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The Use of Cold Spray Deposition for the Fabrication of NDE Qualification Samples

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June 22, 2016

CSAT Conference

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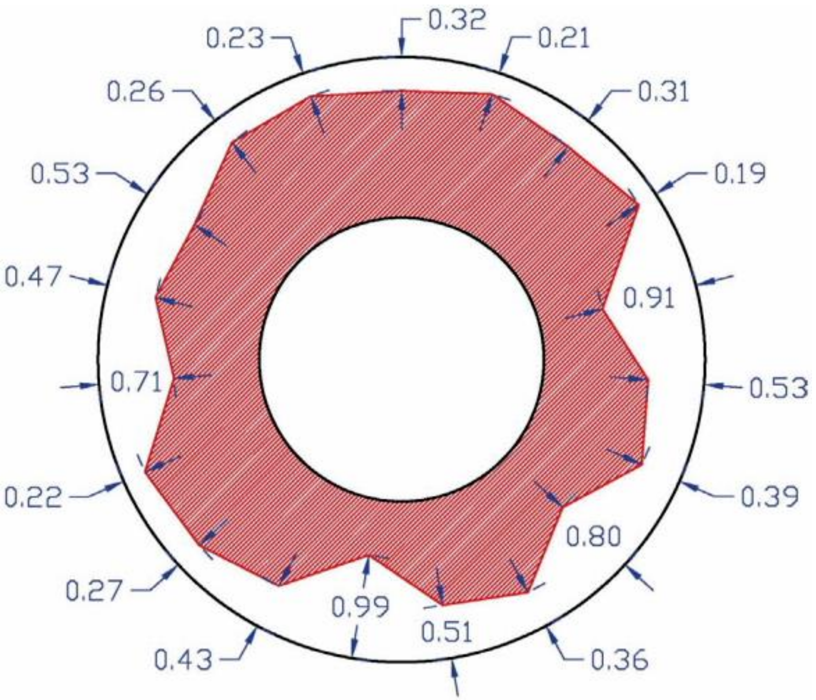
- Acknowledgments
  - Vic Champagne, Army Research Lab, for support in obtaining samples
  - Aaron Nardi, United Technology Research Center, for performing the cold spray coatings
  - Mike Larche, Matt Prowant, and Ken Ross, Pacific Northwest National Laboratory, for technical support

Cold Spray NDE Samples

- Nuclear power plant based emphasis
- All NDE techniques require some level of Performance Demonstration using realistic flaw mockups (ASME Code and NRC requirements)
- Current technology for mockup fabrication is limited to surface-connected flaws (simulated service-induced corrosion)
  - Welded implants of fatigue cracks
  - EDM notches that are squeezed closed using hot isostatic pressure (HIP)
  - Lab-grown stress corrosion cracks (SCC)
- Undetected weld fabrication flaws are subsurface
  - Inclusions
  - Lack of fusion

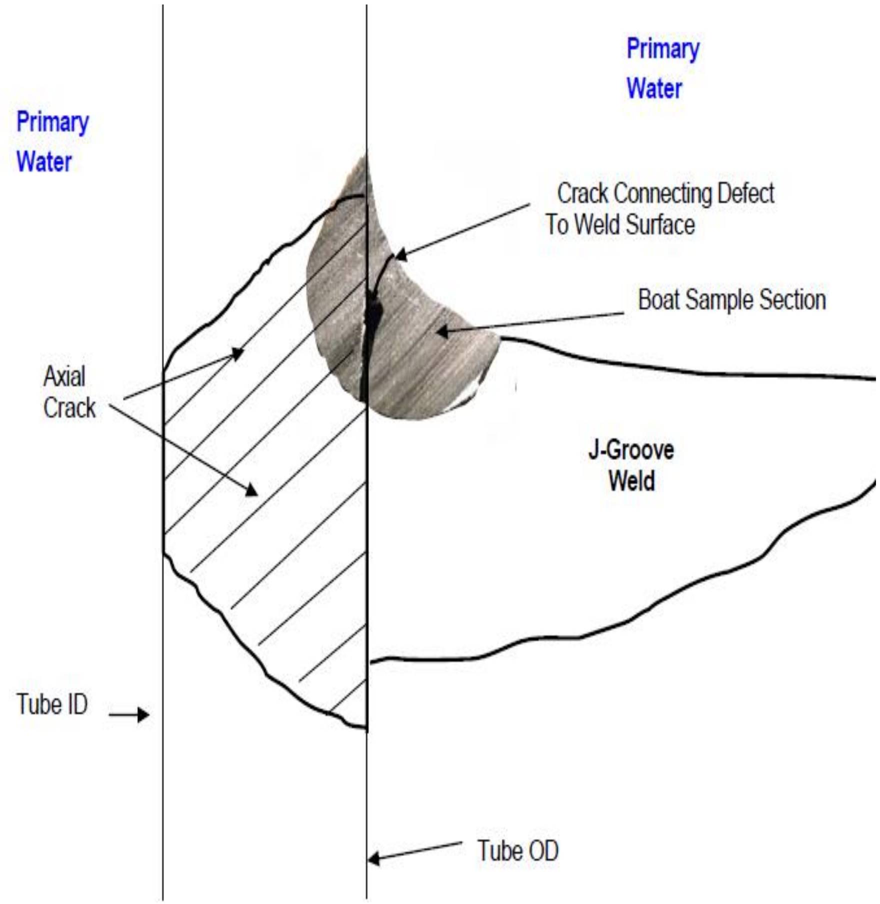
False Positive UT Results

- UT weld inspections rely on high sensitivity tip diffraction techniques
- Often, small internal, benign reflectors are mistaken for crack tips resulting in alarming false positive crack calls
- One instance misinterpreted data to show a 360-degree very deep crack
  - NRC issued potential shutdown orders for 12 operating plants
  - Industry impact was in the $100s M



Undetected Near Surface Flaws

- Occasionally welding flaws exist in the near subsurface zone and are missed by the final penetrant testing (PT)
- The remaining ligament can be ruptured over time by thermal and mechanical stresses
- Exposing subsurface welding inclusions to high temperature water creates a highly caustic environment
- Cracking has resulted in primary system leakage
- Industry impact was in the $100s M



Cold Spray Mockups

- The primary system pressure boundary in a nuclear plant is comprised of either stainless steel or high nickel alloy material

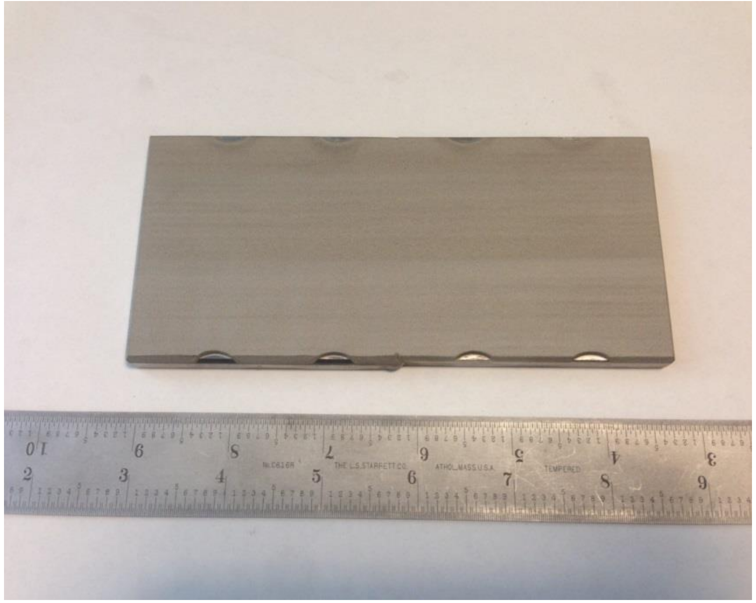
- Coating powders selected were
  - 316 stainless steel
  - Inconel 625 (annealed and non-annealed)
  - Substrate was 304 SS

- Samples were designed to
  - demonstrate the ability of UT to detect and distinguish subsurface flaws
  - demonstrate that eddy current testing (ET) could detect near subsurface flaws

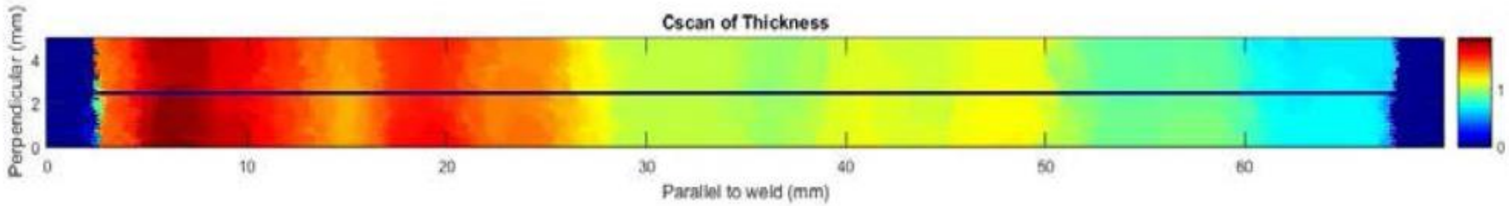
316 SS Sample

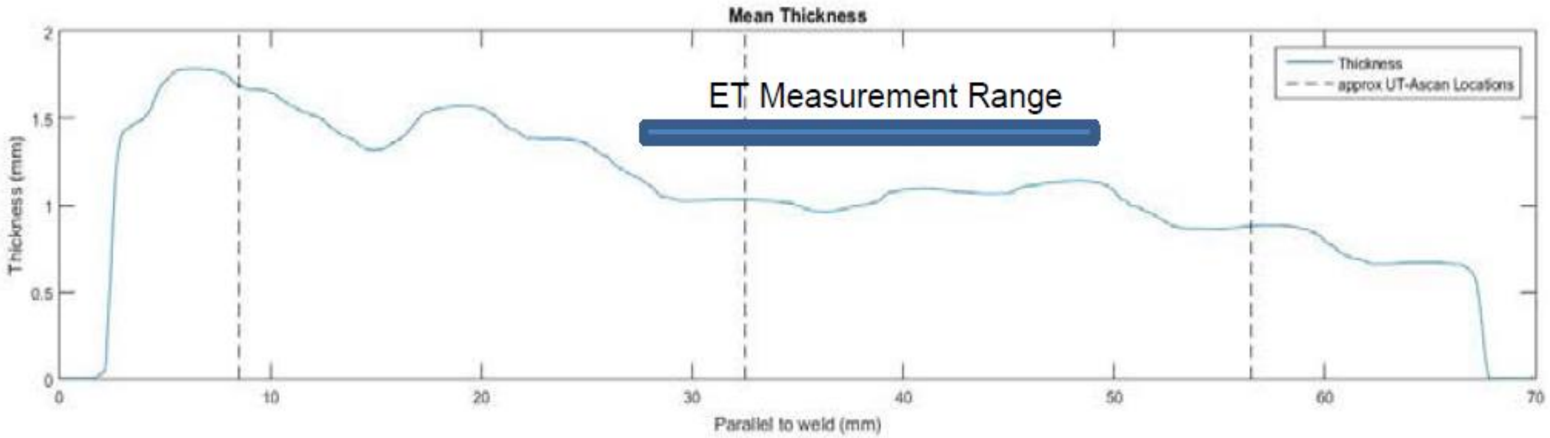
Side View: Two plates welded together with the seam simulating a subsurface flaw

Top View: Three bands of thicknesses ranging from 0.7 to 1.5 mm nominally



316 SS Coating Thickness and Surface Contour (Ultrasonic Microscope)





316 SS Coating Thickness

Differential Probe (0.12" Footprint)

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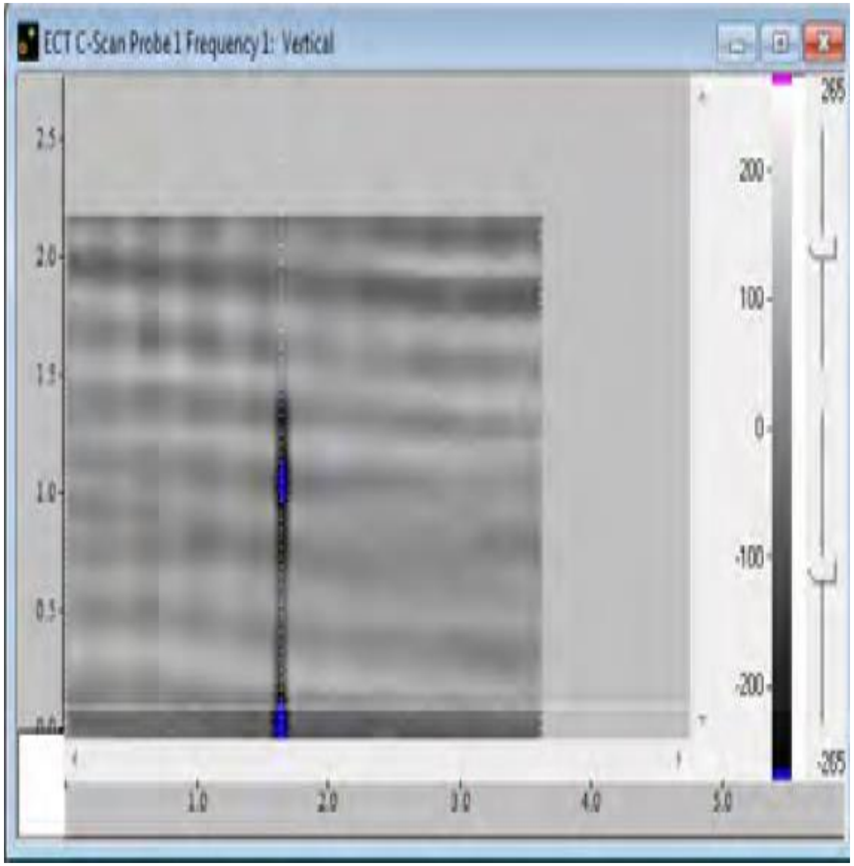
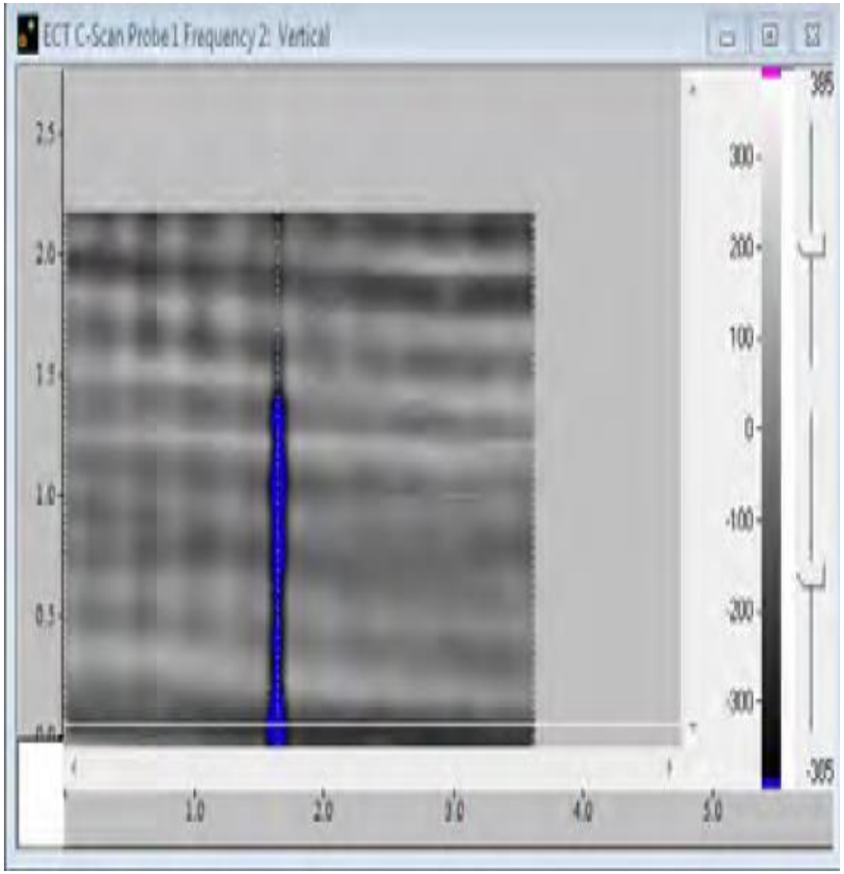
400 kHz Flaw Detection



200 kHz Flaw Detection



ET Response at Various Coating Thicknesses

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	Pk-Pk M	400 kHz % of Ref	Φ	Pk-Pk M	Φ	200 kHz % of Ref
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

ET Observations

- Small footprint probe used to accommodate actual part geometry
  - Larger probes do better for subsurface flaws
- Objective of detecting planar flaws up to 1 mm below the surface was met
- The cold spray 316 SS coating closely mimicked the ET properties of plate material for this application
- Signal attenuation and phase delay provided an indirect measurement of apparent bulk conductivity
  - This was not the intent of this study and surface roughness was too high to make accurate quantitative measurements
- Can we use ET measurement of “apparent conductivity” to assess coating quality?

ET "Spectroscopy"

- Work performed at Wright-Paterson AFB addressed using ET to measure "apparent conductivity" at several test frequencies
  - Application was for residual stress measurements after peening in high Ni alloys
- A similar approach is being studied to assess cold spray coating properties
  - This effort is just getting started
- Alloys of interest are Inconel 625 and SS 316

Conductivity Mosaic Absolute Pancake ET Probe

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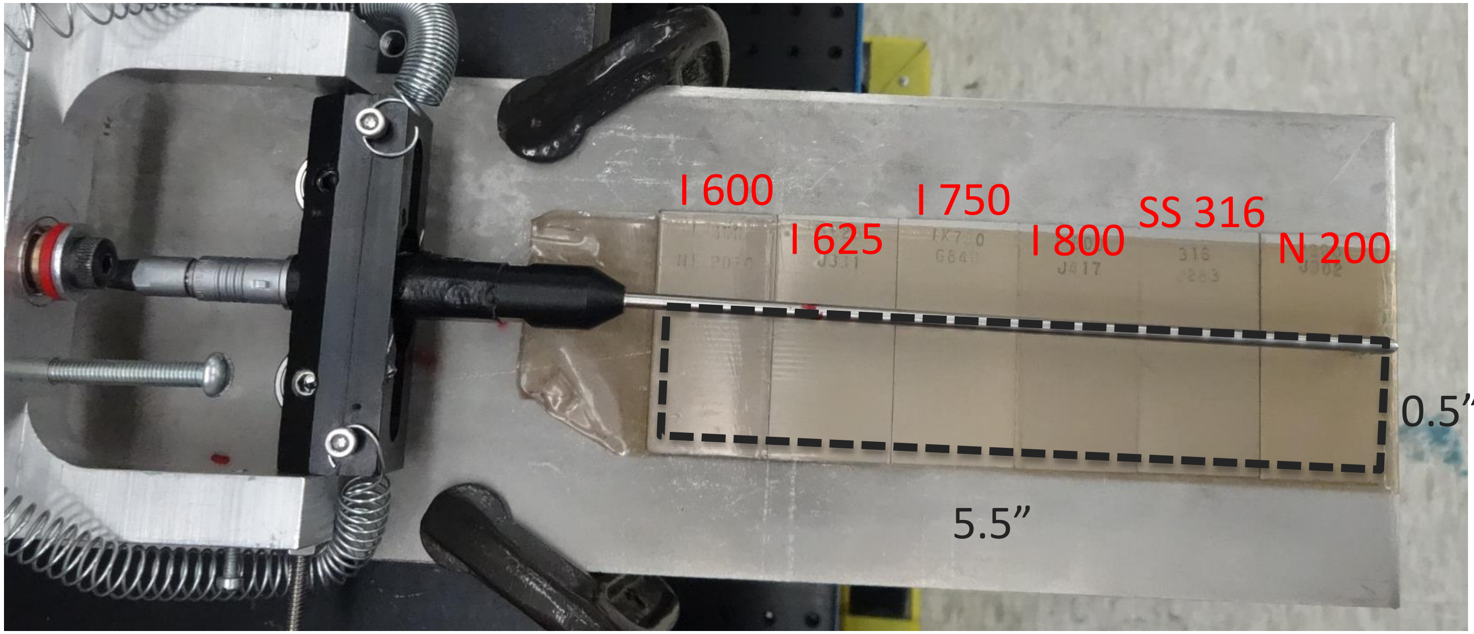
- Data collected with 4 frequencies (1.5, 1.0, 0.75, & 0.5 MHz)
- Balanced on Alloy 600 conductivity sample
- Scan and index resolution of 0.050”



Absolute Pancake Data – Conductivity Mosaic

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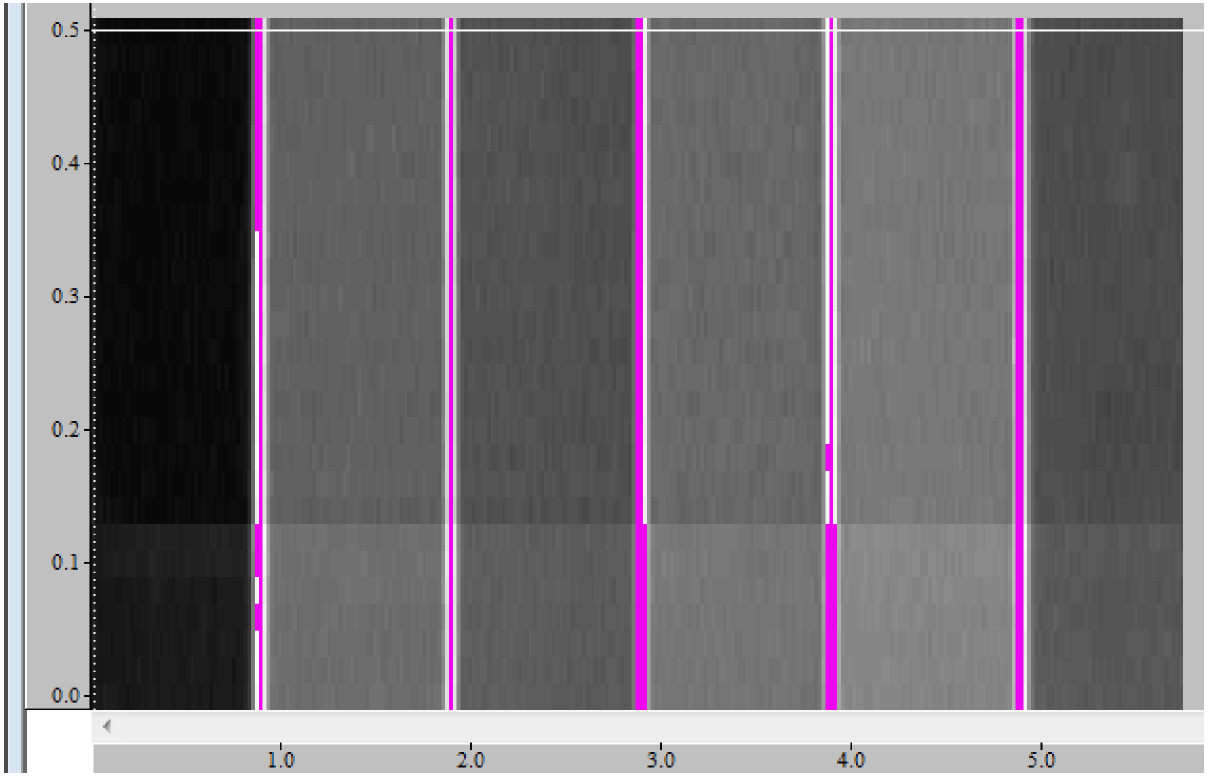
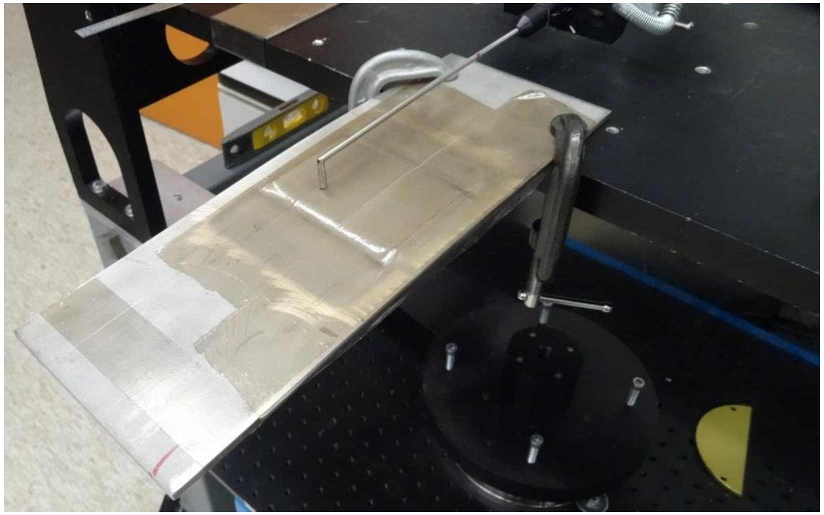
Sample Order from Left to Right:

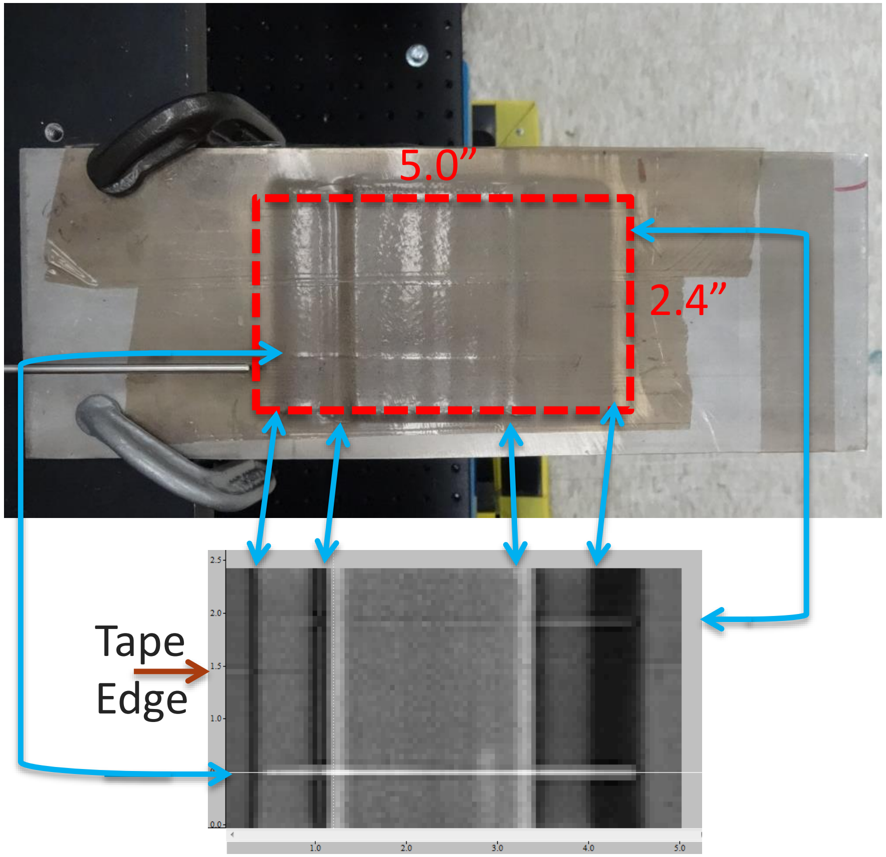
- Inconel 600
- Inconel 625
- Inconel X750
- Incoloy 800
- Incoloy 825
- Nickel 200



Inconel 625 Cold Spray Coating Scan

- Data collected using same setup from conductivity mosaic
- Scan dimensions: 5.0 x 2.4”

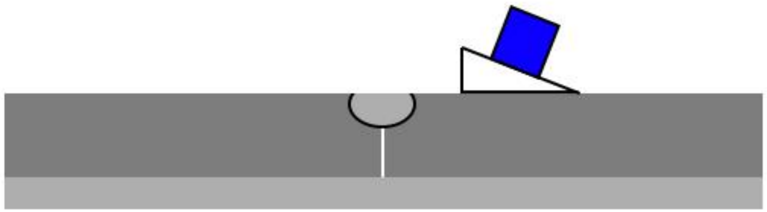




Blue arrows indicate surface thickness changes that caused liftoff

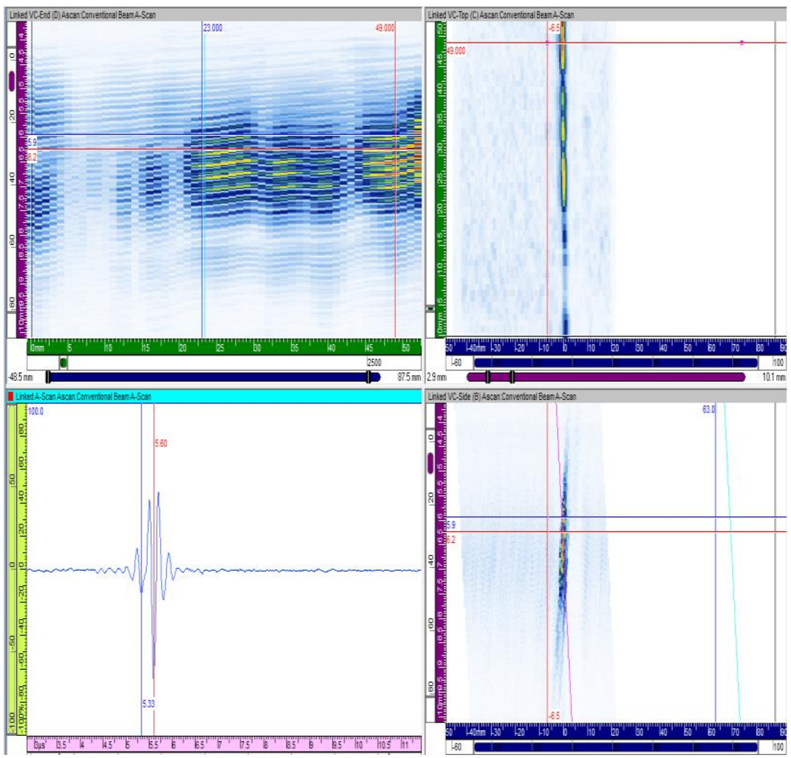
UT Scanning Arrangement

- Probe was placed on the smooth substrate surface
- 45-degree shear wave and 60- degree longitudinal waves used
- Coating surface contour satisfied ASME requirement for UT (<0.8 mm variation over 25 mm)
- Due to relatively thin cross section, 5 MHz used

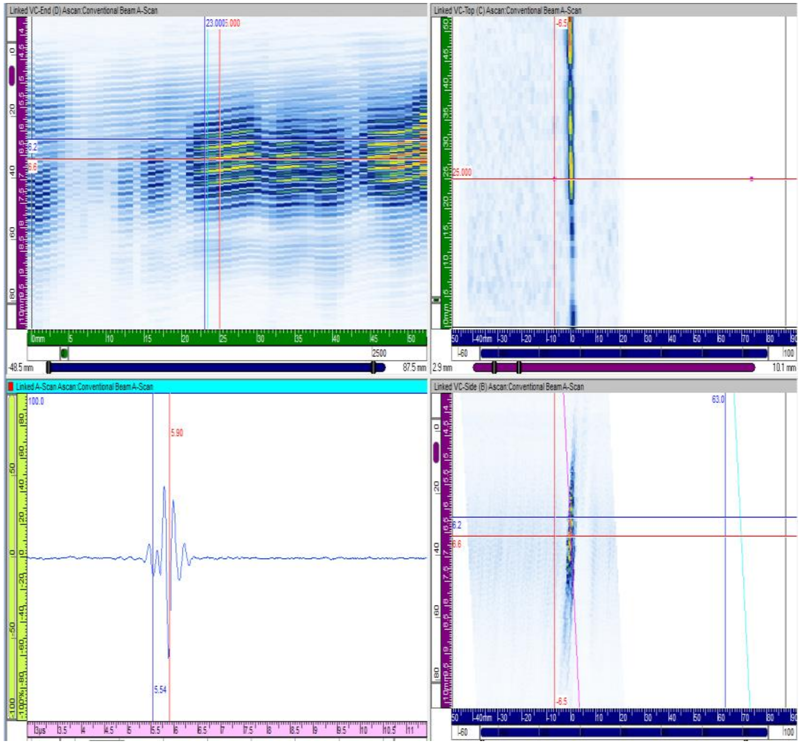


45 Degree Shear Wave Results

0.5 mm coating thickness: no discrimination from backwall



1 mm coating thickness: barely separable signals

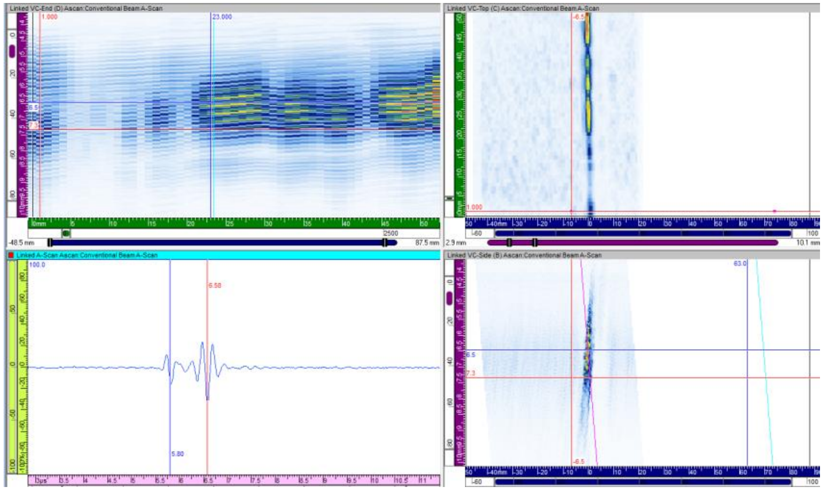


45 Degree Shear Wave Results

Conclusions

- Subsurface determination is possible for ligaments with a minimum thickness somewhere between 1.0 and 1.5 mm
- This corresponds to approximately 2 wavelengths
  - This result is wavelength dependent, so lower frequencies would require a correspondingly thicker ligament

1.5 mm coating thickness: clearly separable signals



60 Degree Longitudinal Wave Results

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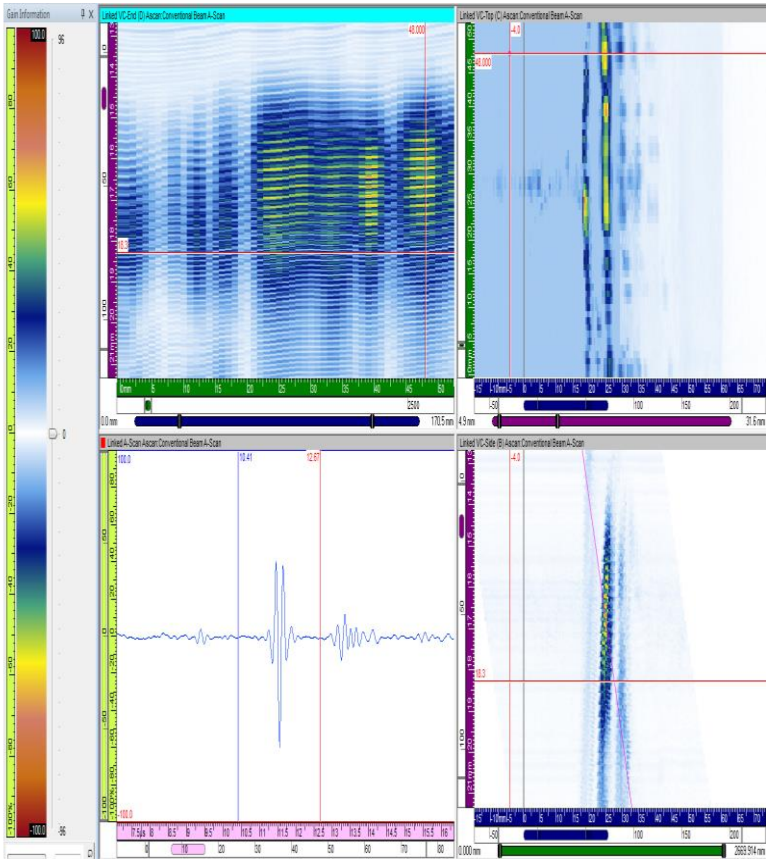
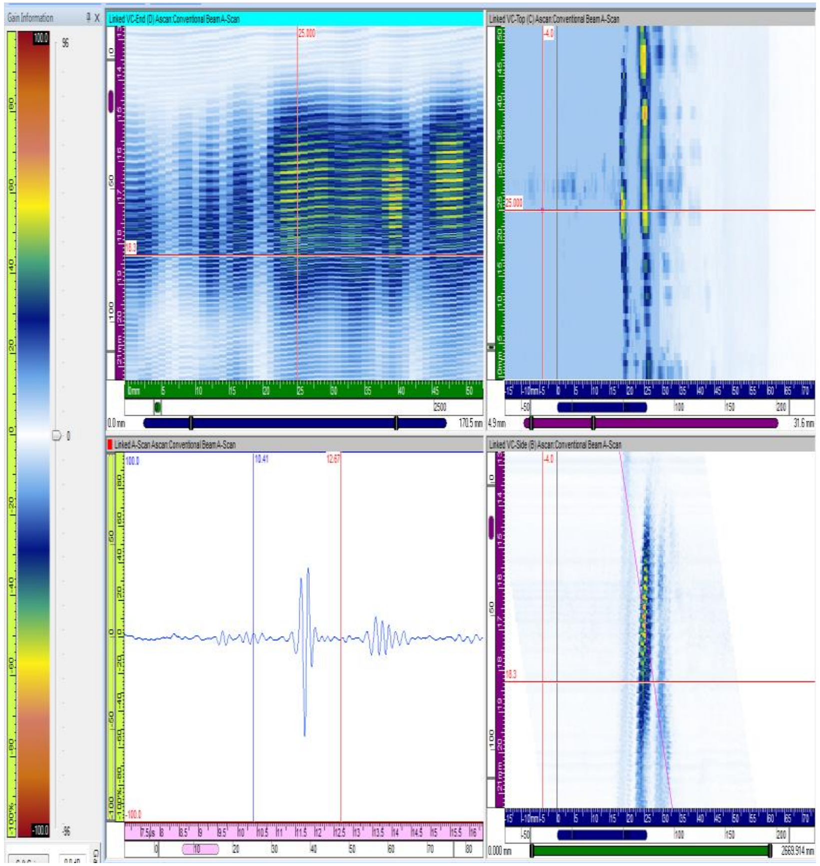
0.5 mm coating thickness: no discrimination from backwall



1.0 mm coating thickness: no discrimination from backwall



60 Degree Longitudinal Wave Results

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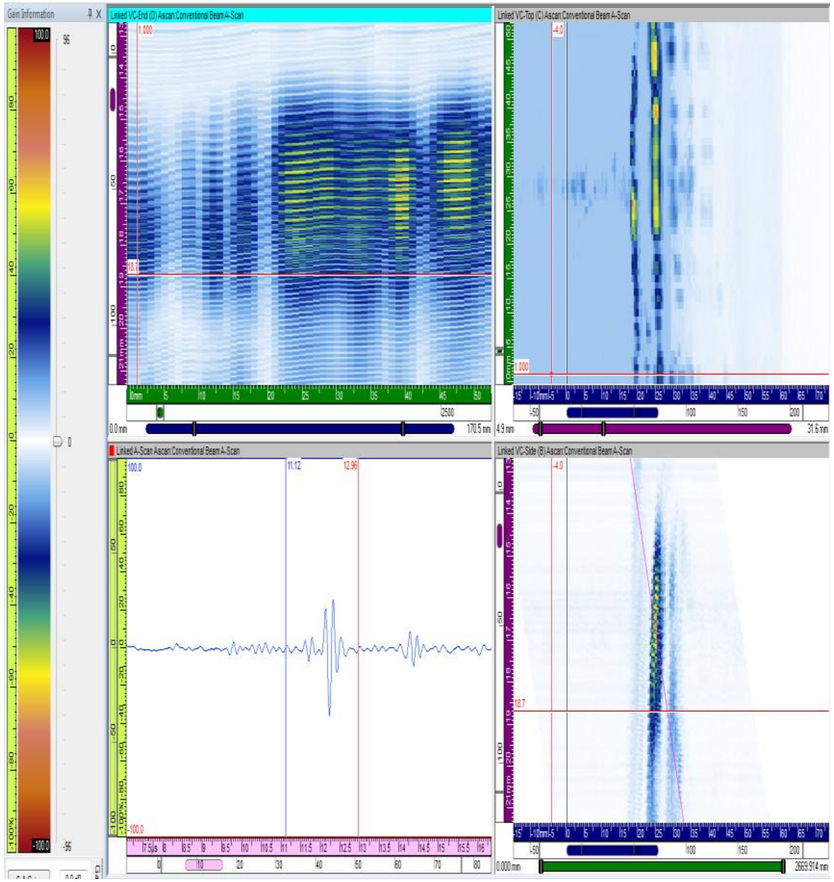
Conclusions

- The longer wavelength of the longitudinal wave requires a greater ligament thickness for discrimination of subsurface flaws
- For most actual field applications, a discrimination level of 2 mm would be adequate
- Longitudinal waves are actually the preferred method for high alloy welds

1.5 mm coating thickness: slightly separated signals



Future Work with UT

- Bond quality assessment will be investigated
  - Conventional high frequency 0 degree UT has been shown to be ineffective
  - Contaminants that cause weak bonds also act as ultrasonic couplant and transmits the sound
- Alternate wave modes are being studied
  - Interface waves that are only produced at well bonded interfaces of similar metals
  - Layer modes (one free surface and one well bonded surface)