Some R&D needs related to areas of high hardness in pipeline materials

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PRESENTED TO DOT R&D WORKSHOP

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RSI Pipeline Solutions
Reliability • Safety • Integrity

What we'll discuss

Brief recap of industry experience with high hardness areas

Some things we know already

Some recent findings from PRCI research

A few knowledge gaps that would benefit from research

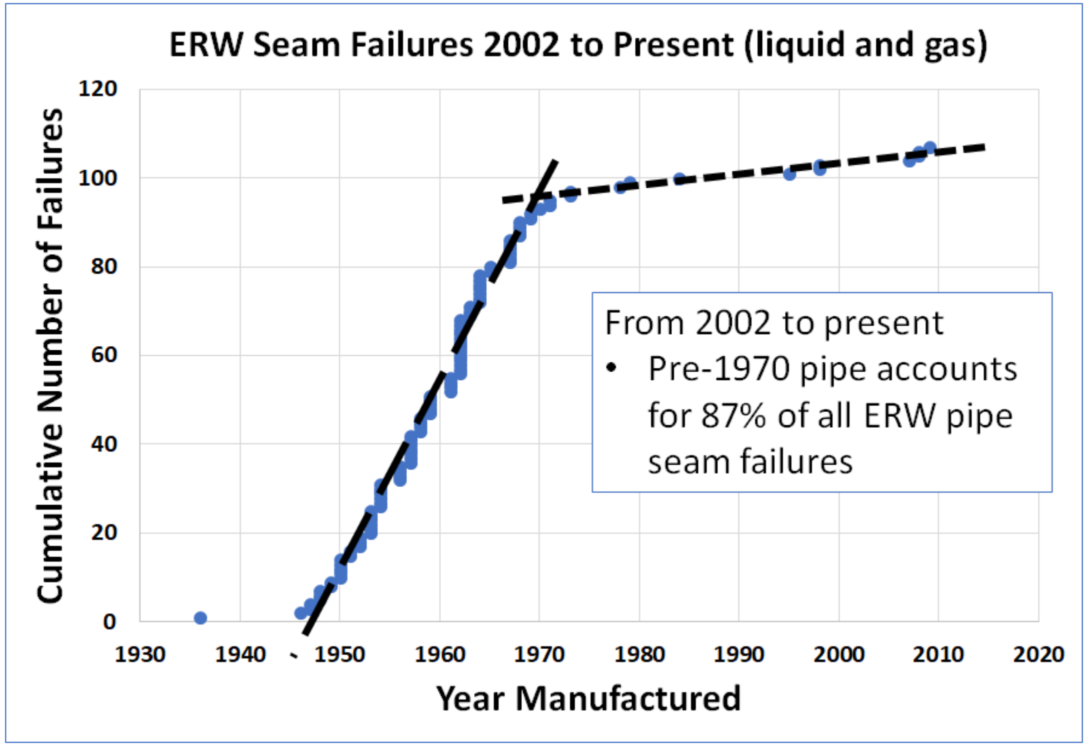
Industry experience

Areas of high hardness occur in:

- Pipe body
  - Generally associated with post-WWII to 1970
  - Tend to occur in C-Mn pipe
  - May be more prevalent with some manufacturers
- ERW seam HAZ
  - Generally associated with pre-1966 vintages
  - Generally associated with non-PWHT seams
  - May be more prevalent with some manufacturers
- Girth weld HAZ
  - Tend to occur with high-CE base metals
  - Welding parameters that promote rapid solidification
  - Not prevented by standard WPS qualification protocols
- Hard microstructures are potentially susceptible to hydrogen cracking; Hydrogen may come from:
  - Cathodic protection
  - Certain corrosion reactions
  - Hydrogen or H2 blend
  - Welding (girth welds only)

High hardness ERW seams

- Very high hardness levels observed in seams not subject to PWHT
- Some ERW pipe received PWHT by early 1950s but it was not a requirement for selling pipe
- PWHT of ERW seams to eliminate hard microstructures was required by API 5L/5LX starting in 1967
    - Note: HF-ERW does not necessarily mean it was PWHT
- Improved ERW performance post-1968 reflects combined effects of API 5L requiring NDE (1963), PWHT (1967), and NDE performance (1968)



High hardness ERW seams

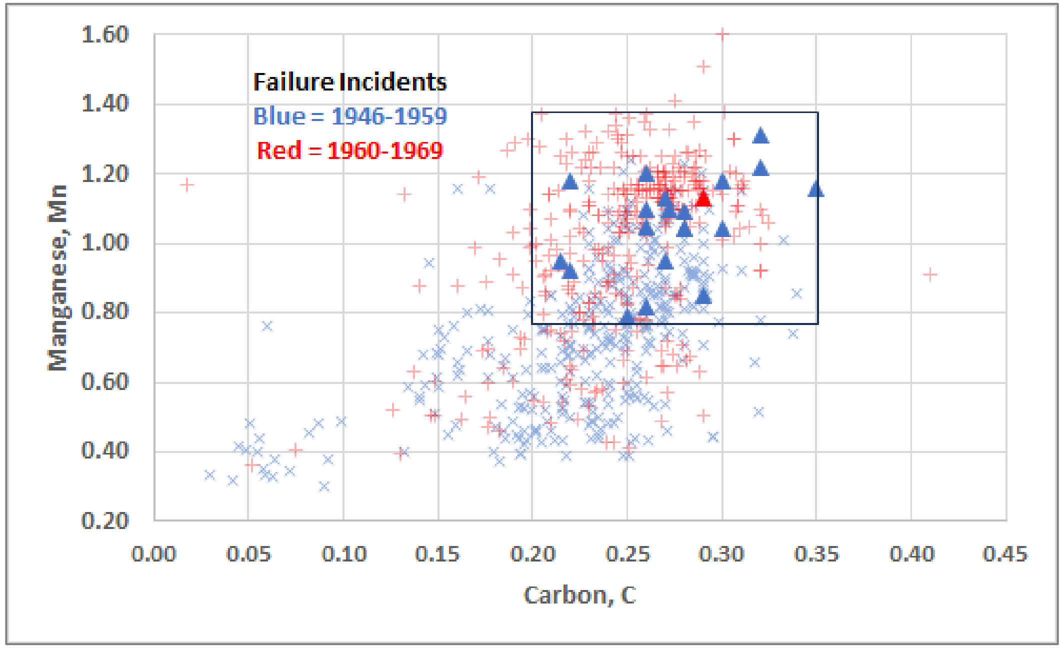
- Hard seam HAZ microstructures may be relatively intolerant of ERW seam defects such as cold welds, hook cracks, or selective seam weld corrosion
- Cracking influenced by hydrogen has been relatively rare in total count of ERW seam failures from all causes
  - Attention focused by a few very significant failures
- ILI detection of hard seam microstructures has not been demonstrated

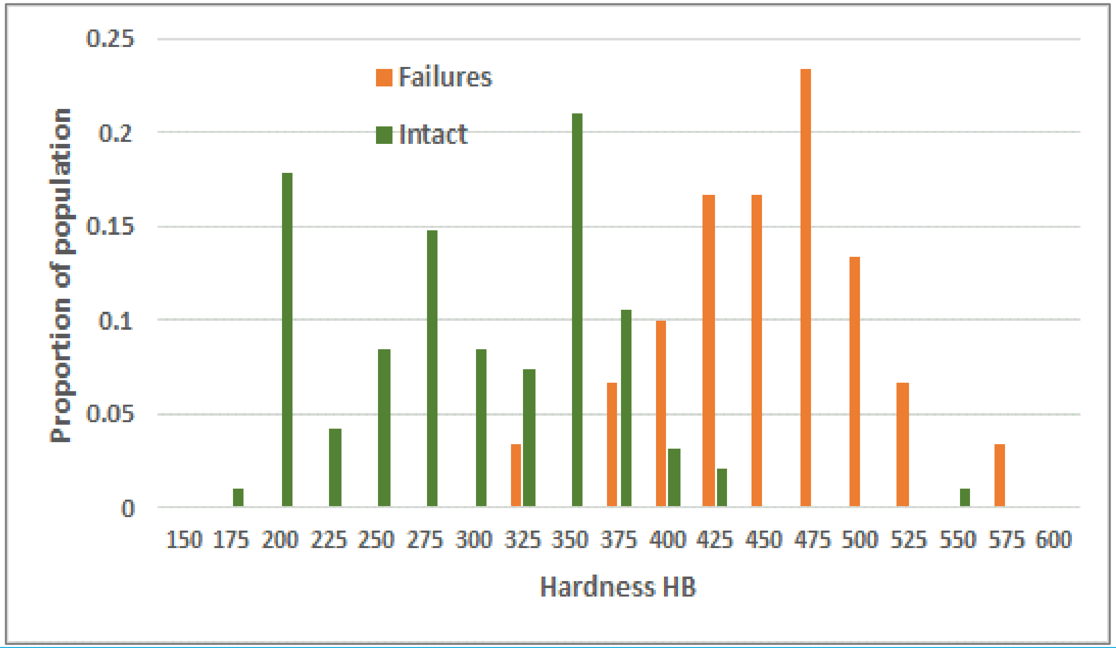
Pipe body hard spots

- Some operators experienced dozens of failures – both leaks and ruptures
- Observed in SAW, FW, and ERW pipe
- Various manufacturers, but AOS is prominent
- Hard areas vary in size and hardness level
- Failures focused in 1945-1970 vintage pipe with high C-Mn, grades B-X70 but most often X52
- Some failures due to hydrogen cracking, some due to SCC

Pipe body hard spots

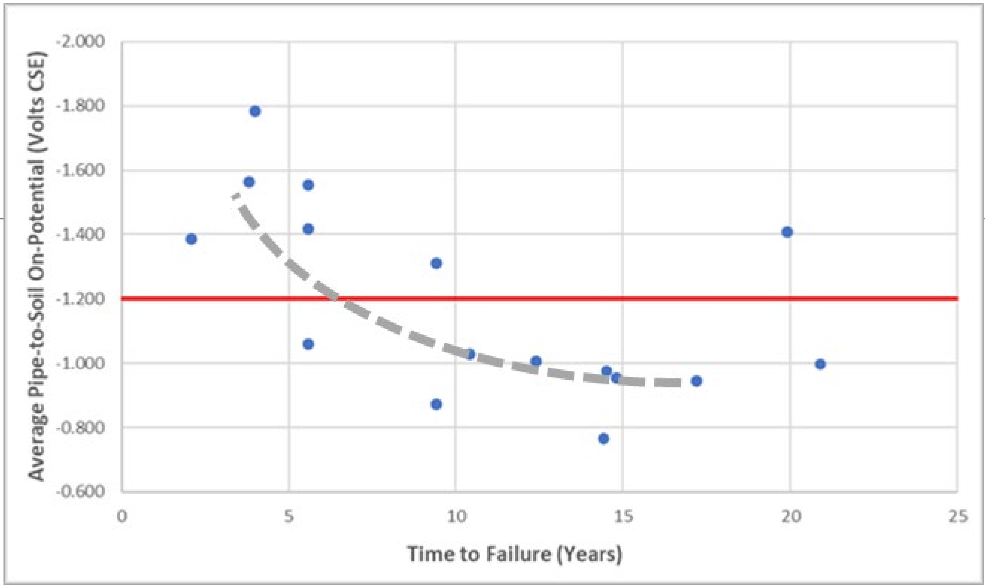
- Hardness distributes higher in those that failed than intact areas, but some overlap
- Hardness = function of steel chemistry and cooling rate

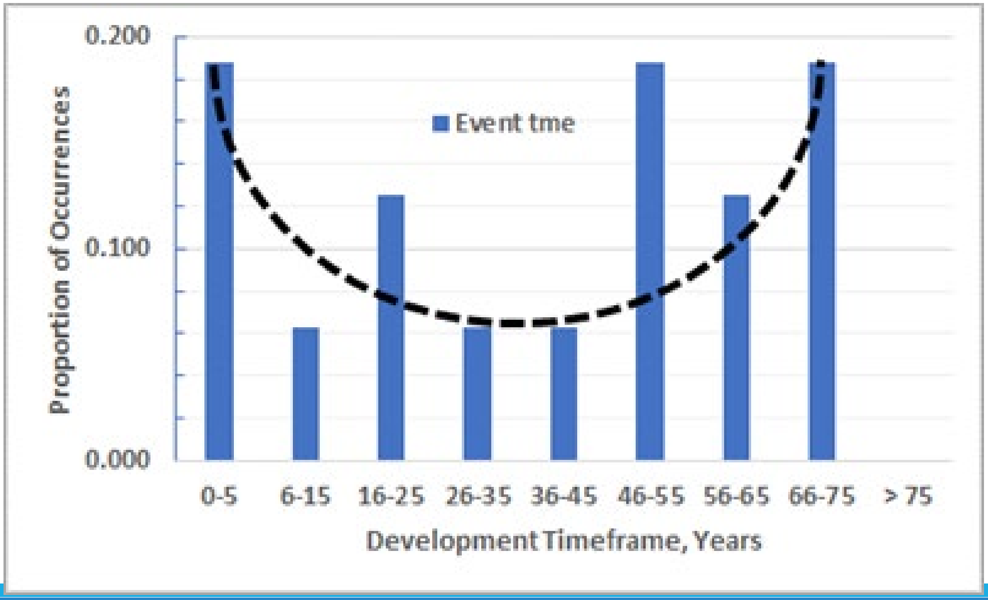




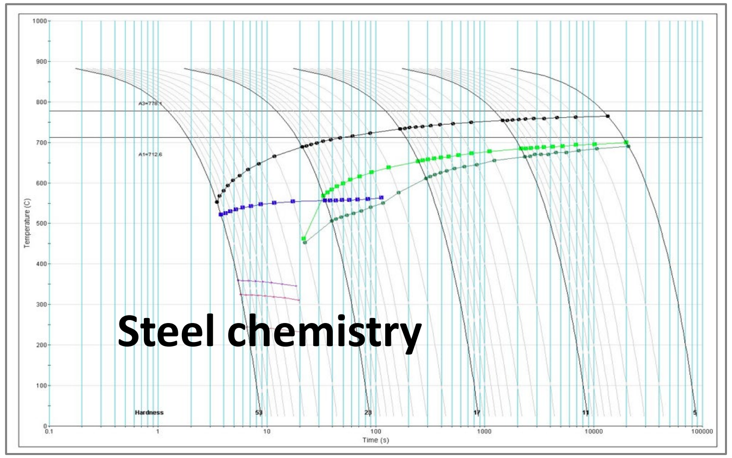
Time to failure

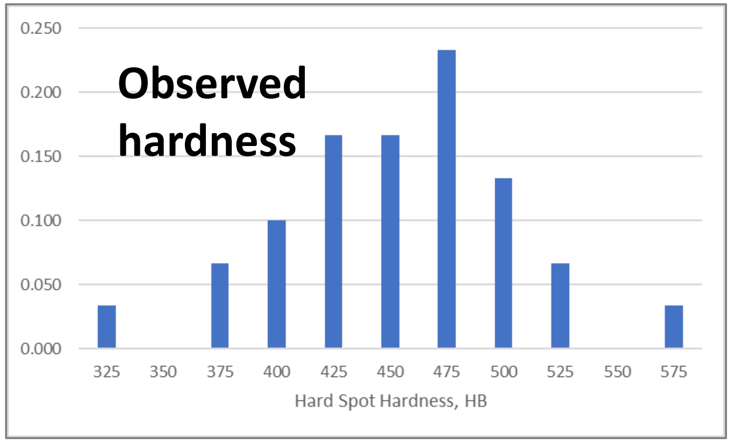
- Time to failure is not precise.
- Garrity (REX23) observed that the time to failure in hard areas can be reduced when pipe-soil potentials increase above -1.2 V.
- PRCI MAT-8-3 identified possible bathtub failure curve trend for cracking due to hydrogen in hard areas.
- Cracking can be triggered by changes in operating conditions. Those changes can include:
  - CP performance
  - Operating temperature
  - Flow reversal
  - Coating condition

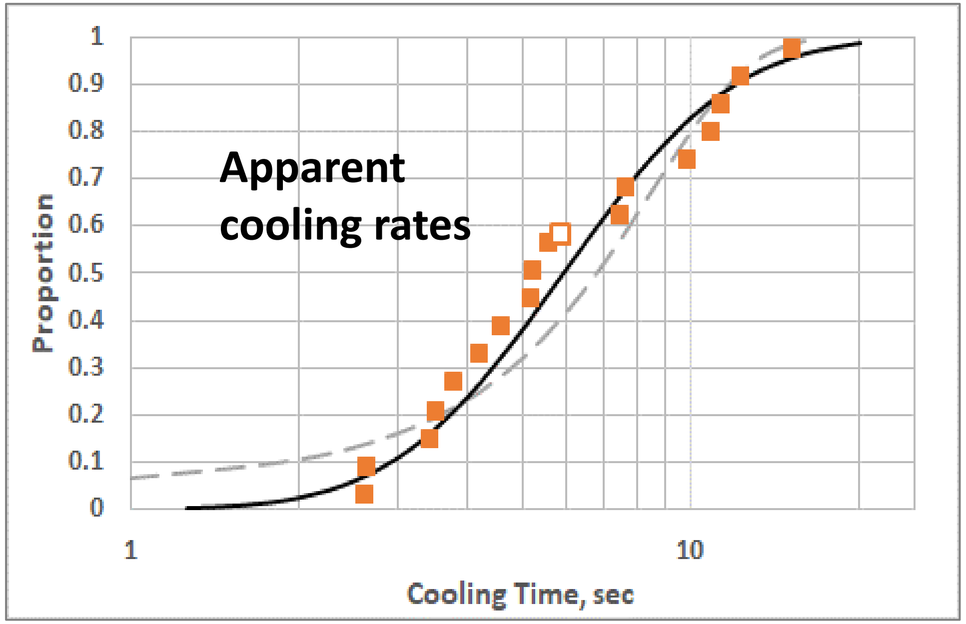




Some gap areas







Cooling rates

- Based on steel chem and observed hardness, 3-10 sec from Ac1 (>1300F) to 100F.
- How is that possible?
- Water flow rate, plate thickness
- FEA, tests

Some gap areas

Indicated by ILI confirmed in ditch

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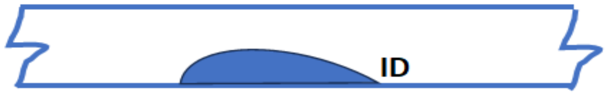
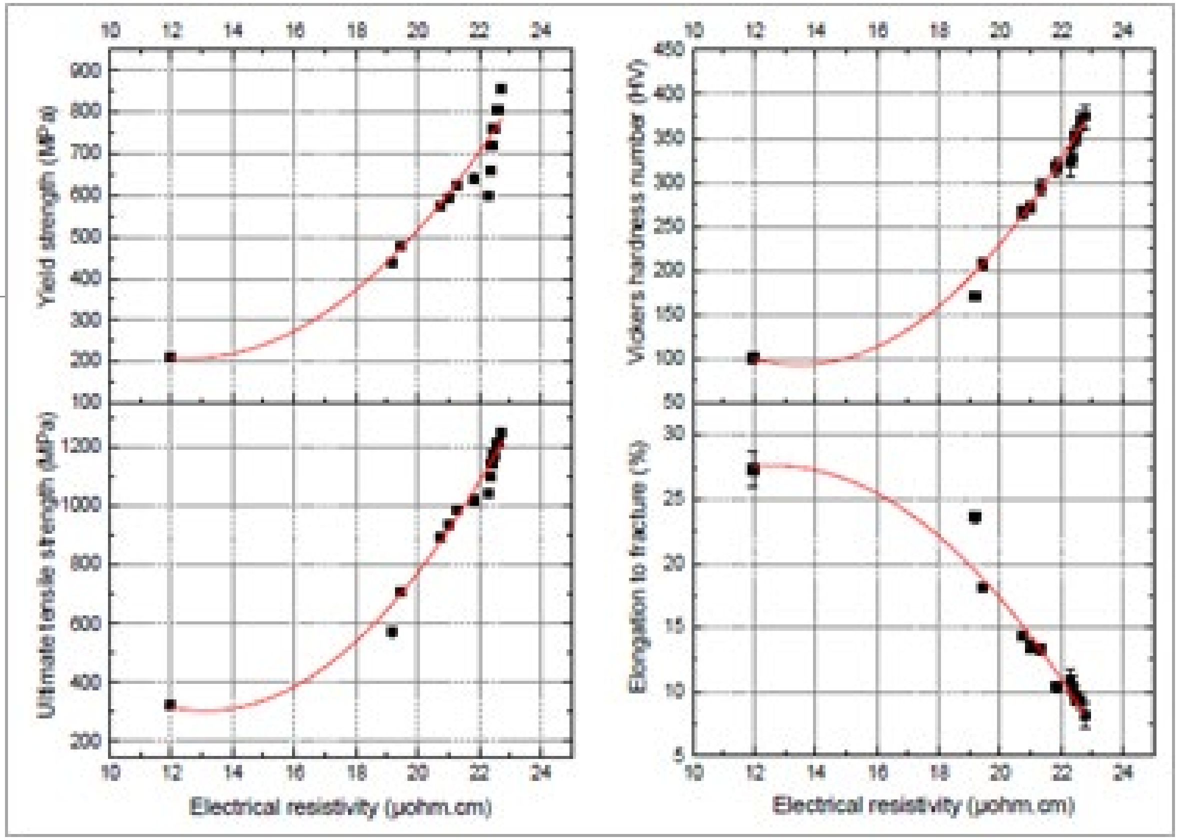


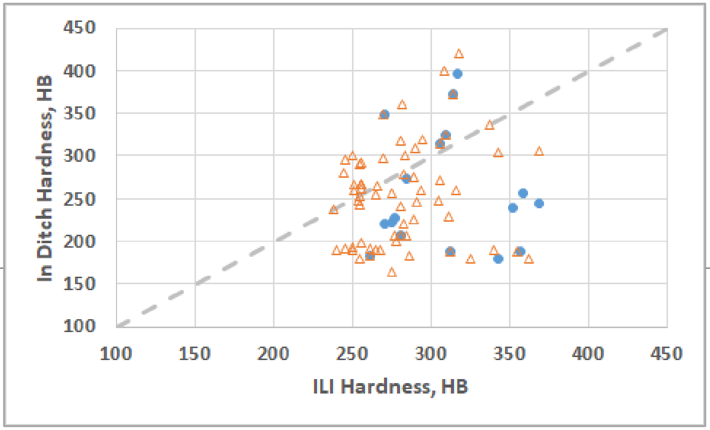
Indicated by ILI *not confirmed* in ditch

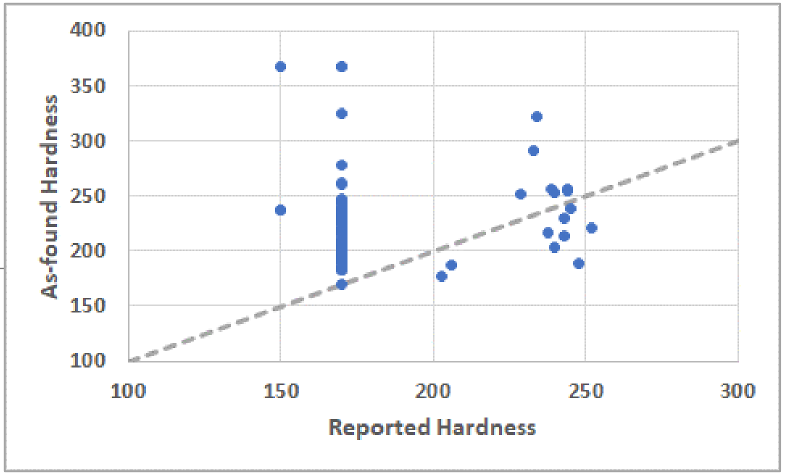


Oliviera Anicio Costa, I.M., Batkova, M., Batko, I., Benabou, A., Mesplont, C., and Vogt, J.-B., “The Influence of Microstructure on the Electromagnetic Behavior of Carbon Steel Wires”, MDPI, 2020.

- Problem: How to determine whether hard spot is superficial or through-wall, or confirm if on ID
- Possible solution: Properties such as electrical resistance vary with hardness. This suggests an in-ditch probe that can confirm hard spot through wall extent.

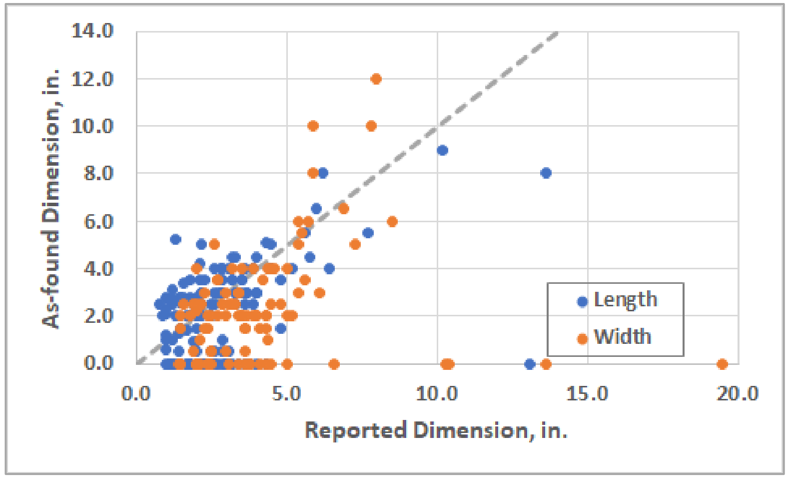
Some gap areas





ILI capabilities still evolving:

- Significant scatter in reported hardness and sizing relative to actual
- Some missed hard spots have failed
- Detecting large numbers of anomalies that are not very important
- Able to identify different hard spot types
- Have not yet demonstrated hard seam capabilities



Some gap areas

Tran, K., Slater, S., Edwards, J., “Know your enemy -- improvements in managing the threat of hard spots”, IPC2022-88362.

Pipe Manufacturer	Inspected Length (miles)	ILI reported anomalies	ILI reported anom/mile
AOS	739	282	0.38
NatTube	232	197	0.85
Republic	170	79	0.46
Kaiser	96	27	0.28
Bethlehem	67	30	0.45
ConWest	46	10	0.22
Claymont	33	5	0.15
Aggregate	**1383**	**630**	**0.456**

Same team, 2-3 yrs later:

Pipe Type	Pipe Manufacturer	Inspected Length (miles)	ILI reported anomalies	ILI reported anom/mile
FW	AOS	1369.08	486	0.355
SAW	Bethlehem	266.62	456	1.710
SAW	Claymont	58.96	6	0.102
SAW	ConWest	306.54	87	0.284
SAW	Kaiser	229.12	131	0.572
ERW	Lonestar	10.21	4	0.392
SAW	NatTube	363.76	68	0.187
SMLS	NatTube	70.45	6	0.085
SAW	Republic	410.03	84	0.205
SAW	USS-DSAW	96.50	39	0.404
ERW	YS&T	57.13	6	0.105
	UNK	9.62	78	8.110
	Aggregate	**3248.01**	**1451**	**0.447**

Some gap areas

Clark, E.B., Leis, B.N., and Eiber, R.J., "Integrity Characteristics of Vintage Pipelines" INGAA, 2005.

Pipe Type	Pipe Source	Production Year	No. HS incidents
FW	AO Smith	1952 1954 1955 1957	17 1 1 1
SAW	Bethlehem Kaiser Republic	1957 1955 1949 1957	2 1 2 1
ERW	YS&T	1947 1950 1960	1 1 1

- Incidents reported by INGAA report, carried over from prior reports
- Only failures, not actual population of hard spots
- Not normalized by mileage
- This data is virtually meaningless
- The ILI data is by mileage but biased by what is inspected, small sample size, still evolving
- Need pipeline mileage by manufacturer for risk models but this data does not exist!
- Possible solution: approach major P/L operators to compile and review their pipe inventories by manufacturer

Some gap areas

More ideas:

- Best repairs for hard areas: What works, what doesn't? Are composite wraps effective for hard areas? Surface treatment for hydrogen barrier? Do hard areas need a CP shield?
- If H is generated by corrosion or MIC process, does this create scenario of hydrogen cracking at low CP pipe-soil potentials?
- Role of residual stresses in hard zone criticality.
- Better definition for the right CP to prevent both corrosion and cracking in susceptible materials

Thank you

Questions? Contact presenter:

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