Eddy Current Verification of Macros
Semi-Automated and Manual EC

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The Problem

- **Many planar flaws marked on metallographic macros with sizes usually considered detectable were not actually detected by most or all of AUT vendors**
- **Macros do not provide data on whether the flaw is too tight or even fused. If the feature identified on the macro as flaw is too tight or fused, it will be transparent to ultrasonic waves and undetectable.**
- **Accounting of very tight or fused flaws as missed flaws in the POD sample of data might lead to unrealistically conservative AUT detection capabilities estimates or in the worst case will question the AUT usefulness.**

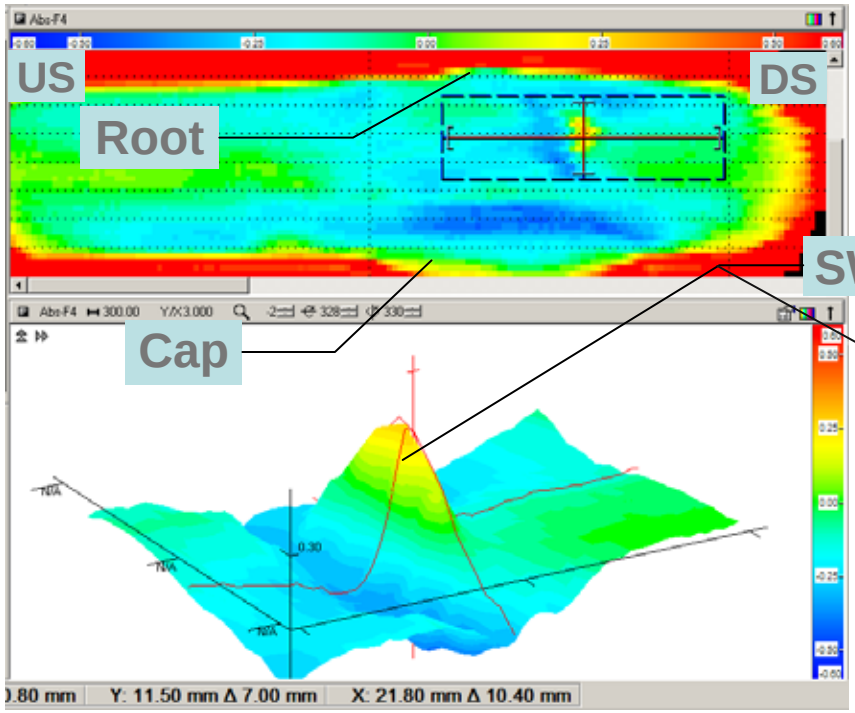
Possible Solution

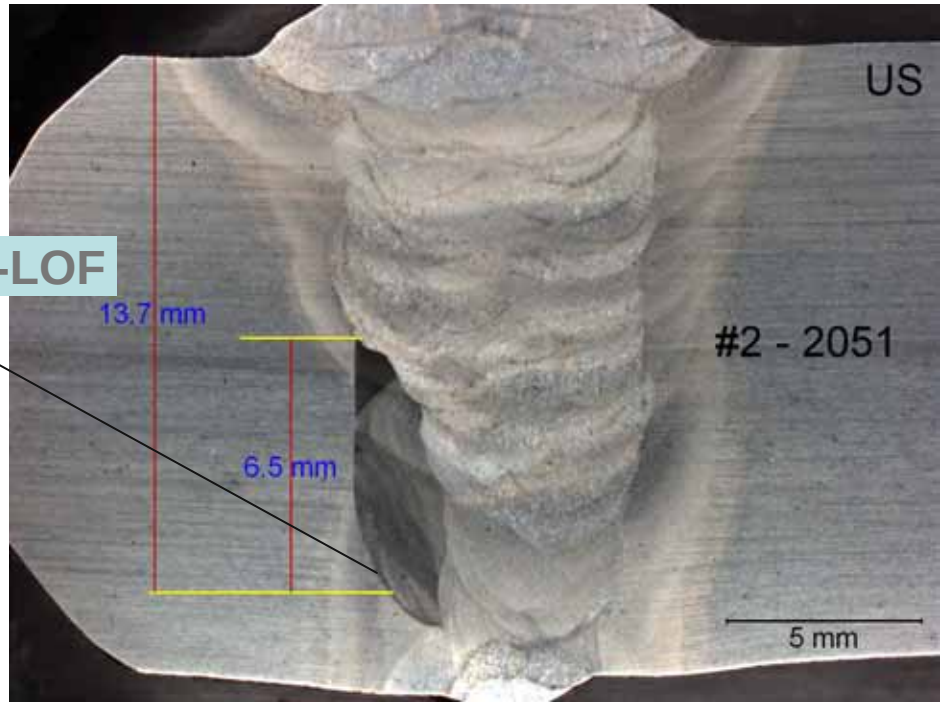
- **High-resolution advanced eddy current (EC) techniques for surface breaking and slightly subsurface flaws might provide data on whether the flaws are too tight or fused**
- **Small diameter (~1.5 mm) surface EC probes was attached to scanner to generate C-scan presentation of macros with flaw indications**
- **Macros surface raster scanned with increment of 0.5 mm transverse to and 0.2 mm along the direction of scanning**
- **Scanning performed through teflon tape to avoid scratching of macros surface**

Possible Solution (Con'd)

- **Four frequencies used simultaneously to perform the scanning – 20, 80, 240, and 480 kHz**
- **Data for frequency 480 kHz shown in this presentation as having the highest resolution and sensitivity to surface-breaking flaws**
- **Additional manual EC (at 120 kHz) performed where the scanner resolution was considered insufficient in detecting flaws with height smaller than 1 mm**
- **EC results compared to AUT and fingerprinting results for the same flaws and locations**

Section W2-2051





- **EC**
  - Shorter (3-mm height) side wall lack of fusion (SW-LOF) confirmed
  - All-feature height 7 mm
  - SW-LOF top and bottom sections might be fused
- **AUT**
  - Flaw 6.5 mm missed by fingerprinting and all 5 AUT vendors

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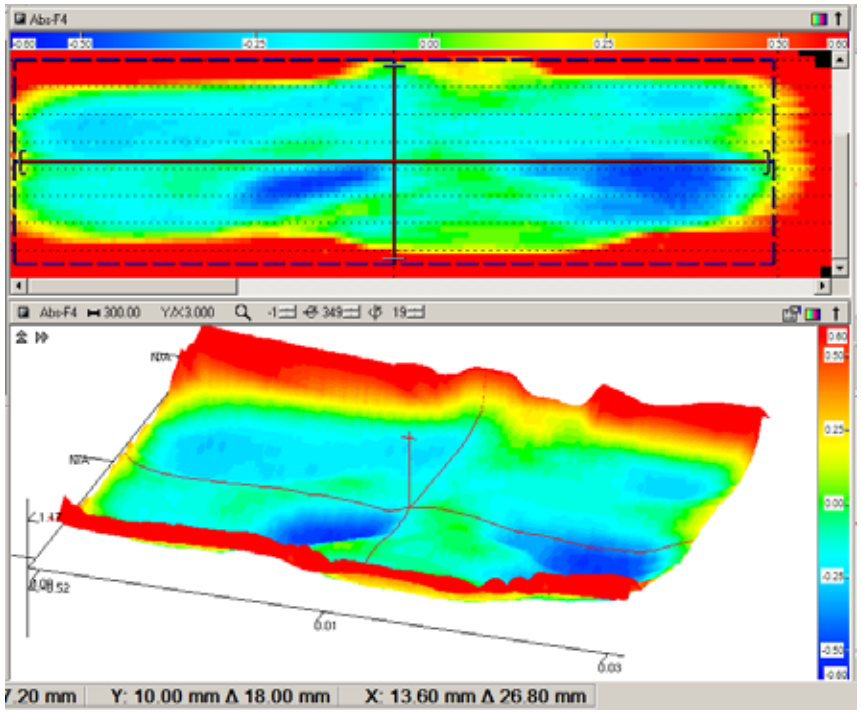
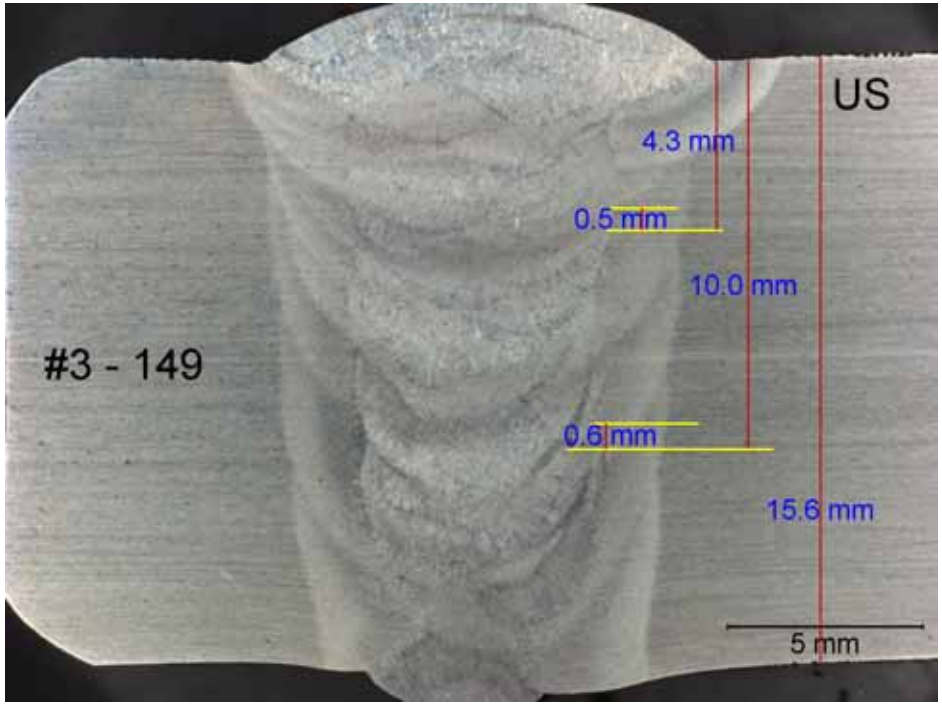
Section W3-149





- **EC**
  - No confirmation of small flaws
- **AUT**
  - Flaws 0.5 and 0.6 mm missed by fingerprinting and all 4 AUT vendors

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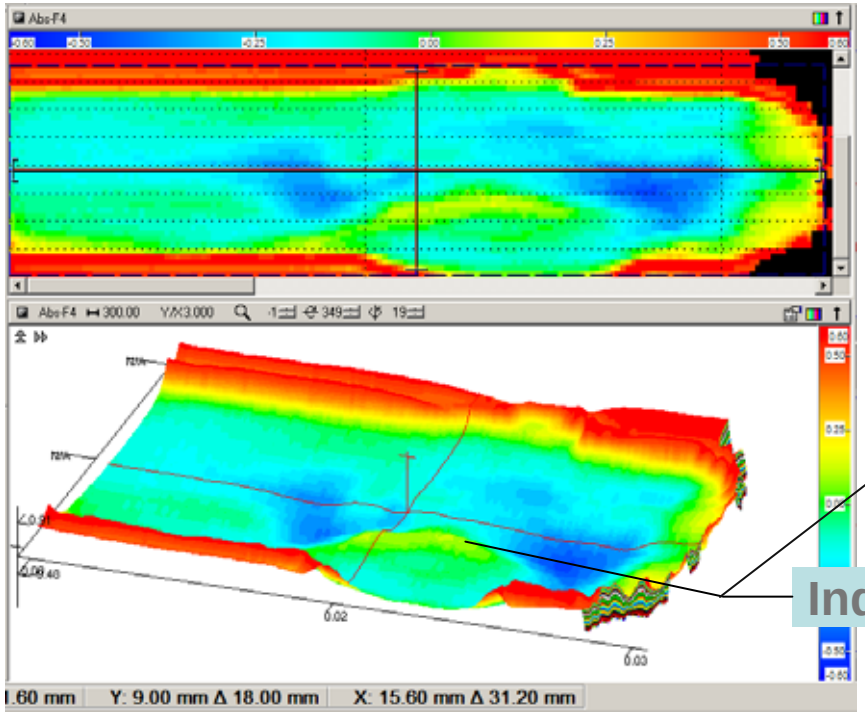
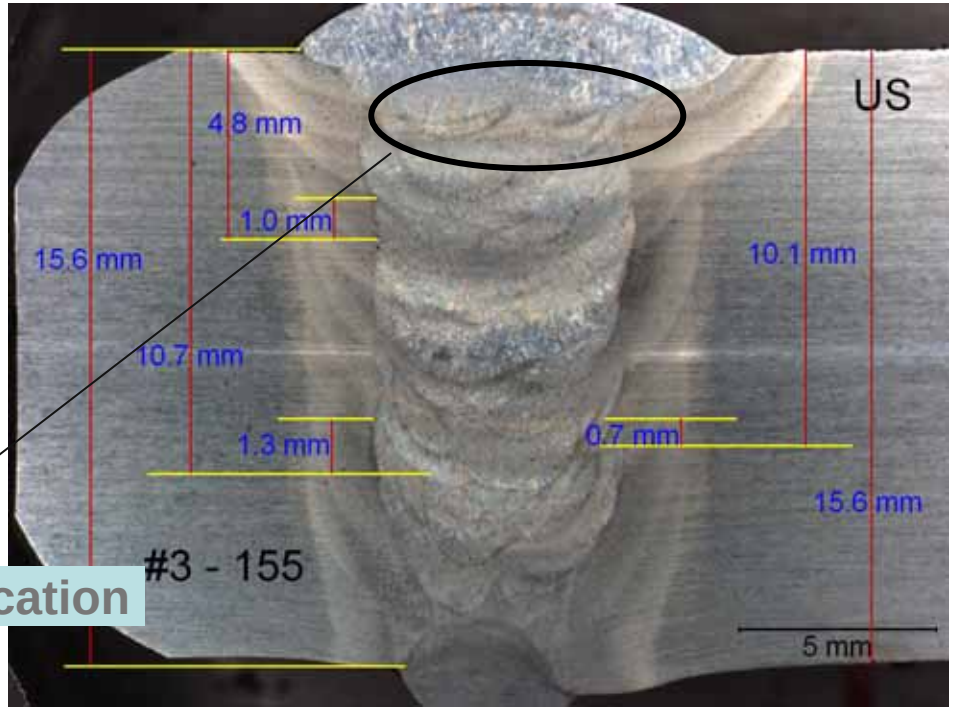
Section W3-155





- **EC**
  - No confirmation of any flaw
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 1 mm part of flaw 1.1 mm on W3-158 (see slide …W3-158)
  - Flaw 1.3 mm detected by fingerprinting but missed by all 4 AUT vendors
  - Flaw 0.7 mm missed by fingerprinting and all 4 AUT vendors

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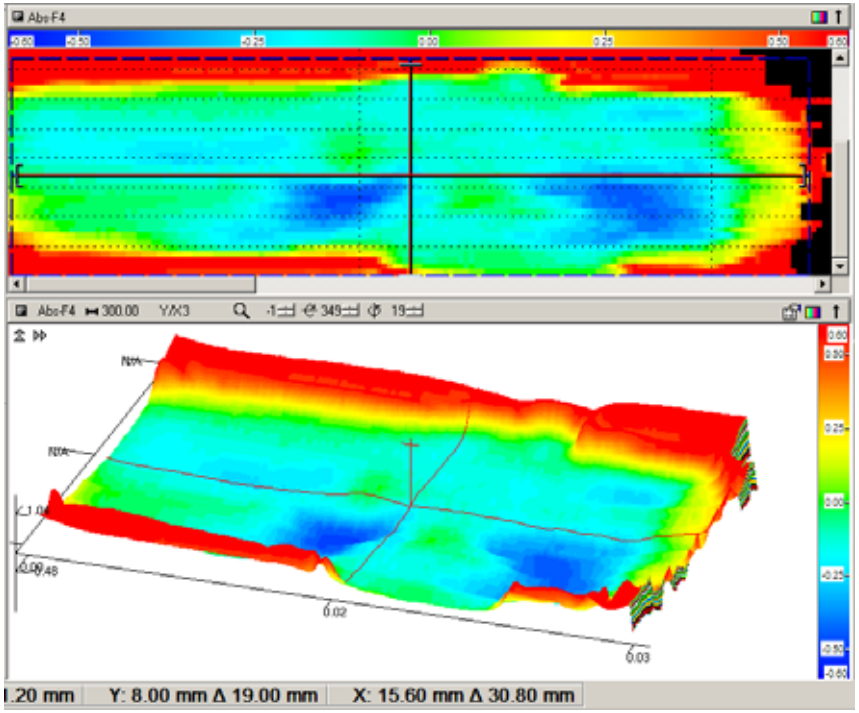
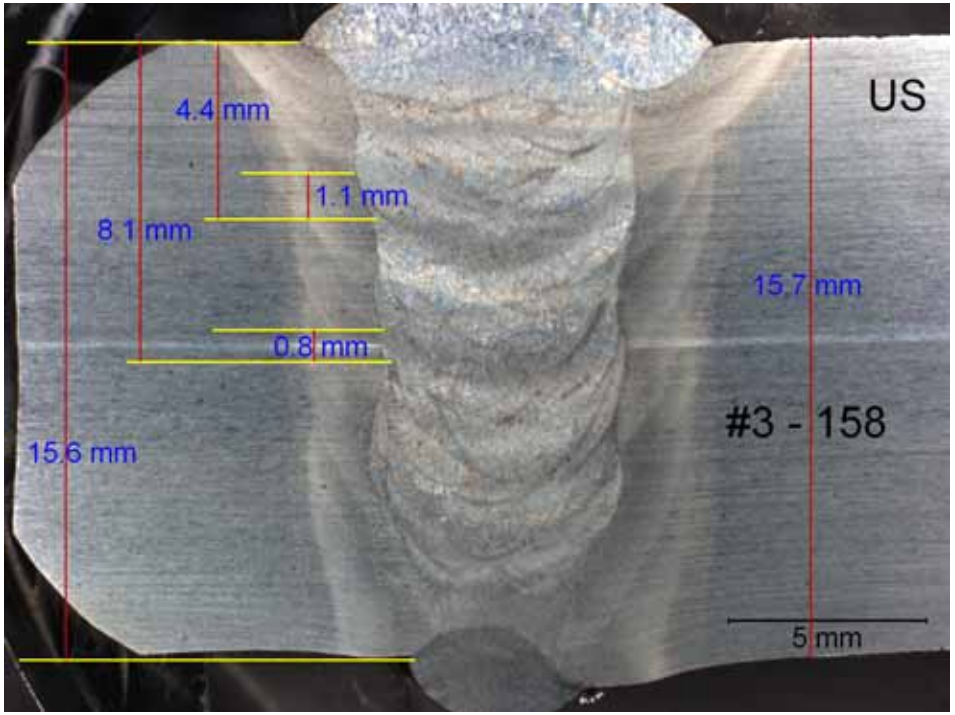
Section W3-158





- **EC**
  - No confirmation of any flaw
- **AUT**
  - Flaw 1.1 mm detected by fingerprinting but missed by all 4 AUT vendors
  - Flaw 0.8 mm missed by fingerprinting and all 4 AUT vendors

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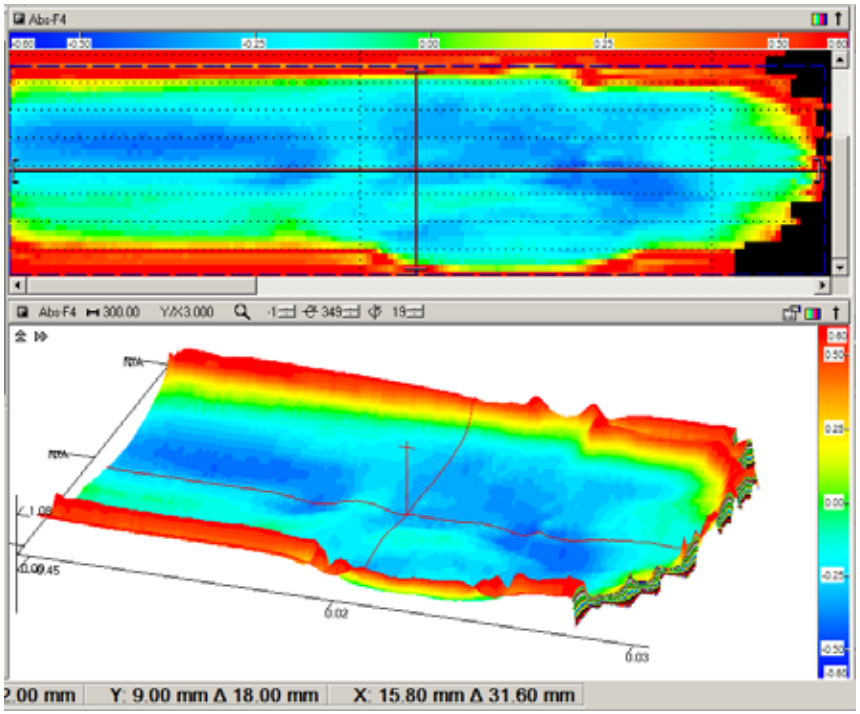
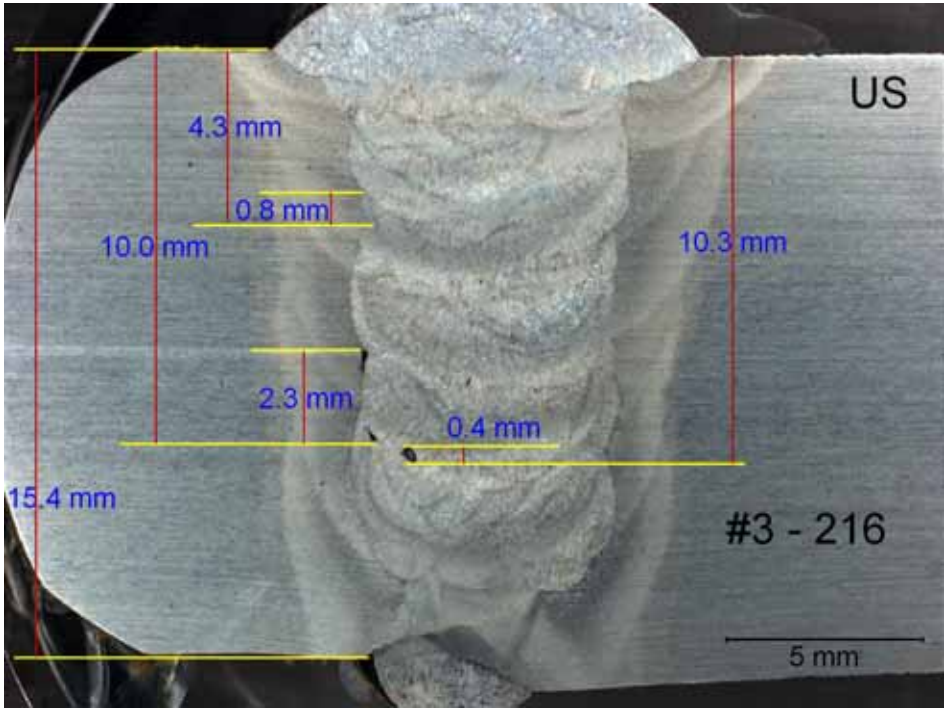
Section W3-216





- **EC**
  - No confirmation of any flaw on C-scan
  - Only pores part of 2.3 mm (no 2.3-mm link) and 0.4 mm confirmed by manual EC
- **AUT**
  - Flaw 2.3 mm detected by fingerprinting but missed by all 4 AUT vendors
  - Flaws 0.8 and 0.4 mm missed by fingerprinting and all 4 AUT vendors

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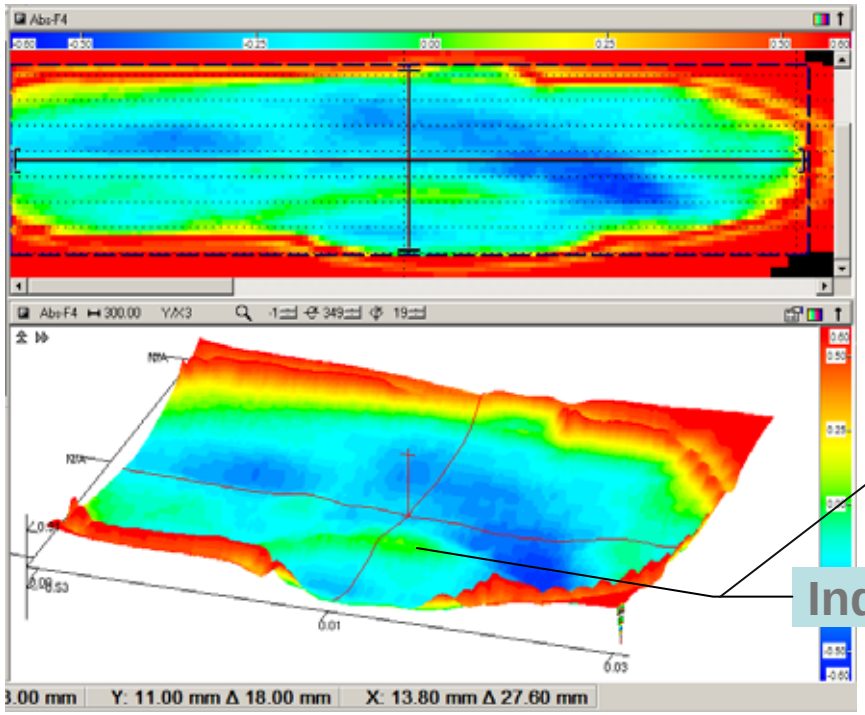
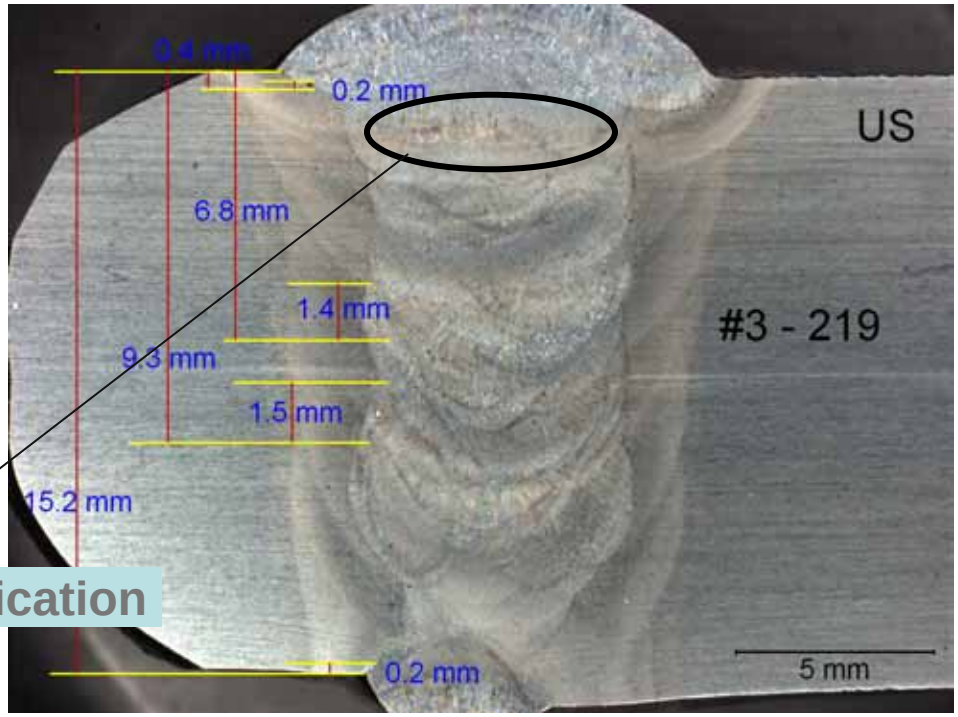
Section W3-219





Indication

- **EC**
  - No confirmation of any flaw
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 1.5 mm part of 2.3 mm flaw on W3-216 (see slide …W3-216)
  - Flaws 1.4 and two 0.2 mm missed by fingerprinting and all 4 AUT vendors

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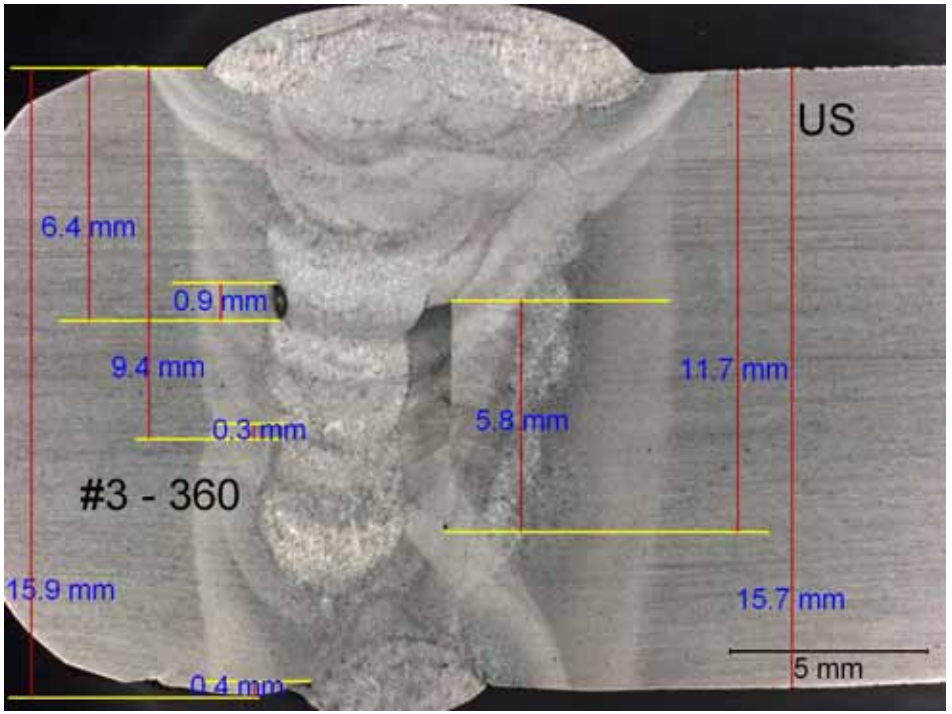
Section W3-360



- **Not tested**

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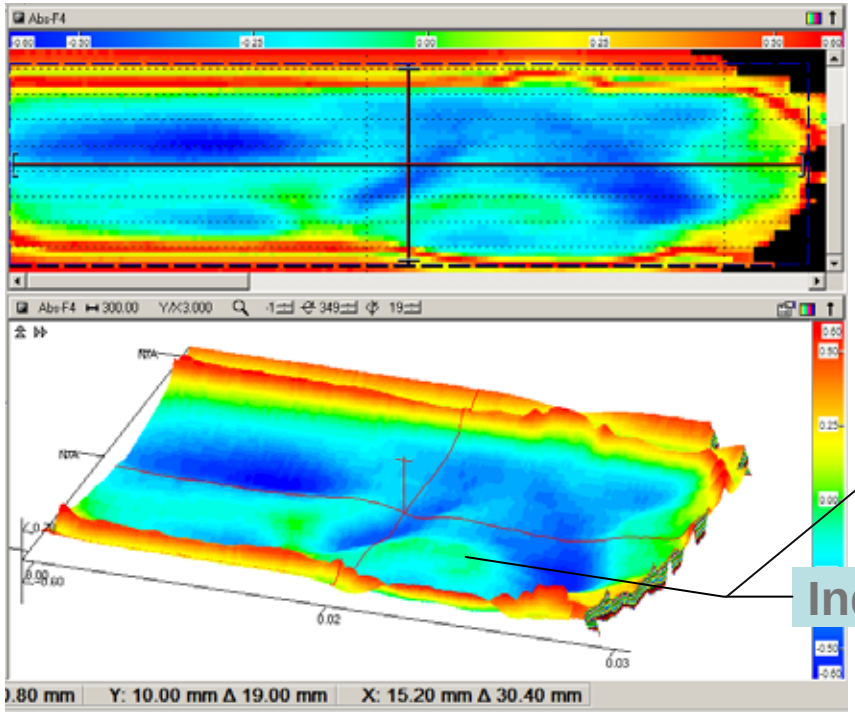
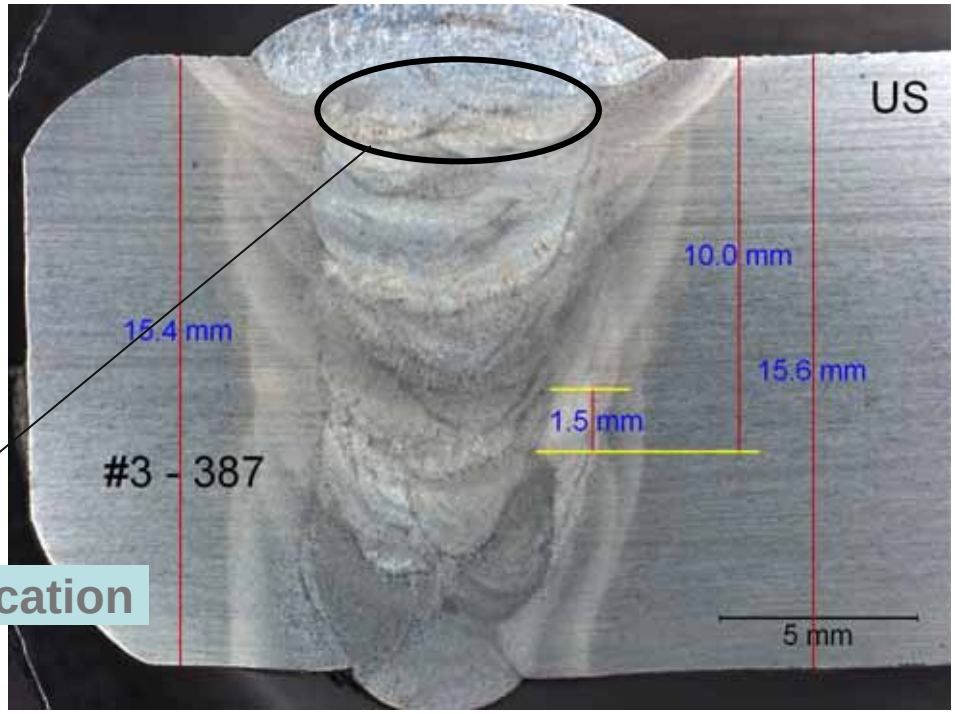
Section W3-387





Indication

- **EC**
  - No confirmation of any flaw
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 1.5-mm part of 1.8-mm flaw on W3-390. Flaw 1.8 mm detected by fingerprinting and AUT V4 but missed by other 3 AUT vendors

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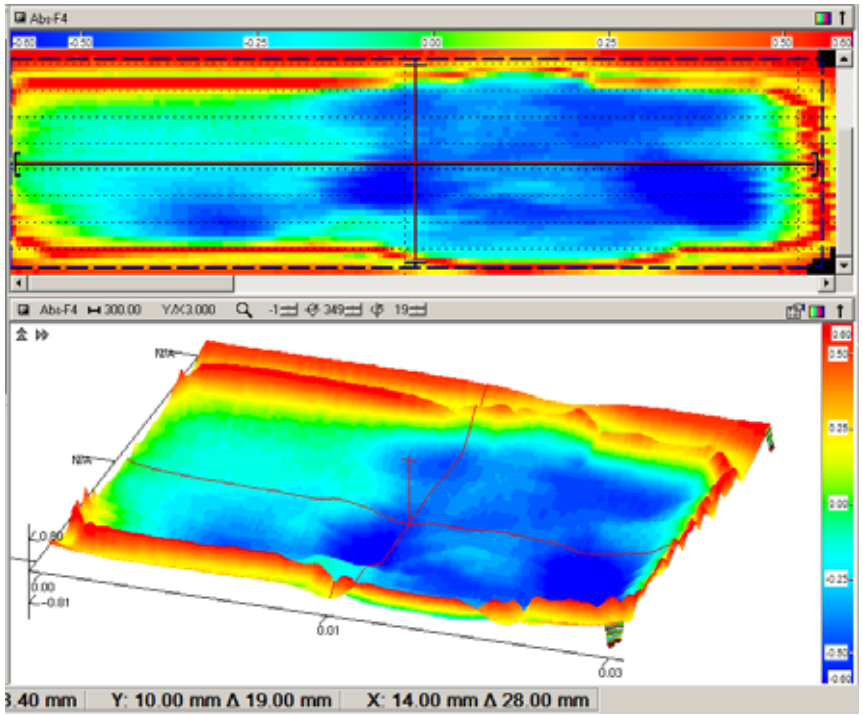
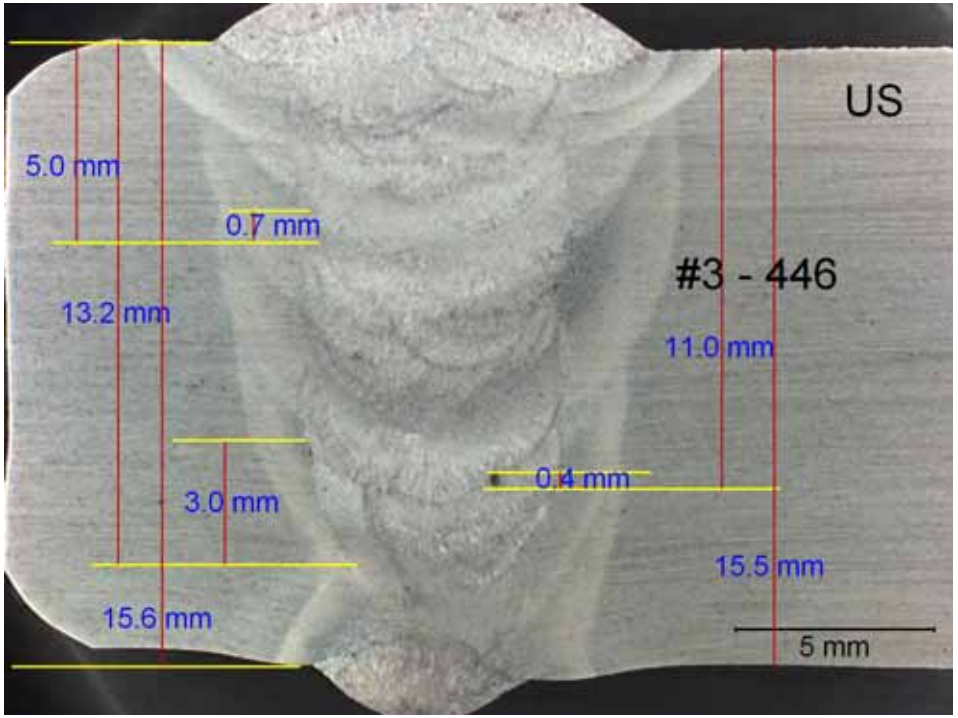
Section W3-446





- **EC**
  - No confirmation of any flaw on C-scan
  - Only 0.4 mm pore confirmed by manual EC
- **AUT**
  - Flaws 0.4 and 0.7 mm missed by fingerprinting and all 4 AUT vendors
  - Flaw 3.0-mm part of 3.6 mm on W3-449. Flaw 3.6 mm detected by fingerprinting and AUT V1 but missed by other 3 AUT vendors

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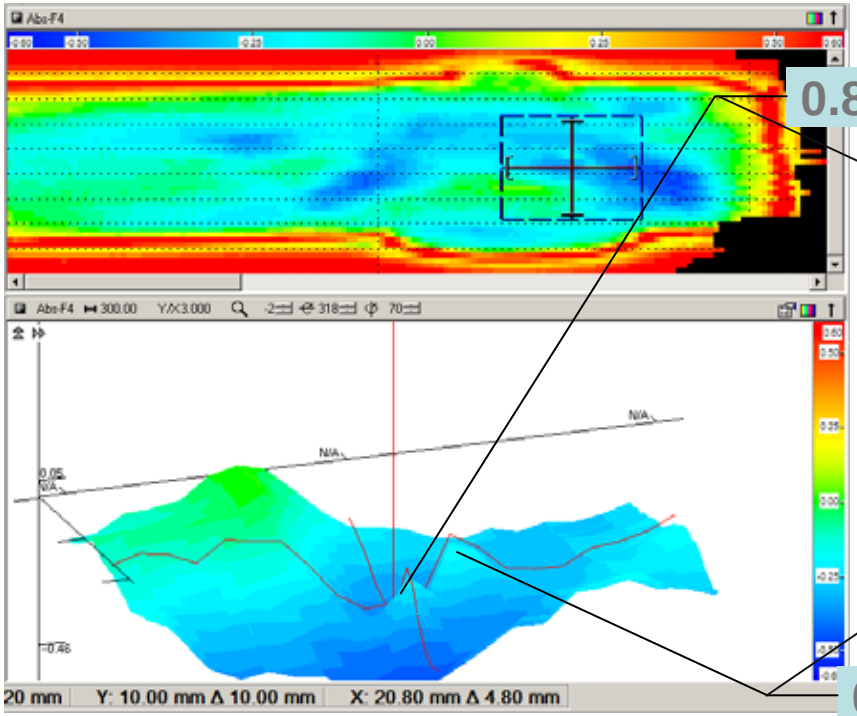
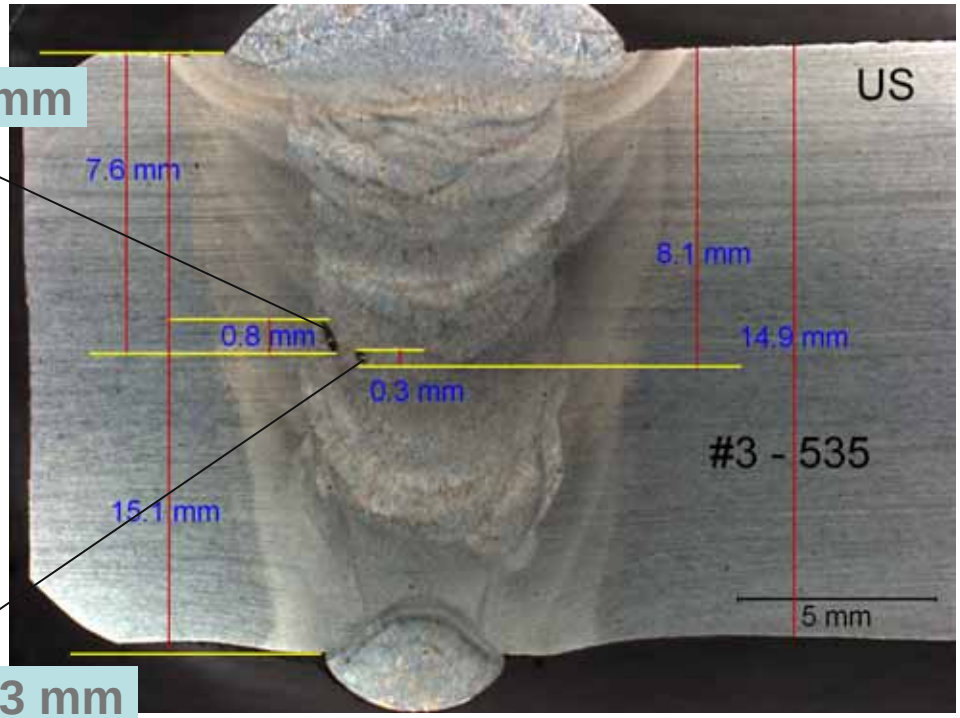
Section W3-535





0.8 mm

0.3 mm

- **EC**
  - All flaws confirmed on C-scan and manual EC
- **AUT**
  - Flaws 0.8 and 0.3 mm missed by fingerprinting and all 4 AUT vendors

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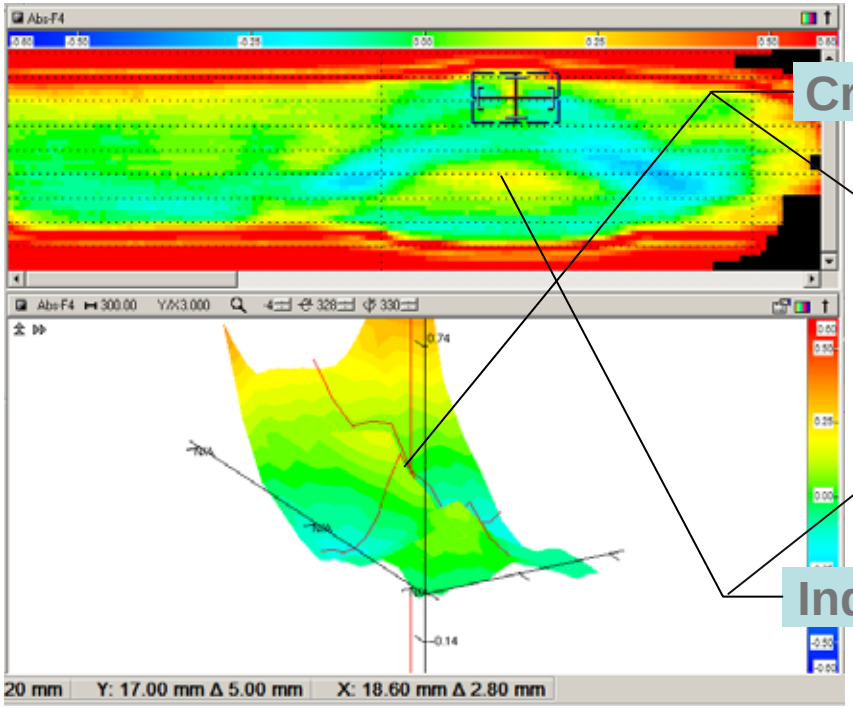
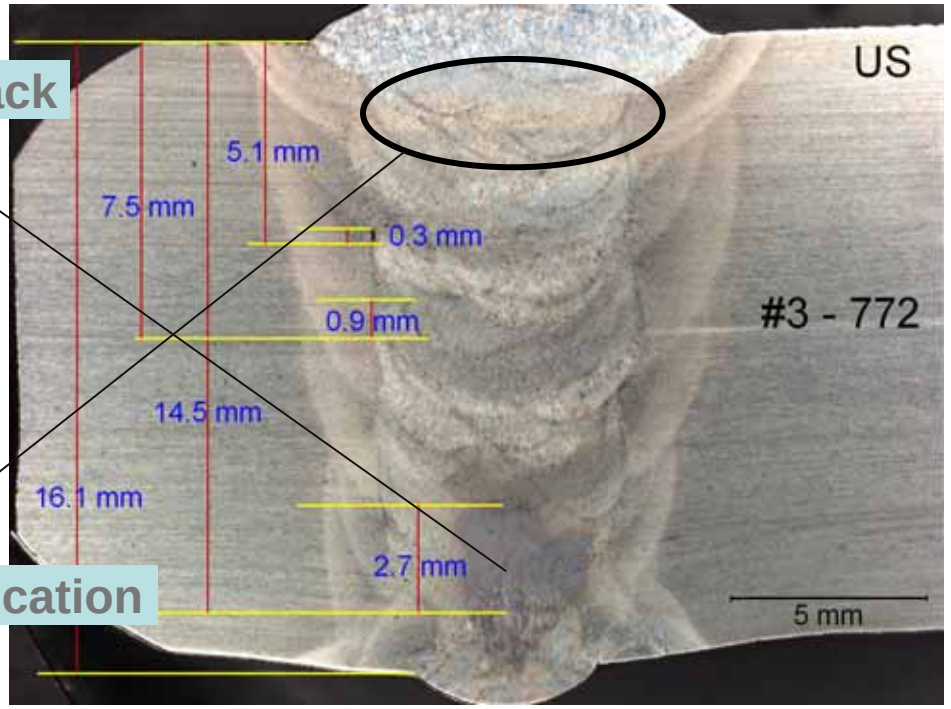
Section W3-772





Crack

Indication

- **EC**
  - Crack 2.7 mm confirmed on C-scan. Difficult to detect. Might be tight or partially fused.
  - Pore 0.3 mm confirmed with manual EC
  - Flaw 0.9 mm was not confirmed
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 2.7 mm detected by fingerprinting and AUT V1 but missed by other 3 AUT vendors
  - Flaws 0.9 and 0.3 mm missed by fingerprinting and all 4 AUT vendors

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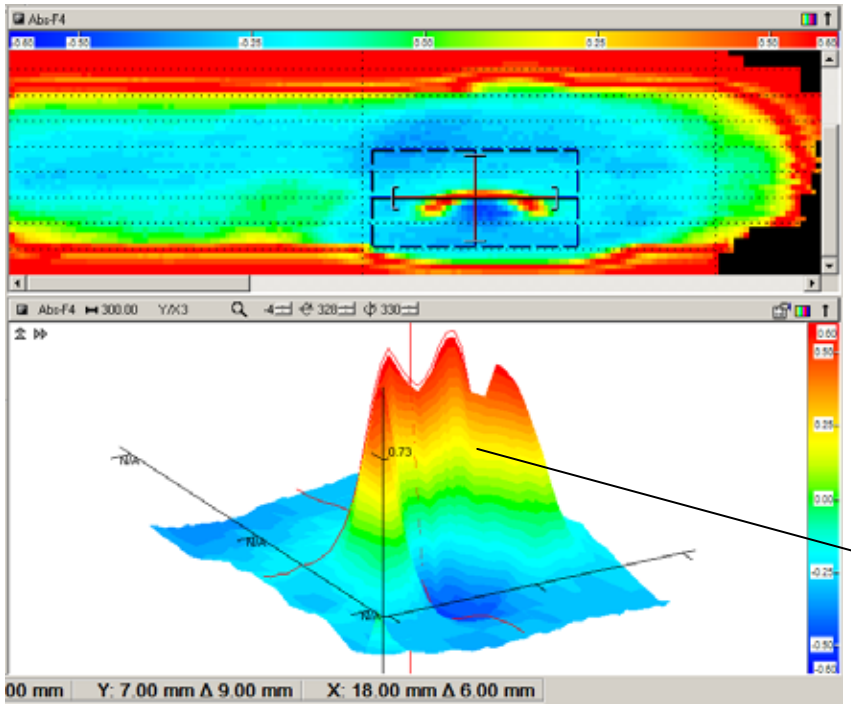
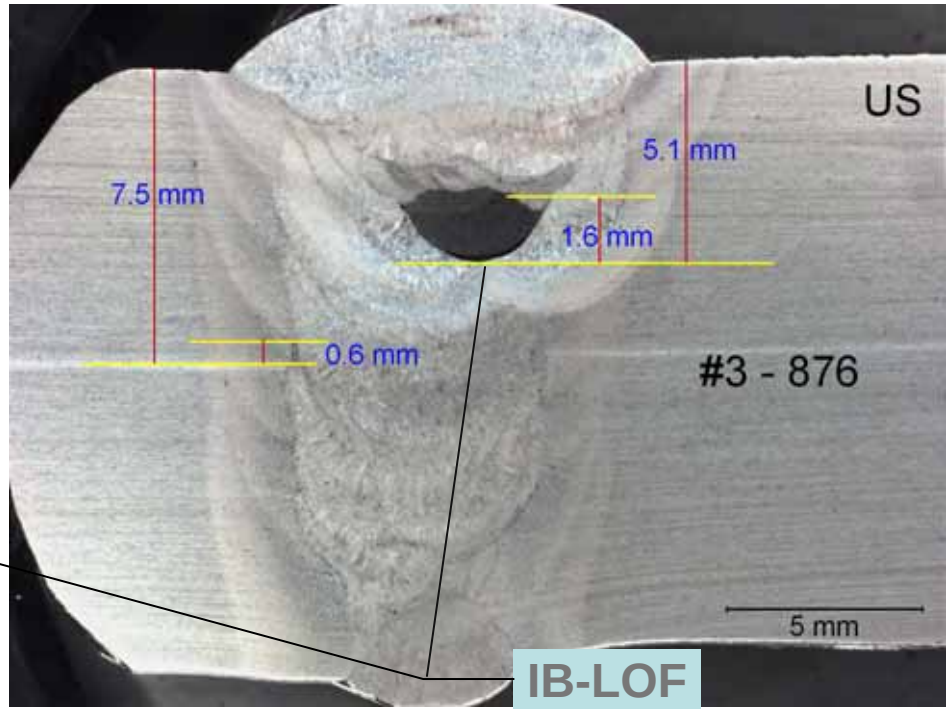
Section W3-876





- **EC**
  - Inter-bead lack of fusion (IB-LOF) easily confirmed on C-scan
  - Flaw 0.6 mm confirmed with manual EC
- **AUT**
  - Flaw 1.6 mm part of 1.7 mm on W3-870. Flaw 1.7 mm detected by fingerprinting and all 4 AUT vendors
  - Flaw 0.6 mm part of 0.7 mm flaw on W3-870. Flaw 0.7 mm detected by fingerprinting but missed by all 4 AUT vendors.

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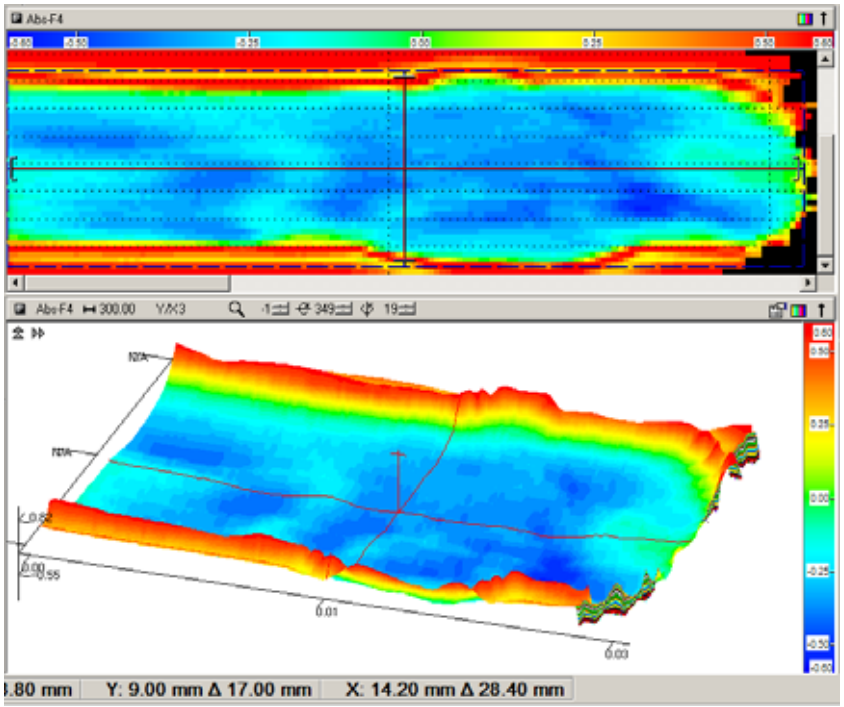
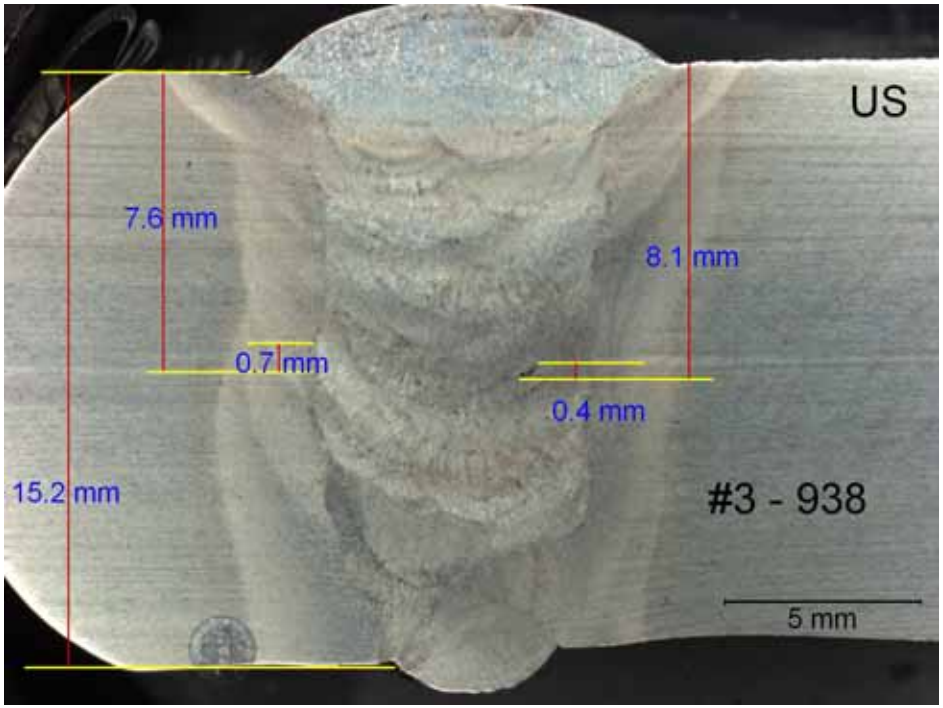
Section W3-938





- **EC**
  - No confirmation of 0.7 mm flaw
  - Flaw 0.4 mm confirmed with manual EC
- **AUT**
  - Flaws missed by fingerprinting and all 4 AUT vendors

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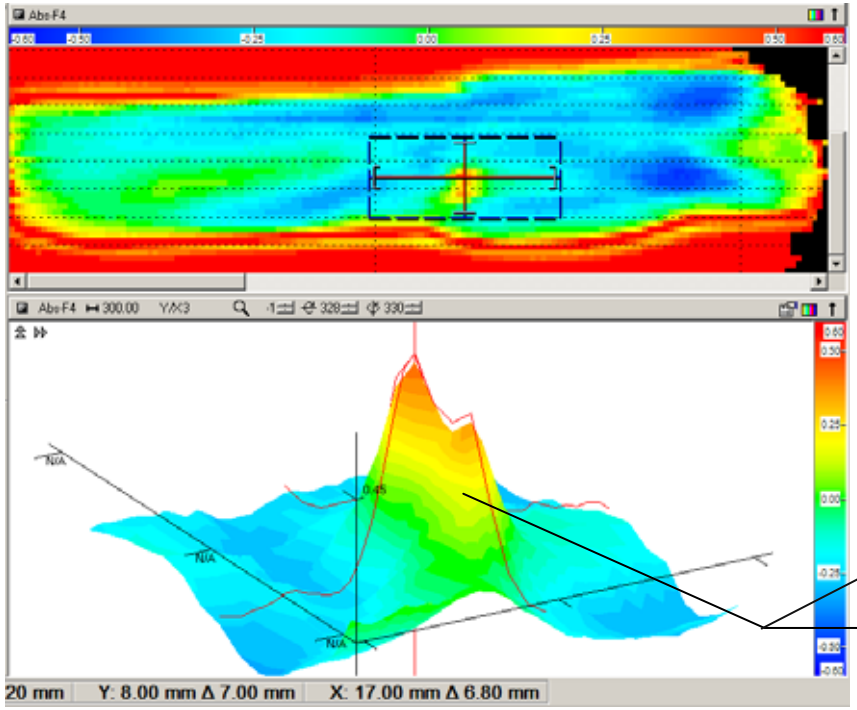
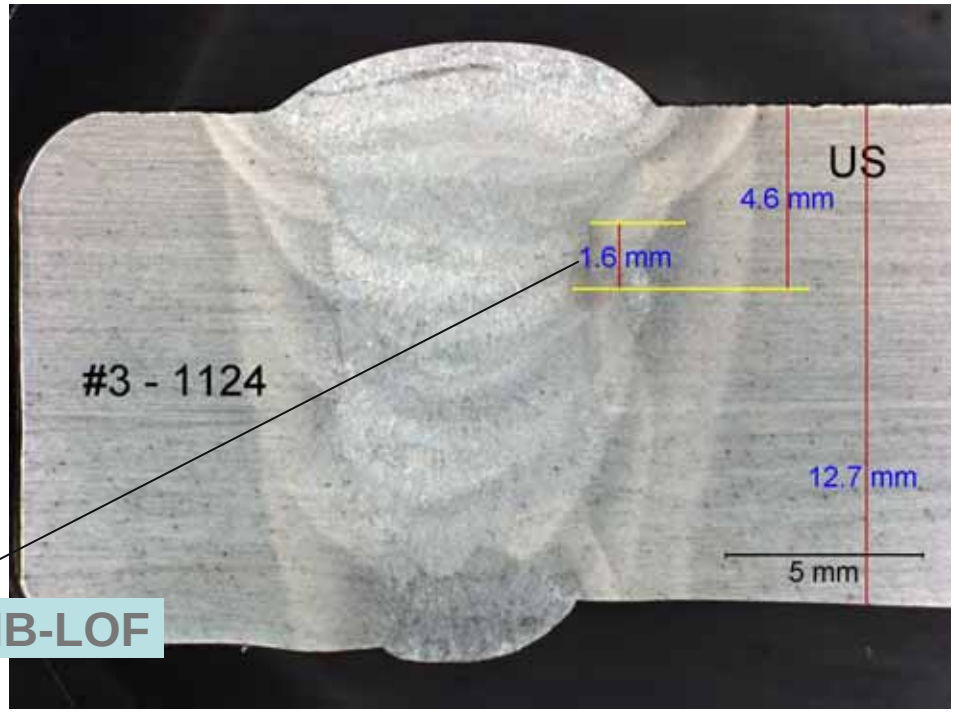
Section W3-1124





- **EC**
  - IB-LOF easily confirmed on C-scan
- **AUT**
  - Flaw 1.6 mm is possibly part of 2.8 mm on W3-1132 (implanted from 1129 to 1144). Flaw 2.8 mm detected by fingerprinting and AUT V1 but missed by other 3 AUT vendors

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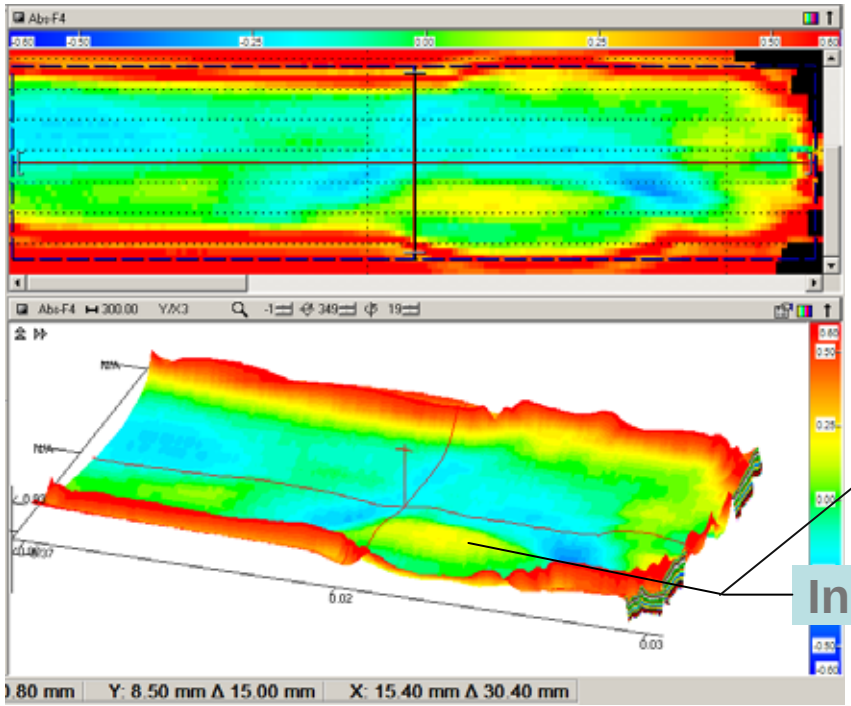
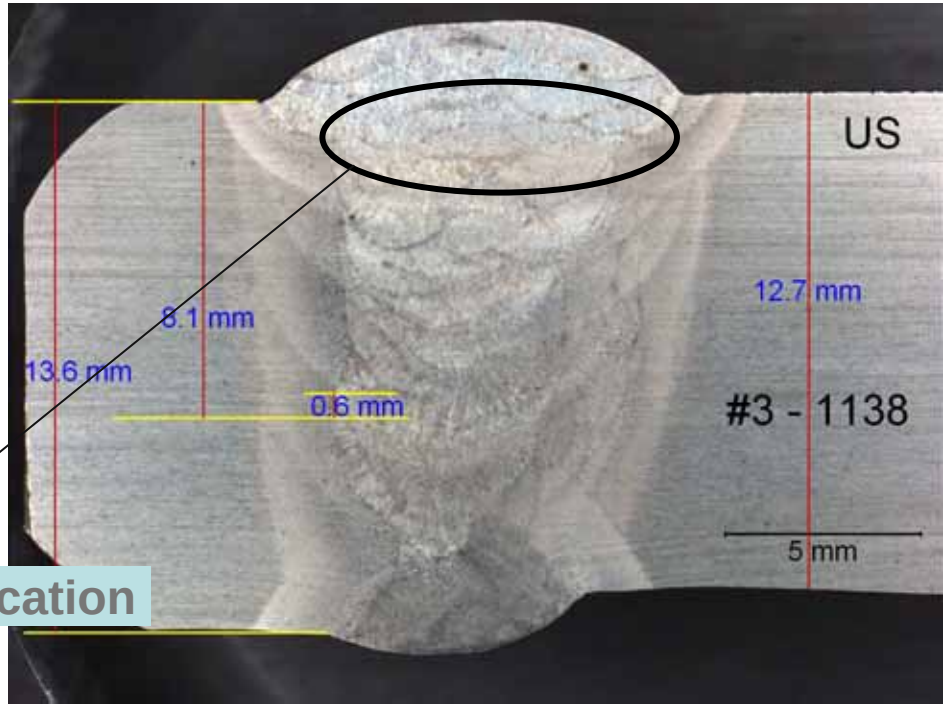
Section W3-1138





- **EC**
  - No confirmation of 0.6 mm flaw
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 0.6 mm missed by fingerprinting and all 4 AUT vendors

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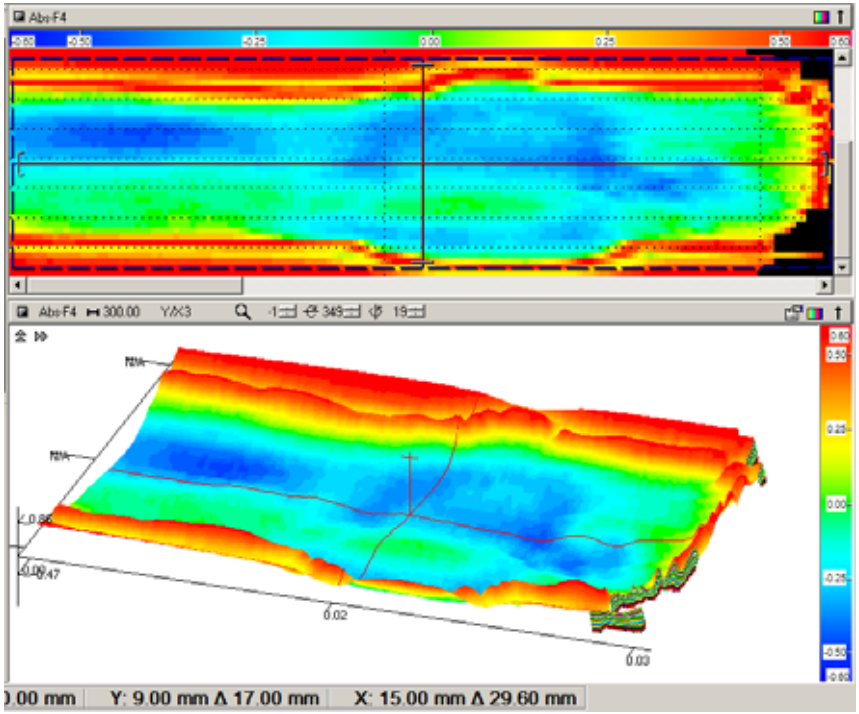
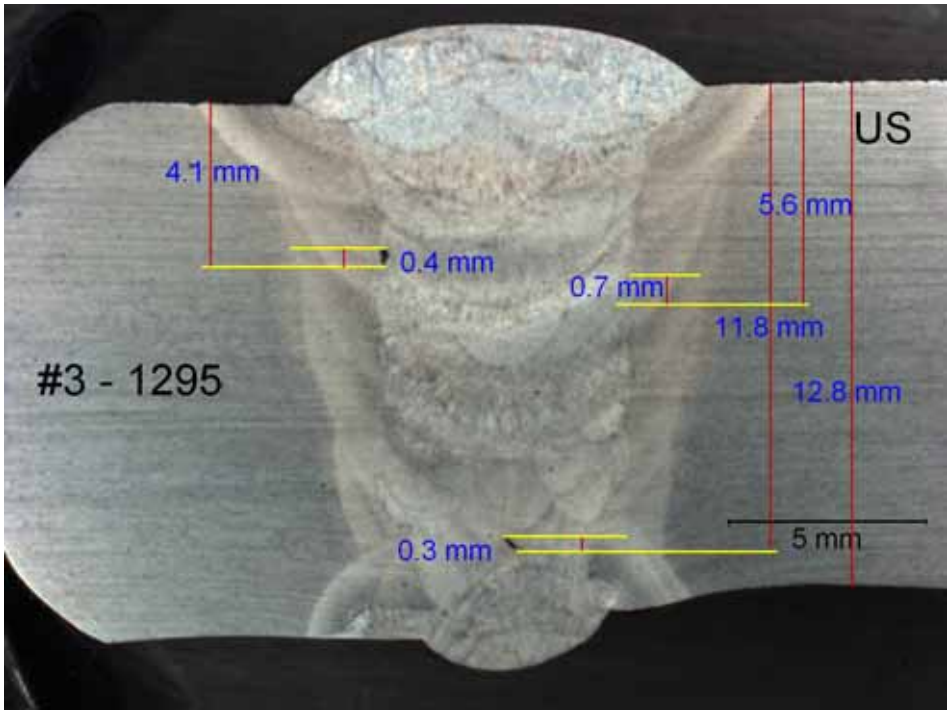
Section W3-1295





- **EC**
  - No confirmation of any flaw
- **AUT**
  - Flaws missed by fingerprinting and all 4 AUT vendors

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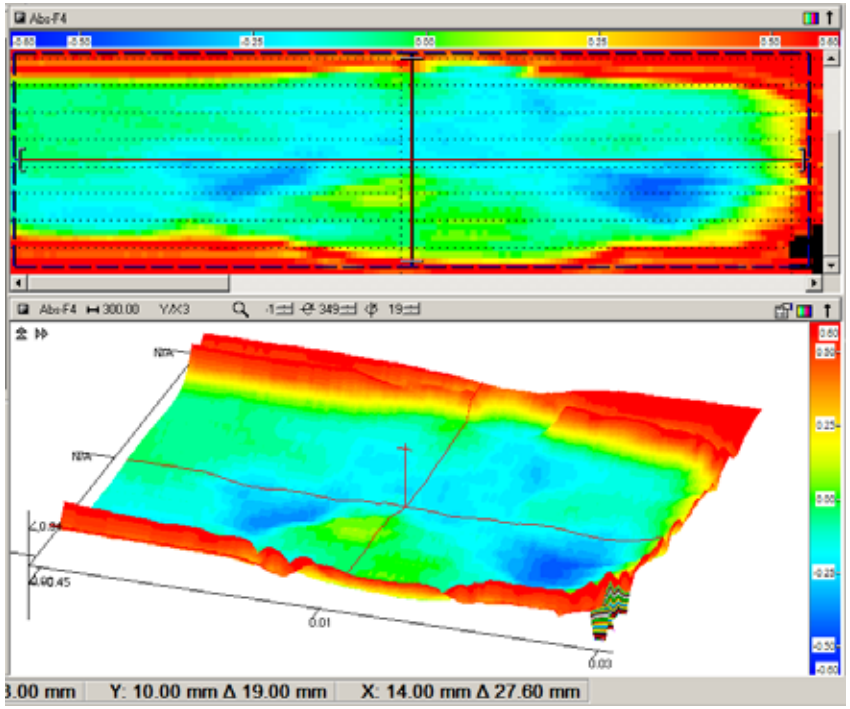
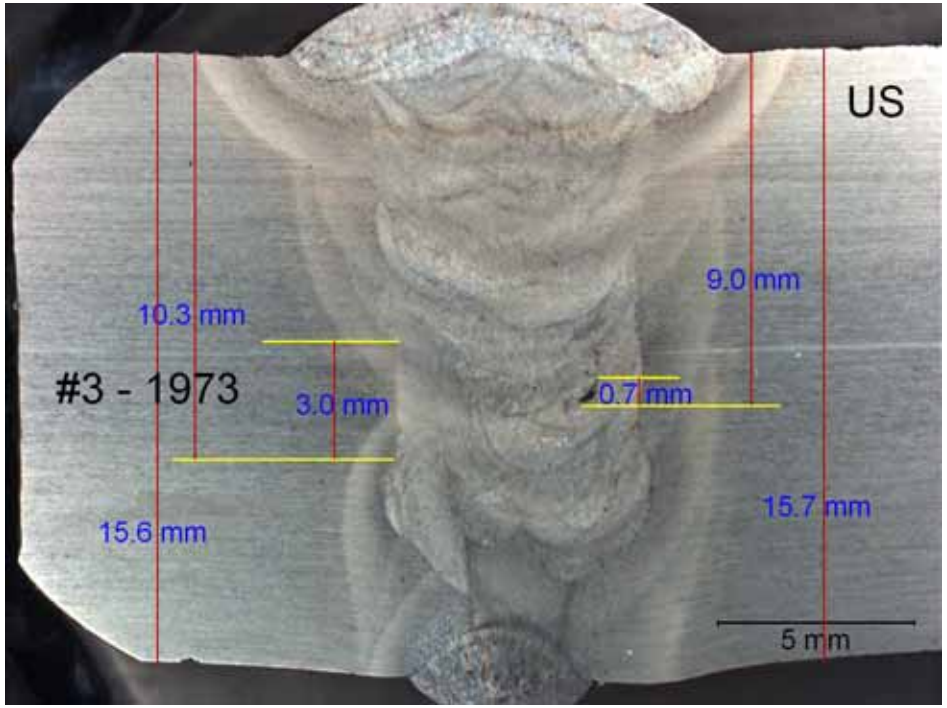
Section W3-1973





- **EC**
  - Side-wall lack of fusion 3 mm was not confirmed on C-scan. Might be tight or fused.
  - Flaw 0.7 mm confirmed with manual EC
- **AUT**
  - Flaw 3.0 mm detected by fingerprinting and AUT V4 (high sizing error) but missed by other 3 AUT vendors
  - Flaw 0.7 mm missed by fingerprinting and all 4 AUT vendors

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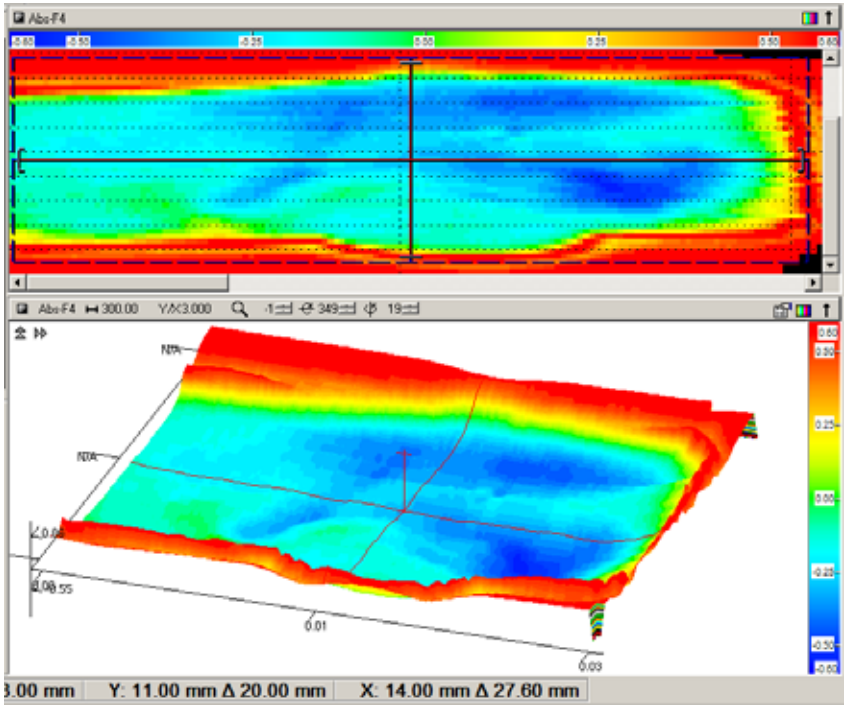
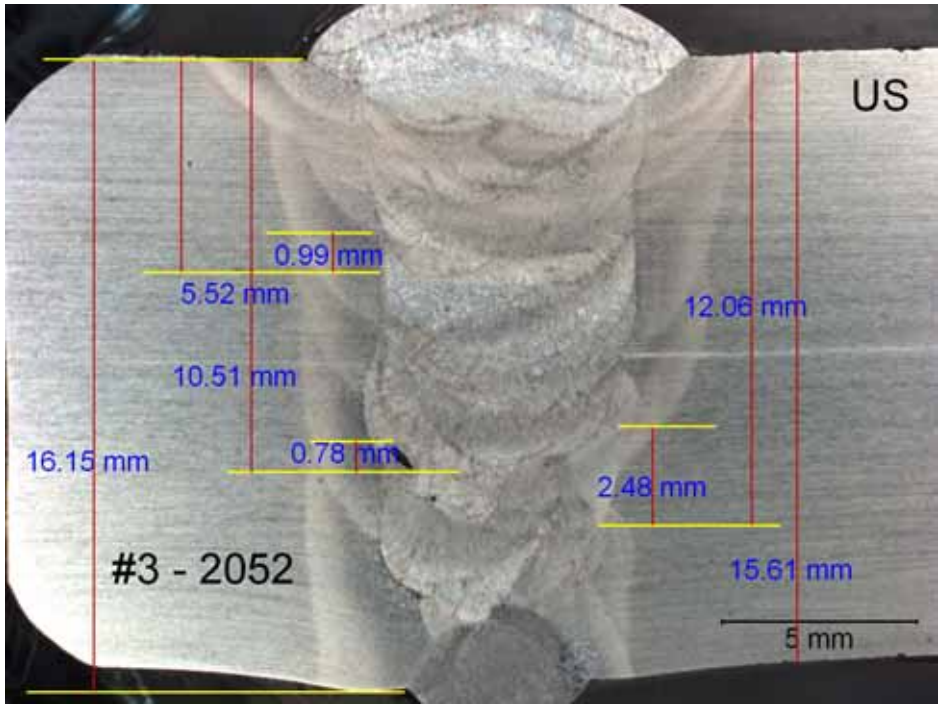
Section W3-2052





- **EC**
  - Flaw 0.99 mm was not confirmed on C-scan
  - Flaw 2.48 mm was not confirmed on C-scan either. Might be tight or fused.
  - Flaw 0.78 mm confirmed with manual EC
- **AUT**
  - Flaw 0.99 mm detected by AUT V4 but missed by fingerprinting and 3 AUT vendors
  - Flaw 2.48-mm part of 2.51 mm on W3-2055. Flaw 2.51 mm detected by fingerprinting and AUT V4 (high sizing error) but missed by other 3 AUT vendors
  - Flaw 0.78 mm detected by fingerprinting but missed by all 4 AUT vendors

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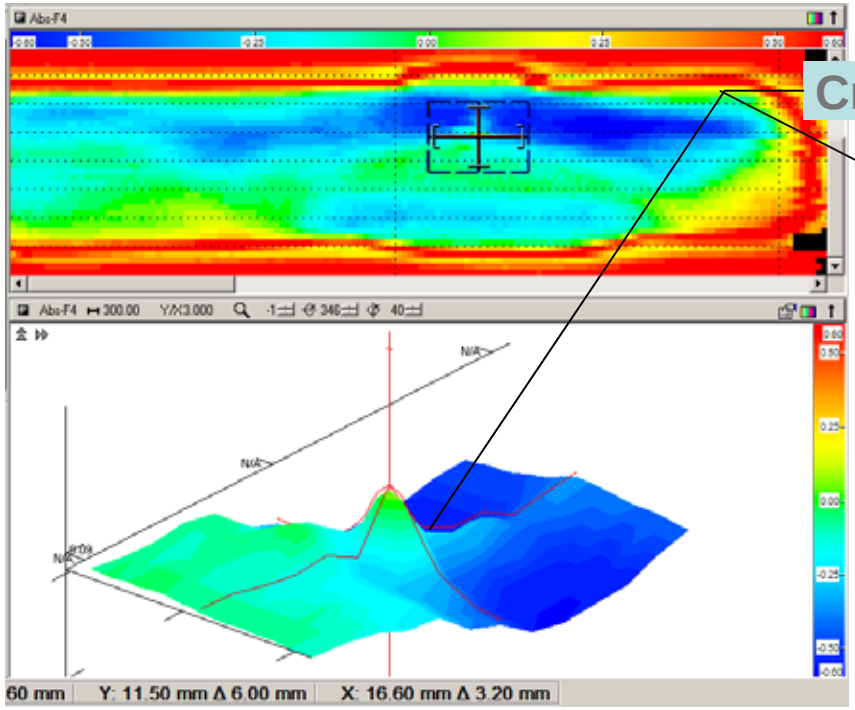
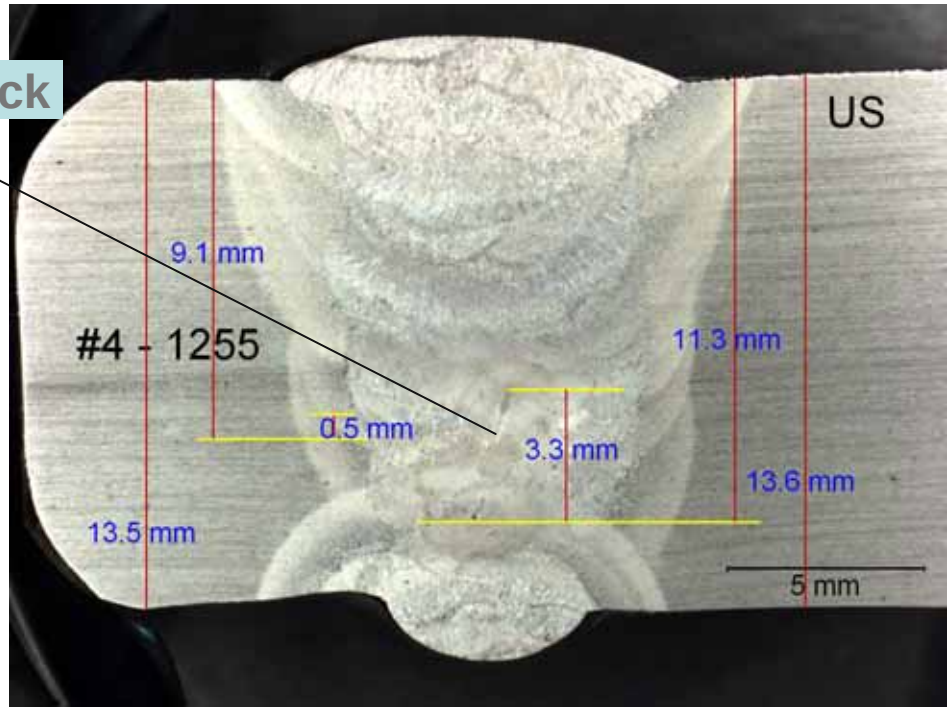
Section W4-1255





- **EC**
  - Crack 3.3 mm confirmed on C-scan. Difficult to detect. Might be tight or partially fused.
  - Flaw 0.5 mm not confirmed
- **AUT**
  - Crack 3.3 mm is part of 3.8 mm crack on W4-1252. Crack 3.8 mm detected by all with exception of AUT V3
  - Flaw 0.5 mm missed by fingerprinting and all 5 AUT vendors

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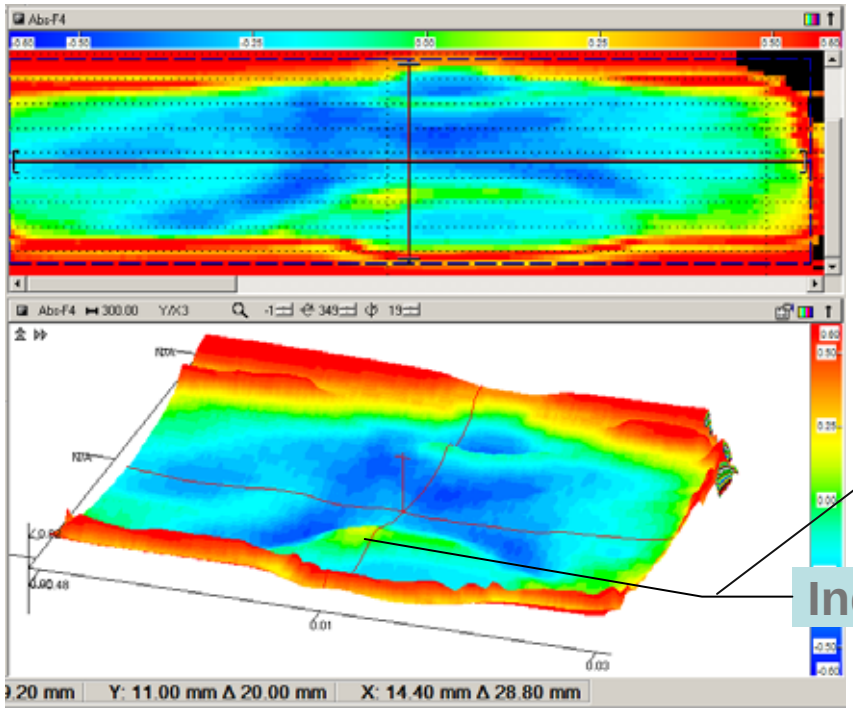
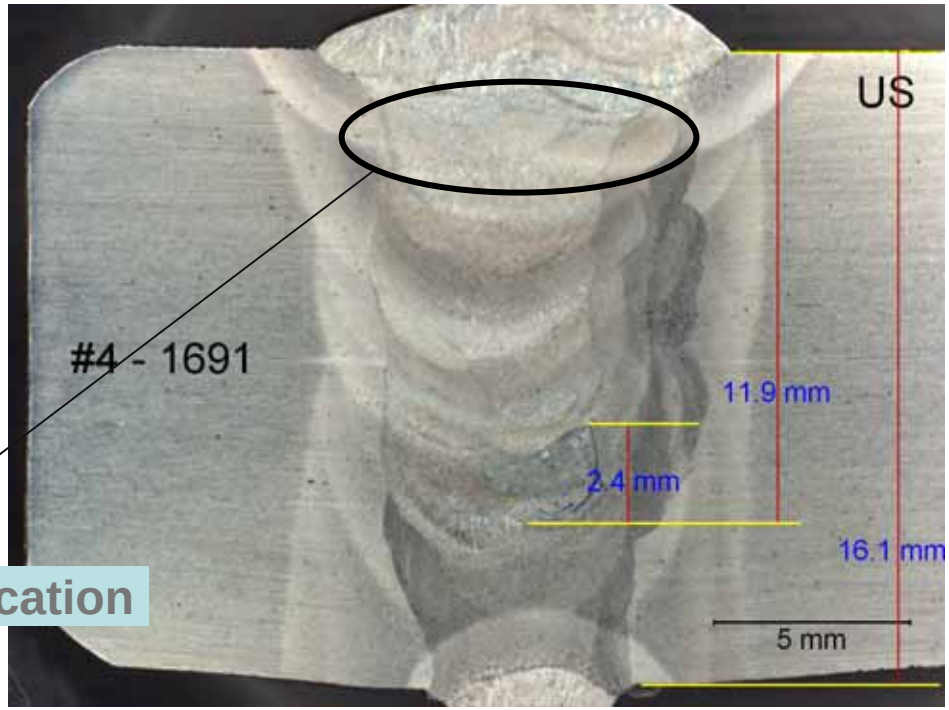
Section W4-1691





- **EC**
  - IB-LOF 2.4 mm not confirmed
  - Pronounced inter-bead transition
- **AUT**
  - Flaw 2.4 mm missed by fingerprinting and all 5 AUT vendors

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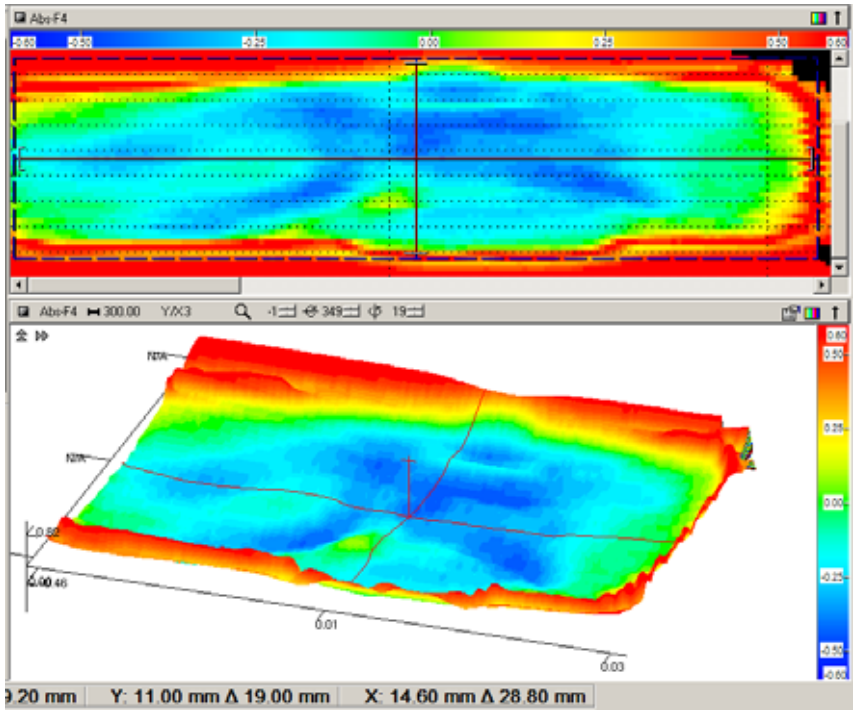
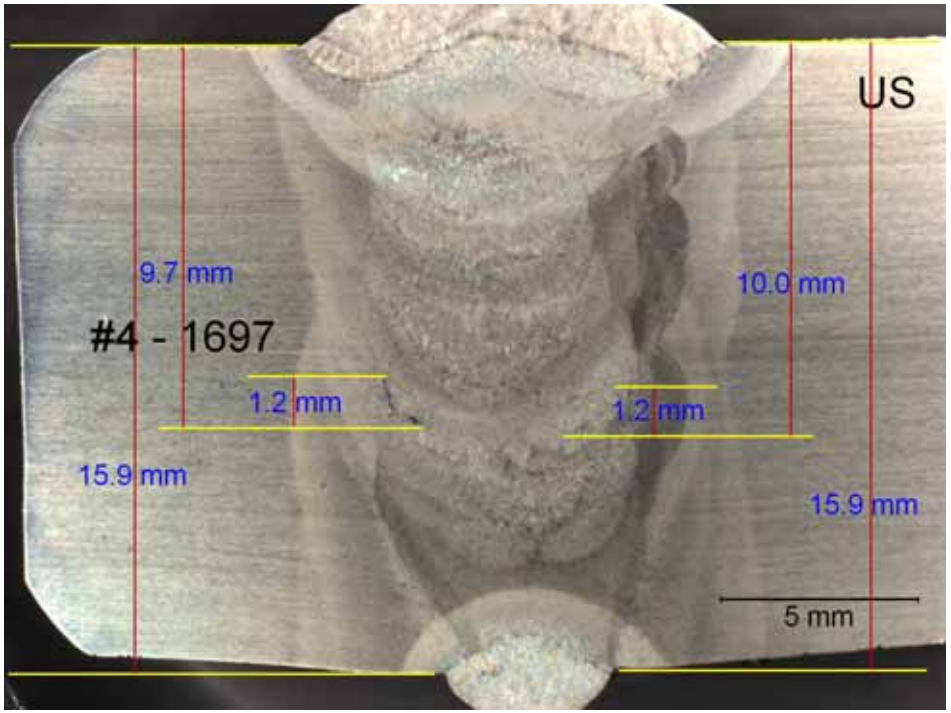
Section W4-1697





- **EC**
  - No confirmation of any flaw
- **AUT**
  - Flaw 1.2-mm DS detected by fingerprinting but missed by all 5 AUT vendors
  - Flaw 1.2-mm US missed by fingerprinting and all 5 AUT vendors

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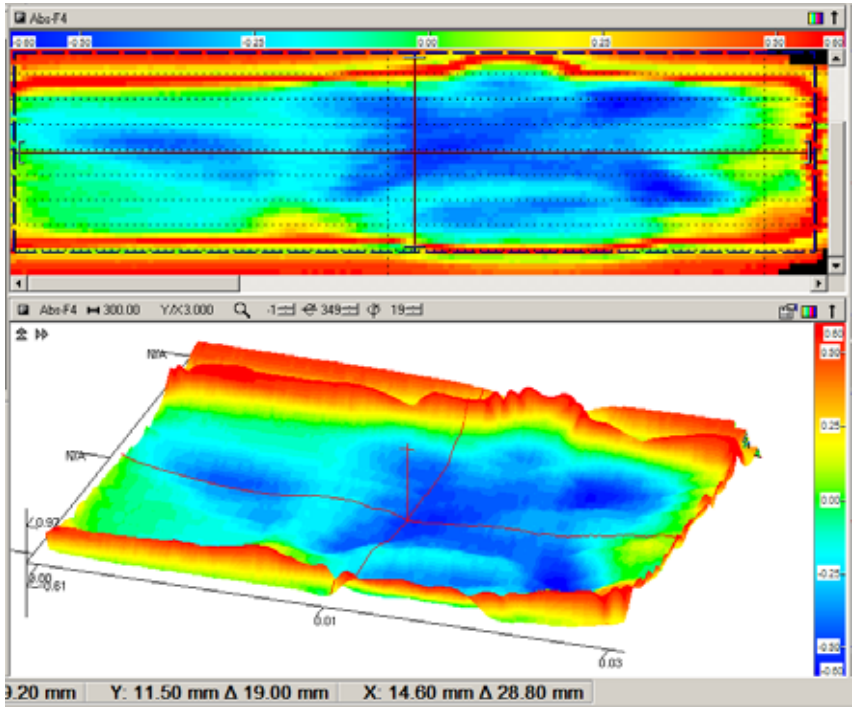
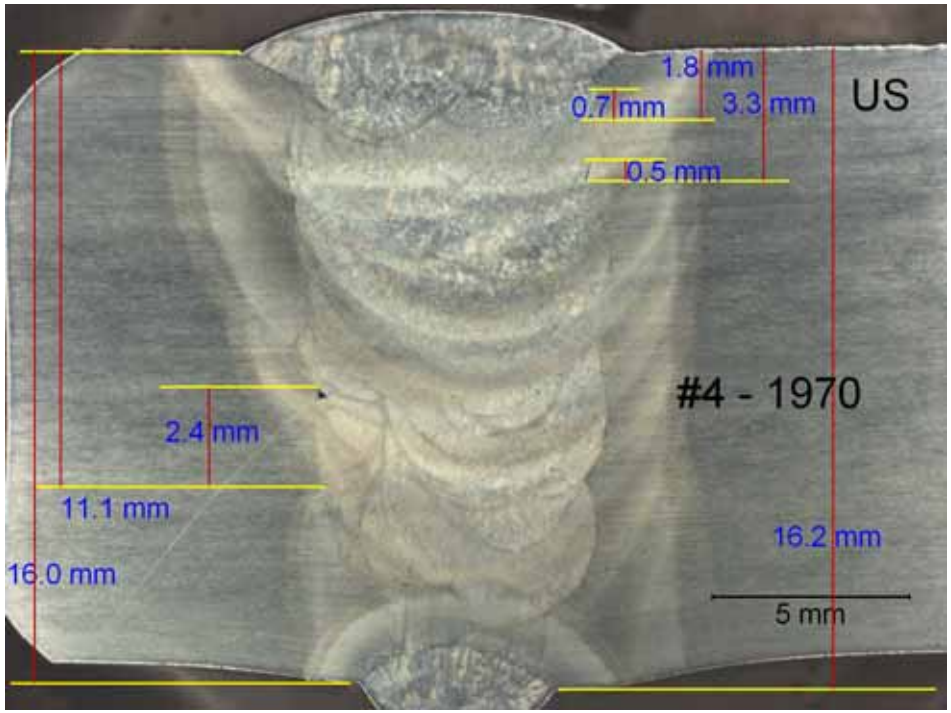
Section W4-1970





- **EC**
  - No confirmation of 0.5 or 0.7 mm flaws
  - Flaw 2.4 mm was not confirmed either. Might be tight or fused.
- **AUT**
  - Flaws 0.5 or 0.7 mm missed by fingerprinting and all 5 AUT vendors
  - Flaw 2.4 mm is part of 3.5 mm crack on W4-1976 (see slide …W4-1976)

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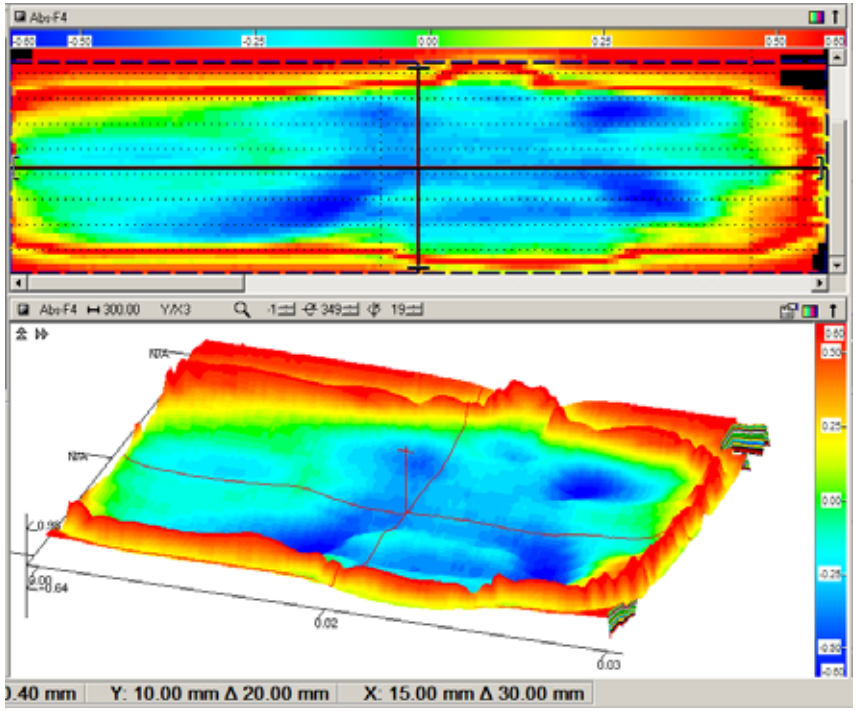
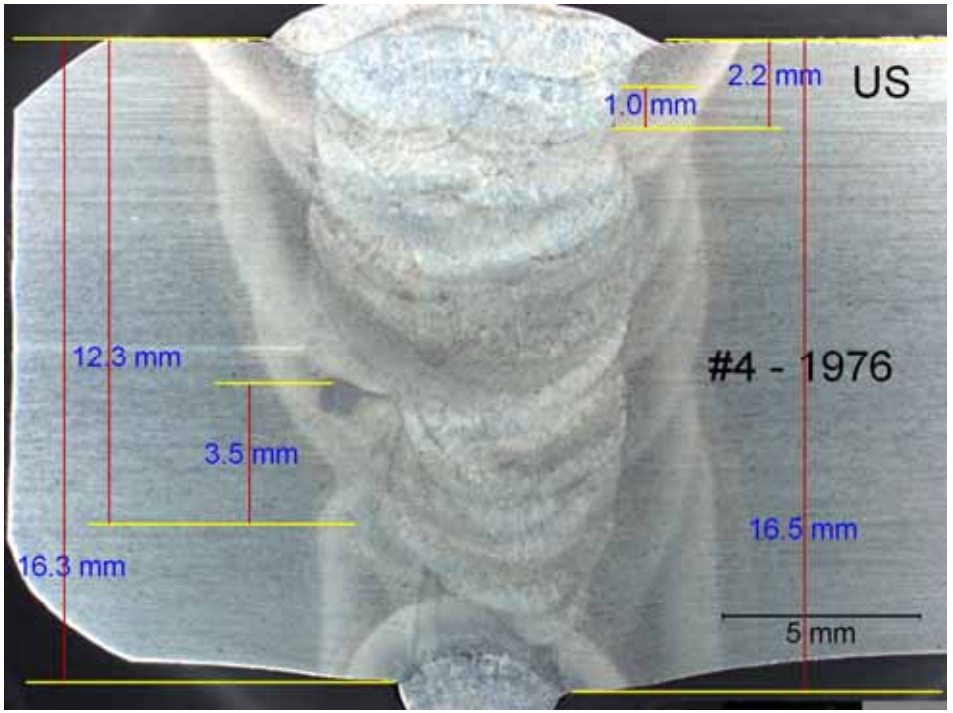
Section W4-1976





- **EC**
  - No confirmation of 1 mm flaw
  - Flaw 3.5 mm was not confirmed either. Might be tight or fused.
- **AUT**
  - Flaw 1.0 mm missed by fingerprinting and all 5 AUT vendors
  - Flaw 3.5 mm detected by all with exception of AUT V3

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Conclusions

- **Total of 29 planar flaws with height smaller than or equal to 1 mm tested:**
  - EC confirmed 9 or 31%
  - Fingerprinting detected 3 or 10%
  - AUT detected less than 1% (1 flaw by 1 vendor out of 122 opportunities)
- **EC performance for smaller flaws was not adequate**
- **It is unknown whether the problem is limited scanning resolution (large scan increments, large probe diameter, probe rocking etc.) or those flaws were very tight or even fused**

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Conclusions (Con'd)

- **Total of 15 planar flaws with height larger than 1 mm tested:**
  - EC confirmed 6 or 40%. 3 out of those 6 were difficult to detect. Consequently, reliably confirmed (easy to detect) were only 3 or 20%.
  - Fingerprinting detected 12 or 80% (many of those called during review of fingerprinting data after destructive test)
  - AUT was positive in 15 cases out of 64 opportunities or 23%. Only 2 out of 15 flaws were detected by more than half of the AUT vendors
- **Good comparison between EC (20%) and AUT (23%)**
- **Discrepancy for 7 flaws in range from 1.1 to 3 mm missed by EC but detected by fingerprinting**

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Conclusions (Con'd)

- **High level of noise from the weld material and heat-affected zone interfered with the flaw/discontinuity detectability by EC**
- **Additional source of noise might be the variability of surfaces stresses induced by macro polishing operation**
- **Off-the-shelf EC probes were not optimized to perform this precise scanning**

Recommendations

- **Suggested that flaw with the largest height 6.5 mm (see slide …W2-2051) missed by fingerprinting and all 5 AUT vendors be removed from the sample. EC indicated partial fusion or extreme tightness**
- **More flaws with height larger than 1 mm might be removed from the sample to improve POD if the discrepancy (7 larger flaws) between the EC and fingerprinting is resolved and EC is improved**
- **EC performance for detection of surface and slightly subsurface (smeared opening due to cutting and polishing) discontinuities must be improved especially for flaws with height larger than 1 mm**

Questions

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