THE MATERIALS JOINING EXPERTS

Project Status Meeting
Edison Welding Institute
Columbus, Ohio
February 5, 2008

Define, Optimize and Validate Detection and Sizing Capabilities of Phased-Array Ultrasonic Technique to Inspect Joints in Polyethylene Pipes

Mark Lozev	Chief Engineer/NDE Technology Leader
Nancy Porter	Project Manager
Roger Spencer	Applications Engineer
Evgueni Todorov	Senior Engineer
Perry White	Applications Engineer

Agenda

- Welcome & Introductions *Porter*
- Project Review & Status *Lozev*
- Laboratory Demonstration *Lozev*
- Proposed Additional Work on Butt and Saddle Samples *Lozev*
- Use of EF Samples for Next Phase Project, "Destructive Testing & Acceptance Criteria" *Fabiano*
- Technology Transfer Workshop *Lozev*

THE MATERIALS JOINING EXPERTS

Objectives

- Define detection and sizing capabilities of current state-of-the-art PA UT techniques for inspection of electrofusion (EF) joints in polyethylene (PE) gas distribution pipelines
- Develop optimized PA UT procedure (s)
- Determine the performance of the technique and proposed improvements for EF joints
- Define applicability of PA UT for inspecting butt-fusion (BF) and saddle-fusion (SF) joints in PE gas distribution pipelines (U.S. DOT expanded scope)

THE MATERIALS JOINING EXPERTS

Sponsors, Contributors and Contractors

- U.S. Dept. of Transportation Pipeline and Hazardous Materials Safety Administration (DOT/PHMSA) Research and Development Program – main sponsor
- NYSEARCH – sponsor and In-kind contributor
- Olympus NDT (former RD Tech) - In-kind contributor
- GE Inspection Technologies - In-kind contributor
- Harfang - In-kind contributor
- Technology Design - In-kind contributor
- M2M - In-kind contributor
- Mechanical Integrity - In-kind contribution
- JANX - In-kind contributor
- NiSource Pipeline Group (NiSource) - In-kind contributor
- AGA (Plastic Pipe Materials Committee) - In-kind contributor
- Edison Welding Institute, USA – main contractor
- The Welding Institute, UK – EWI subcontractor for tasks 1 & 2

EWI THE MATERIALS JOINING EXPERTS

Technical Approach

- Assess the detection limits and defect-sizing accuracy of PA UT technique for inspection of joints in PE gas distribution pipelines using a combination of:

  - UT modeling and simulations

  - experimental nondestructive testing

  - independent NDE and destructive verification

  - statistical analysis

THE MATERIALS JOINING EXPERTS

Task 1 – EF Lap Joints Testing Matrix and Protocol (Funding Source: NYSEARCH Project 49265CSP)

- NYSEARCH identified the material (PE 100), pipe size (6" and 2") and 5 major type defects
- High end matrix and detail tables for open/blind (confidential) trials were completed on time.
- Testing protocols for the open and blind trials were completed on time
- The test matrix details from a similar program supported by the European Community was investigated and adopted.
- No duplication with EC program - (5" and 10" pipe of PE 100 material and focused on developing instrumentation for thermography and PA UT)

THE MATERIALS JOINING EXPERTS

Task 1 – EF Lap Joints Testing Matrix and Protocol (Funding Source: NYSEARCH Proj. 49265CSP)

Attachment I - High End Matrices for NDE and DT Trials

NYSEARCH - High End Matrix for NDE and DT Trials
Matreail PE100, 6" pipe size, Central coupling

Open trial welds

Flaws	Welds	Tests	Comments
No flaws	10	2 Calibration welds + [8 welds for PA (open and blind trials)+DT]	
No scraping/scraping	10	to study the oxidation level with PA + DT	
Short stab	7	PA + sectioning + training + DT	16-36mm distances
Sand/dirt	7	PA + sectioning + training+ DT	Light-Medium-Heavy (1-20%)
Dust	7	PA + sectioning + training + DT	Light-Medium-Heavy (1-20%)
Water droplets/grease	7	PA + sectioning + training+ DT	2-25mm AL disk: one disk/weld
Total Open trial welds	**48**		

Blind trial welds

Flaws	Welds	Tests	Comments
Short stab	30	PA + DT	16-36mm distances
Sand/dirt	30	PA + DT	Light-Medium-Heavy (1-20%)
Dust	30	PA + DT	Light-Medium-Heavy (1-20%)
Water droplets/grease	12	PA + DT	2-25mm AL disk; miltiple disks/weld
Total Blind trial welds	**102**		
Total welds	**150**		

PA=Phased Array UT - 150 welds to be used for NDE during the current phase
DT=Destructive testing - 148 welds to be use for the next phase of the project

THE MATERIALS JOINING EXPERTS

Task 1 – EF Lap Joints Testing Matrix and Protocol (Funding Source: NYSEARCH Proj. 49265CSP)

NYSEARCH - High End Matrix for NDE and DT Trials
Matreail PE100, 2" pipe size, Friatec coupling

Open trial

Flaws	Welds	Tests	Comments
No flaws	3	1 Calibration weld +[2 weld PA (open and blind trials) +DT]	
No scraping/scraping	5	to study the oxidation level with PA + DT	
Short stab	3	PA + sectioning + training	16-36mm distances
Sand/dirt	3	PA + sectioning + training	Light-Medium-Heavy (1-20%)
Dust	3	PA + sectioning + training	Light-Medium-Heavy (1-20%)
Water droplets/grease	3	PA + sectioning + training	2-25mm AL disk: one disk/weld
Total Open trial welds	**20**		

Blind trial

Flaws	Welds	Tests	Comments
Short stab	0	PA + DT	16-36mm distances
Sand/dirt	30	PA + DT	Light-Medium-Heavy (1-20%)
Dust	0	PA + DT	Light-Medium-Heavy (1-20%)
Water droplets/grease	0	PA + DT	miltiple disks/weld2-25mm AL disk
Total Blind trial welds	**30**		
Total welds	**50**		

PA=Phased Array UT - 50 welds to be used for NDE during the current phase
DT=Destructive testing - 37 welds to be use for the next phase of the project

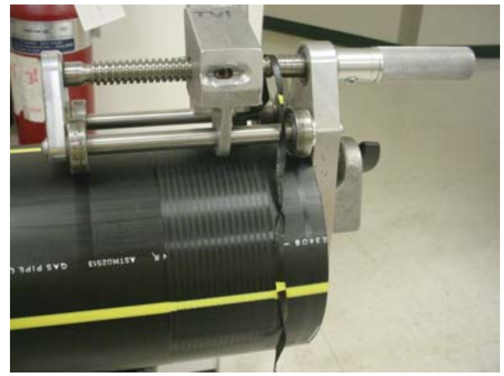
Task 2 – EF Lap Joints Sample Fabrication (Funding Source: NYSEARCH Proj. 49265CSP and In-kind)

- 252 EF joints fabricated (200 planned)
- ~ 600 flaws (defects) were implanted
- ~20-50 natural flaws are expected
- Materials were supplied by funding companies.
- EWI prepared test samples in accordance with the approved matrix and tables
- Some joints contained only one defect and was used for procedure (s) development, training and may be used for long term destructive testing in the next phase of the project
- Some joints contained multiple defects and was used for procedure (s) validation and performance determination – POD and sizing .

THE MATERIALS JOINING EXPERTS

Electrofusion Welding (EF)

- Electrofusion welding involves pipe surface and end preparation, and inserting pipe ends into electrofusion couplers
- Couplers have wire windings that are heated when electric current is applied
- As the pipe heats, thermal expansion provides the required welding pressure



EWI
THE MATERIALS JOINING EXPERTS

EF Welding Procedures

- All samples were welded using a Friatec FRIAMAT II universal electrofusion processor

- Barcode reader used to scan each coupler prior to welding to notify the processor what parameters to use for welding and cooling

- Parameters used for each welded sample:

Coupler Size (in.)	Coupler Type	Voltage	Weld Time	Cool Time
2"	Friatec	34 volts	53 seconds	10 minutes
6"	Central	40 volts	500 seconds	20 minutes

- All samples were cooled while still fixed into the clamps

EWI
THE MATERIALS JOINING EXPERTS

EF Defects

- Defects
  - Short stab
  - Sand
  - Talc
  - Water (Aluminum disks)
  - None
- Three contamination levels (light, medium, and heavy) were used for the sand and talc samples
- The following aluminum disk diameters were incorporated into the matrix: 0.5, 1, 1.5, 2, 4, 6, 8, 9, 10, 12, 15, 18, 25, and 50 mm

EWI THE MATERIALS JOINING EXPERTS

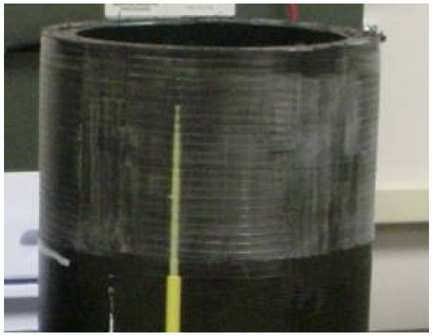
EF Sand Defects Example

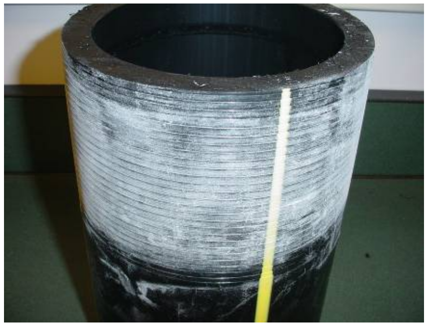
- A rubber roller was used to pick up sand and apply it to the welding surface
  - Light contamination - pipe was rotated twice during sand application
  - Medium and heavy contamination required four and six coatings, respectively

EF Talc Defects Example

- Talc was transferred to the pipe surface using soft brush and roller
- Light contamination
  - soft brush used to brush medium coated pipe

Medium contamination
  - pipe was rotated twice
- Heavy contamination
  - pipe was rotated four times

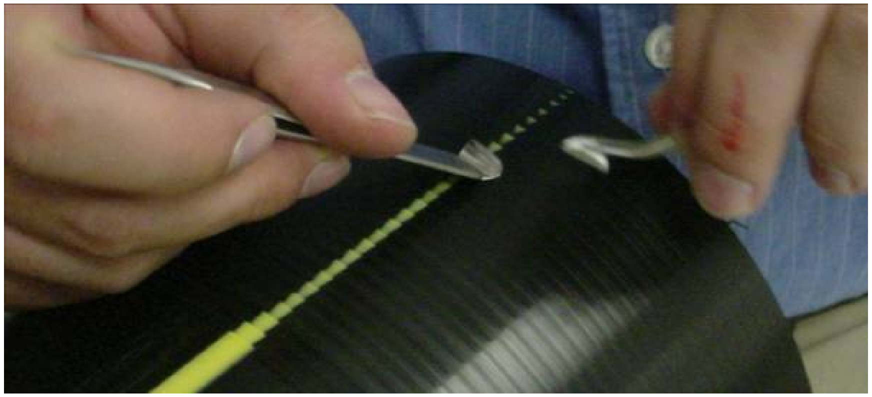




EWI
THE MATERIALS JOINING EXPERTS

EF Aluminum Disk Defects Example

- Disk samples were punched out of adhesive backed aluminum sheet (.001”) using hand punches into the following diameters: 0.5, 1, 1.5, 2, 4, 6, 8, 9, 10, 12, 15, 18, 21, 25, and 50 mm



THE MATERIALS JOINING EXPERTS

Task 3 – Define Detection & Sizing Capabilities for EF Lap Joints (Funding Source: NYSEARCH Proj. 49265CSP)

- The limitations of the state-of-the-art PA with respect to the matrix of materials, pipe sizes and defects identified in Task 1 was to defined.
- PA simulations were performed using UT software for beam modeling and interactions in complex geometries.
- The simulations provided estimations for the detection and sizing capabilities of the current PA probes and generate ideas for their optimization and design of new probes.
- Verification of the predictions was performed using the most current PA techniques and equipment.

THE MATERIALS JOINING EXPERTS

Velocity & Attenuation (Pipe)

L-WAVE VELOCITY (M/s)														
	Black #15; PE100, 110mm		**Black #16; PE100, 110mm**		**Black #25; PE100, 110mm**		**Black #26; PE100, 110mm**		**ASTM D2513; 4" Black with Yellow stripes PE3408**		**4" Yellow Pipe Section "F"**		**4" Yellow Pipe, PE2406 for Flaw Samples**	
	2 MHz	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**
	---	2319	2286	2319	---	2324	2301	2324	2240	2286	2195	2200	2177	2202
	---	2324	2278	2319	---	2337	2289	2324	2261	2278	2195	2197	2182	2192
	---	2324	2294	2324	---	2329	2286	2324	2243	2273	---	---	2169	2207
Avg.	---	***2322***	***2286***	***2321***	---	***2330***	***2292***	***2324***	***2248***	***2279***	***2195***	***2198***	***2176***	***2200***

ATTENUATION (dB/in. [mm])							
Black #26; PE100, 110mm		**ASTM D2513; 4" Black with Yellow stripes PE3408**		**4" Yellow Pipe Section "F"**		**4" Yellow Pipe, PE2406 for Flaw Samples**	
2 MHz	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**	**2 MHz**	**5 MHz**
15.6 [0.6]	27.2 [1.1]	15.8 [0.6]	30.0 [1.2]	15.1 [0.6]	26.9 [1.1]	16.9 [0.7]	27.6 [1.1]

EWI® THE MATERIALS JOINING EXPERTS

Velocity & Attenuation (Electrofusion Fitting)

L-WAVE VELOCITY (M/s)			
Black 2" Connector		Black 6" Connector	
2 MHz	5 MHz	2 MHz	5 MHz
2207	2256	2322	2337

ATTENUATION (dB/in. [mm])			
Black 2" Connector		Black 6" Connector	
2 MHz	5 MHz	2 MHz	5 MHz
17.8 [0.7]	41.3 [1.6]	12.1 [0.5]	22.5 [0.9]

THE MATERIALS JOINING EXPERTS

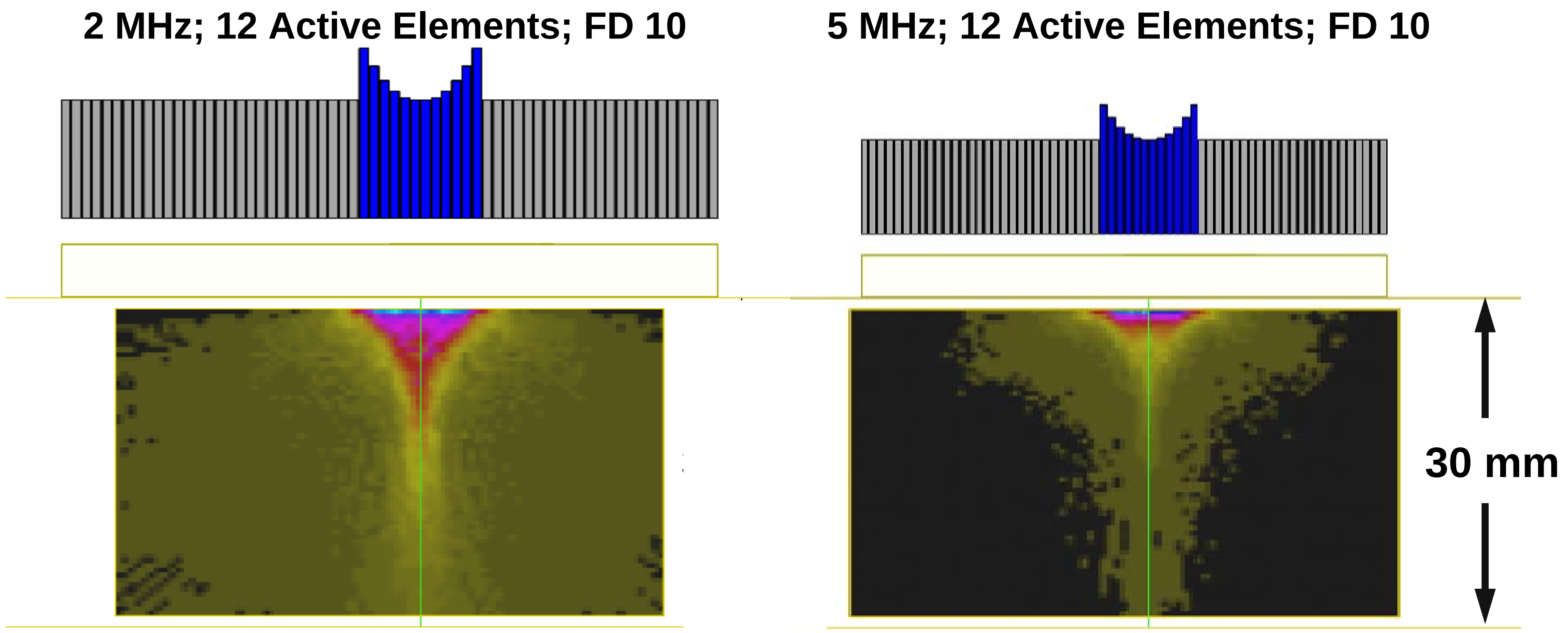
Probe/Technique Naming Convention

PA5-64/15 FD20

- **PA** – Linear Phased Array Probe
- **5** – Frequency (MHz)
- **64** – Total Number of Elements in the Probe
- **15** – Number of Active Elements
- **FD20** – Electronic Focal Depth (mm)

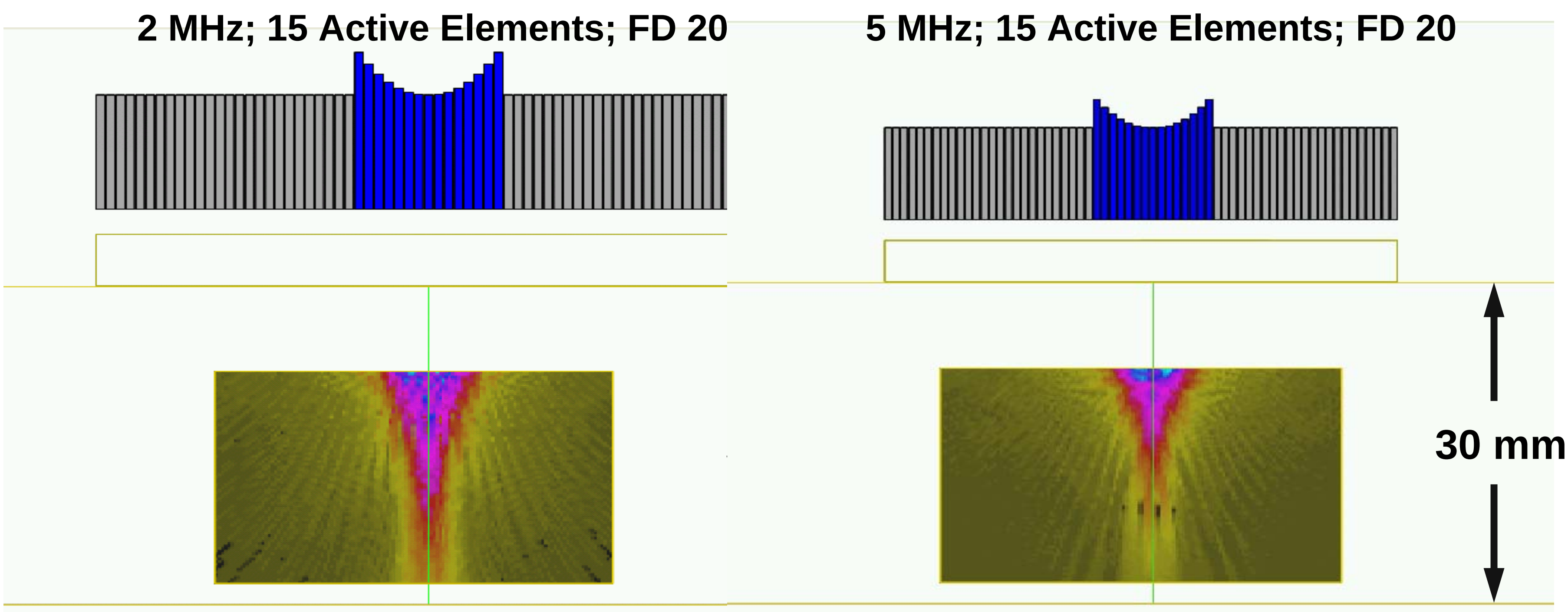
THE MATERIALS JOINING EXPERTS

2 MHz & 5 MHz, 64/12 el. FD 10



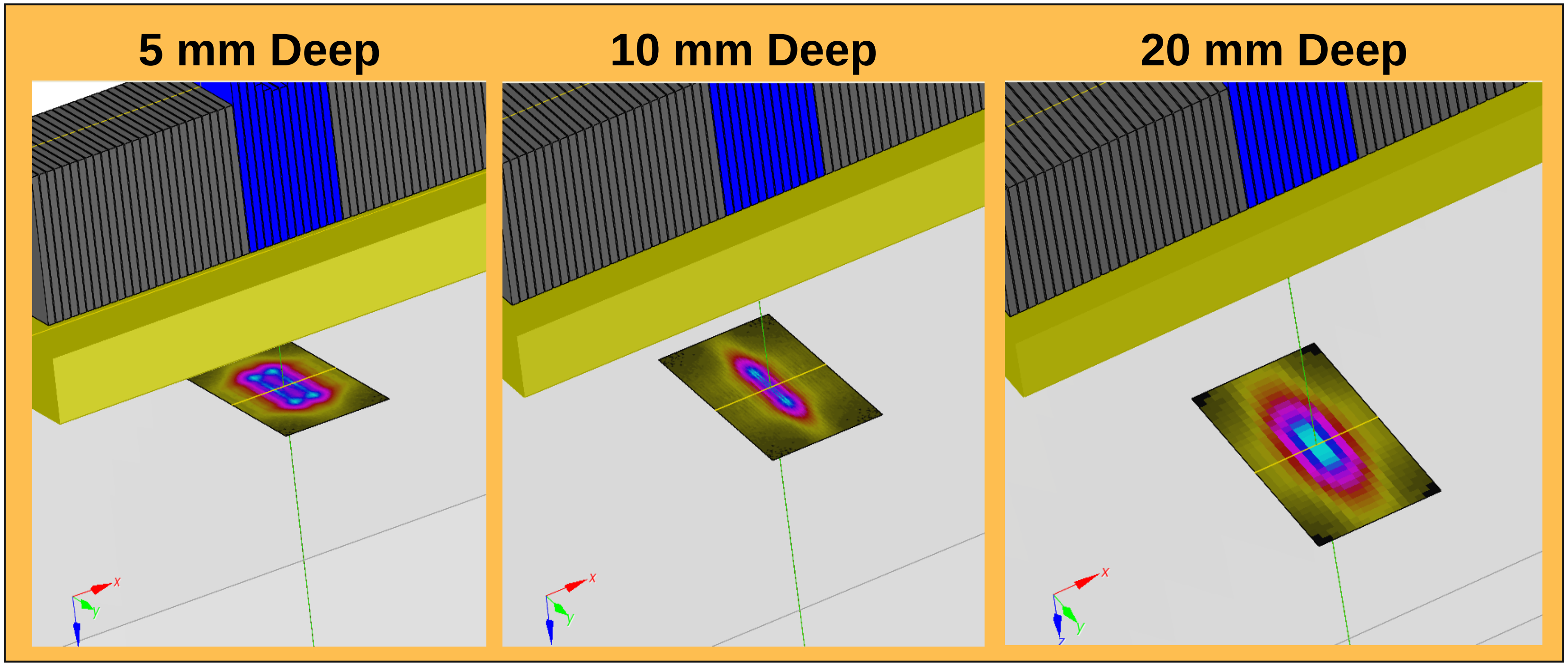
PE 3408 Coupler

2 MHz & 5 MHz, 64/15 el. FD 20



PE 3408 Coupler

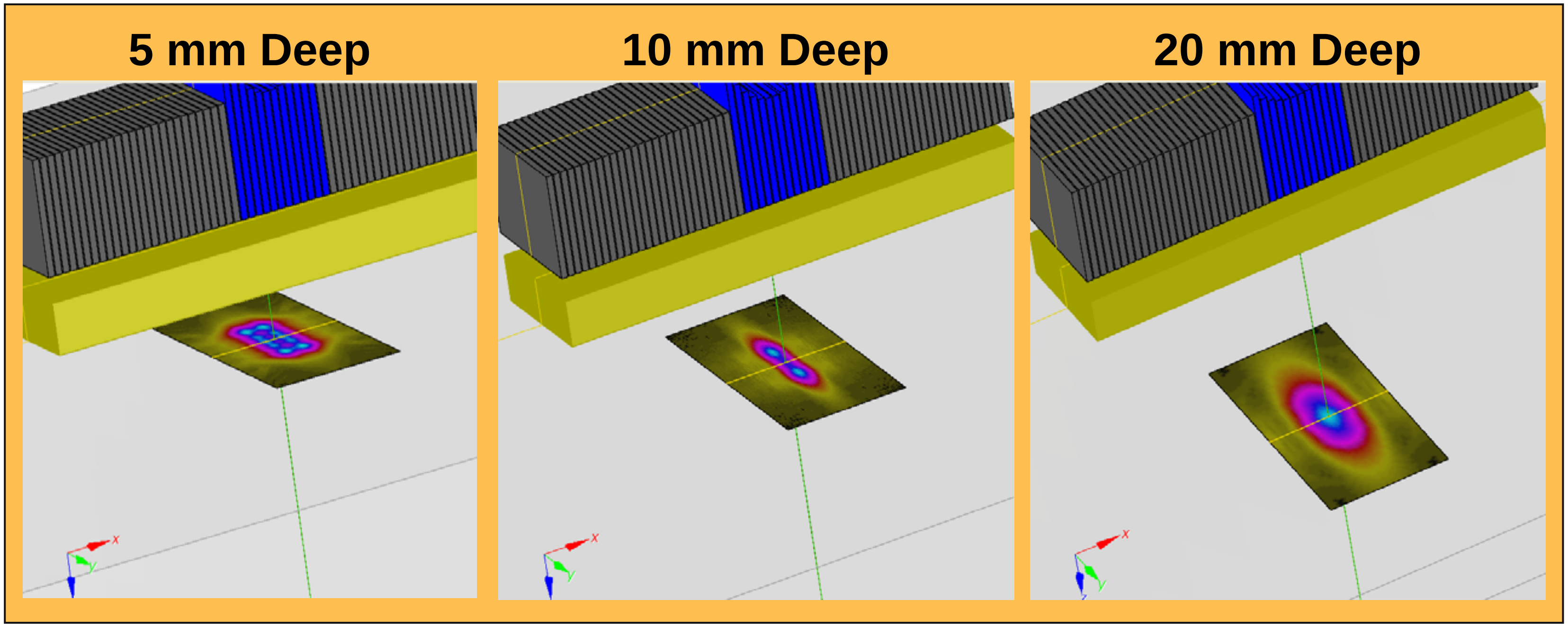
Comparison 2 MHz, 64/12 el. FD 10 at Depths of 5, 10, & 20 mm



PE 3408 Coupler

THE MATERIALS JOINING EXPERTS

Comparison 5 MHz, 64/12 el. FD 10 at Depths of 5, 10, & 20 mm

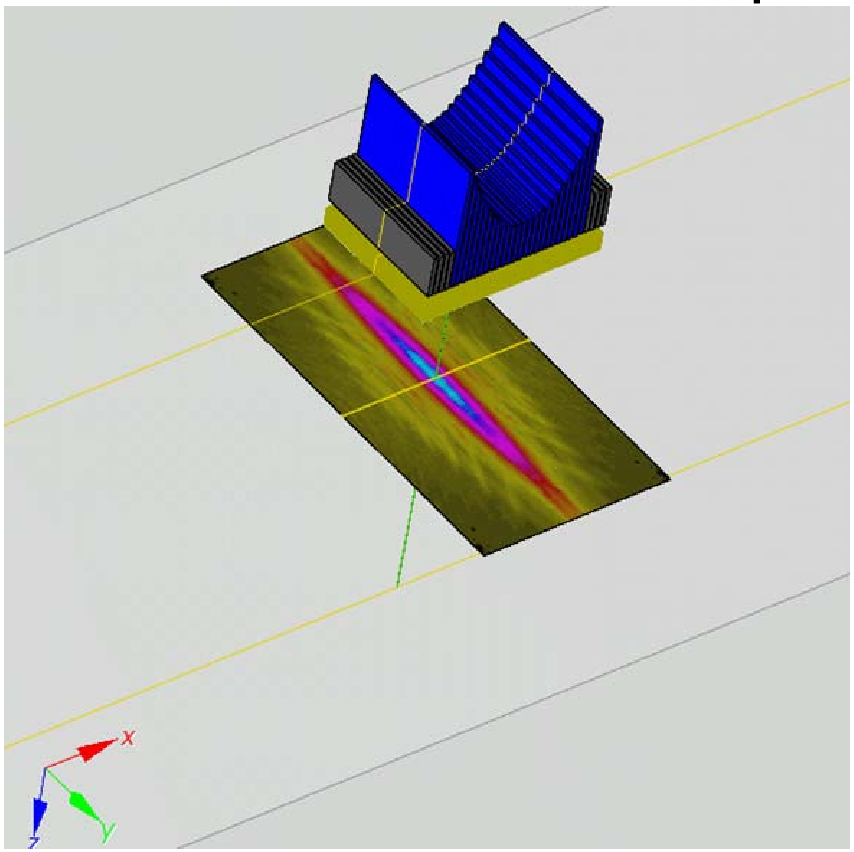


PE 3408 Coupler

EWI THE MATERIALS JOINING EXPERTS

10 MHz, 32/24 el. FD 8

Beam Cross Section at 8 mm Depth



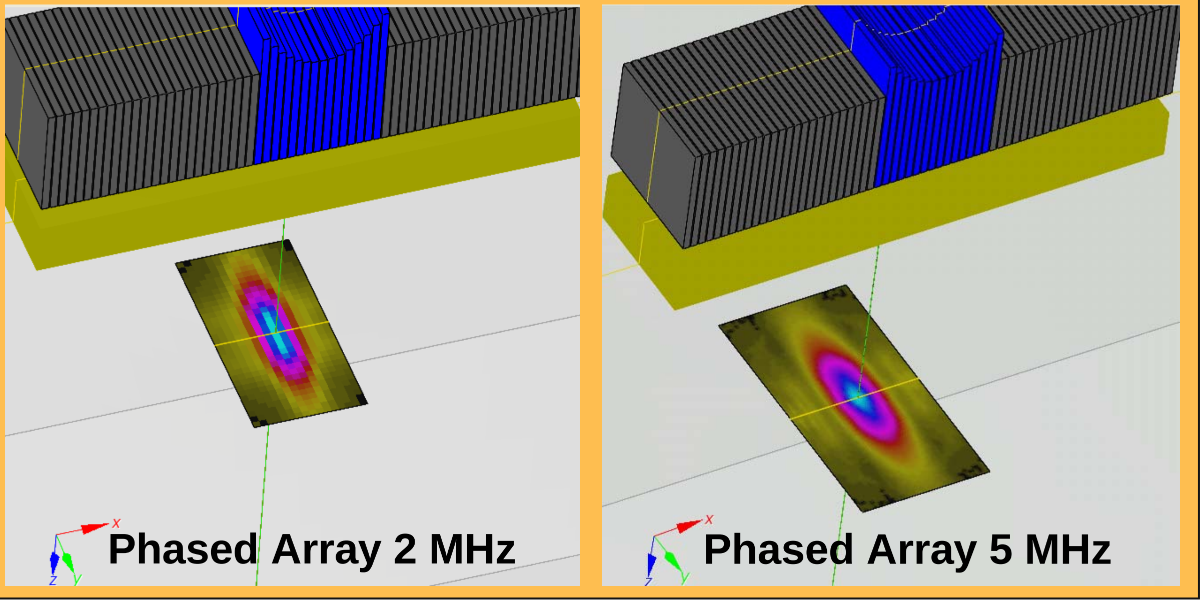
Depth (mm)	6dB		12dB	
	X (mm)	Y (mm)	X (mm)	Y (mm)
8	0.7	8.3	1.1	11.8

PE 3408 Coupler

THE MATERIALS JOINING EXPERTS

Use of Beam Modeling as a Tool for Selection of Probe Parameters

Comparison of Probe Frequency on Beam Shape & Size



Modeling the ultrasonic beam is very important for selecting the correct probe for the inspection application.

THE MATERIALS JOINING EXPERTS

Beam Size Summary

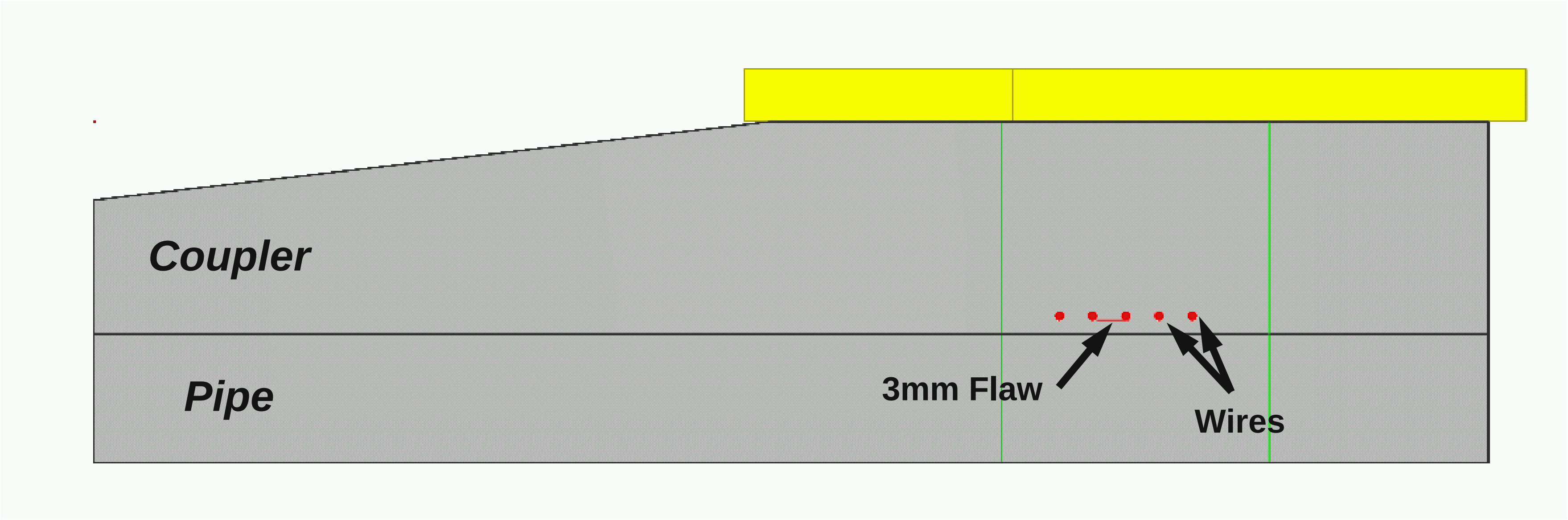
Transducer Parameters	Cross Section Depth (mm)	Focal Depth (mm)	6 dB Spread		12 dB Spread	
			[1] X (mm)	[1] Y (mm)	[1] X (mm)	[1] Y (mm)
PA2-64/12	5	10	3.3	10.0	4.0	11.3
PA2-64/10	6	8	1.0	9.8	1.5	11.3
PA2-64/12	10	10	1.5	9.0	2.0	10.8
PA2-64/12	20	20	2.9	8.0	4.1	10.7
PA2-64/15	20	20	2.2	8.0	3.2	10.7
PA5-64/12	5	10	2.6	8.1	3.3	9.3
PA5-64/12	10	10	1.2	7.0	1.7	8.8
PA5-64/12	20	20	2.7	6.3	3.9	8.3
PA5-64/15	20	20	2.2	6.3	3.1	8.5
PA10-32/24	8	8	0.7	8.3	1.1	11.8

Notes: 1. "X" is beam spread along longitudinal pipe axis; "Y" is circumferential beam spread

PE 3408 Coupler

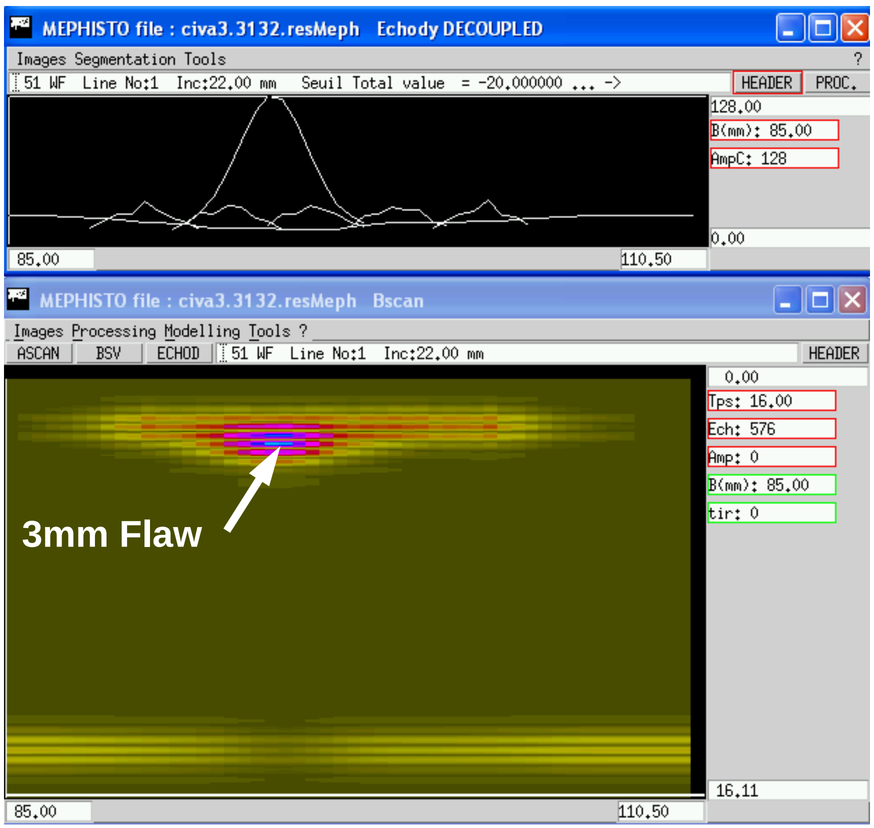
THE MATERIALS JOINING EXPERTS

Flaw Interaction Model
(6 inch Connector)

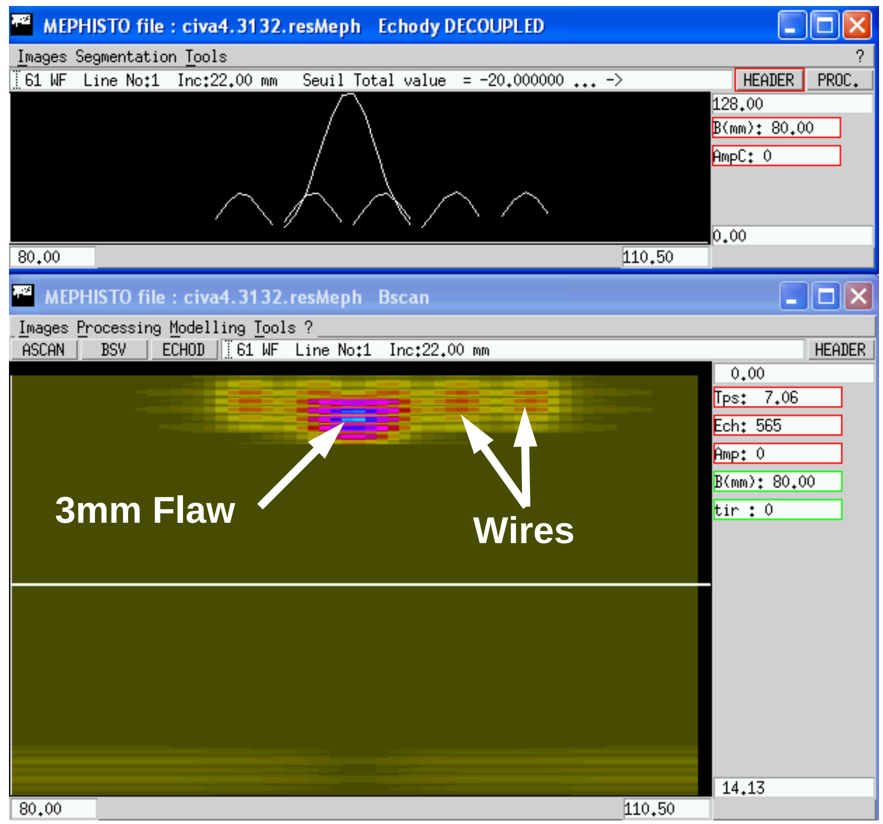


EWI
THE MATERIALS JOINING EXPERTS

2 MHz & 5 MHz Flaw Interaction Comparison (6 inch Connector)



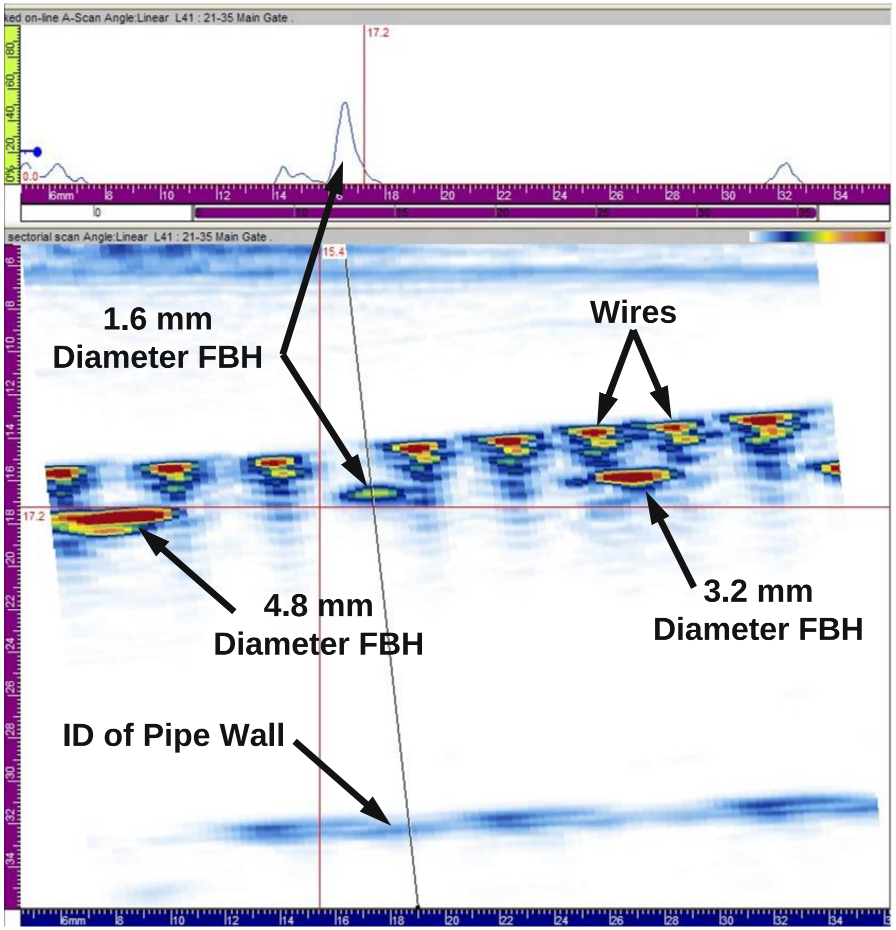
PA2-64/15



PA5-64/15

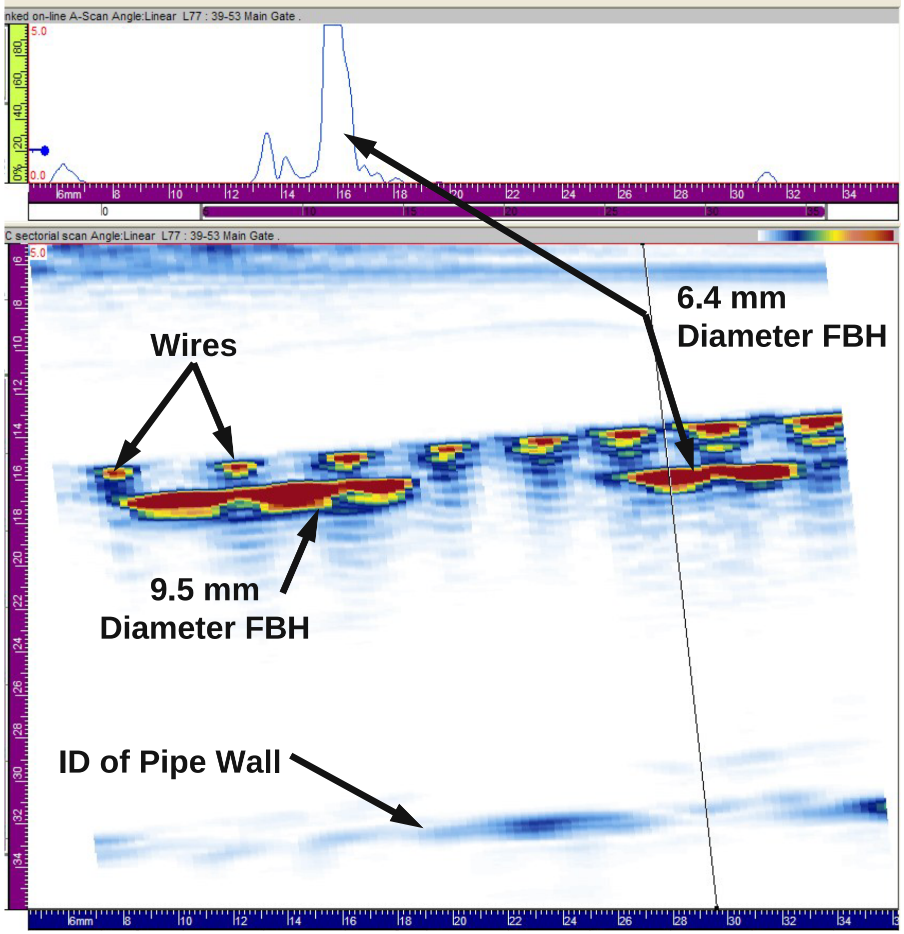
THE MATERIALS JOINING EXPERTS

PA5-64/15 20FD - 6 inch Connector, 1.6, 3.2 and 4.8mm Cal. FBH



THE MATERIALS JOINING EXPERTS

PA5-64/15 20FD - 6 inch Connector, 6.4 and 9.5 mm Cal. FBH

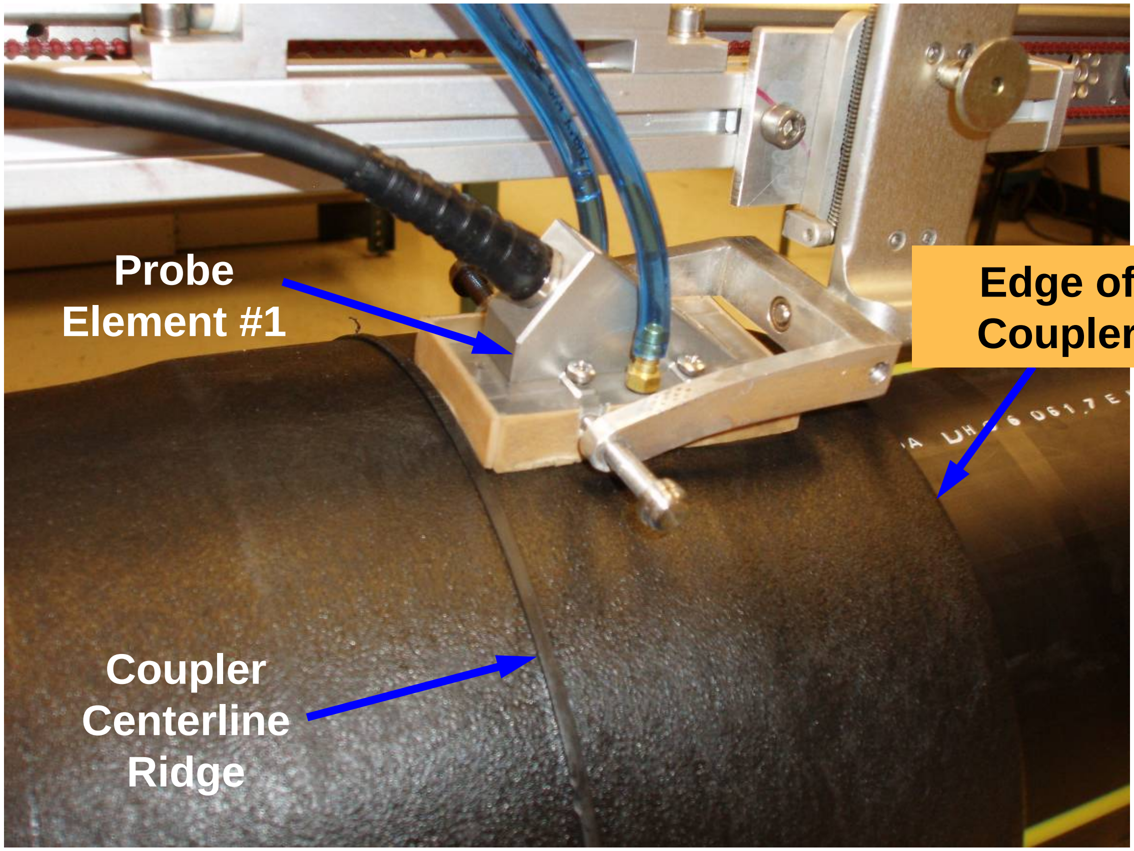


Task 4 – Develop an Optimized PA Procedure (s) (Funding Source: DOT-OPS and Industry In-kind)

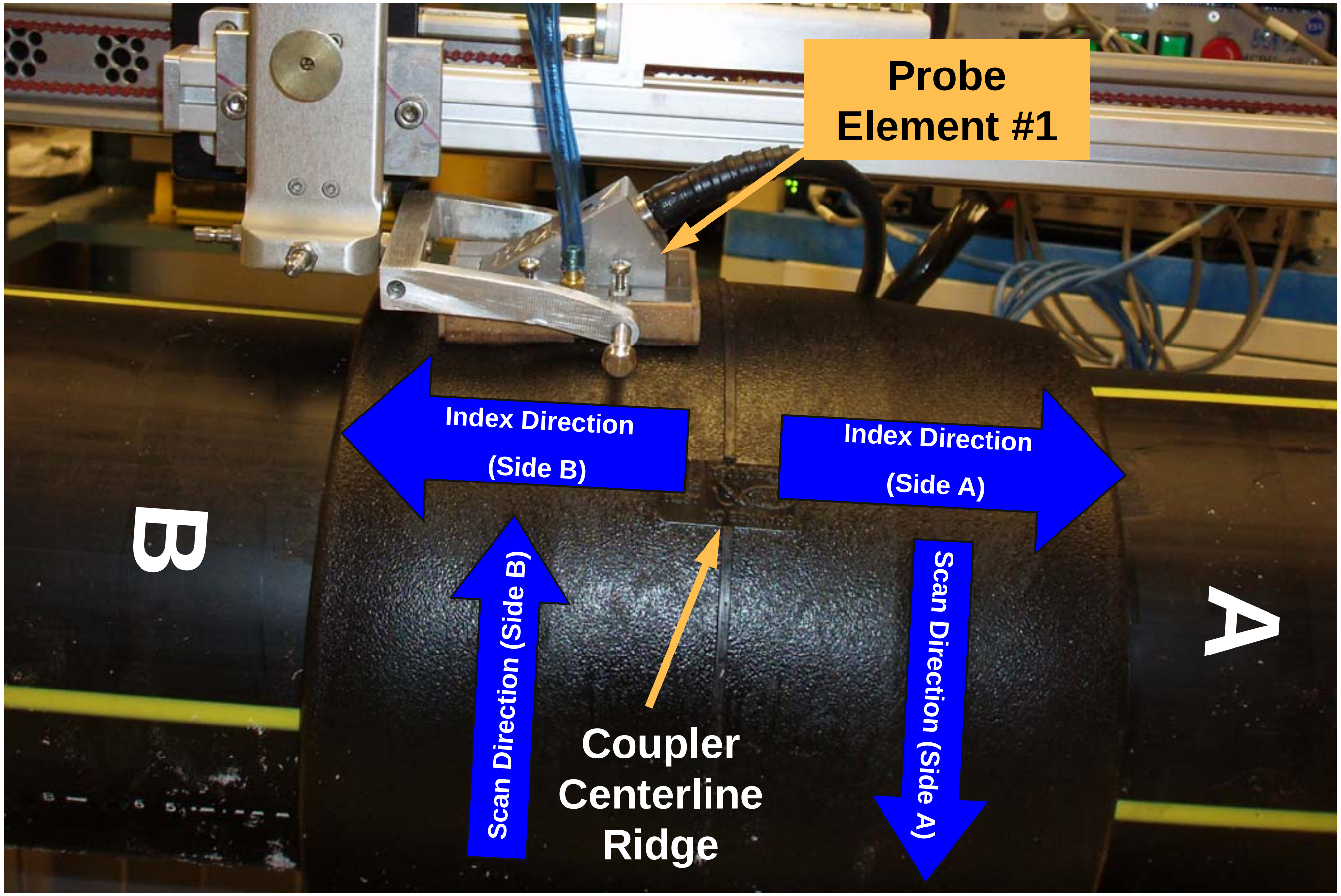
- Optimized PA detection and sizing draft procedures were developed and later finalized.
- The procedures identified the equipment, the best transducers, scan types, locating, and sizing techniques for the defects being considered.
- Limited UT simulations were performed to define PA limitations for inspection of one typical butt-fusion joint and one saddle-fusion geometry (expanded DOT scope).
- 102 butt-fusion and saddle-fusion joints (4” MDPE material) with about 100 most common defects were fabricated (expanded DOT scope - 50 joints were planned)).
- Test materials were purchased by EWI and EWI prepare test samples with implanted flaws.
- 40 joints contained only one defect and were used for procedure (s) development, open trials and demonstrations.
- 60 joints contained one or multiple defects and will be used for procedure (s) validation and capabilities determination during the blind trials (expanded DOT scope).

EWI THE MATERIALS JOINING EXPERTS

Probe Positioning
(6 inch Connector Cal. Sample)

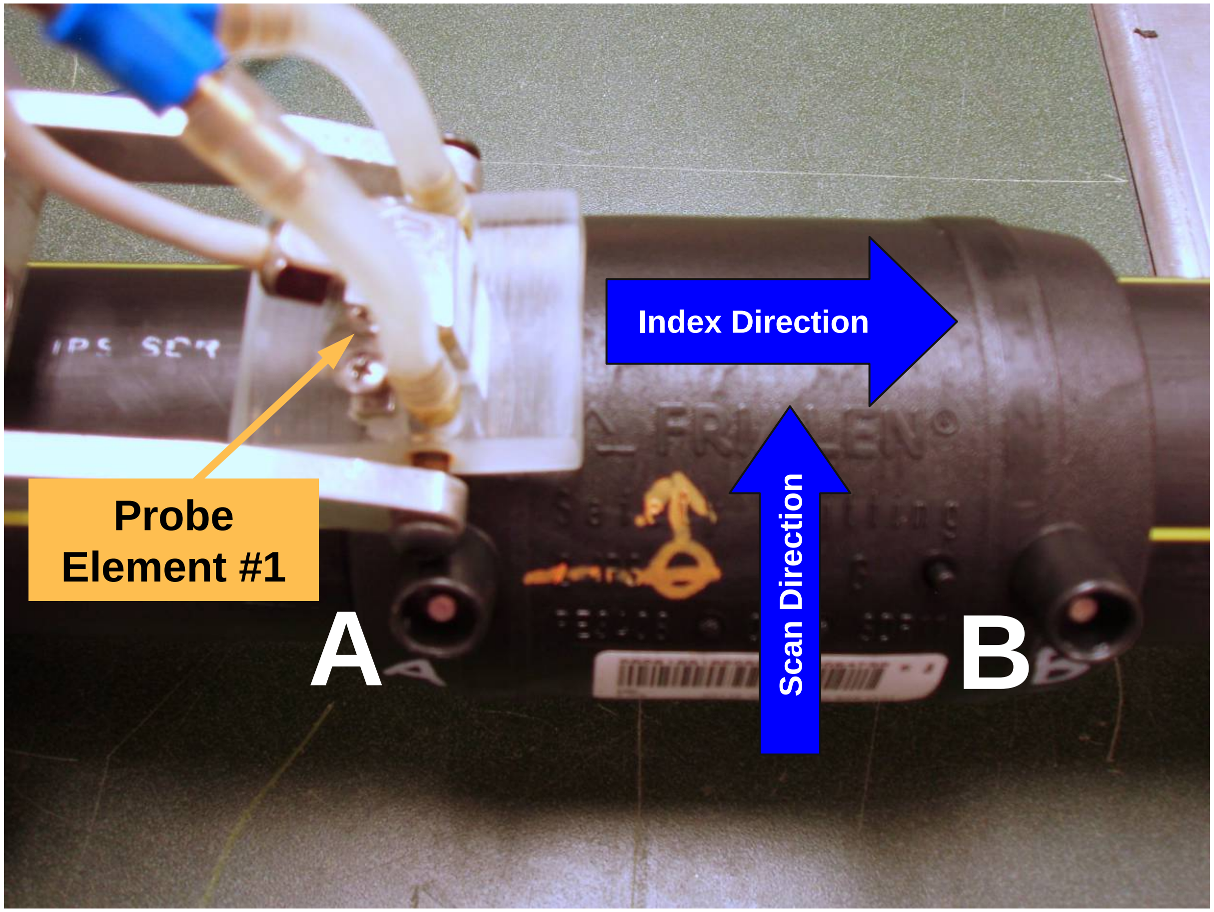


Probe Scan & Index
(6 inch Connector Cal. Sample)

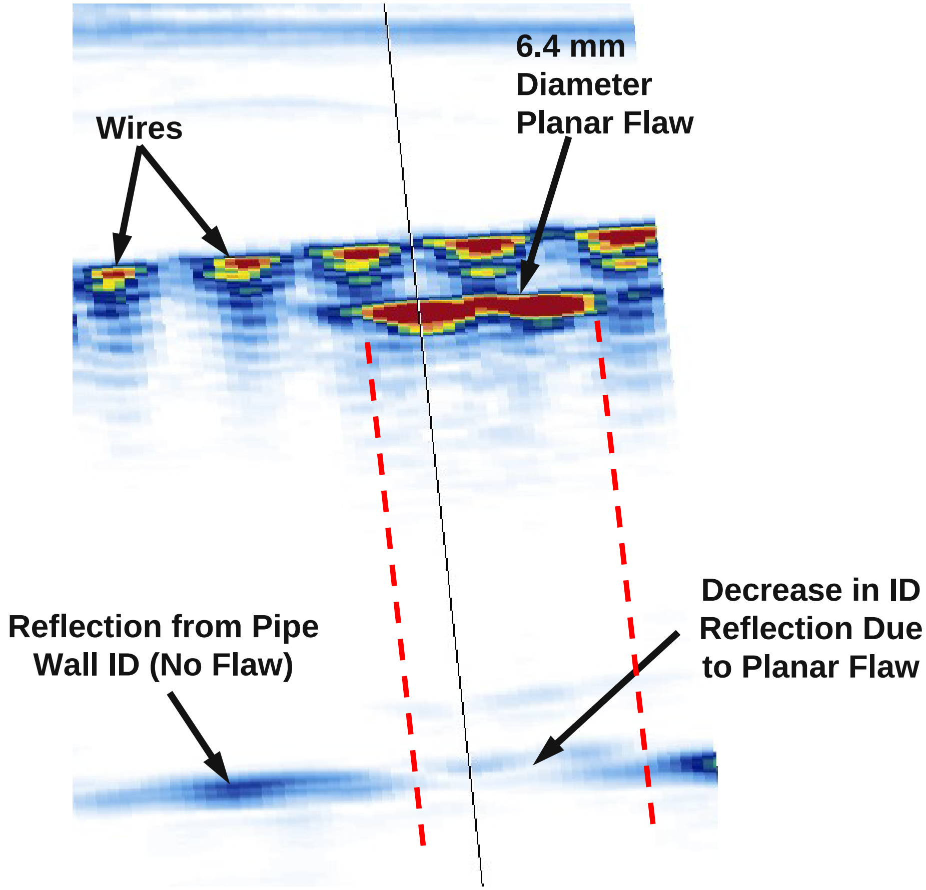


EWI THE MATERIALS JOINING EXPERTS

Probe Scan & Index
(2 inch Connector Cal. Sample)

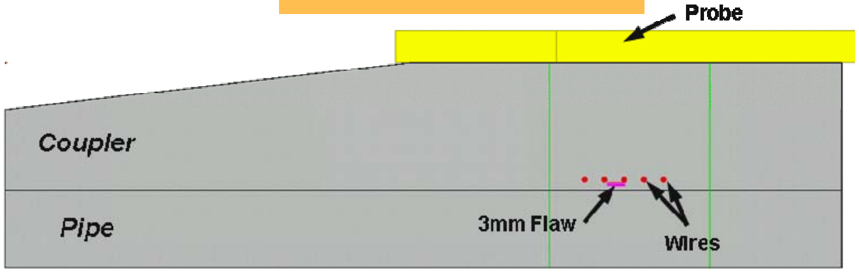


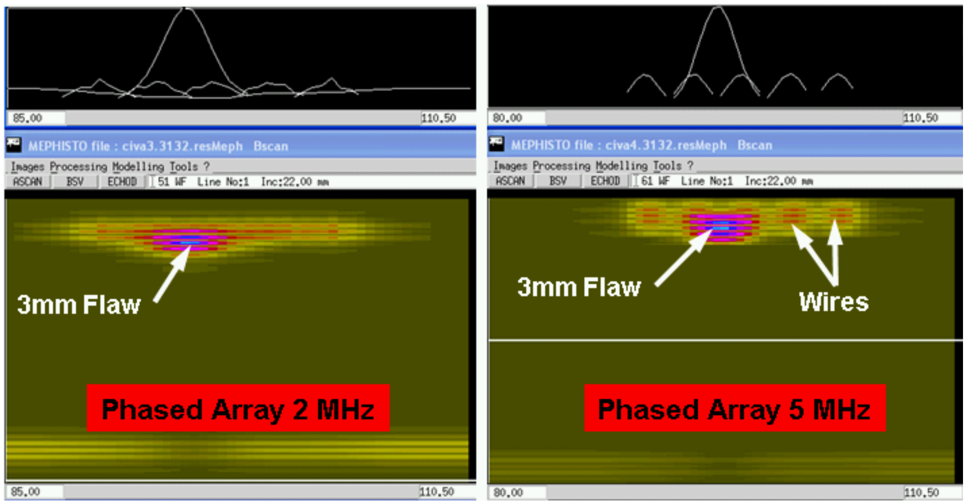
Effect of Flaw on ID Reflection



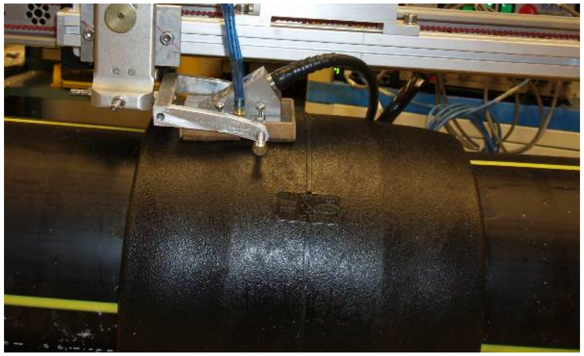
Ultrasonic Inspection Simulation and Flaw Interaction with Experimental Validation

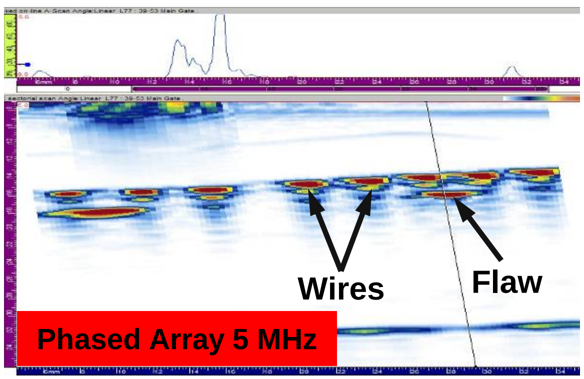
Simulation





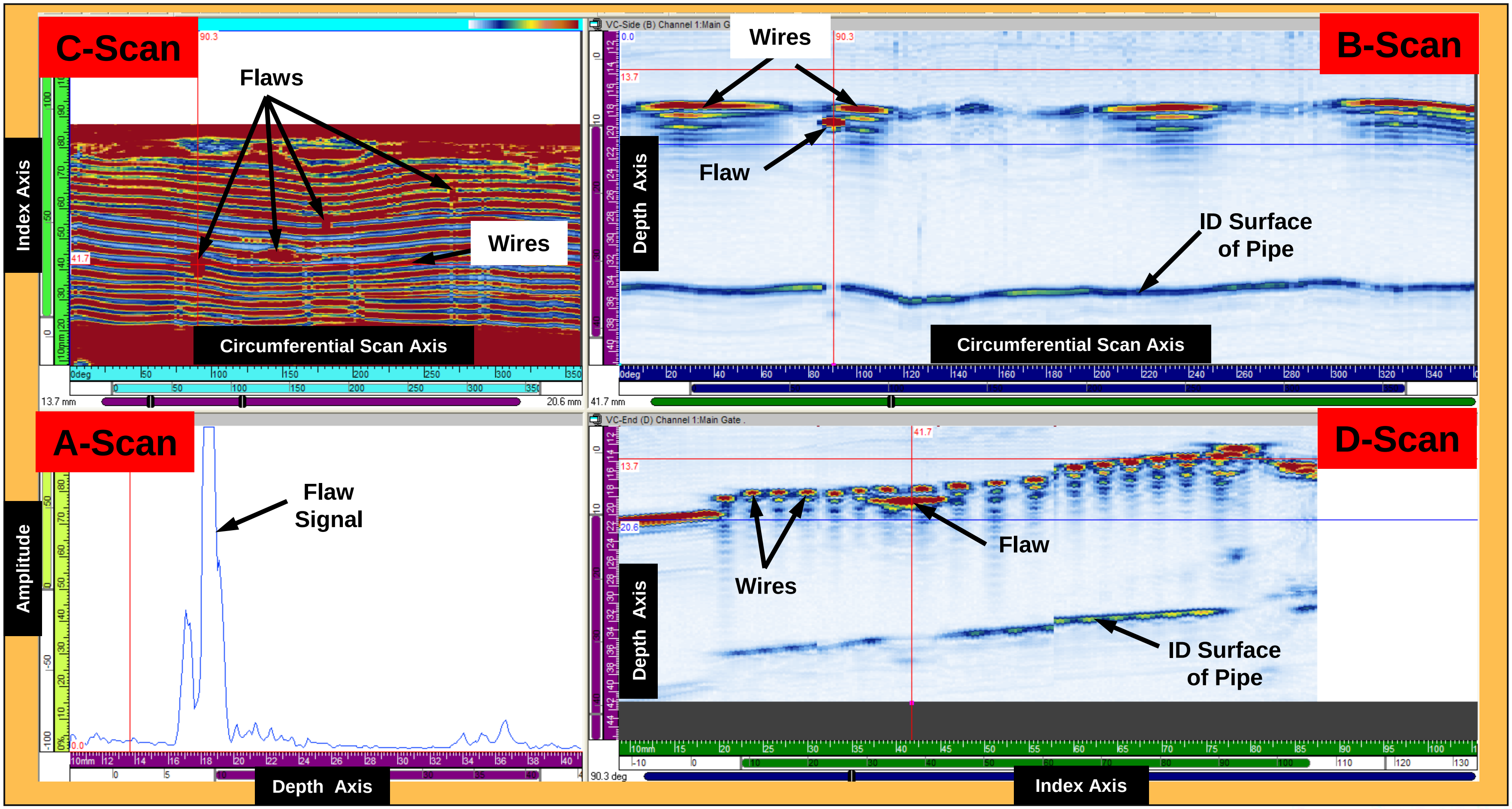
Experimental





Software simulation of the ultrasonic inspection technique provides essential information for inspection technique selection. Inspection technique simulation can be used to quickly determine if the inspection parameters will provide the necessary levels of resolution and flaw detection.

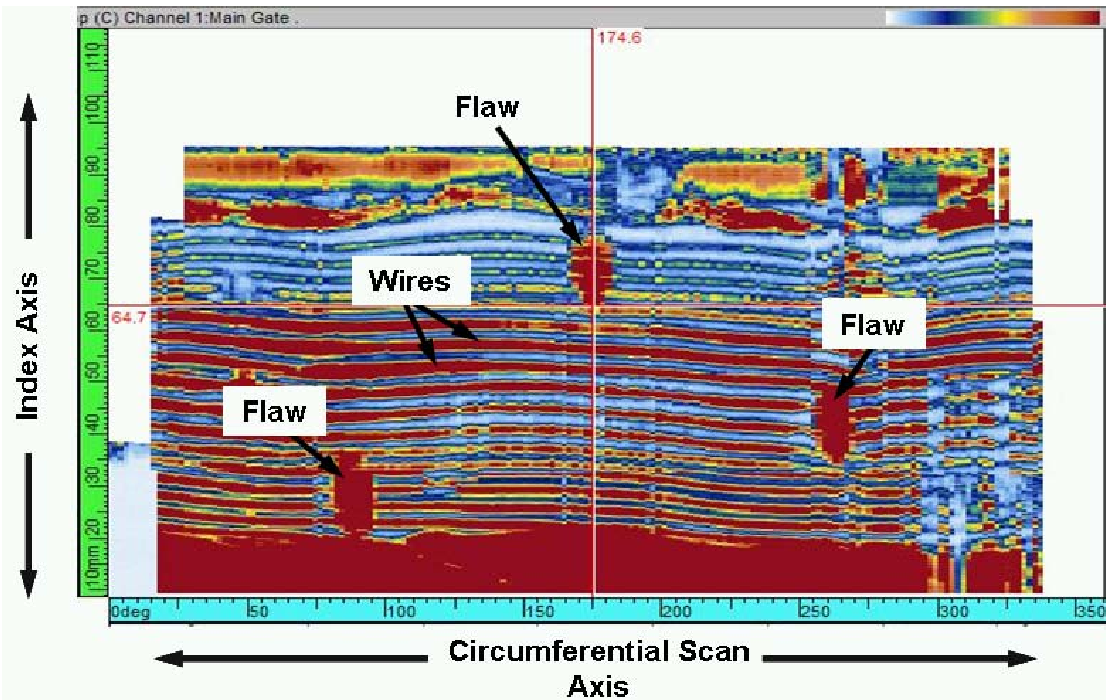
Multiple UT Scan Displays of Plastic Pipe Inspection Data



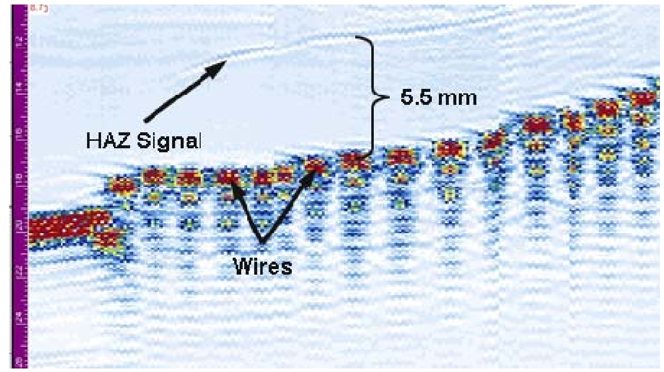
Multiple views of the ultrasonic data provides top, end, and circumferential position and sizing information

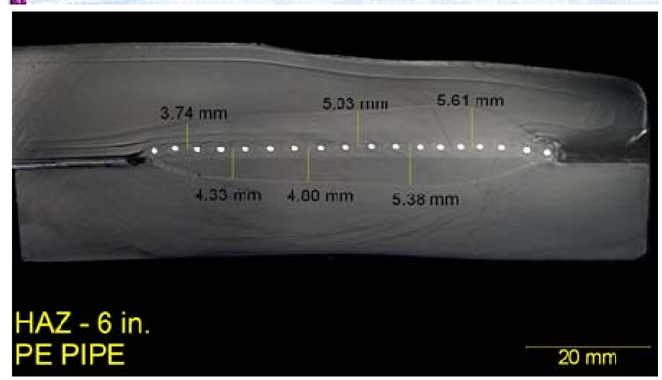
THE MATERIALS JOINING EXPERTS

C- and D-Scan Images of 6 inch Diameter EF Joint



The C-Scan image provides a complete 360° view of the entire joint area. Good imaging of the ultrasonic data is critical for quick and accurate determination of joint quality.



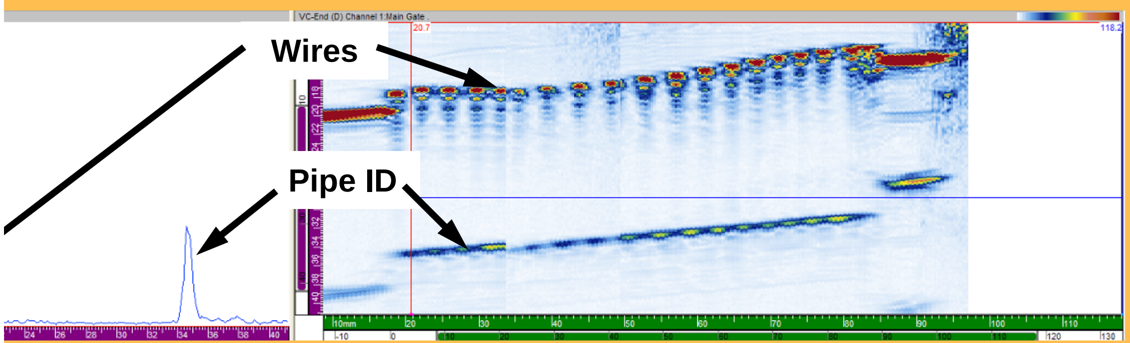


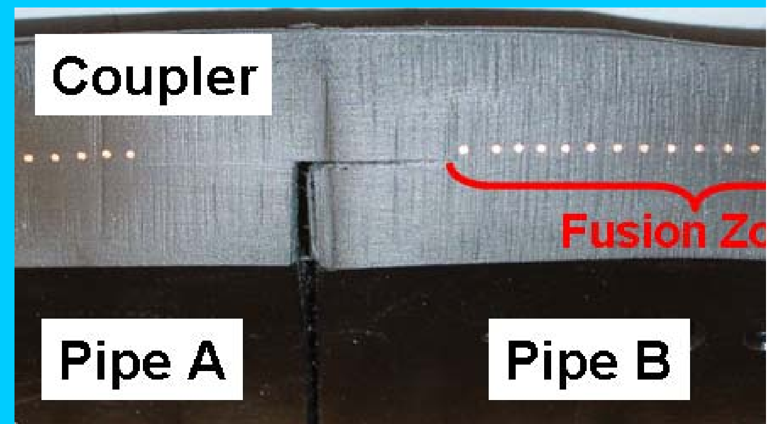
The D-Scan view can be used to determine depth of the heat affected zone (HAZ) and access the quality of the joint.

EWI®
THE MATERIALS JOINING EXPERTS

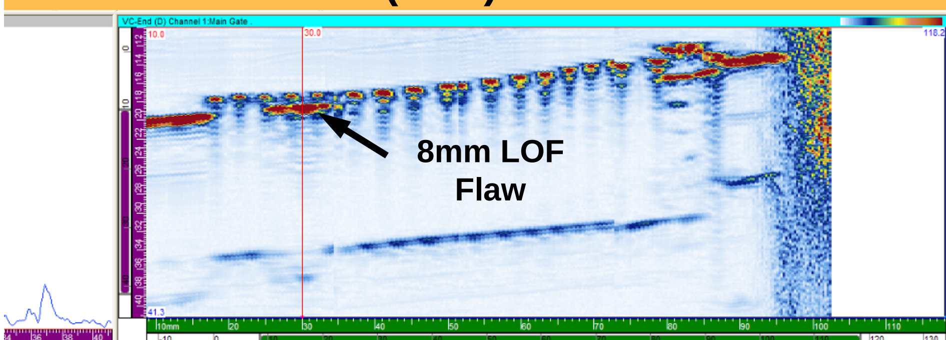
Examples of Flaws Detected by Phased Array UT

No Flaws

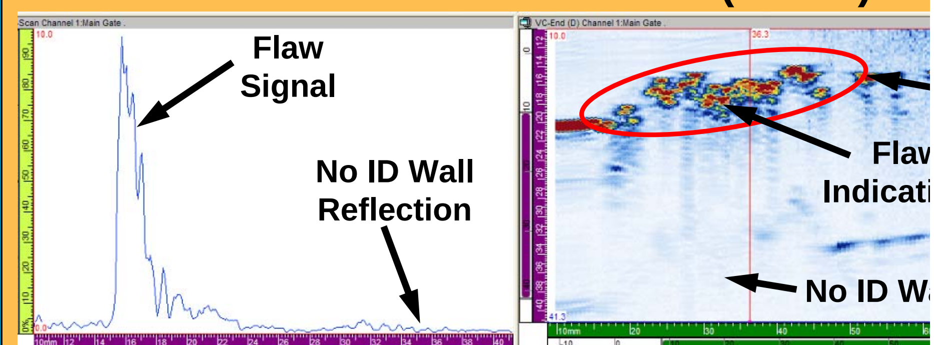




Lack of Fusion (LOF)

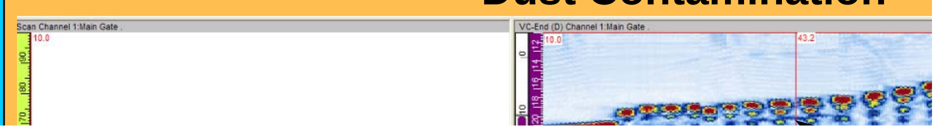


Short Stab (45mm)



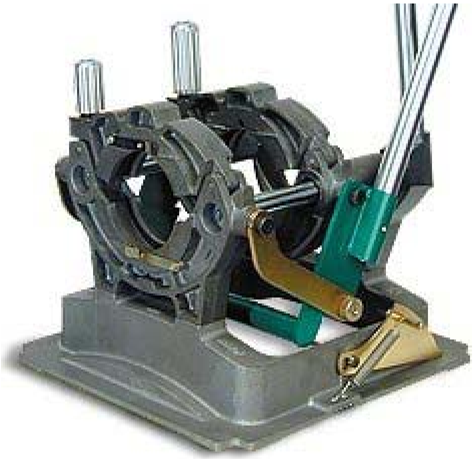
Sand Contamination

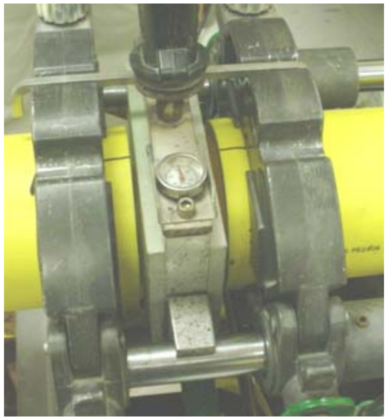
Dust Contamination

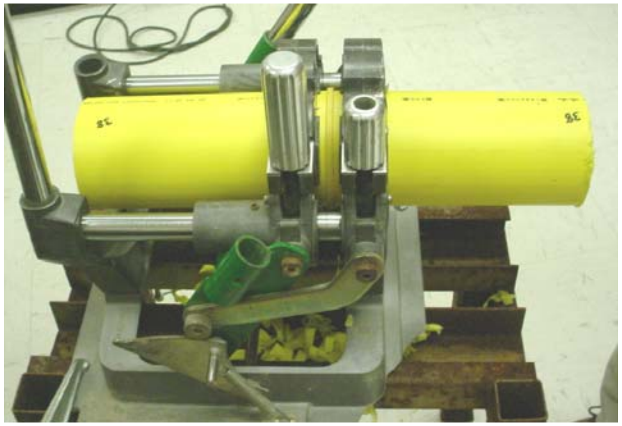


Phases of Fusion Welding

- Surface Preparation
  - Remove contaminates from surfaces
- Heating
  - Soften or melt polymer
  - EF is a thermal heating method
- Pressing
  - Intimate contact by flow and wetting
- Cooling
  - Material re-solidification







THE MATERIALS JOINING EXPERTS

BF Insertion of Flaws

- Flaws were inserted after separating the hot plate from the pipe ends prior to the forging phase

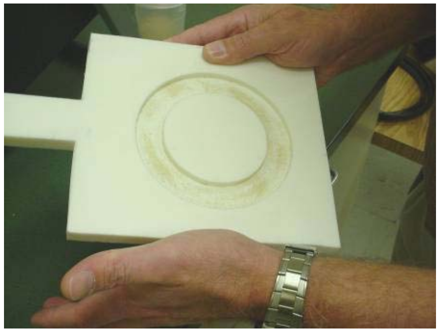
- Directly inserted flaws
  - Lack of fusion (polyimide adhesive tape)
    - 2, 3, 4, 5, 6, 7, 8 and 9 mm widths
  - Sand
    - Light (.5 grams), medium (1 gram), and heavy (1.5 grams)
  - Talc
    - Light (.3 grams), medium (.6 grams), and heavy (.9 grams)
  - Water (aluminum disks)
    - 2, 3, 4, 5, 6, 7, 8 and 9 mm diameters (.001" thick)

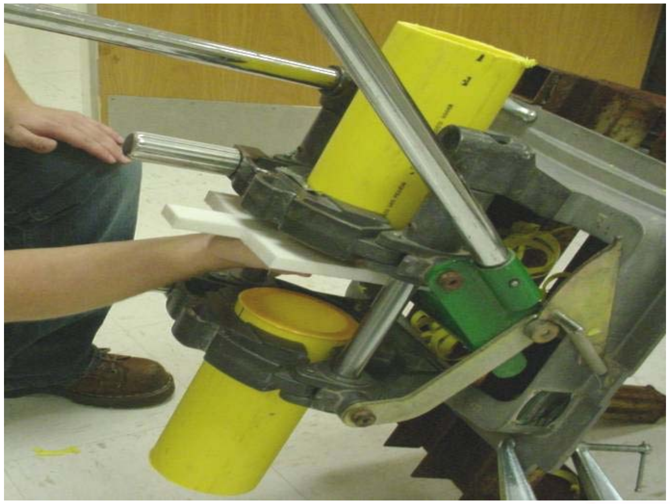
- Cold joints were the only defect that didn't introduce anything directly into the weld beads

THE MATERIALS JOINING EXPERTS

BF Sand/Talc Defects

- Sand or talc was evenly distributed within a machined channel
- Butt fusion welding machine was tilted and the tray was lightly pressed against the top weld bead
- It was applied quickly during change-over time between heating and forging





THE MATERIALS JOINING EXPERTS

BF Aluminum Disk Defects

- Aluminum disks of various sizes were quickly inserted during change-over time between heating and forging
  - One aluminum disk per sample

- Placed in the center of the weld bead to reduce the risk of squeezing the disk out during forging

THE MATERIALS JOINING EXPERTS

BF Cold Joint Defects

- In attempt to create cold joints, a limited number of samples were made in the following manner:
  - All 2 minute heating times (unless noted)
    - 1 open/ 1 blind samples: extended change-over time (20 sec.)
    - 3 open/ 4 blind samples: extended change-over time (40 sec.)
    - 1 open/ 1 blind samples: high forging pressure
    - 1 open/ 1 blind samples: pressure during end of heating (normal forging pressure)
    - 1 blind sample: pressure during end of heating (high forging pressure)
    - 2 open/ 3 blind samples: high pressure last 2-3 seconds of heating, light forging pressure
    - 1 blind sample: heating time 1 minute

EWI THE MATERIALS JOINING EXPERTS

BF Open Trial Matrix Table

- See BF open trial tables
- 3 no flaw samples
- 4 lack of fusion (polyimide adhesive tape) samples
  - Widths: 2, 5, 7, and 9 mm
- 8 cold joint samples
  - Specifics listed in previous slide
- 3 sand samples
  - 1 light, 1 medium, and 1 heavy contamination
- 3 talc samples
  - 1 light, 1 medium, and 1 heavy contamination
- 4 aluminum disk samples with multiple disks
  - 2, 5, 7, and 9 mm diameters

THE MATERIALS JOINING EXPERTS

BF Blind Trial Matrix Table

- Blind trial BF tables (confidential)

THE MATERIALS JOINING EXPERTS

Saddle Fusion Welding

- Saddle fusion welding involves heating a branch saddle fitting and pipe and bringing them together under pressure

SF Preparing Surfaces

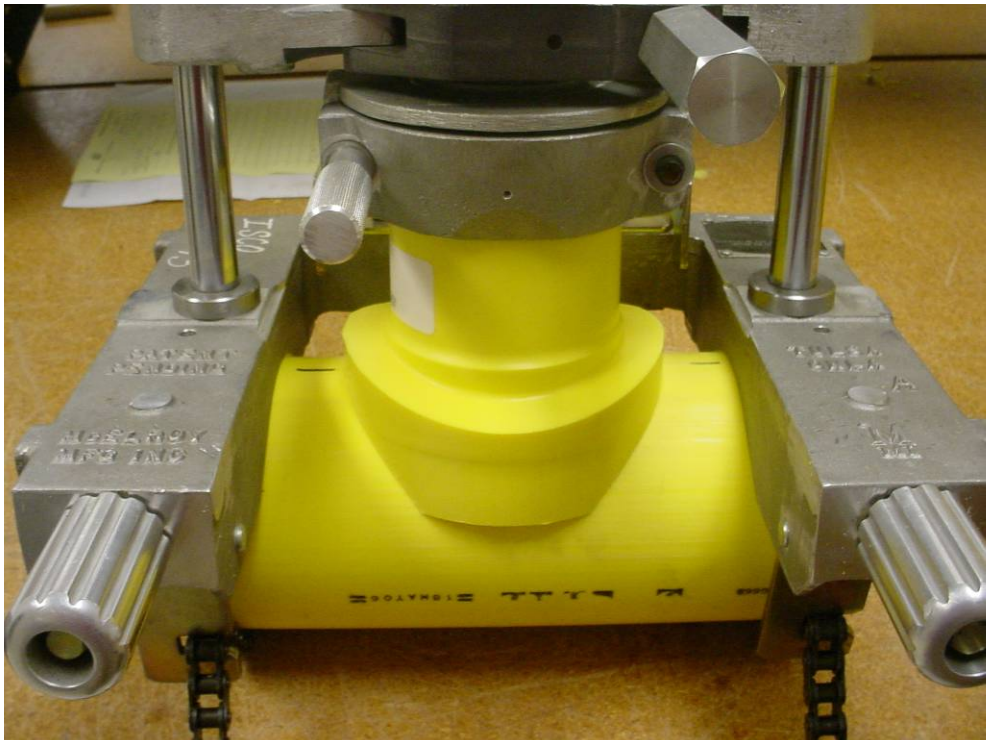
- 60 grit sand paper was used to remove oxidation layer and contaminants on both saddle and main
- Surfaces were wiped with clean, dry cloth

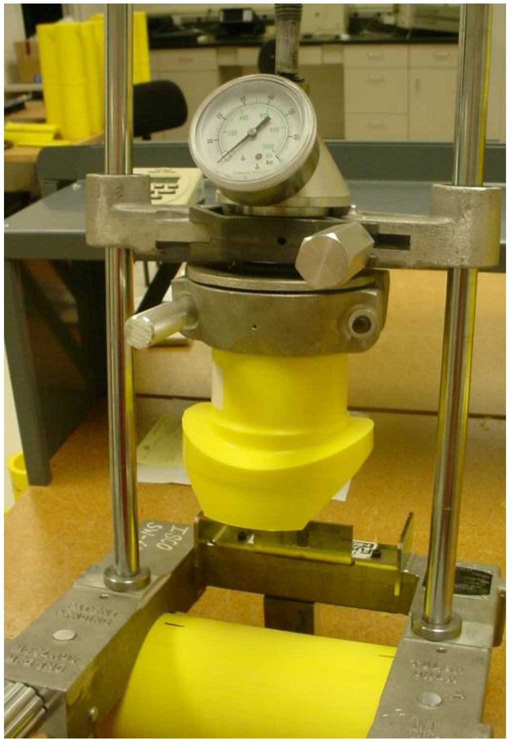


EWi THE MATERIALS JOINING EXPERTS

SF Sample Preparation

- Position branch to properly seat onto main
- Prepare for heating





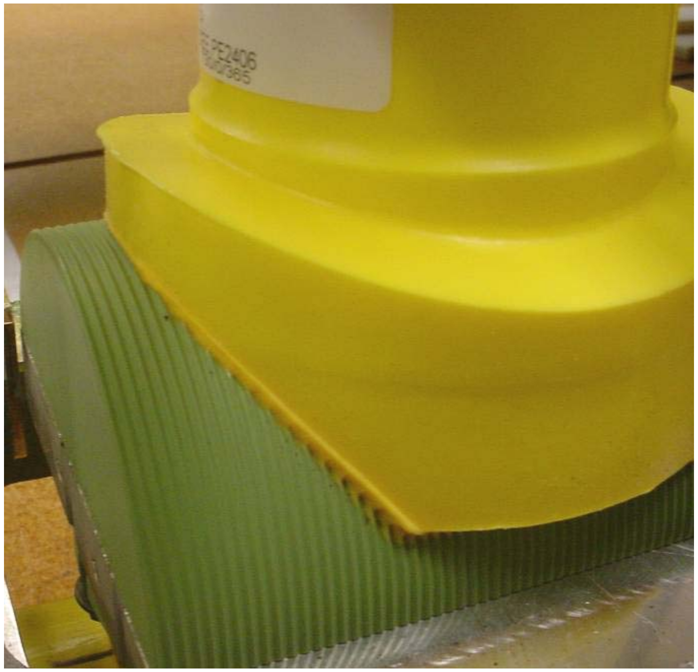
THE MATERIALS JOINING EXPERTS

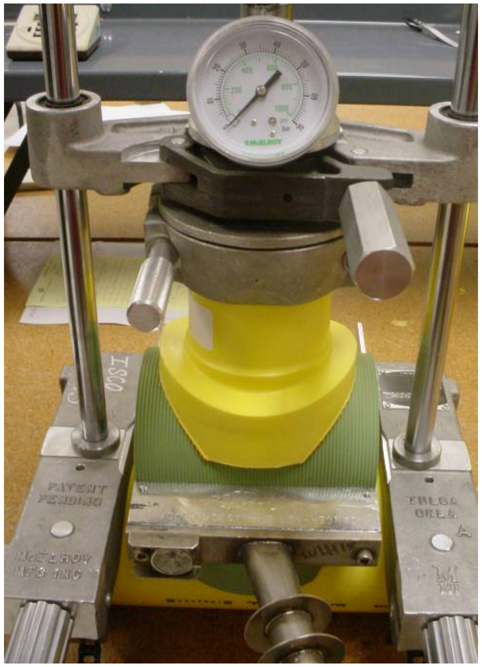
SF Initial Bead Formation

- Insert heating tool
  - Set – 450°F
  - Measured – 400°F
- Apply initial heat force
  - Suggested: 730 psi

SF Initial Bead Formation

- Reduce to heat soak pressure (0 psi) when bead starts to develop on crown of main





THE MATERIALS JOINING EXPERTS

SF Fusion/Cooling

- Allow heat to soak for 1 minute
- Immediately bring saddle fitting down to main
- Apply fusion pressure (suggested: 365 psi)
- Allow to cool for 10 minutes
  - 30 minutes before rough handling

EWI THE MATERIALS JOINING EXPERTS

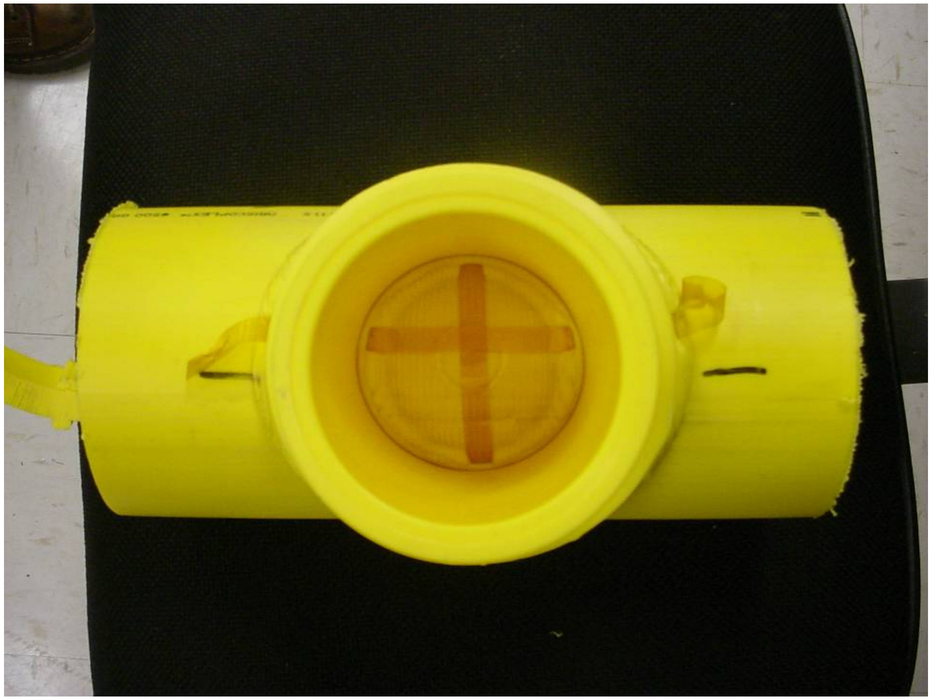
SF Defect Insertion

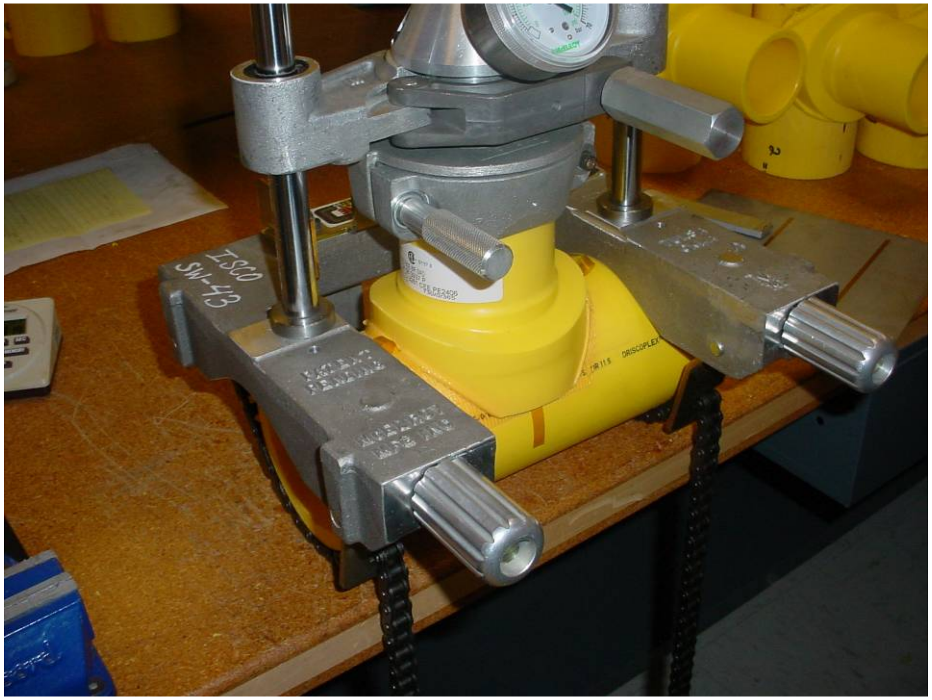
- Defects were inserted after separating the heater plate from the main and saddle fitting prior to the forging phase

- Directly inserted flaws
  - Lack of fusion (polyimide adhesive tape)
    - 2, 4, 6, 8 and 10 mm widths in crossing pattern
  - Water (aluminum strips)
    - 2, 4, 6, 8 and 10 mm diameters (.001” thick) in crossing pattern

EWI THE MATERIALS JOINING EXPERTS

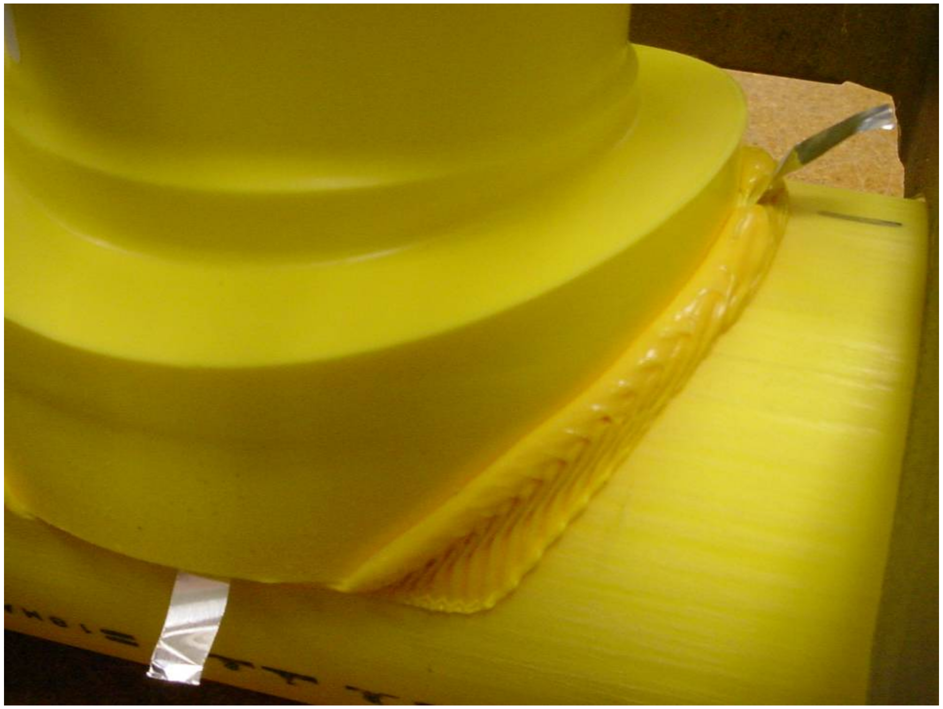
SF Lack of Fusion Defects

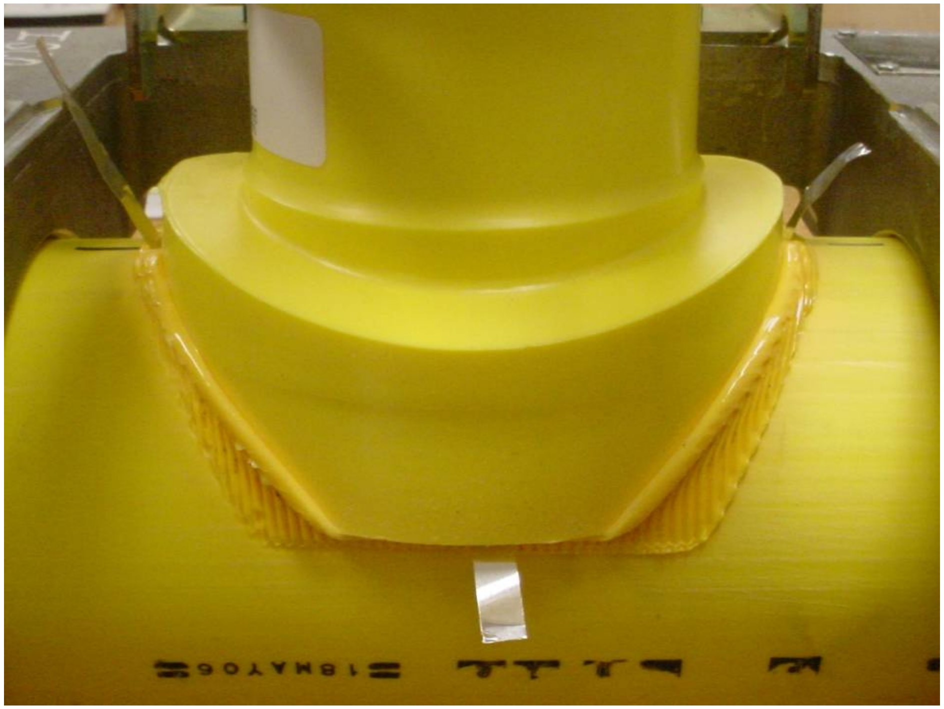




THE MATERIALS JOINING EXPERTS

SF Aluminum Strips Defects





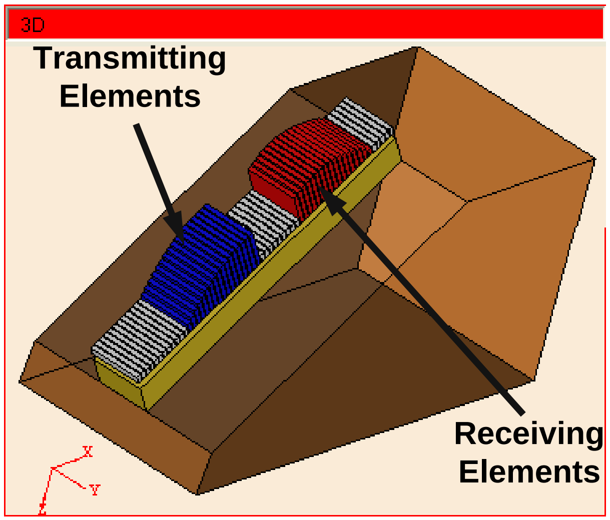
THE MATERIALS JOINING EXPERTS

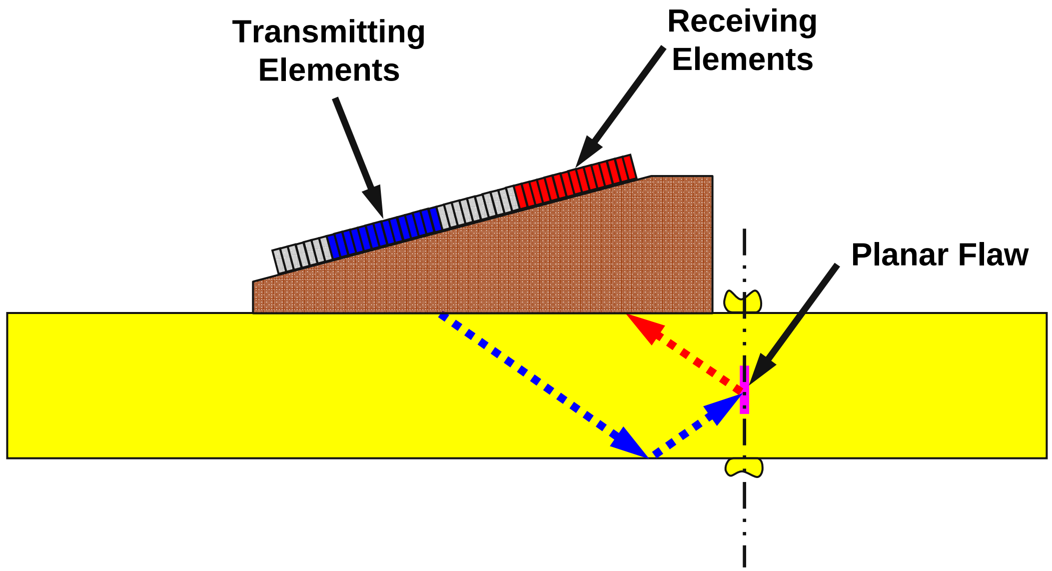
SF Open Matrix Table

- See SF open trial tables
- 2 no flaw samples
- 6 lack of fusion (polyimide adhesive tape) samples
  - Widths: 2, 4, 6, 8, and 10 mm
- 6 aluminum strip samples
  - 2, 4, 6, 8, and 10 mm diameters

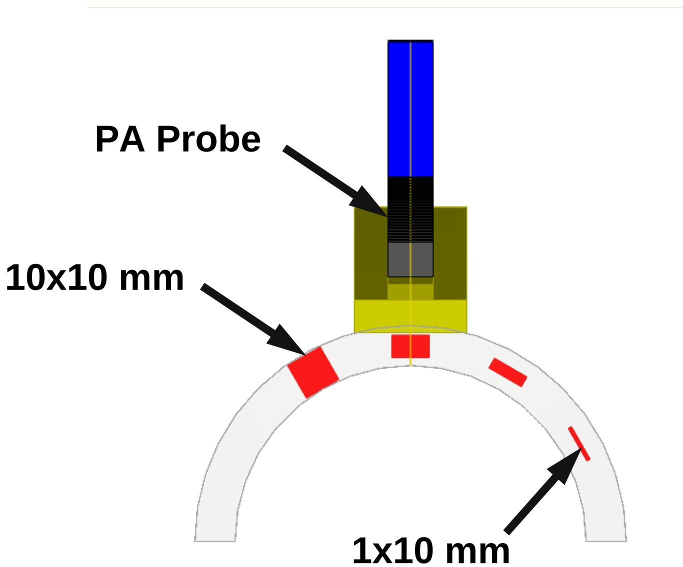
THE MATERIALS JOINING EXPERTS

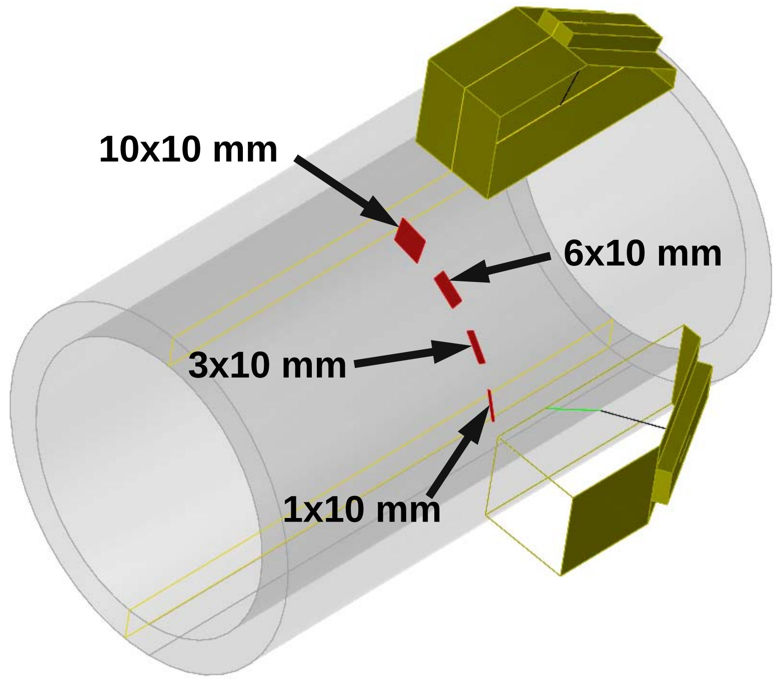
Pitch Catch (Tandem) Technique on Butt Fusion Joint





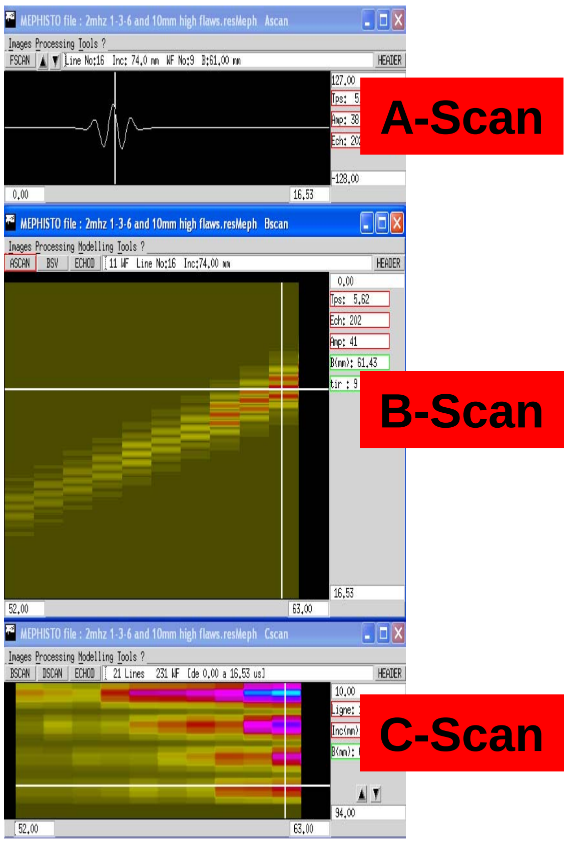
Butt Weld Flaw Interaction Tandem Technique

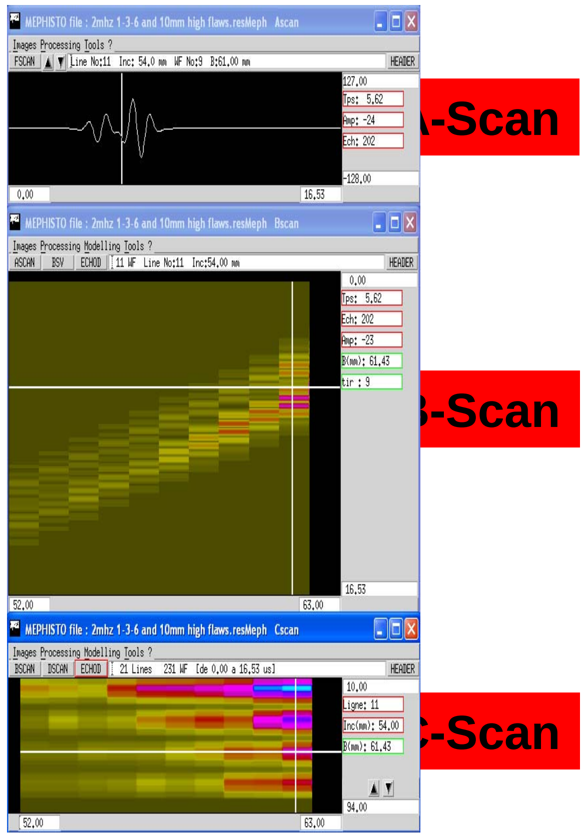


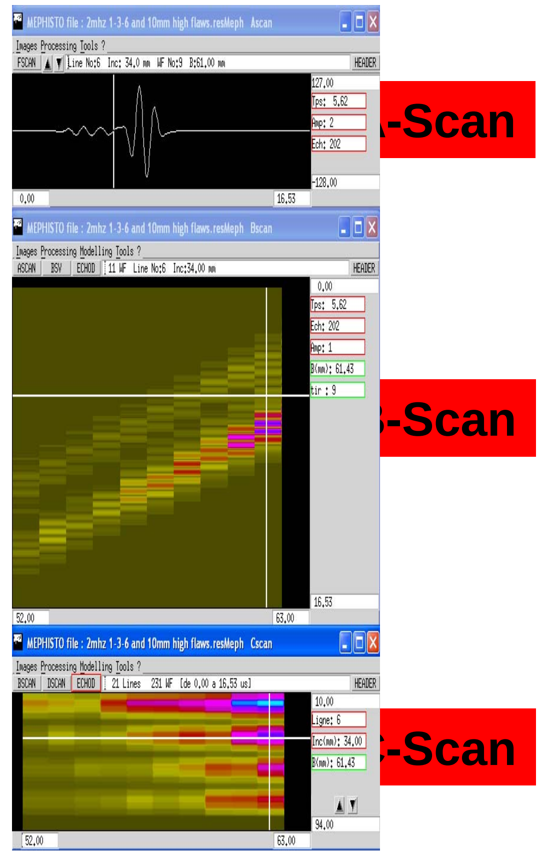


THE MATERIALS JOINING EXPERTS

Butt Weld Flaw Interaction Response (1, 3, 6 x 10 mm Flaws)







THE MATERIALS JOINING EXPERTS

Task 5 – Validate the Optimized PA Procedures (Funding Source: DOT/PHMSA and Industry In-kind)

- An open trial on 70 EF samples was performed to validate optimized PA procedures using EWI equipment (Focus and LT Focus).
- An open trial on 18 EF samples was performed to validate optimized PA procedures using Omniscan (Olympus –RD Tech) TD Focus (TD), M2M (M2M), Phasor (GE Inspection) and X-32 (Harfang) equipment.
- Mechanical Integrity and JANX operators/inspectors were trained to perform PA testing of EF joints using the optimized procedures. EWI provided the best calibration techniques, equipment settings, scanners and scan techniques for the variety of detects in the optimized PA procedure. Provided training materials are presented in Appendix C.

EWI THE MATERIALS JOINING EXPERTS

Task 5 – Validate the Optimized PA Procedures (Funding Source: DOT/PHMSA and Industry In-kind) (cont.)

- An open trial on 40 butt-fusion and saddle-fusion joints was performed to validate optimized PA procedures using EWI equipment Focus and LT Focus. (expanded DOT scope).
- Optimized PA findings were validated destructively on limited samples to verify some defects.

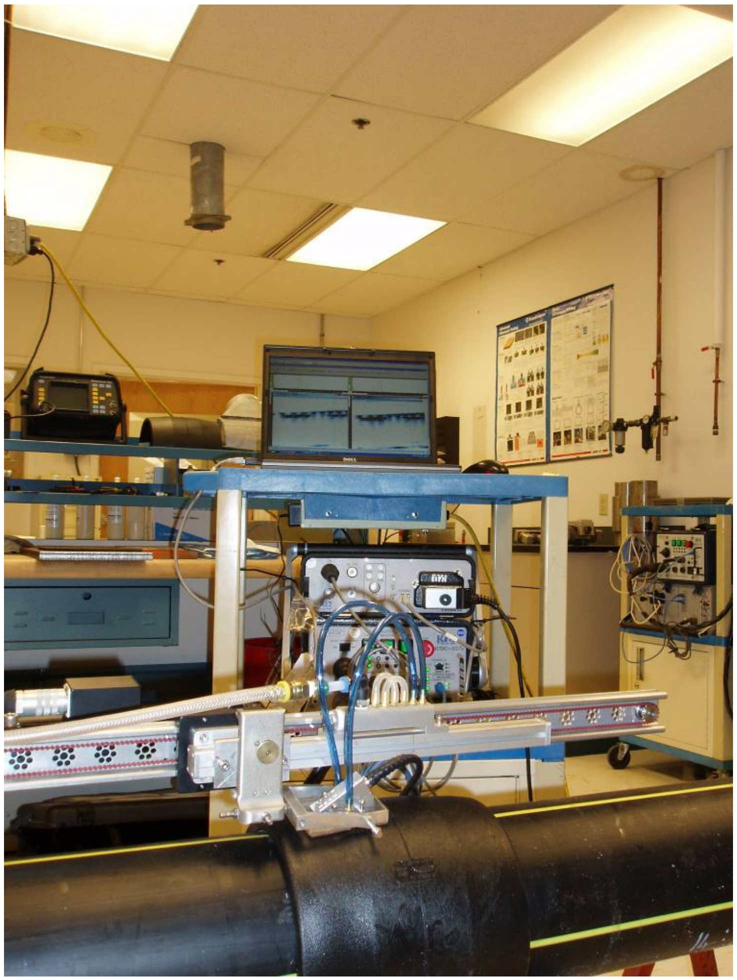
EWI THE MATERIALS JOINING EXPERTS

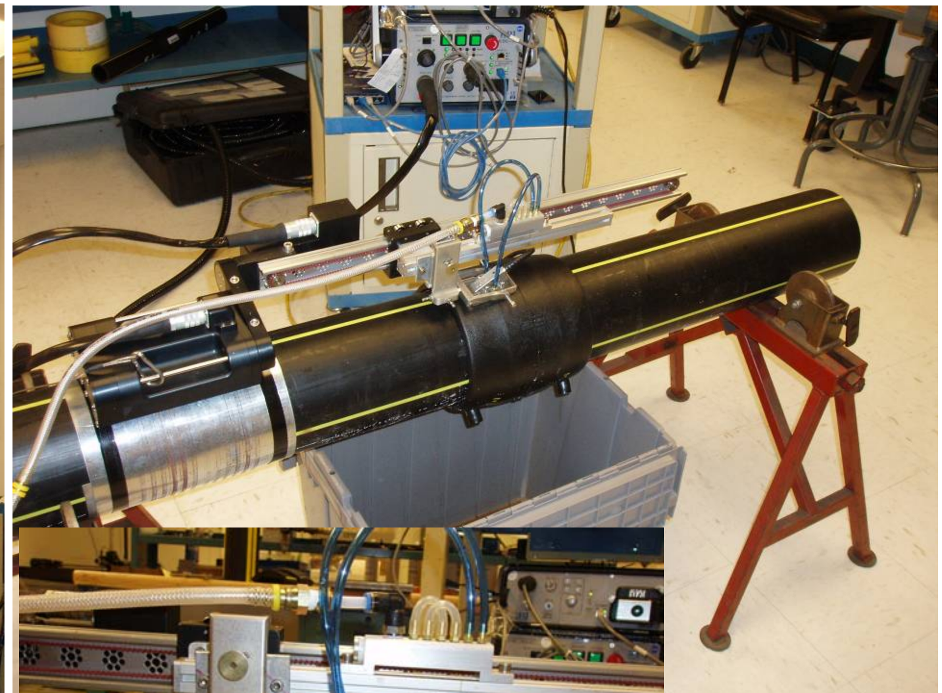
Task 5 – Instruments Used

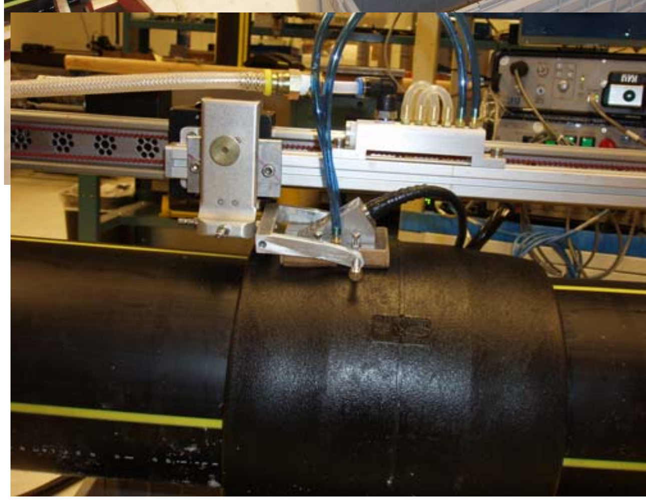
- Olympus NDT: Focus
- Olympus NDT: Focus LT
- Olympus NDT: Omni Scan
- Technology Design: TD-Focus
- Bercli: M2M
- GE: Phasor XS
- Harfang: X-32

THE MATERIALS JOINING EXPERTS

Validation of Optimized PA Procedures – Focus & Focus LT

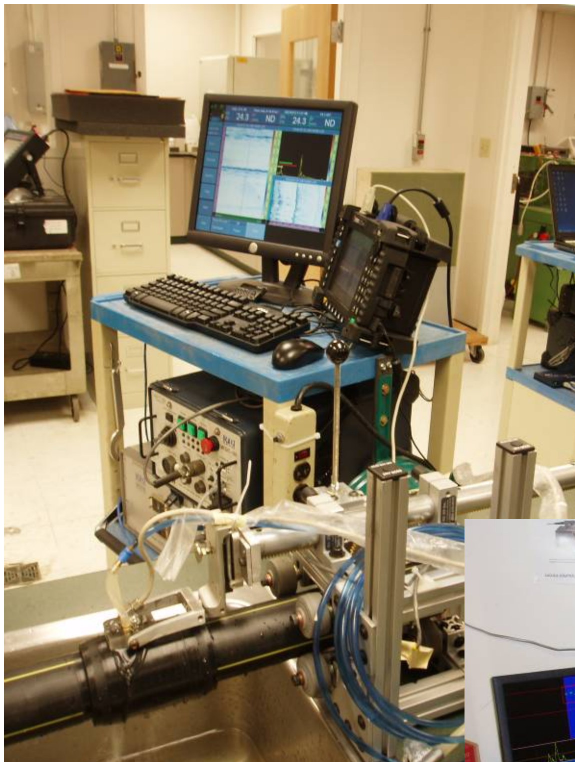


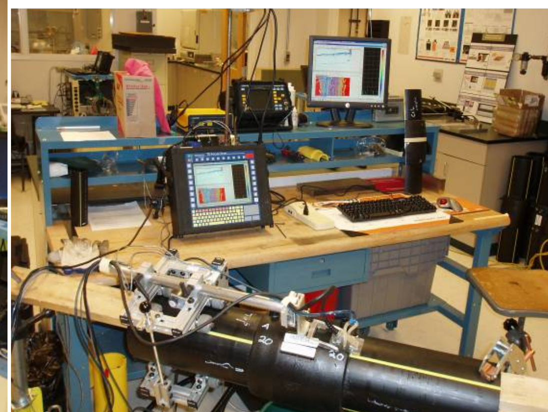


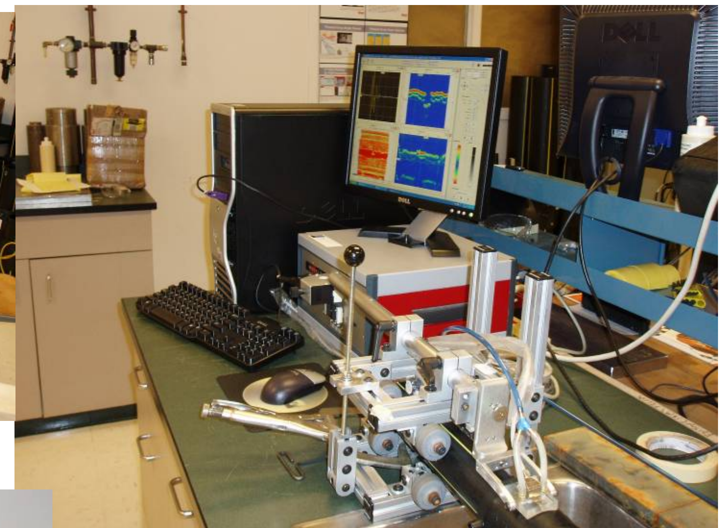


THE MATERIALS JOINING EXPERTS

Validation of Optimized PA Procedures – Omniscan & TD Focus & M2M & X-32 & Phasor







EWI
THE MATERIALS JOINING EXPERTS

6 inch Instrument Comparisons (see IC file)

THE MATERIALS JOINING EXPERTS

6 inch Comparisons

Flaw	Comparison Parameter	Tomoscan		Omniscan		TD Focus		M2M	
		Circ.	Long.	Circ.	Long.	Circ.	Long.	Circ.	Long.
Alum. Disk	Systematic Error	7.2	1.3	6.5	0.9	8.2	0.8	6.4	NA
	Range	5.6	3.9	4.7	3.9	10.5	3.3	8.8	NA
	Std. Dev.	1.5	1.2	1.6	1.2	3.4	1.0	2.9	NA
	95% Limit against undersizing	-4.7	0.7	-3.9	1.0	-2.6	0.8	-1.6	NA
Short Stab	Systematic Error		-1.6		3.3		2.5		3.3
	Range		9.0		11.8		7.8		12.0
	Std. Dev.		3.6		4.3		2.9		5.1
	95% Limit against undersizing		7.4		3.8		2.3		5.0
Heavy Sand	Amplitude (%)		100		72.5		80.7		85
Heavy Sand	Amplitude (%)		100		91		93.3		100
Medium Sand	Amplitude (%)		100		100		95.6		85
Medium Sand	Amplitude (%)		100		100		64		85
Light Sand	Amplitude (%)		63.1		58.4		55.8		85
Light Sand	Amplitude (%)		50.2		31.8		29.3		90
Heavy Talc	Amplitude (%)		47.5		23.9		21.4		50
Heavy Talc	Amplitude (%)		43.5		22		21		35
Medium Talc	Amplitude (%)		23.9		0		0		30
Medium Talc	Amplitude (%)		24.7		0		13.3		15
Light Talc	Amplitude (%)		0		0		0		20
Light Talc	Amplitude (%)		19.6		0		0		0

EWI
THE MATERIALS JOINING EXPERTS

2 inch Comparisons

Flaw	Comparison Parameter	Tomoscan		Omniscan		TD Focus		M2M	
		Circ.	Long.	Circ.	Long.	Circ.	Long.	Circ.	Long.
Alum. Disk	Systematic Error	2.2	-0.3	3.3	-0.4	3.8	-0.2	0.6	-0.9
	Range	5.3	1.3	5.1	1.3	1.3	1.5	3.2	1.9
	Std. Dev.	2.2	0.5	2.2	0.6	0.6	0.7	1.6	0.8
	95% Limit against undersizing	1.4	1.2	0.3	1.4	-2.9	1.3	2.0	2.2
Short Stab	Systematic Error		0.8		2.1		0.8		0.8
	Range		5.2		4.4		5.2		3.6
	Std. Dev.		2.0		1.6		2.0		1.5
	95% Limit against undersizing		2.5		0.6		2.5		1.6
Heavy Sand	Amplitude (%)		38.4		29.8		34.5		0
Medium Sand	Amplitude (%)		37.3		29		28.9		0
Light Sand	Amplitude (%)		22.7		0		15.8		0
Heavy Talc	Amplitude (%)		0		0		0		0
Medium Talc	Amplitude (%)		0		0		0		0
Light Talc	Amplitude (%)		0		0		0		0

THE MATERIALS JOINING EXPERTS

6” Pipe – Focus Lens and Matrix Probe Comparisons

- See Tabbed Sections in Back of Book
  - "Scans with Focusing Lens"
  - "Scans with Matrix Probe"

6” Pipe – Cold Joints and UV Damage

- See Tab Section in Back of Book
  - "HAZ of UV Damage"

THE MATERIALS JOINING EXPERTS

PA Training and Blind Trials – Focus, Focus LT, TD Focus & Omniscan

THE MATERIALS JOINING EXPERTS

Task 6 – Determine the Performance (Funding Source: DOT/PHMSA and Industry In-kind)

- Participating service providers and EWI engineers performed blind EF trials with optimized Focus, TD Focus and Omniscan equipment and procedure.
- POD and sizing capabilities of multiple PA systems and multiple inspectors were evaluated on statistically valid examples with Al disks with limited destructive validation.

THE MATERIALS JOINING EXPERTS

Task 6 – Determine the Performance (Funding Source: DOT/PHMSA and Industry In-kind) (cont.)

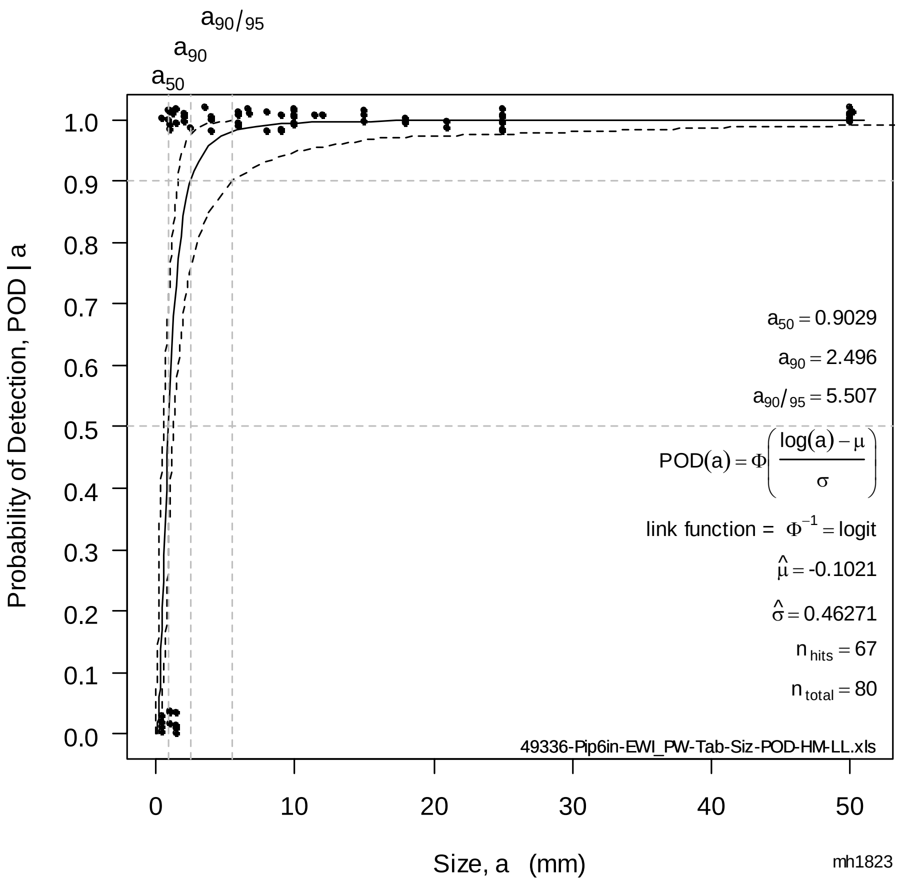
- Probability of detection (POD) and accuracy of sizing curves for EF joints were developed for samples with implanted Al disk .
- POD and accuracy of sizing curves for the remaining EF joints will be developed after the destructive testing of the samples during the Phase III of EF joints program.

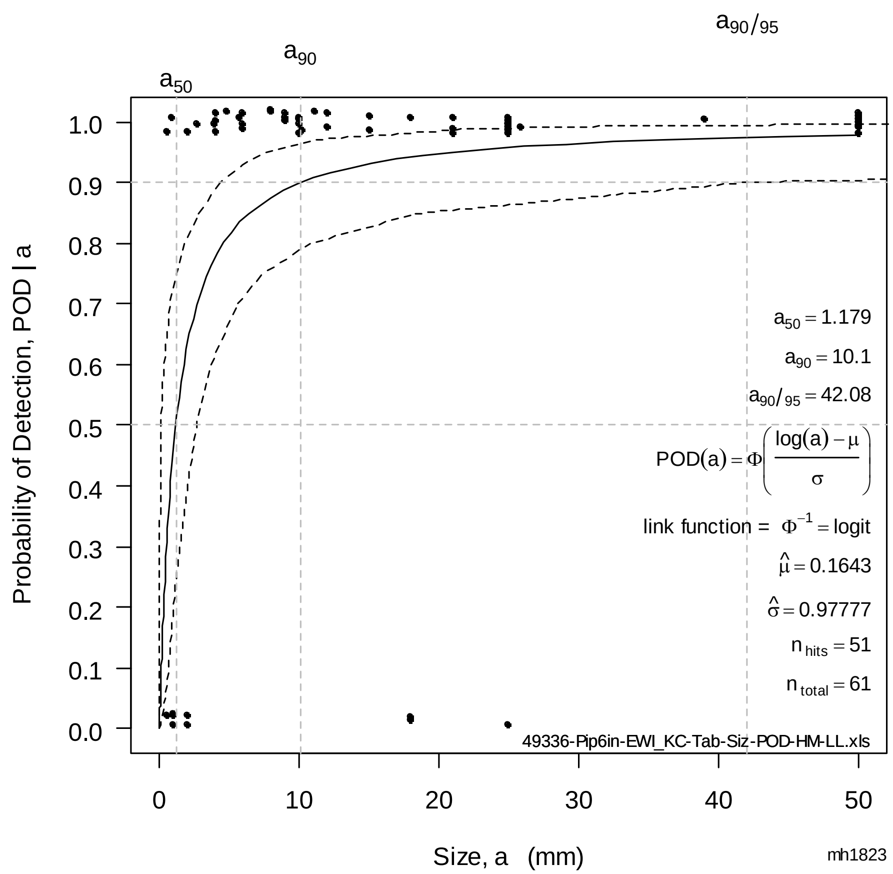
EWI THE MATERIALS JOINING EXPERTS

POD Analysis - a50, a90 and a90/95

- **a50** – defect size with 50% POD and 50% confidence. This means that 50% of the defect with this size will be detected and this is true in 50% of the inspections under similar conditions (equipment, operators, environment etc.)
- **a90** – defect size with 90% POD and 50% confidence. This means that 90% of the defect with this size will be detected and this is true in 50% of the inspections under similar conditions (equipment, operators, environment etc.)
- **a90/95** – defect size with 90% POD and 95% confidence. This is the most quoted parameter in the literature. It means that 90% of the defect with this size will be detected and this is true in 95% of the inspections under similar conditions (equipment, operators, environment etc.)

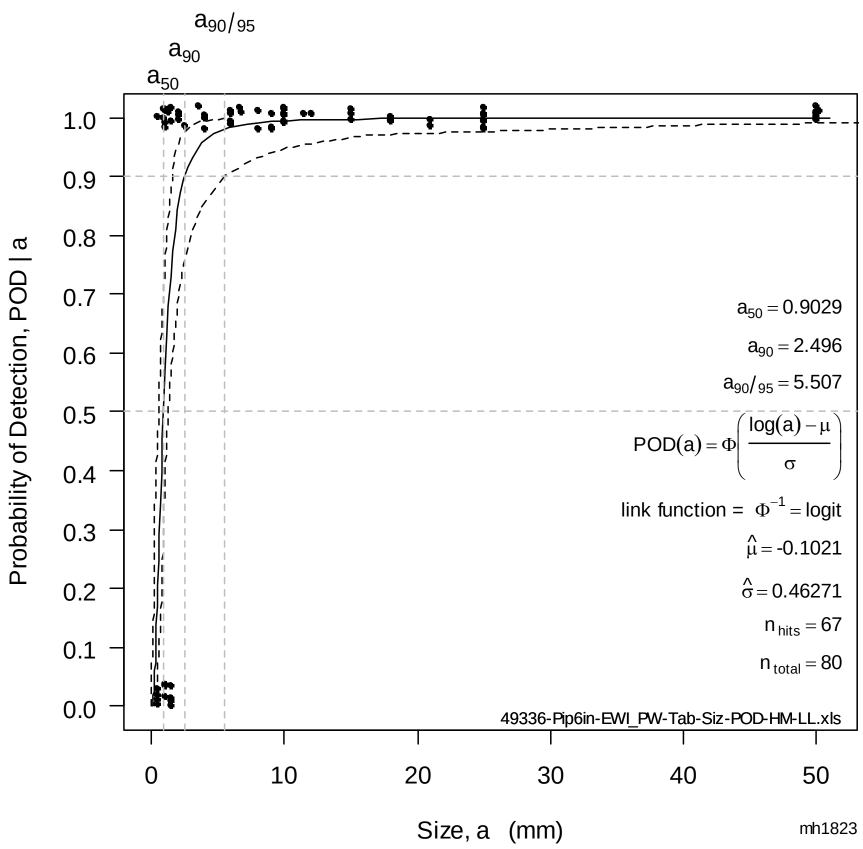
POD Plots – Company 1, Operator 1 vs. 2

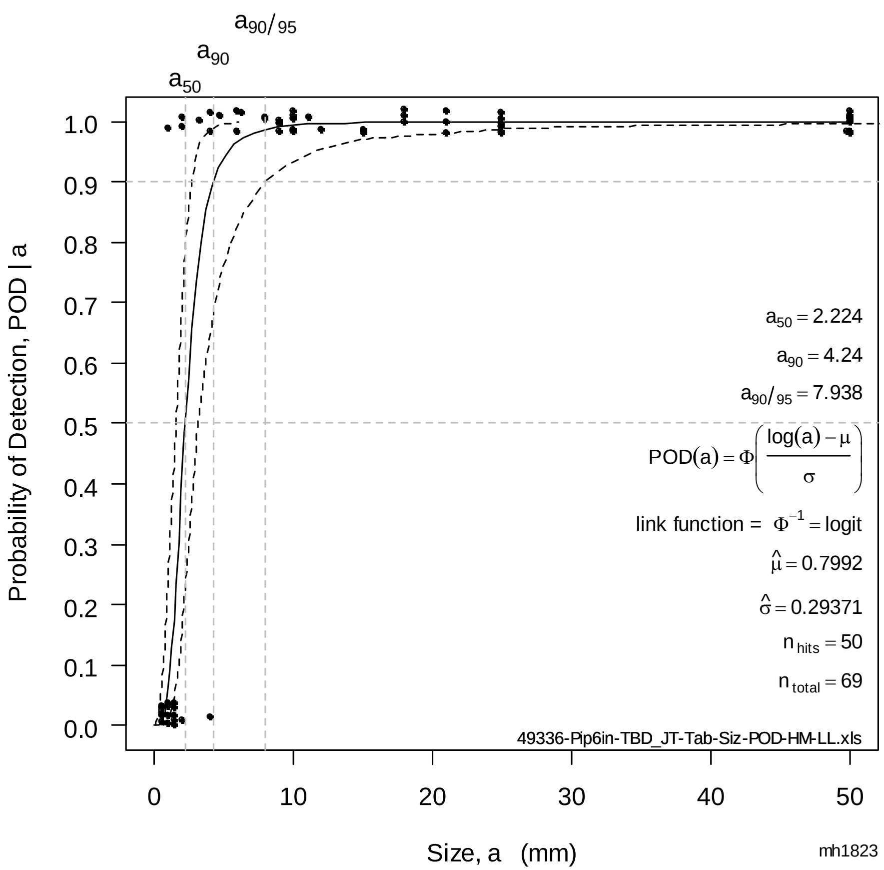




EWI THE MATERIALS JOINING EXPERTS

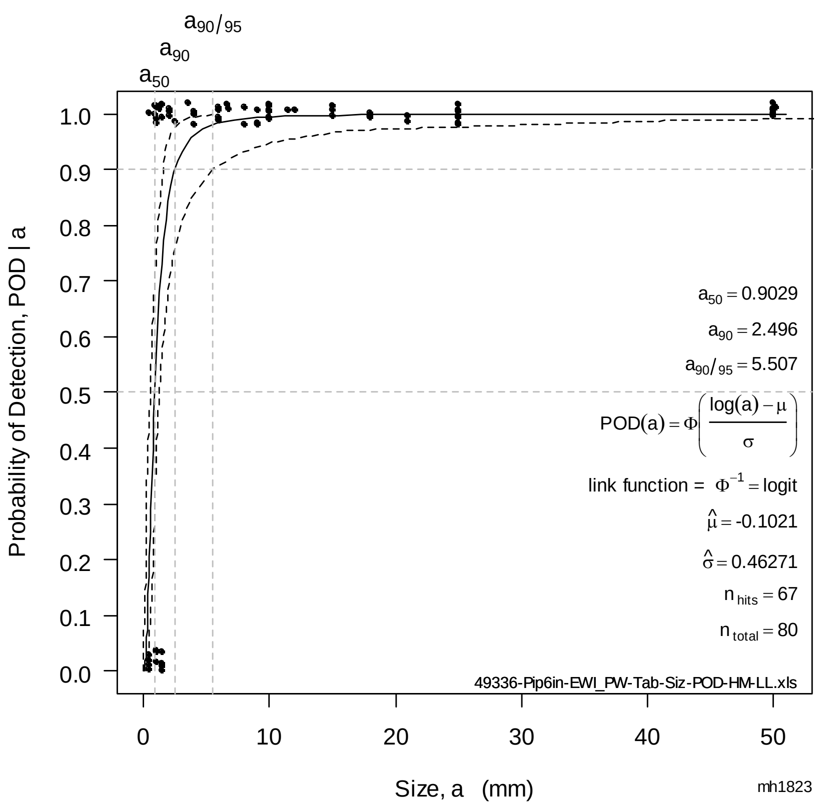
POD Plots - Instrument 1, Operator 1 vs. 3

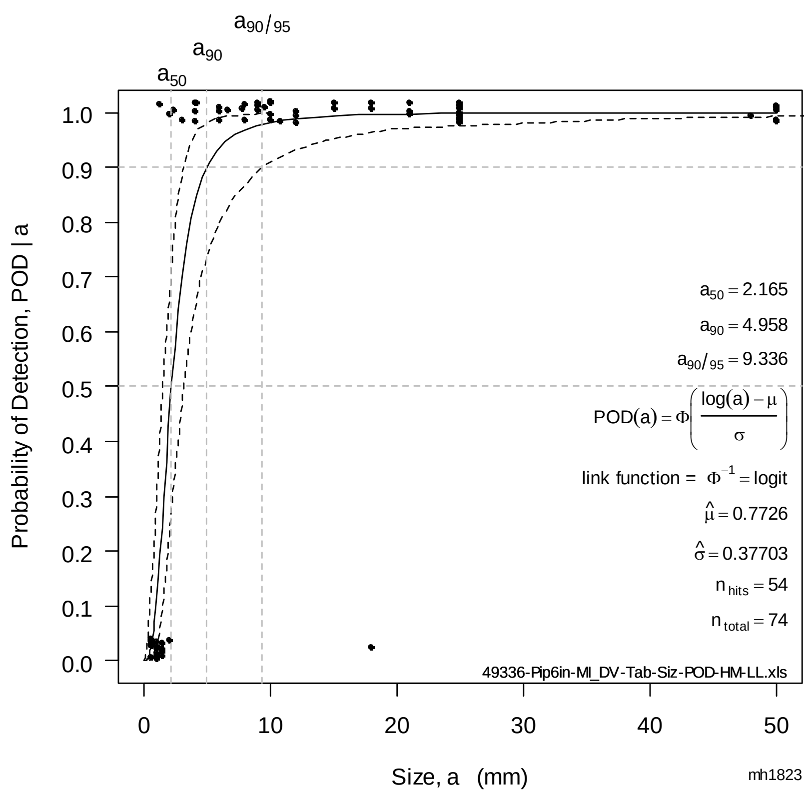




THE MATERIALS JOINING EXPERTS

POD Plots - Instrument 1 and 2 , Operator 1 and 4





THE MATERIALS JOINING EXPERTS

Sizing Analysis - Average and Standard Deviation 95% Lower Limit Against Under-Sizing

(6) $$\bar{\varepsilon} = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)}{n}$$

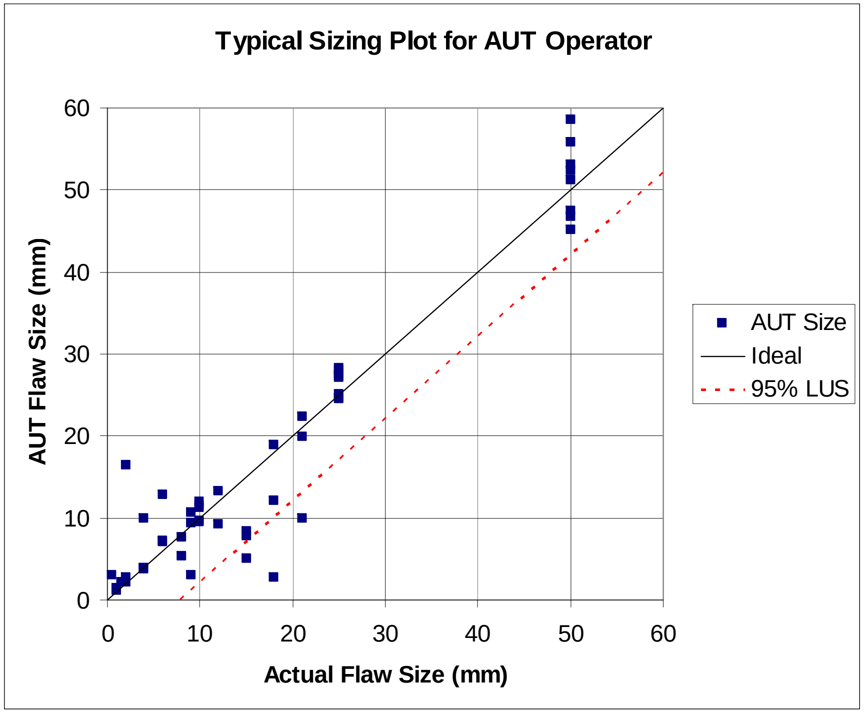
(7) $$sd_{\varepsilon} = \sqrt{\frac{\sum_{i=1}^{n} (\varepsilon_i - \bar{\varepsilon})^2}{n-1}}$$

(8) $$-95\%LUS = t.sd_{\varepsilon} - \bar{\varepsilon},$$

Where t is Student's distribution with 5% one tail probability. The t is usually assumed to be 1.645 for large number of detected defects (degrees of freedom). The 95% lower limit against under-sizing is used as under- or over-sizing correction of NDE measurements depending on whether the systematic error is negative or positive respectively.

EWI®
THE MATERIALS JOINING EXPERTS

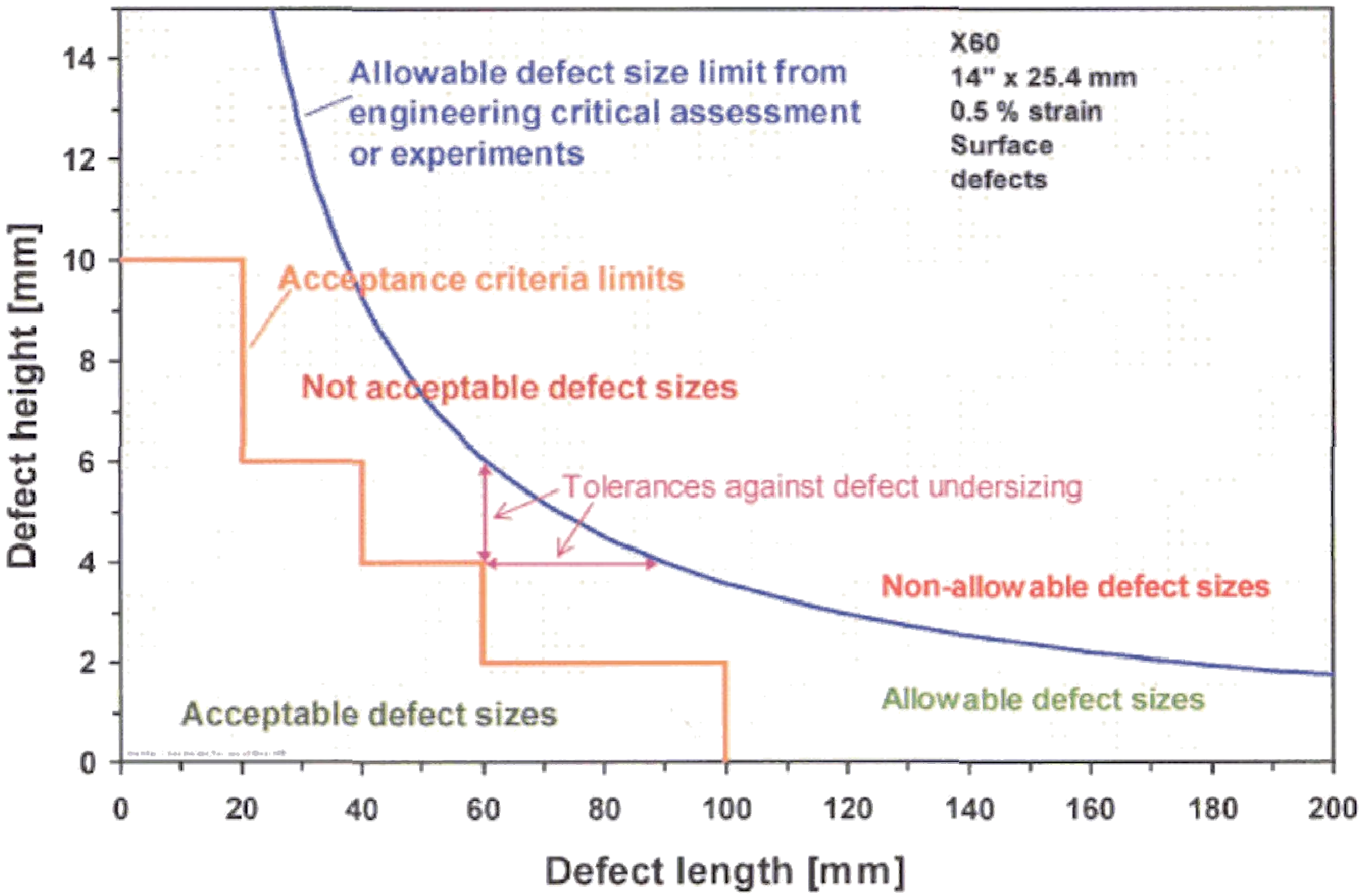
Sizing Plots



	95 % LUS, mm			
	Operator 1	Operator 2	Operator 3	Operator 4
Company 1	8	15		
Instrument 1	8		9	
Instruments 1 and 2	8			10

THE MATERIALS JOINING EXPERTS

Allowable and Acceptable Defect Sizes



THE MATERIALS JOINING EXPERTS

Task 6 – Determine the Performance (Funding Source: DOT-OPS and Industry In-kind) (cont.)

- The results for some of the butt-fusion and saddle-fusion joints were presented in a relevant graphical format (expanded DOT scope – see BF and SF files)
- One PA field trial on “real” PE pipe joints was be conducted (expanded DOT scope – see the next slide).

Task 7 – Develop Reference Library & Guidance
(Funding Source: DOT/PHMSA & NYSEARCH Proj. 49265CSP)

- A reference library of all PA images and limited destructive digital images of EF lap joints, butt-fusion and saddle-fusion joints with defects was developed.
- Guidance for PA capabilities to inspect EF lap joints in PE gas distribution pipelines and applicability to determine the defect acceptance criteria is under development.
- The guide will include an operator's procedure, scan technique, and specification of equipment needed for the defects being tested.

EWI® THE MATERIALS JOINING EXPERTS

Task 8 – Progress Meetings, Demonstration, Presentation, Commercialization & Reporting
(Funding Source: DOT/PHMSA & NYSEARCH Proj. 49265GTH)

- Conducted kick-off, progress, peer review and final meetings
- Prepared progress reports and a draft final report that includes details of the open and blind validation results
- Prepared and presented a paper at Rio Pipeline Conference – October 2007, AGA – May 2008

Deliverables

- Task 1 – Test Matrix for the Materials, Pipe Sizes, and Defects. Due within 2 months of Agreement Execution.
- Task 2 – Testing Samples with Implanted Defects. Due within 5 months of Agreement Execution.
- Task 3 – Modeling and Simulation and Detection and Sizing Results. Due within 11 months of Agreement Execution.
- Task 4 – Testing Samples for Butt-Fusion (BF) and Saddle-Fusion (SF) Joints and Optimized PA Detection and Sizing Procedure (s) for EF joints. Due within 11 months of Agreement Execution.
- Task 5 – Results of the Validation Testing for Optimized PA Detection and Sizing Procedure (s). Due within 14 months.
- Task 6 – Phased-Array POD and Sizing Curves of Multiple Systems for Typical Electrofusion (EF) PE Joints and Graphs for Typical Butt-Fusion (BF) and Saddle-Fusion (SF) Joint Results. Due within 19 months.
- Task 7 – Reference Library of PA and Destructive Digital Images and Guidance Documentation. Due within 22 months.
- Task 8 – Project Meetings, Technology Demonstration, Conference Presentations and all Reports. Quarterly status and progress reports and final project report due to DOT in accordance with Article VI.E.1 and 2 of the basic agreement. Final report due to NYSEARCH within 24 months of Agreement Execution.

EWI THE MATERIALS JOINING EXPERTS

Conclusions (EF Joints)

- The PA UT procedures developed during this project were able to detect planar flaws in the fusion zone (represented by implanted Al disks) as small as 1mm.
- POD a90/95 = 6mm was achieved by PA UT operator having at least 3 months experience to inspect PE joints and several years of PA experience.
- 95% LUS=8mm was demonstrated by the best PA UT operator.
- EF cold joint can be classified reliably by PA UT measuring the depth of HAZ.
- Several PA instruments, probes and scanners are available on the market to be used by inspection companies with trained operators to inspect EF joints.

EWI THE MATERIALS JOINING EXPERTS

Conclusions (BF Joints)

- PA pulse-echo, PA tandem, PA pitch-catch, and PA TOFD techniques were evaluated for inspection of butt fusion joints.
- Although the PA pitch-catch technique produced a clean, low noise display, the detection capabilities were not as good as the other PA techniques.
- PA TOFD did a good job detecting planar flaws from approximately mid-wall thickness to the inside surface.
- PA pulse-echo and PA tandem produced similar detection results.
- PA pulse-echo was the only technique that was able to provide some measurement of through wall flaw height.

THE MATERIALS JOINING EXPERTS

Conclusions (SF Joints)

- Because of the relatively complex shape of the saddle fitting and joint, the saddle joints required two ultrasonic techniques for the fitting used for this project.
- The first scan was a scan around the rim of the saddle, and the second technique was a scan on the sides of the saddle fitting.
- While 100% coverage of the fusion zone could not be obtained, these two techniques provided approximately 90% coverage and are capable of detecting flaws that would cause a leak path.

EWI®
THE MATERIALS JOINING EXPERTS

Recommendations

- Organize a demonstration workshop at EWI.
- Complete the experimental work on the remaining 60 BF and SF joints.
- Continue EF study (Phase 3) to determine acceptance criteria for 6” and 2” PE pipe using the samples developed during the current Phase 2 and complete POD/sizing evaluations for the samples with implanted dust, sand and short stubs.

EWI THE MATERIALS JOINING EXPERTS

Contact Information

Nancy Porter
Project Manager
Project Management Office
614-688-5194
nancy_porter@ewi.org

Mark Lozev, Ph.D.
Chief Engineer
NDE Technology Leader
614-688-5188
mark_lozev@ewi.org

THE MATERIALS JOINING EXPERTS

Laboratory Demos

- HAZ Measurement *Perry White*
- Butt Fusion Weld Inspection *Roger Spencer*

You Can Leave your Stuff in the Room

THE MATERIALS JOINING EXPERTS

Mark Lozev

- Proposed Additional Work on Butt and Saddle Fusion Samples

Task	Description	Months					
		1	2	3	4	5	6
1	EF Lap Joints Testing Matrix and Protocol						
2	EF Lap Joints Sample Fabrication						
3	Define Detection & Sizing Capabilities for EF Lap Joints						
4	Complete the Final Optimized PA Procedure to Inspect BF & SF joints	x					
5	Validate the Optimized PA Procedure and collect UT PA data on remaining 60 flaws/samples using at least 3 UT PA sub-techniques		x				
6	Determine the Performance and analyze the data on remaining flaws/samples and at least 3 UT PA sub-techniques			x			
7	Develop Reference Library and Guidance adding the results from the remaining flaws/samples and at least 3 UT PA sub-techniques				x		
8	Progress Report	x	x	x	x	x	x
8	Include the results from the remaining flaws/samples in the Final Report and complete the Final Report					x	x

Angelo Fabiano

- Use of Electrofusion Samples for Next Phase Project, "Destructive Testing and Acceptance Criteria".

THE MATERIALS JOINING EXPERTS

Mark Lozev

- Technology Transfer Workshop at EWI
  - *August 2008 Timeframe*
- Need Industry Support Letters
  - AGA
  - NYSEARCH
  - ____________________________
  - ____________________________
  - ____________________________

EWI THE MATERIALS JOINING EXPERTS

Agenda

- Lunch
- Adjourn
- Jim Merritt move to 104
  - 1:00 - 1:30 Sue Fiore and Suhas Vaze
  - 1:30 - 2:00 Ian Harris and Mark Norfolk

THE MATERIALS JOINING EXPERTS