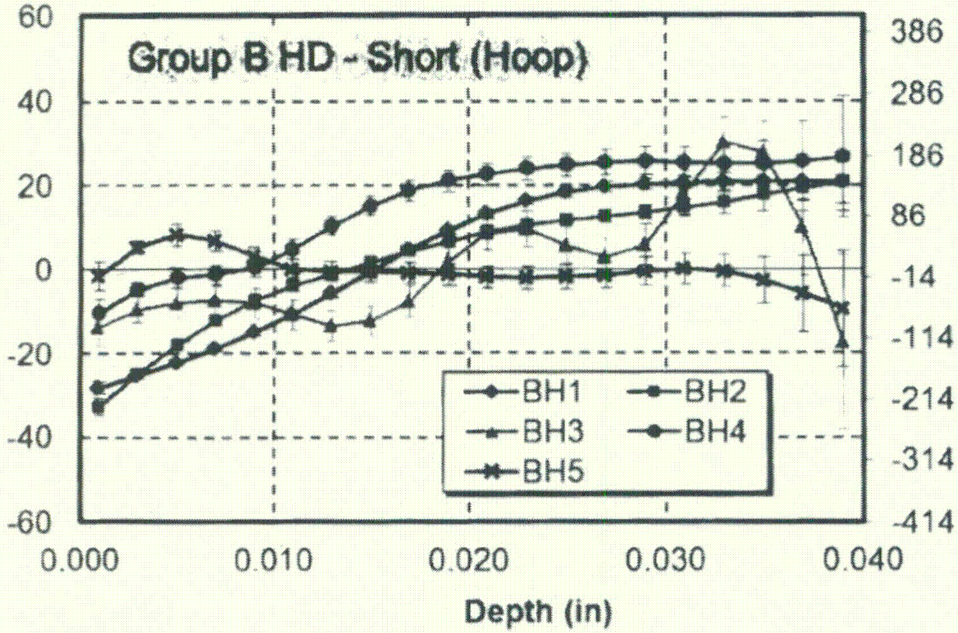
Locations B – Hoop Stress

Hoop is in tube 'hoop' direction (Short) and 'radial' is in the tube radial direction (Long)

Model rotated on symmetry plane added for clarity







FEA = ~ 225 MPa

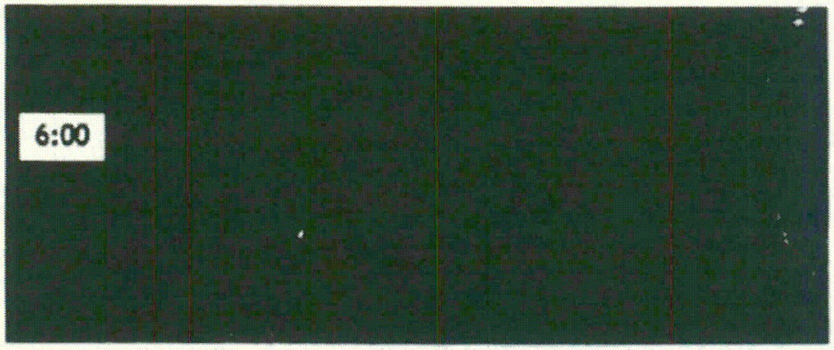
Measured = ~186 MPa

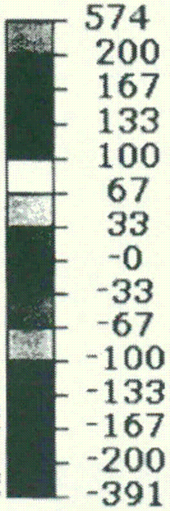
Comparison 53-degree

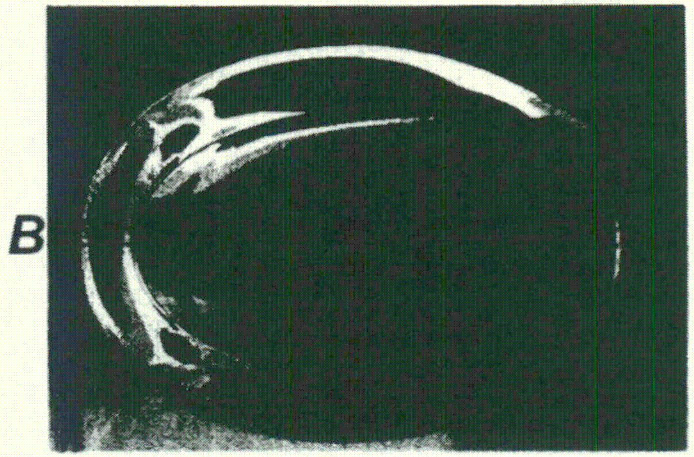
Locations B – Radial Stress

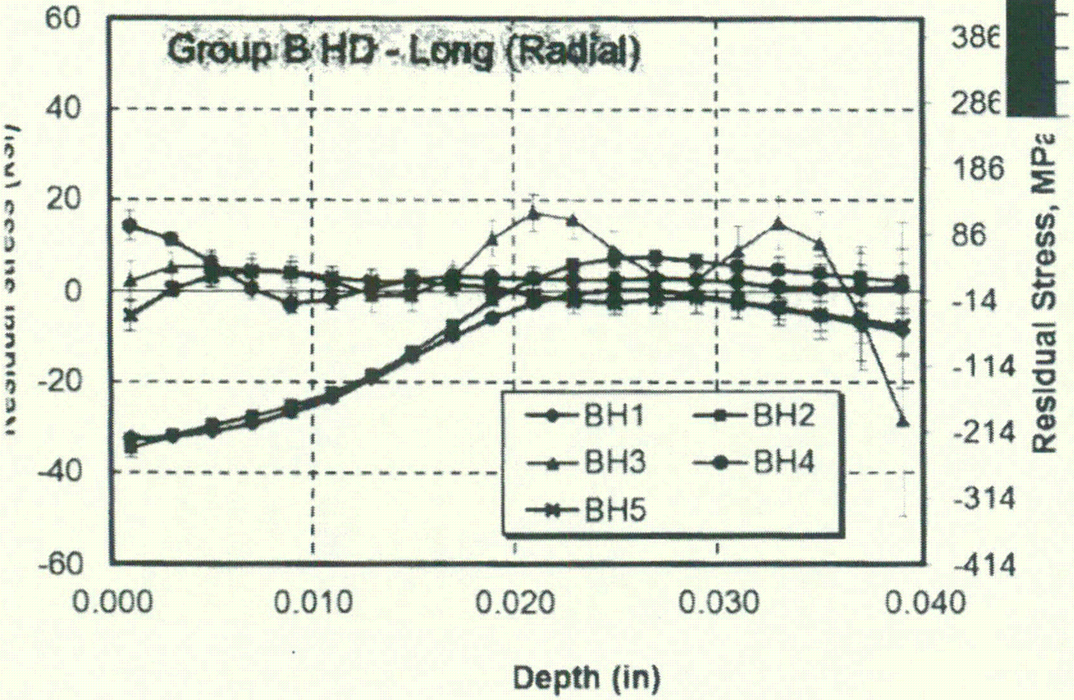
Hoop is in tube 'hoop' direction (Short) and 'radial' is in the tube radial direction (Long)

Model rotated on symmetry plane added for clarity









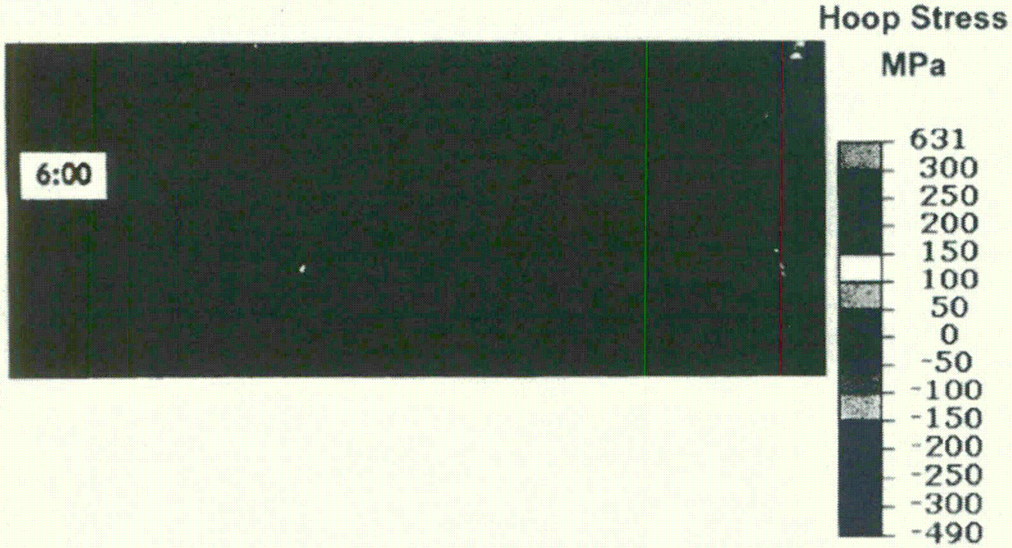
FEA = very low
Measured = low

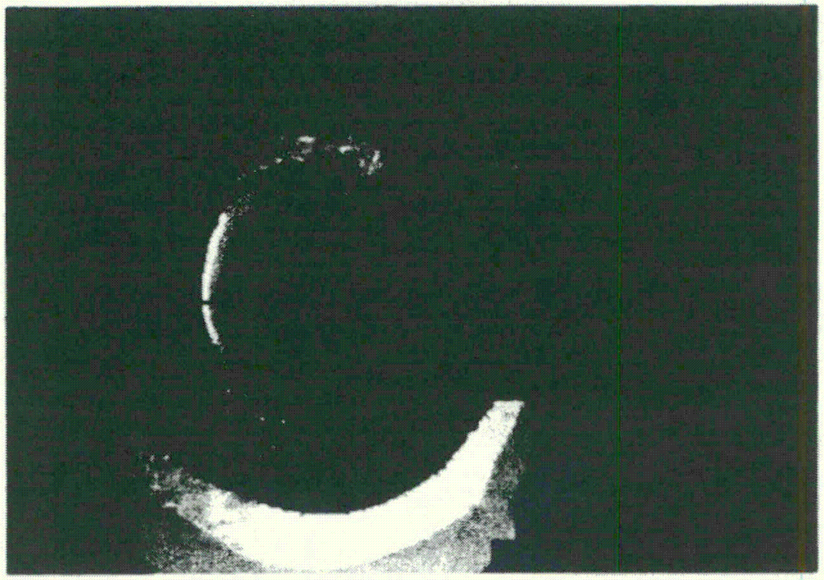
Comparisons (25-degree)

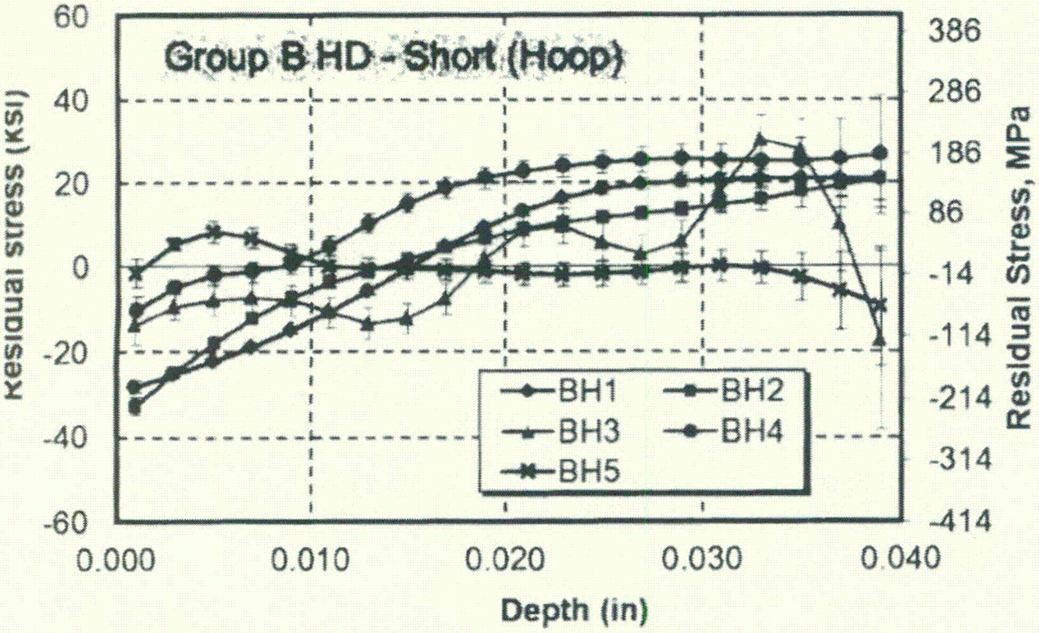
Locations B – Hoop Stress

'radial' is in the tube radial direction (Long)

Model rotated on symmetry plane added for clarity







FEA = ~ 200 MPa

Measured = ~186 MPa

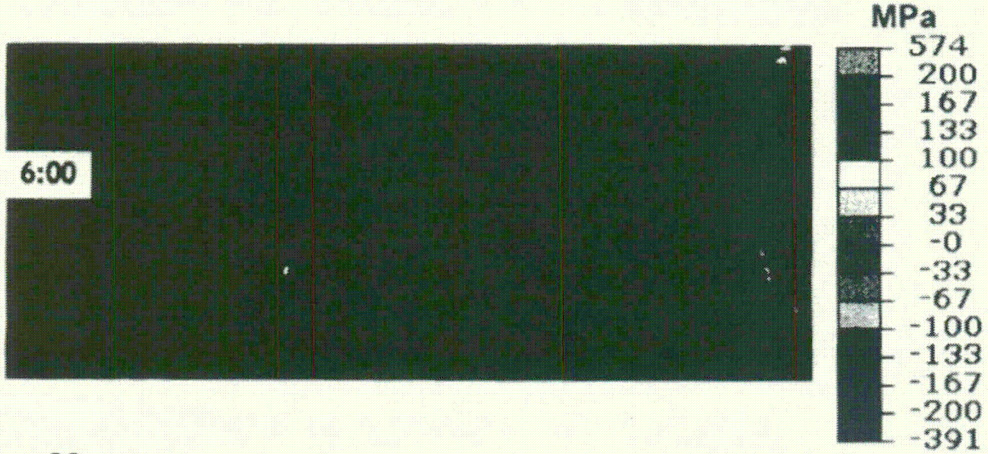
Hoop is in tube 'hoop' direction (Short) and 'radial' is in the tube radial direction (Long)

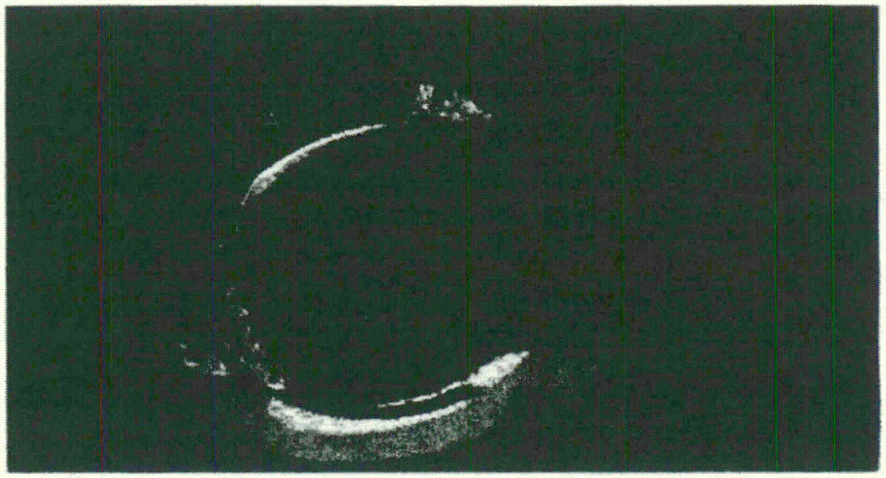
Comparisons (25-degree)

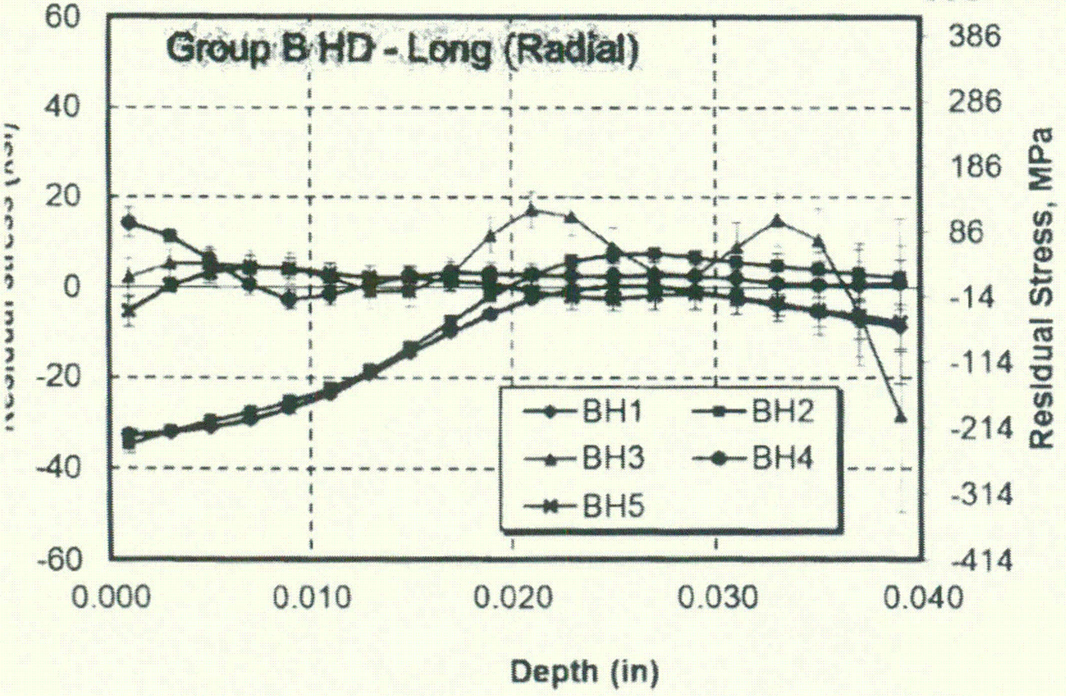
Locations B – Radial Stress

Model rotated on symmetry plane added for clarity

Radial Stress







FEA = very low
Measured = low

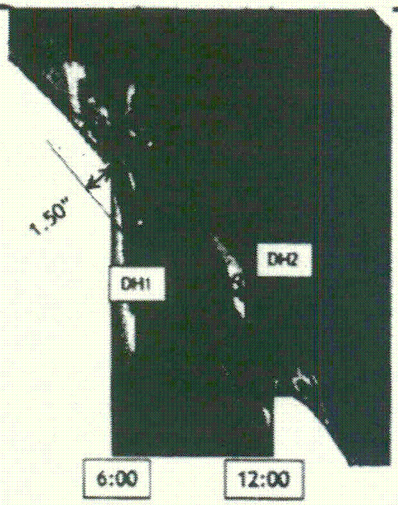
Location D

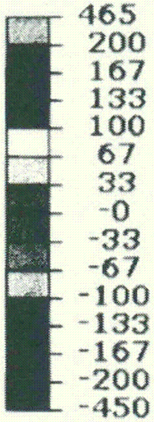
Measurements (53-degree)

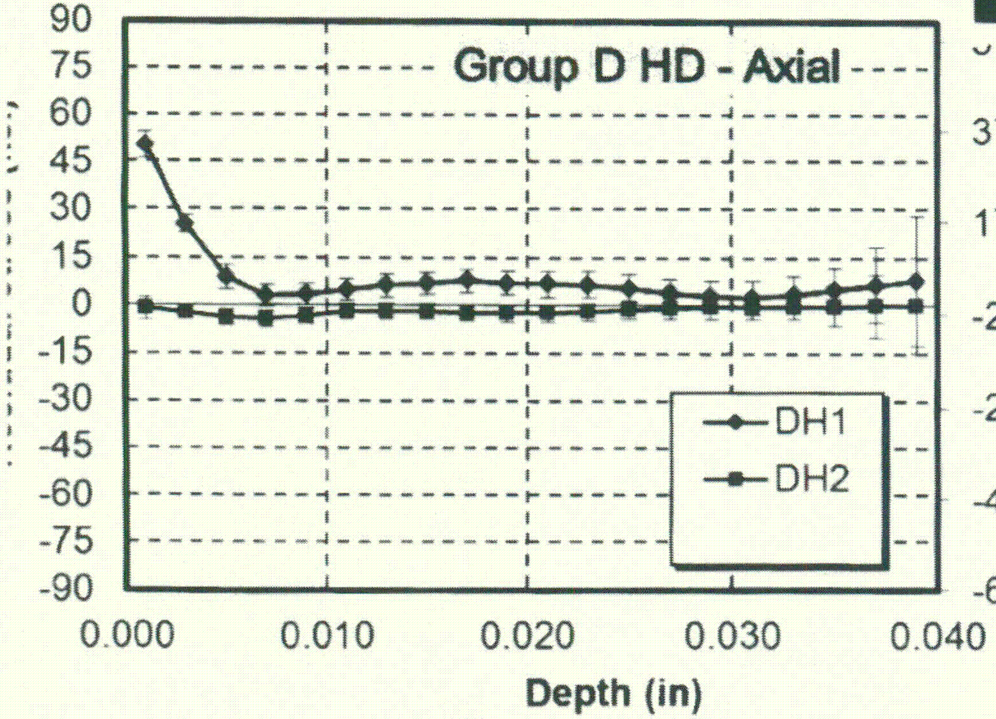
Location D – Axial Stress

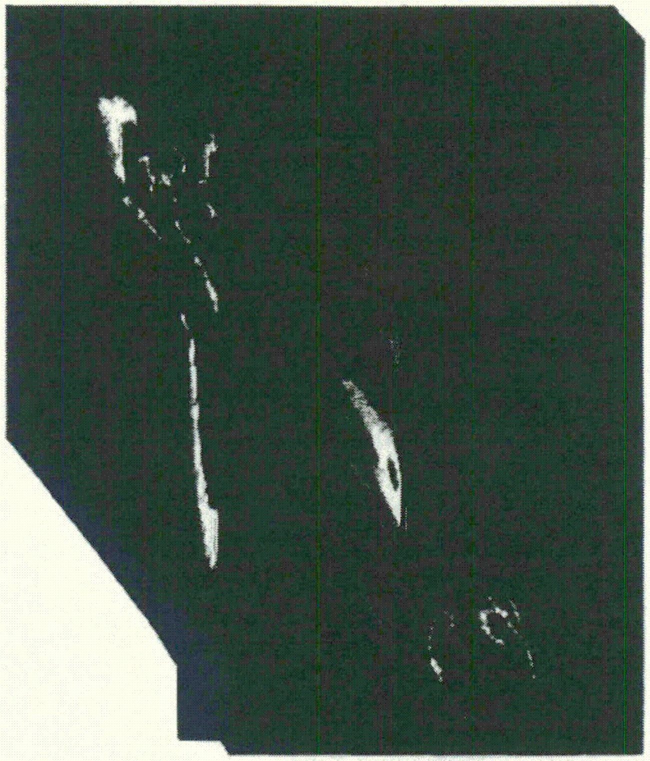
Hoop is in tube 'hoop' direction and 'axial' is in the tube axis direction

Model rotated on symmetry plane added for clarity









FEA = ~ 100 MPa

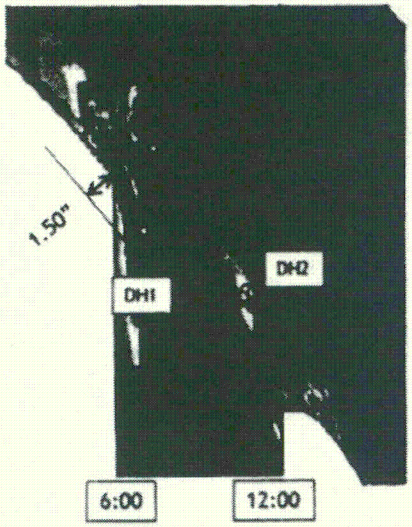
Measured range between 170 and 0 MPa for DH1

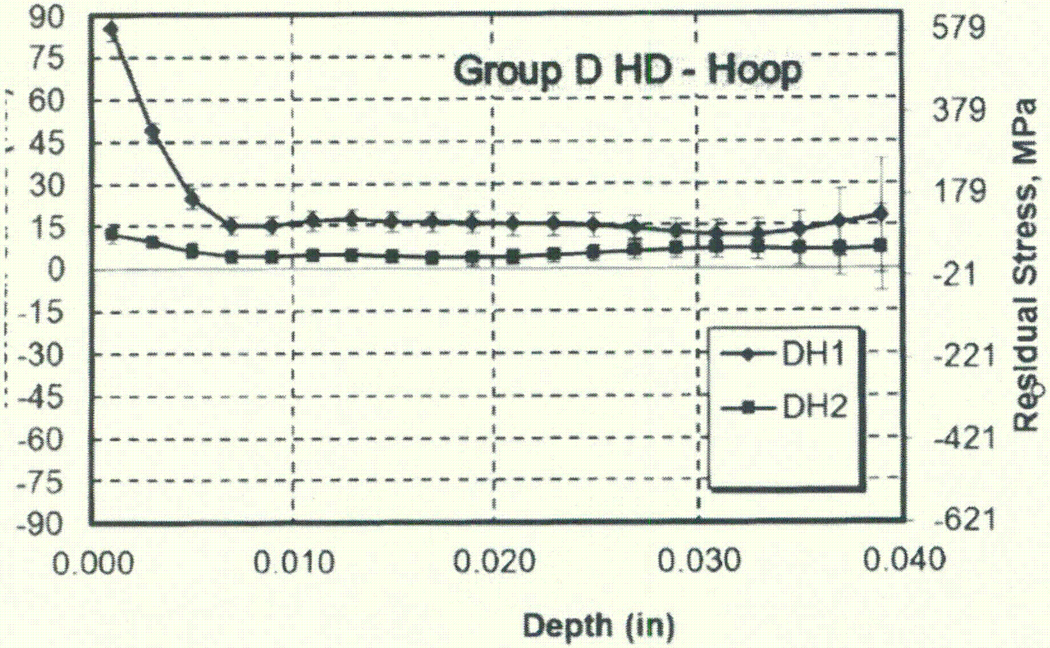
is in the tube axis direction

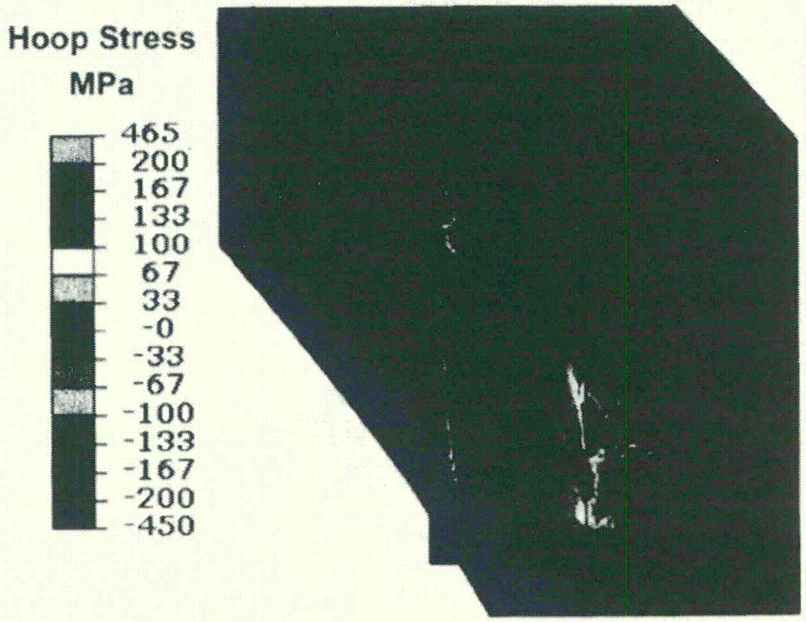
Measurements (53-degree)

Location D - Hoop

Model rotated on symmetry plane added for clarity







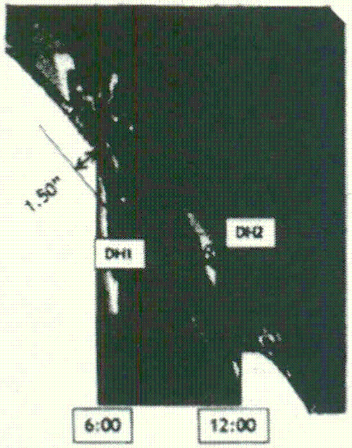
FEA = ~ 150 MPa
Measured range between 210 and 50 MPa for DH1

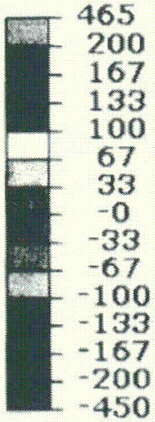
Hoop is in tube 'hoop' direction and 'axial' is in the tube axis direction

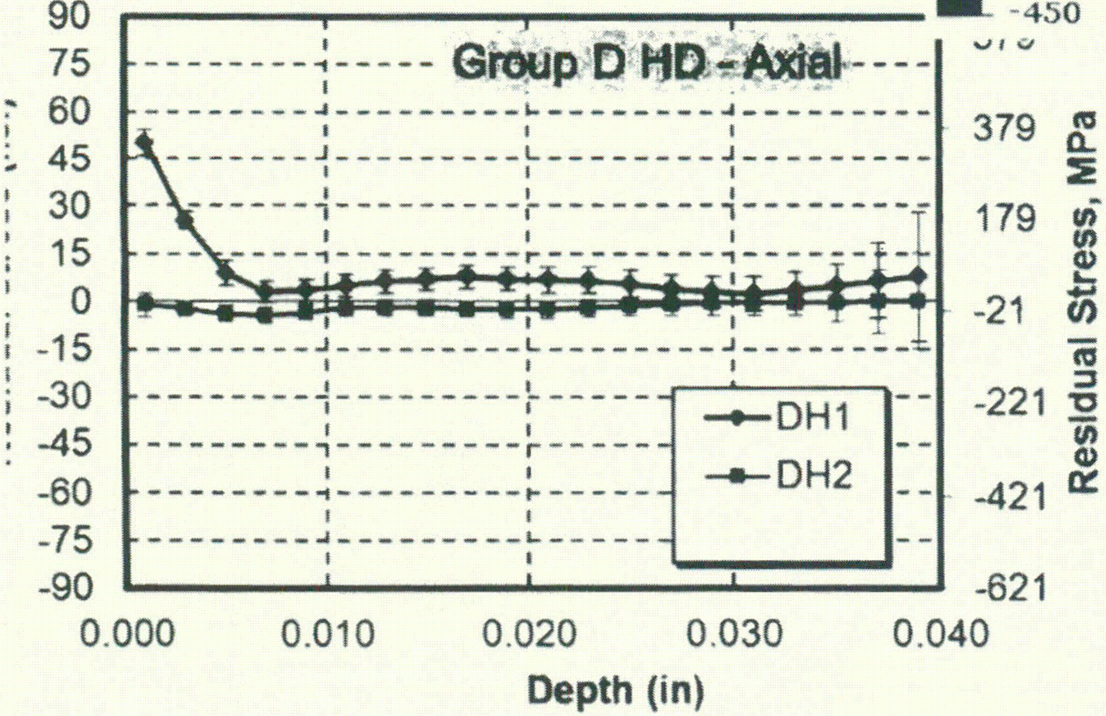
Measurements (25-degree)

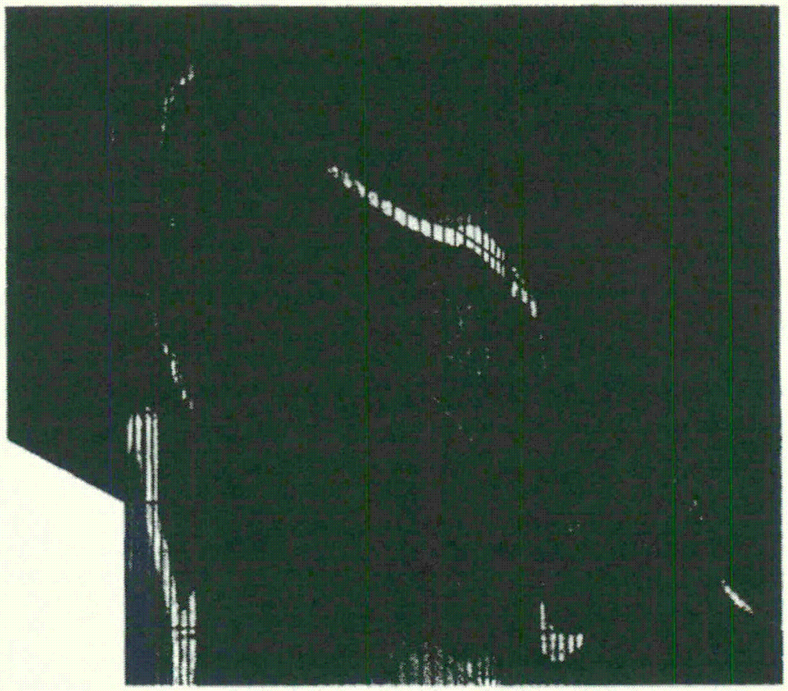
Location D – Axial Stress

Model rotated on symmetry plane added for clarity









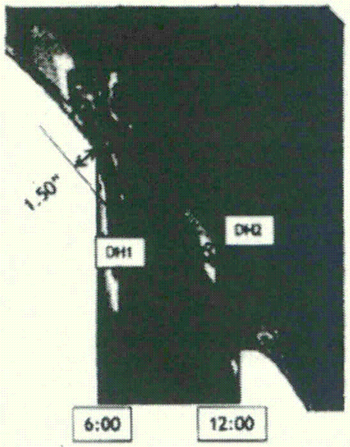
FEA = ~ 110 MPa
Measured range between 170 and 0 Mpa for DH1

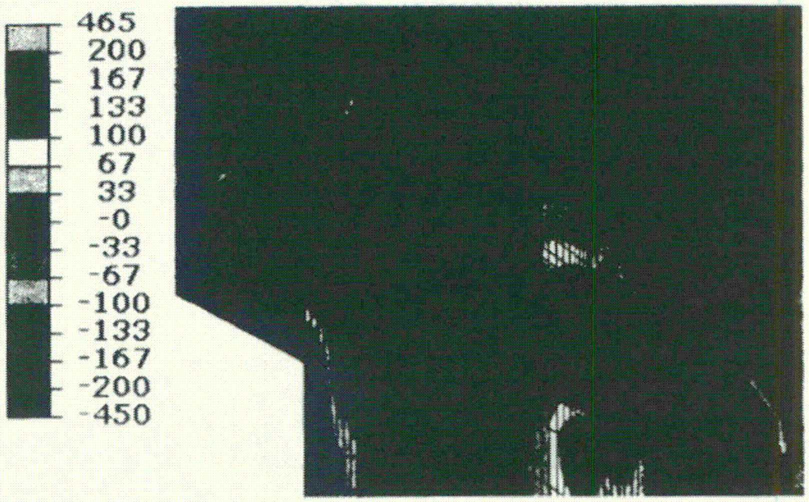
is in the tube axis direction

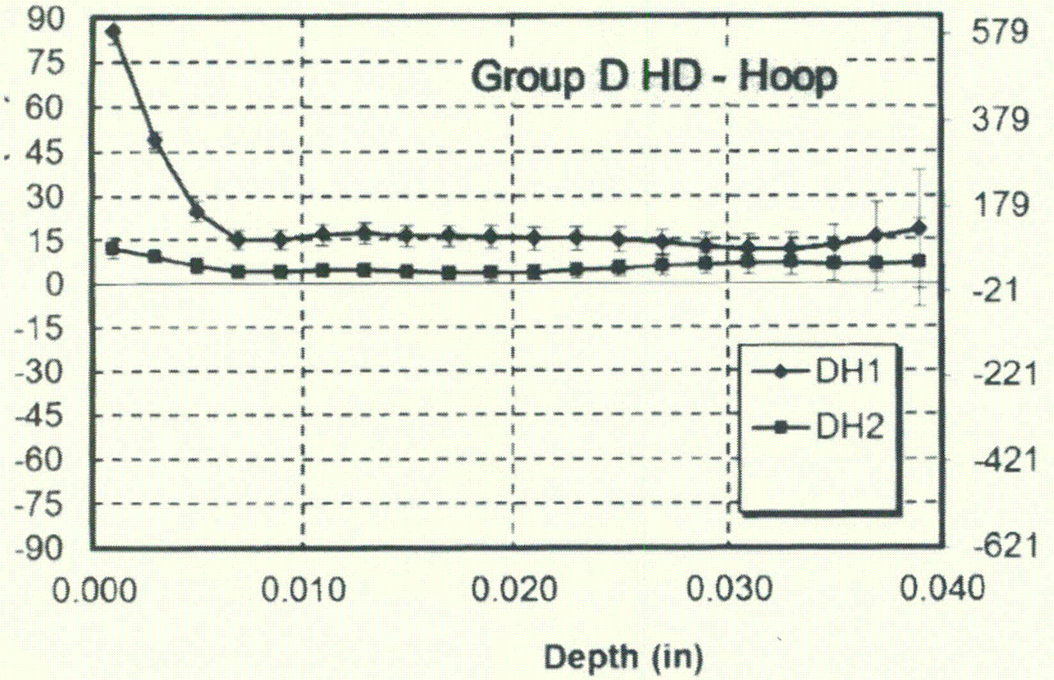
Measurements (25-degree)

Location D – Hoop Stress

Model rotated on symmetry plane added for clarity







FEA = ~ 150 MPa
Measured range between 210 and 50 MPa for DH1

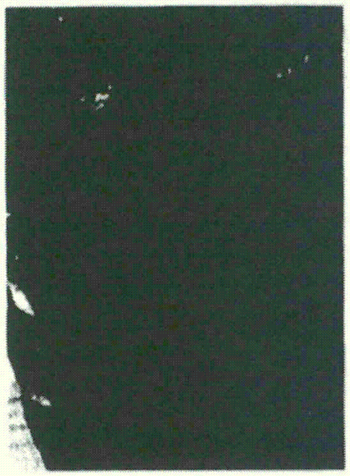
Location E

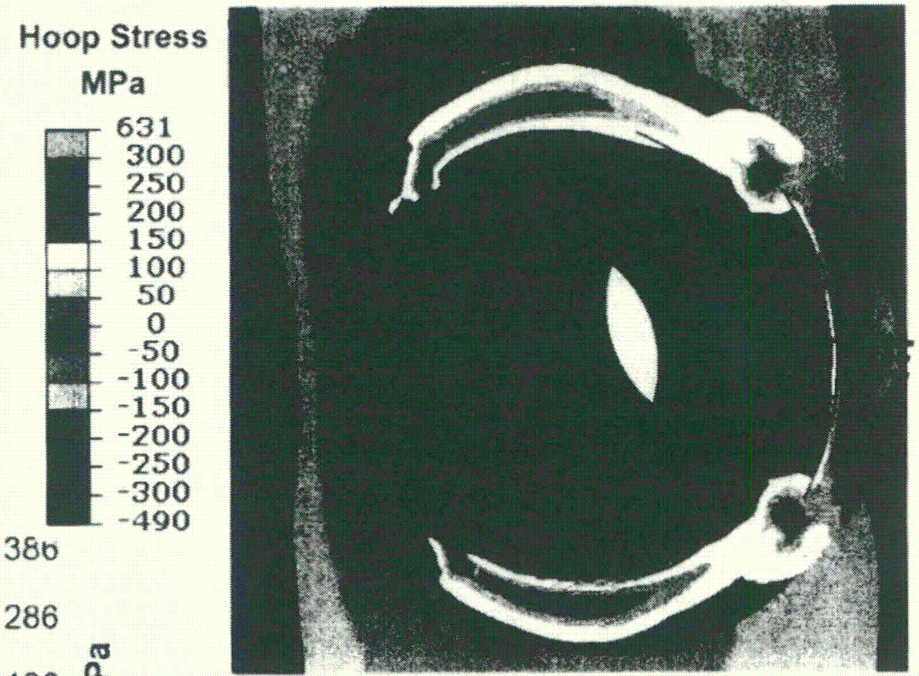
Measurements (53-degree)

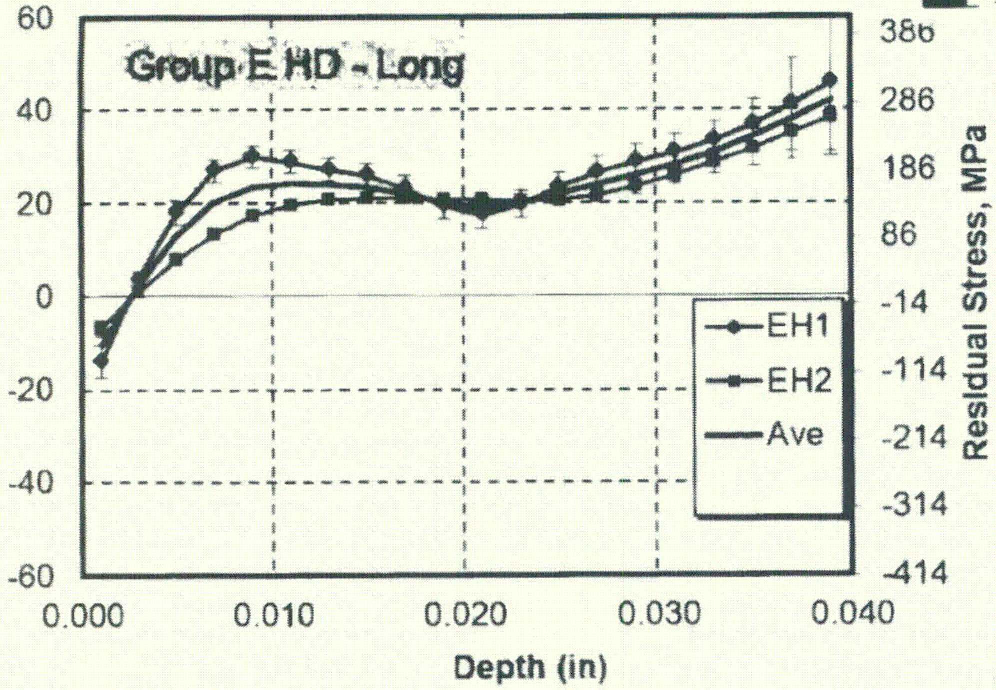
Location E – Hoop (affected by flame cut?)

'radial' is in the tube radial direction (Short)

Model rotated on symmetry plane added for clarity







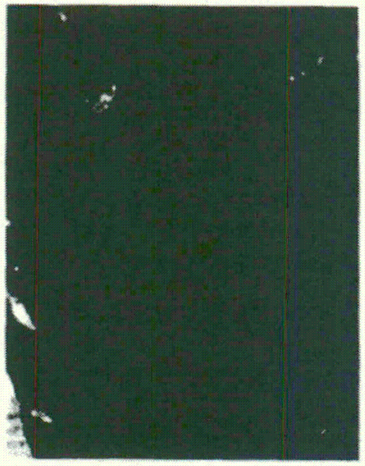
FEA = ~ 350 MPa
Measured range
between 400 and 300

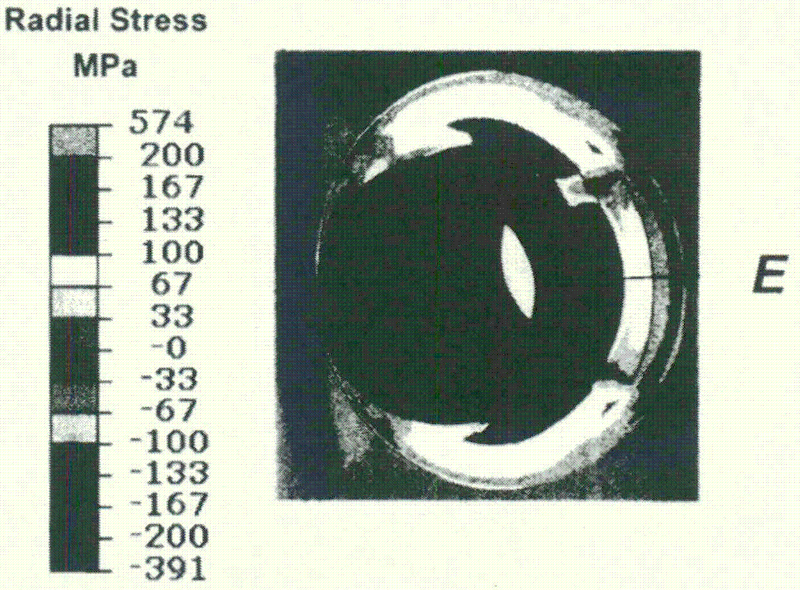
Hoop is in tube 'hoop' direction (Long) and 'radial' is in the tube radial direction (Short)

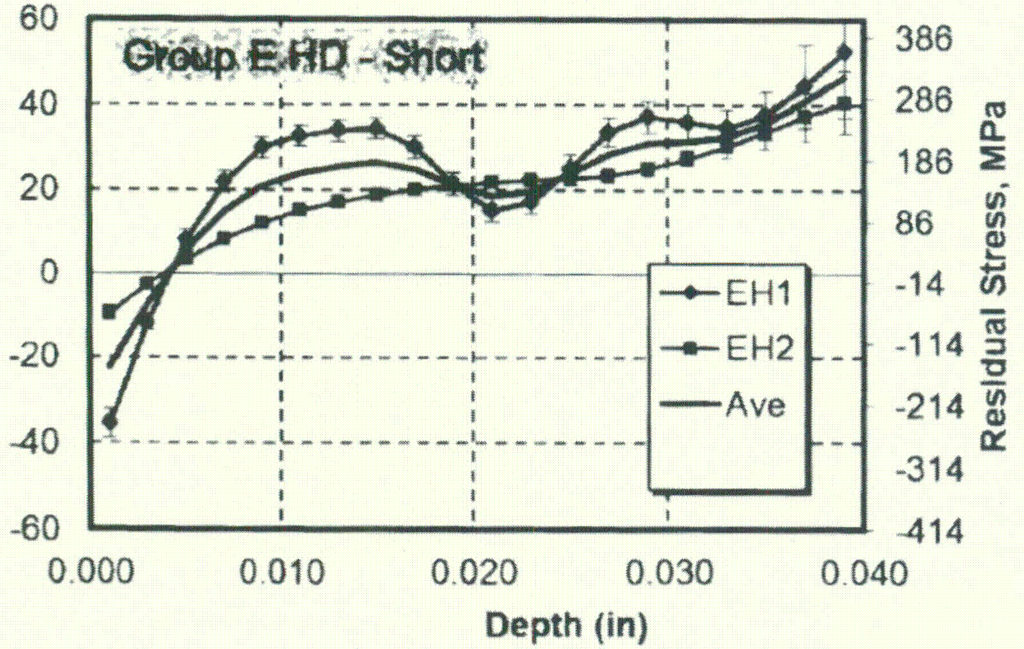
Measurements (53-degree)

Location E – Radial (affected by flame cut?)

Model rotated on symmetry plane added for clarity







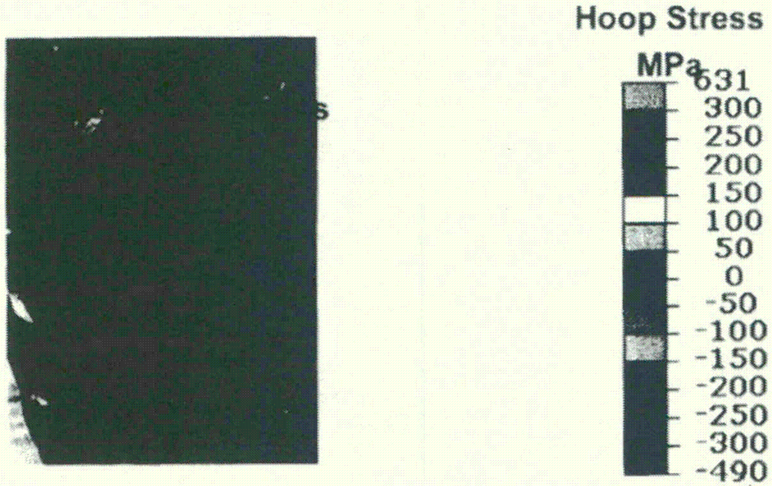
FEA = ~ 150 MPa
Measured range between 400 and 300

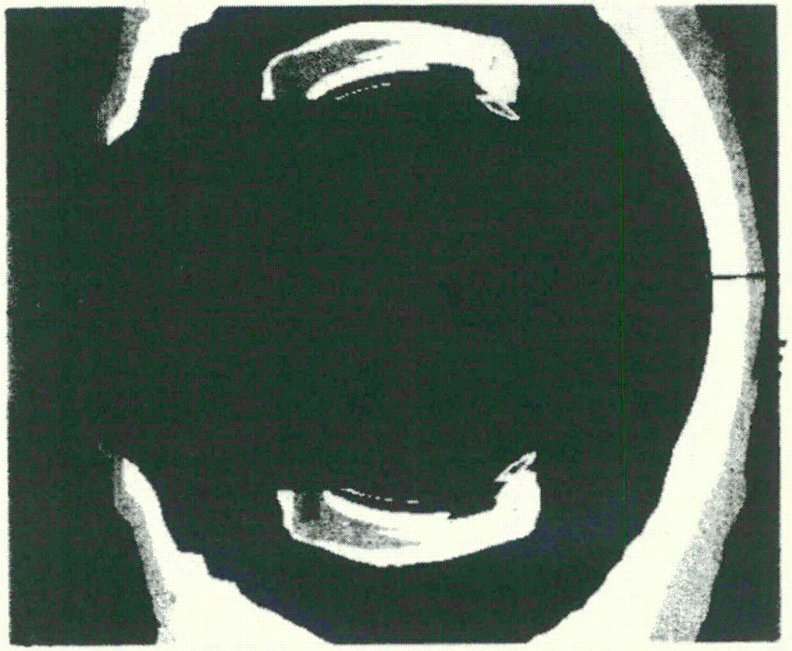
'radial' is in the tube radial direction (Short)

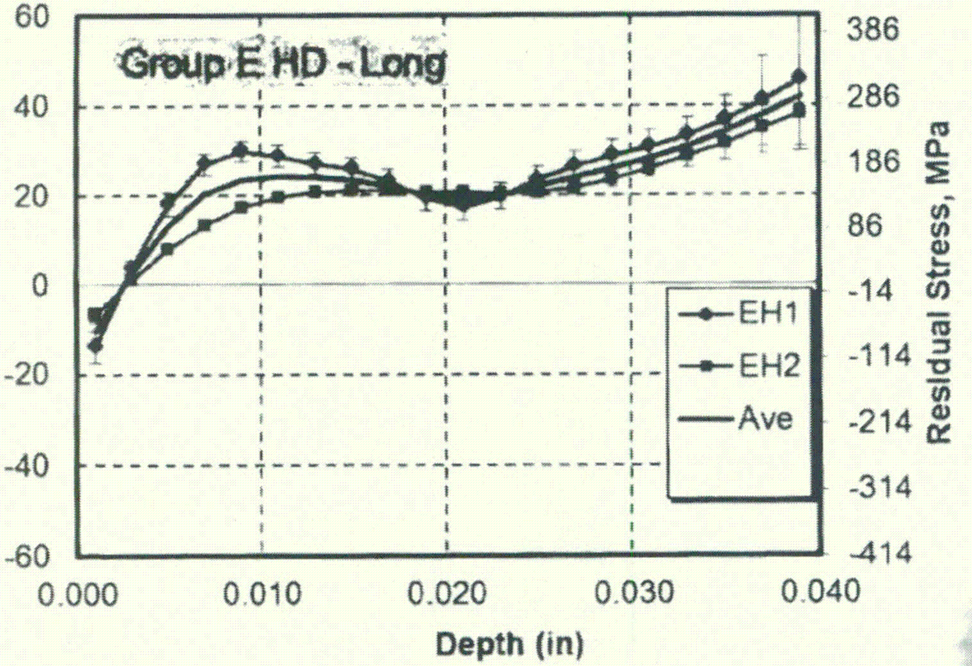
Measurements (25-degree)

Location E - Hoop (affected by flame cut?)

Model rotated on symmetry plane added for clarity







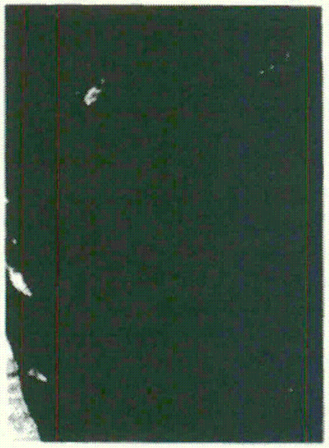
FEA = ~ 225 MPa
Measured range between 400 and 300

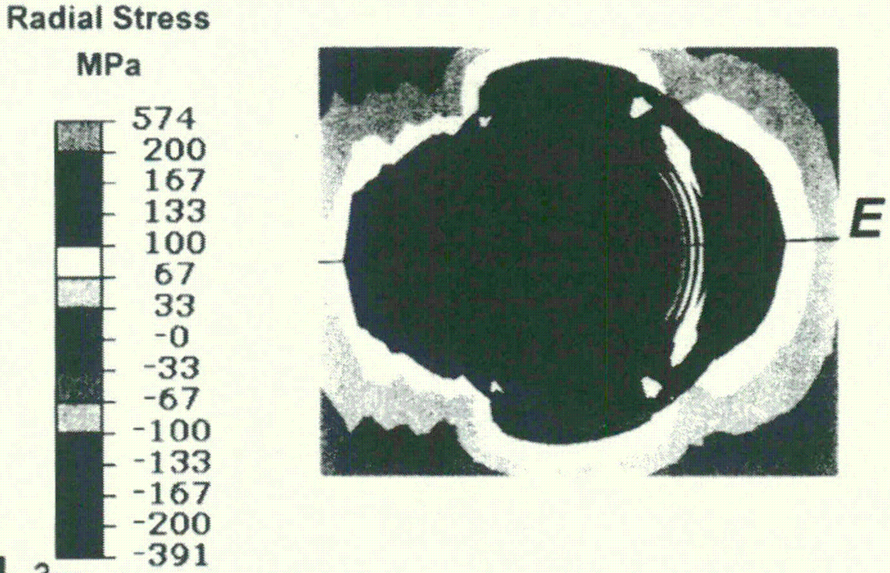
Measurements (25-degree)

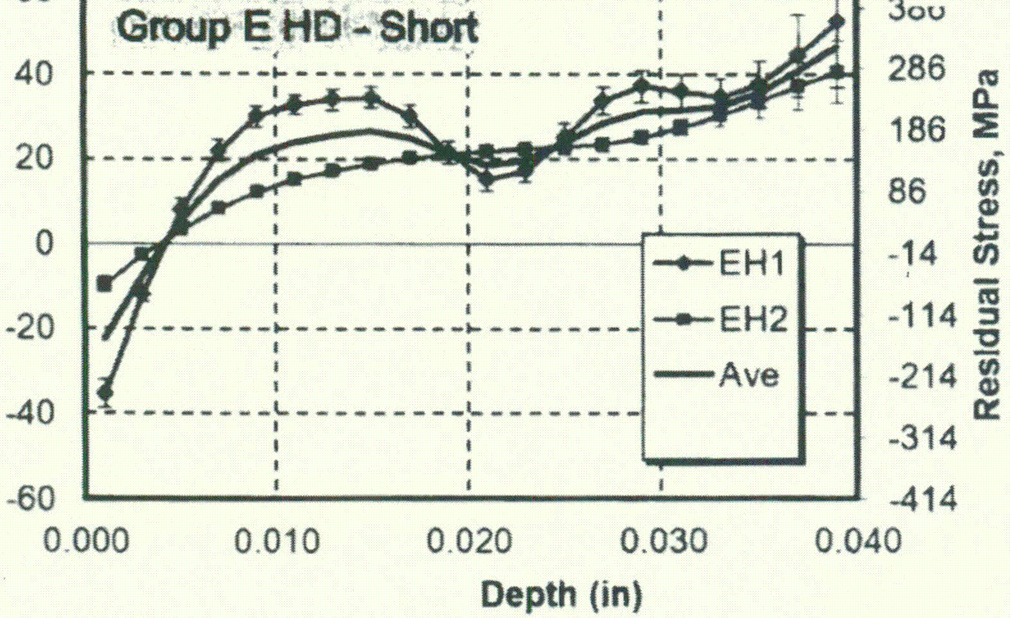
Location E - Radial (affected by flame cut?)

Hoop is in tube 'hoop' direction (Long) and 'radial' is in the tube radial direction (Short)

Model rotated on symmetry plane added for clarity







FEA = ~ 100 MPa
Measured range between 400 and 300

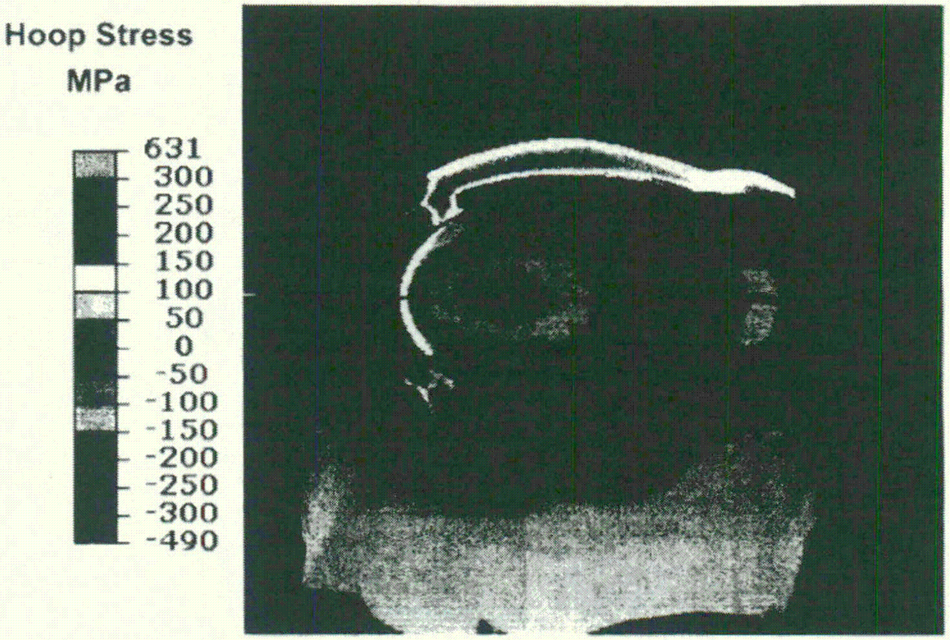
Location A

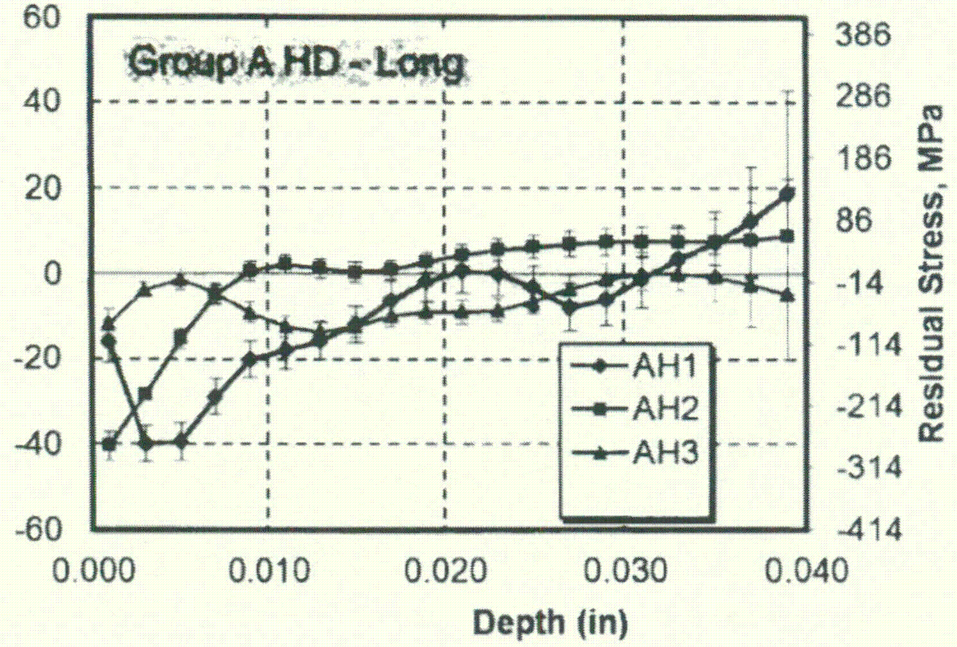
Hoop is in tube 'hoop' direction (Long) and 'radial' is in the tube radial direction (Short)

Comparison 53-degree

Locations A - Hoop

Model rotated on symmetry plane added for clarity





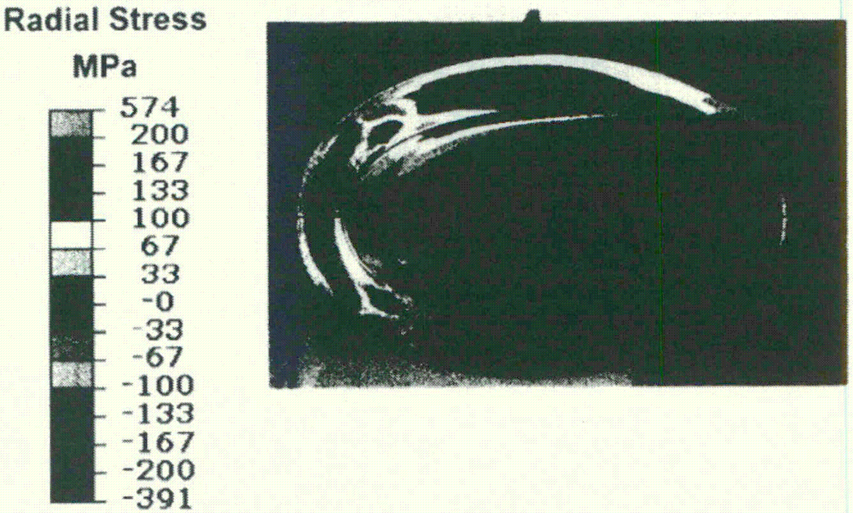
FEA = ~ 100 MPa
Measured range between 300 and 120 (mid fillet)

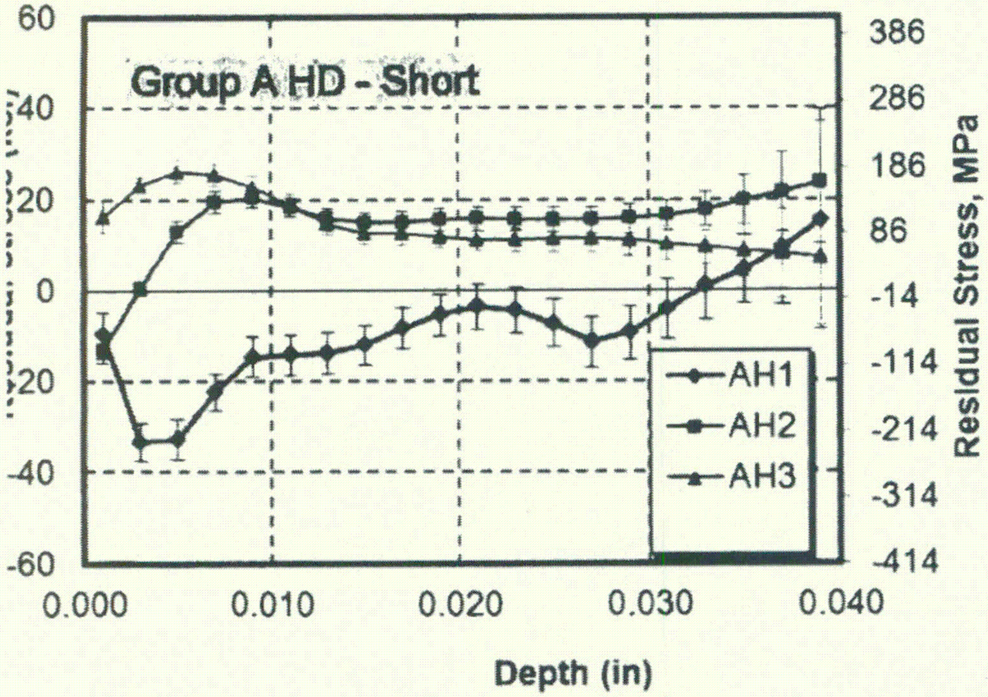
Comparison 53-degree

Locations A - Radial

'radial' is in the tube radial direction (Short)

Model rotated on symmetry plane added for clarity





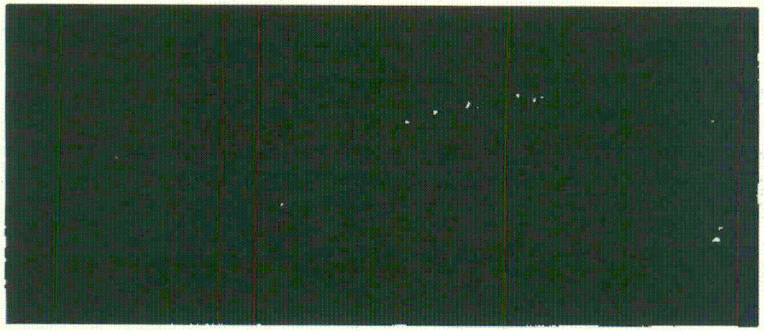
FEA = ~ 200 MPa
Measured range
between 280 and 180
(mid fillet)

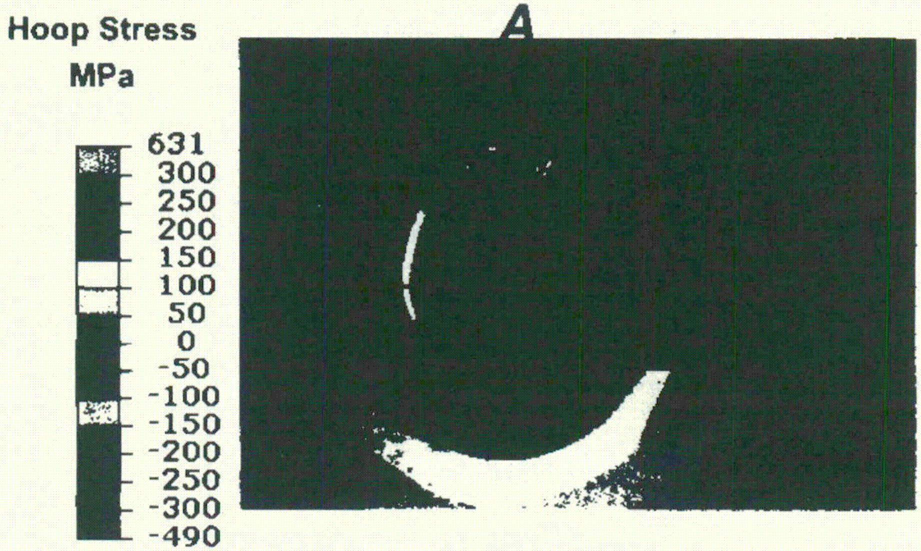
Comparisons (25-degree)

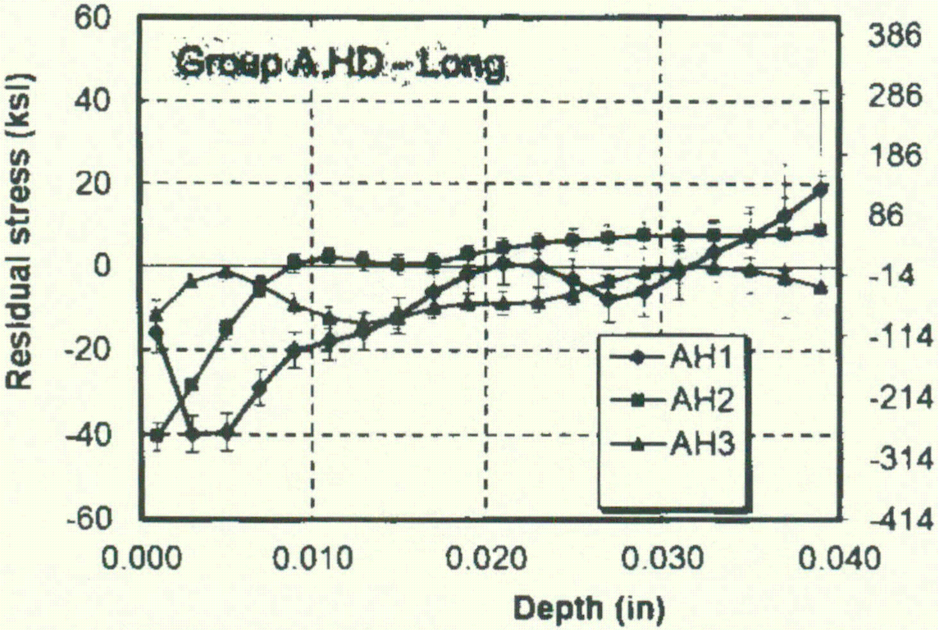
Locations A - Hoop

Hoop is in tube 'hoop' direction (Long) and 'radial' is in the tube radial direction (Short)

Model rotated on symmetry plane added for clarity







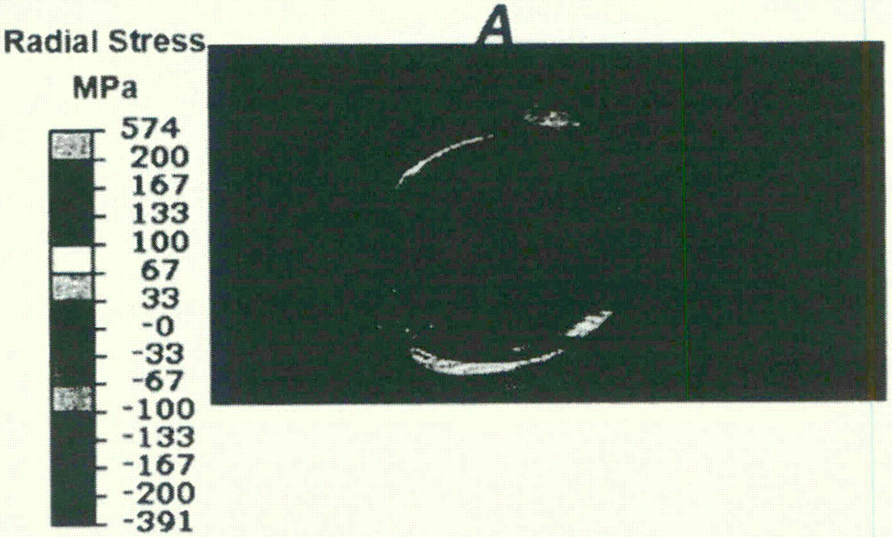
FEA = ~ 250 MPa
Measured range between 300 and 150 (fillet runout)

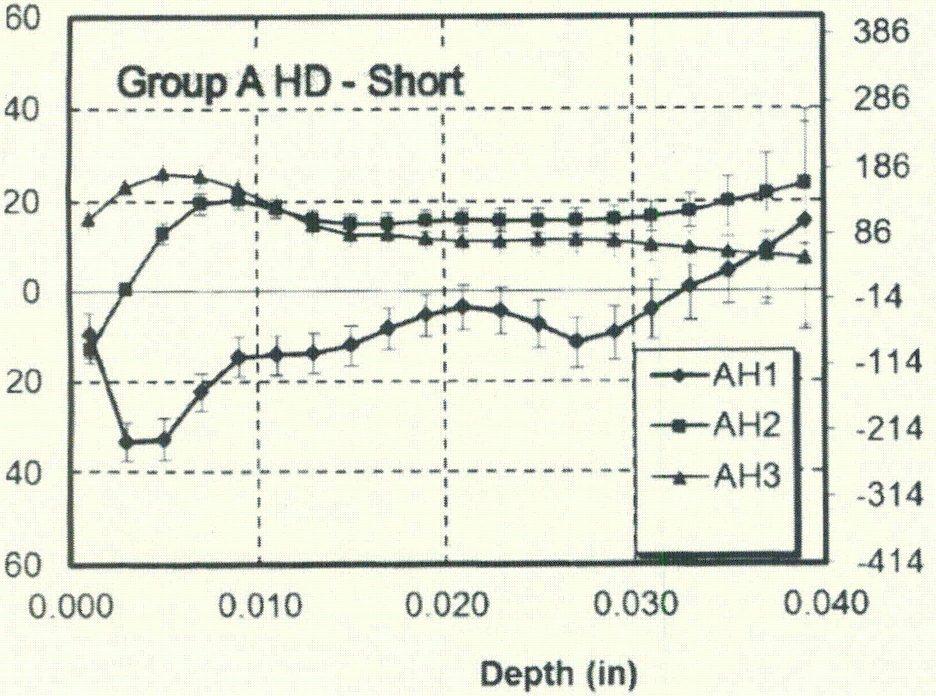
Comparisons (25-degree)

Locations A - Radial

'radial' is in the tube radial direction (Short)

Model rotated on symmetry plane added for clarity





FEA = ~ 170 MPa
Measured range between 300 and 170 (fillet runout)

Summary Observations

- *In general, weld residual stress (WRS) measurements directly at the surface are likely affected by surface effects and should be ignored.*
- *The measurements at a depth of .04-inch should be compared to FE predictions.*
- *The WRS at Location E may have been affected by the flame cut*
- *Predictions are considered reasonable compared with the measurements especially since the angles (25-deg and 53-degree) are not the same. This is encouraging*
- *FEA may be used as a confirmatory tool for assessing the effect of WRS mitigation techniques*