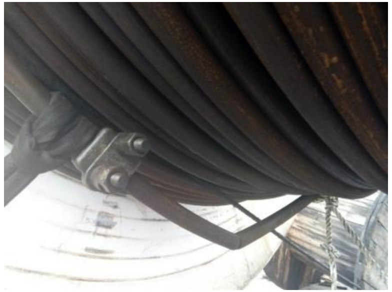


Coiled Tubing String Failures – Past and Present

ICoTA Canada Breakfast Technical Session

May 30th 2018

Tomas Padron – Coiled Tubing Research & Engineering

BAKER HUGHES a GE company

Outline

- What is a CT string failure and examples
- Why doing CT string failure analyses
- CT string failure analysis process
- CT failure statistics
- Main ideas

CT String Failures

- Knowledge and control of fatigue performance

- Improvements in materials and manufacturing processes

Within the company:

- CT failures are analyzed and causes established

- CT failures statistical data

What is a CT Failure?

- CT failure:
  - Loss of pressure integrity of the tubing during service and before the predicted fatigue life has been exceeded.
  - Any condition that renders the string not safe to be used.

It's only a
failure
if you don't
learn
something

What is a CT Failure? – Examples

Pinhole

POOH – PLT run

2-3/8” OD – CT90

Partial Fracture

RIH – Milling

2-3/8” OD – CT100

Total Fracture

Pulling to free string
Cleanout

2” OD – CT90

What is a CT Failure? – Other examples

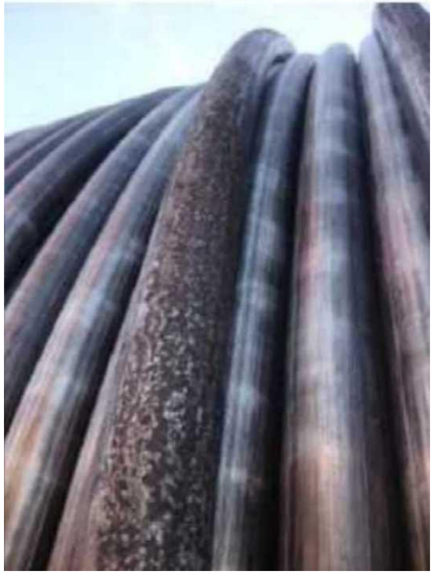
Burst

Pressure testing

1-3/4" OD – CT90

Extensive Damage

POOH Logging job



1-3/4" OD – CT90

Collapse

RIH Cleanout

2-3/8" OD – CT100

???

New string - Inspection

2-3/8" OD – CT80

Why doing CT strings failure analyses?

- Make decisions / take corrective actions based on data and not guesses or "gut feelings"

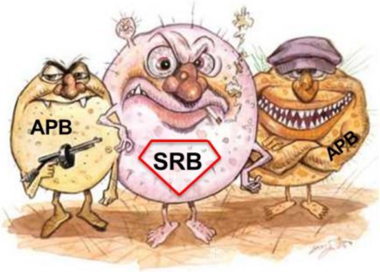
Why doing CT strings failure analyses? – Example

Failure Sequence-Date	Manufacturer	Diameter (in.)	Grade	Days of Service	Runs – Wells	Max. SFL used (%)
First April 9th 2013	A	2	90	26	22 - 7	36
Second May 6th 2013				47	25 - 6	36
Third May 18th 2013	B			24	14 - 6	29
Fourth May 20th 2013				14	11 - 4	17
Fifth July 5th 2013	A			41	22 - 7	50
Sixth July 24th 2013				11	9 – 3	34

“Solutions” initially proposed without any failure analysis:

- “Bad quality” pipe – change manufacturer
- Change the string Grade to YYY
- Limit the fatigue life used to XX%
- Others

All six failures were associated to MIC (fluid contaminated with bacteria)



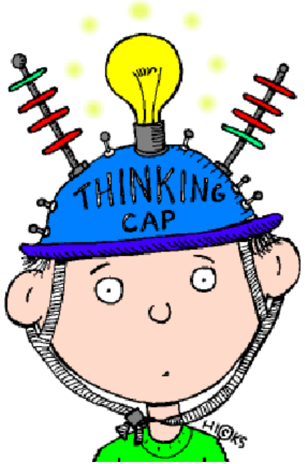
Real solutions:

- Treatment of surface equipment
- Treatment of circulating fluids
- Between-wells stagnant fluids treatment

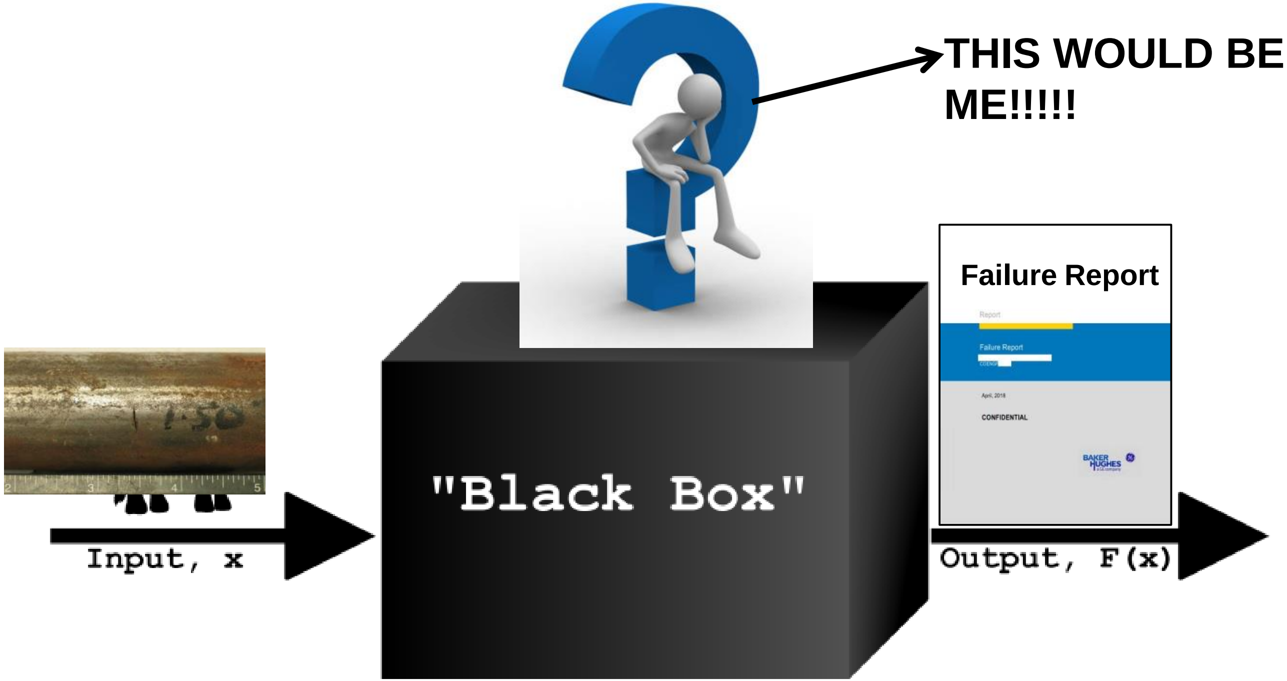
CT string failure analysis process

CT failure analysis:

Logical process of examination to establish the failure cause(s) based on evidence collected and the use of engineering principles.



CT string failure analysis process



Failure analyses are not done with a black box

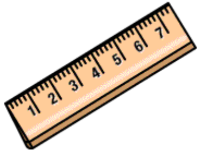
CT string failure analysis process

We don’t use crystal balls either !!!!

CT string failure analysis process

- Most common CT failure analyses include the following stages:
  - Sample(s) collection/preservation
  - Collection of data regarding failure/CT string

  - Visual/stereoscopic examination



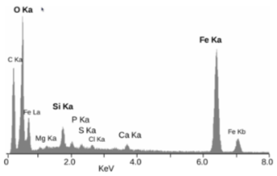
  - Dimensional inspection

  - Metallographic analysis

  - Results analysis and report preparation

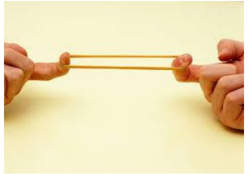
CT string failure analysis process

- Some additional analyses that are required for some particular cases:
  - Energy-Dispersive Spectroscopy (EDS)



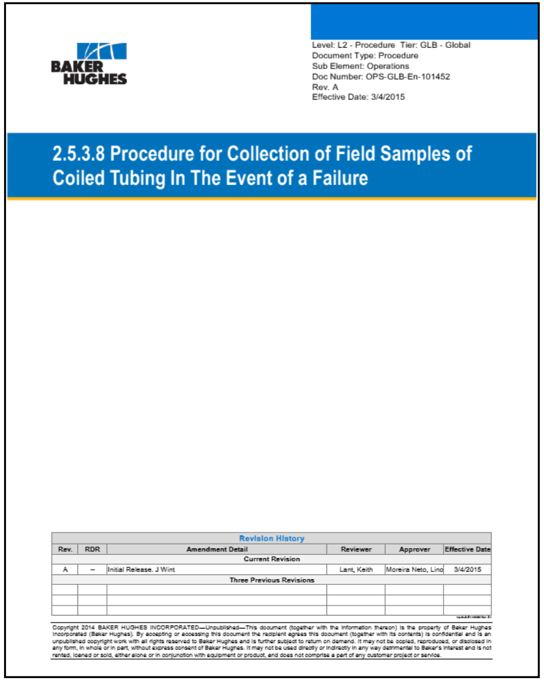
  - Scanning Electron Microscope (SEM) Fractography

  - Tension tests



  - Others: Charpy test, corrosion tests, etc.

CT string failure analysis process – Sample(s) collection / preservation


BAKER HUGHES

Level: L2 - Procedure Tier: GLB - Global
Document Type: Procedure
Sub Element: Operations
Doc Number: OPS-GLB-En-101452
Rev. A
Effective Date: 3/4/2015

2.5.3.8 Procedure for Collection of Field Samples of Coiled Tubing In The Event of a Failure

Rev.	RDR	Amendment Detail	Reviewer	Approver	Effective Date
Current Revision					
A	--	Initial Release. J Wint	Lant, Keith	Moreira Neto, Lino	3/4/2015
Three Previous Revisions					

1.2 Sample Collection

1. Cut at least 1 foot on either side of the failure location. Use a tubing cutter or saw to do this, NOT a cutting torch. The up-hole end should be labeled U1 and the downhole end D1.
2. Cut 7 to 8 foot samples on either side. Use a tubing cutter or saw to do this, NOT a cutting torch. Each end of the sample should be labeled U2 - U3 and D2 - D3.

Figure - 1 Required Sample Marking

CT string failure analysis process – Data collection (Failure/String)

Data about the failure: date, failure type, job, operation, well and customer, tubing depth, any additional information

Failure Report

Date Printed: 5/11/2018

Reel Number: TA-22022
String Number:
String Description: Tapered
String Material:
Accumulated Fatigue: 1.320 %

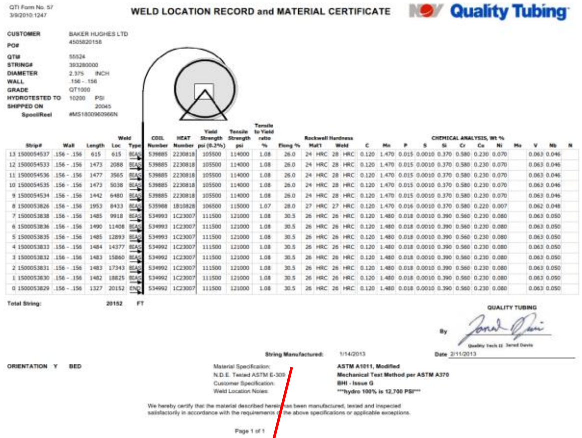
String Length: 21,047.00 ft
Outside Diameter: 1.75 in
Current Volume: 40.567 bbl
District/Boat:
Total RIH Distance: 41,293.00 ft

Cause Of Failure:			9/25/2017 10:00:54 AM
Failure Type	Pin Hole	Operation	Stationary
Failure Place	On the Reel	Job Type	Unspecified
Tubing Depth	13,385.83 ft	Job Ticket No.	
RIH Weight	0.00 lb	Location	
POOH Weight	0.00 lb	Customer	
Overpull Layoff Weight	0.00 lb	Reel No.	TA-22022
CT Pressure	0.00 psi g	Core Diameter	90.000 in
WH Pressure	0.00 psi g	Core Width	86.00 in
Fluid Rate	0.00 bbl/min	Flange Diameter	156.000 in
Fluid Type	Water Based		

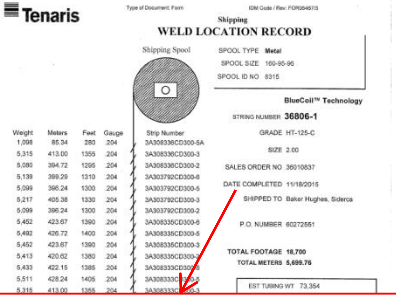
Comments: Leak was found when fluid was pumped into CT string for pressure testing. Failure of string to be defined after the metallurgic test.

CT string failure analysis process – Data collection (Failure/String)

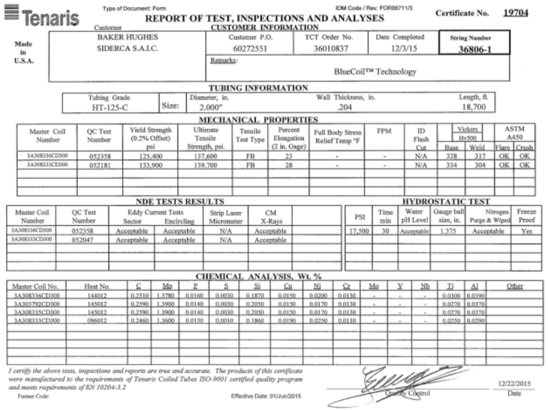
Manufacturer's Mill Certificate



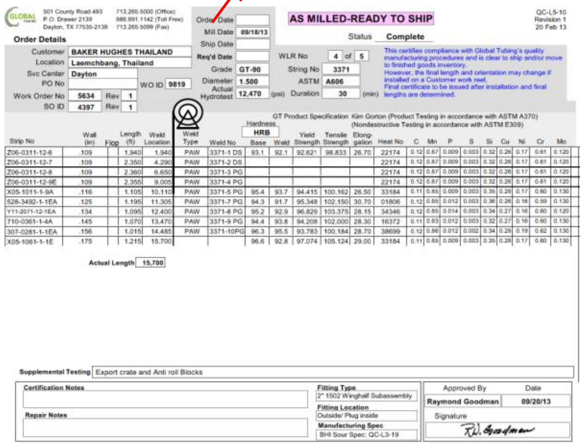
String Manufactured: 1/14/2013



DATE COMPLETED 11/18/2015



Mill Date 09/18/13

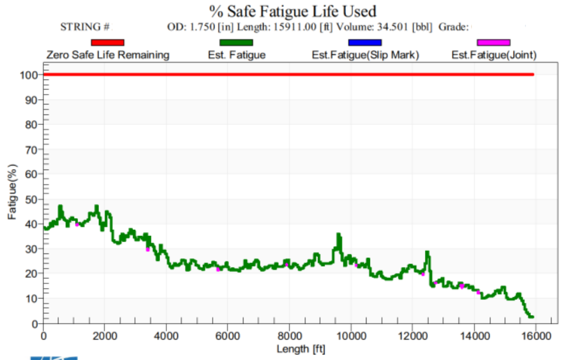


Hint: Milling date gives a good idea on how old was the string

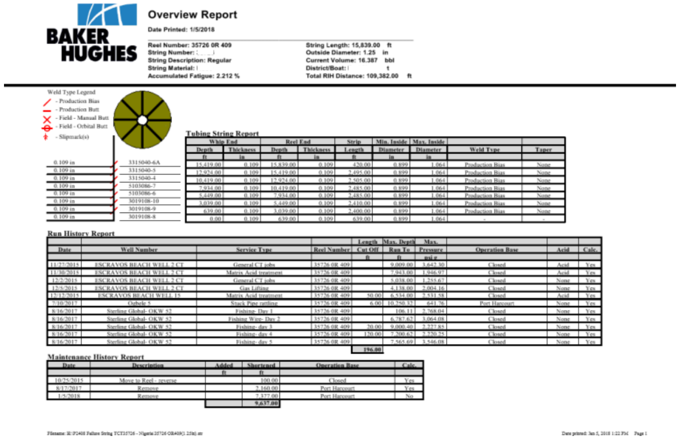
CT string failure analysis process – Data collection (Failure/String)

String records:

- First job date / Most common job
- Average fatigue used / Fatigue used at failure location
- Long term storage periods and corrosion protection activities



BAKER HUGHES



BAKER HUGHES

Overview Report

Date Printed: 1/5/2018

Reel Number: 35726 0R 409
String Number:
String Description: Regular
String Material:
Accumulated Fatigue: 2.212 %

String Length: 15,839.00 ft
Outside Diameter: 1.25 in
Current Volume: 16.387 bbl
District/Boat:
Total RIH Distance: 109,382.00 ft

Weld Type Legend
- Production Bias
- Production Butt
- Field - Manual Butt
- Field - Orbital Butt
- Slipmark(s)

0.109 in	3315040-6A
0.109 in	3315040-5
0.109 in	3315040-4
0.109 in	5103086-7
0.109 in	5103086-6
0.109 in	3019108-10
0.109 in	3019108-9
0.109 in	3019108-8

Tubing String Report

Whip End		Reel End		Strip	Min. Inside	Max. Inside		
Depth	Thickness	Depth	Thickness	Length	Diameter	Diameter	Weld Type	Taper
ft	in	ft	in	ft	in	in		
15,419.00	0.109	15,839.00	0.109	420.00	0.899	1.064	Production Bias	None
12,924.00	0.109	15,419.00	0.109	2,495.00	0.899	1.064	Production Bias	None
10,419.00	0.109	12,924.00	0.109	2,505.00	0.899	1.064	Production Bias	None
7,934.00	0.109	10,419.00	0.109	2,485.00	0.899	1.064	Production Bias	None
5,449.00	0.109	7,934.00	0.109	2,485.00	0.899	1.064	Production Bias	None
3,039.00	0.109	5,449.00	0.109	2,410.00	0.899	1.064	Production Bias	None
639.00	0.109	3,039.00	0.109	2,400.00	0.899	1.064	Production Bias	None
0.00	0.109	639.00	0.109	639.00	0.899	1.064	-	-

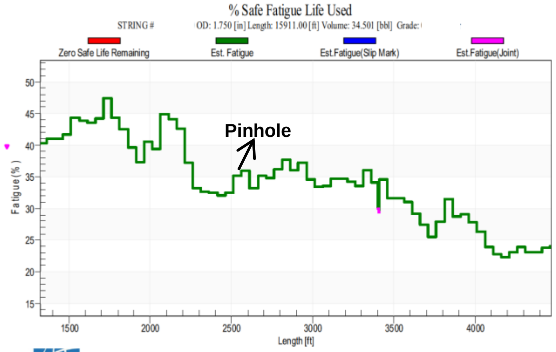
Run History Report

				Length	Max. Depth	Max.			
Date	Well Number	Service Type	Reel Number	Cut Off	Run To	Pressure	Operation Base	Acid	Calc.
				ft	ft	psi g			
11/27/2015	ESCRAVOS BEACH WELL 2 CT	General CT jobs	35726 0R 409		9,009.00	3,642.30	Closed	Acid	Yes
11/30/2015	ESCRAVOS BEACH WELL 2 CT	Matrix Acid treatment	35726 0R 409		7,943.00	1,946.97	Closed	Acid	Yes
12/2/2015	ESCRAVOS BEACH WELL 2 CT	General CT jobs	35726 0R 409		5,038.00	1,255.67	Closed	None	Yes
12/5/2015	ESCRAVOS BEACH WELL 2 CT	Gas Lifting	35726 0R 409		4,138.00	2,004.16	Closed	None	Yes
12/12/2015	ESCRAVOS BEACH WELL 15	Matrix Acid treatment	35726 0R 409	50.00	6,534.00	2,531.58	Closed	Acid	Yes
7/10/2017	Ogbele 5	Stuck Pipe rattling	35726 0R 409	6.00	10,250.32	641.76	Port Harcourt	None	Yes
8/16/2017	Sterling Global- OKW 52	Fishing- Day 1	35726 0R 409		106.11	2,768.04	Closed	None	Yes
8/16/2017	Sterling Global- OKW 52	Fishing Wire- Day 2	35726 0R 409		6,787.62	3,064.08	Closed	None	Yes
8/16/2017	Sterling Global- OKW 52	Fishing- day 3	35726 0R 409	20.00	9,000.40	2,227.85	Closed	None	Yes
8/16/2017	Sterling Global- OKW 52	Fishing- day 4	35726 0R 409	120.00	7,200.62	2,220.25	Closed	None	Yes
8/16/2017	Sterling Global- OKW 52	Fishing- day 5	35726 0R 409		7,565.69	3,546.08	Closed	None	Yes
				196.00					

Maintenance History Report

Date	Description	Added	Shortened	Operation Base	Calc.
		ft	ft		
10/25/2015	Move to Reel - reverse		100.00	Closed	Yes
8/17/2017	Remove		2,160.00	Port Harcourt	Yes
1/5/2018	Remove		7,377.00	Port Harcourt	No
			9,637.00		

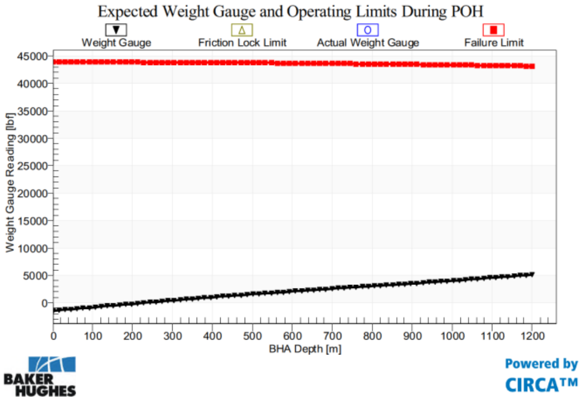
Date printed: Jan 5, 2018 1:22 PM Page 1

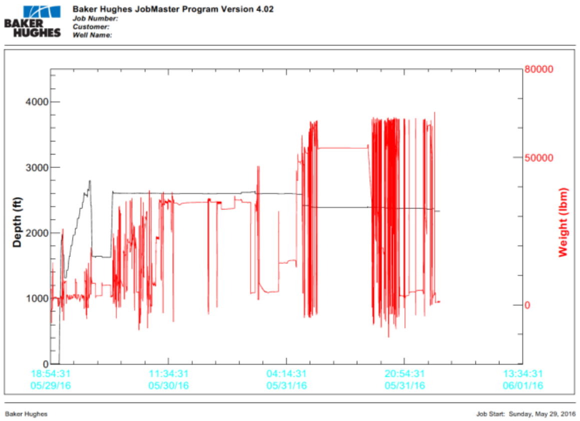


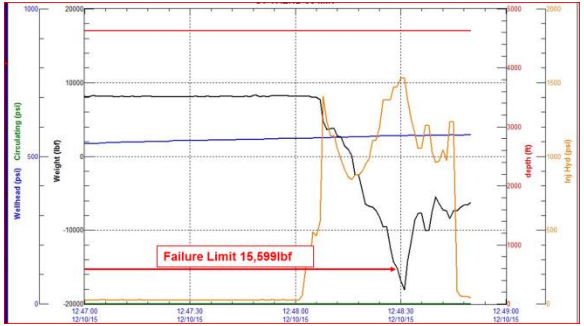
BAKER HUGHES

CT string failure analysis process – Data collection (Failure/String)

Job parameters and operational limits (mainly for overload/buckling failures)



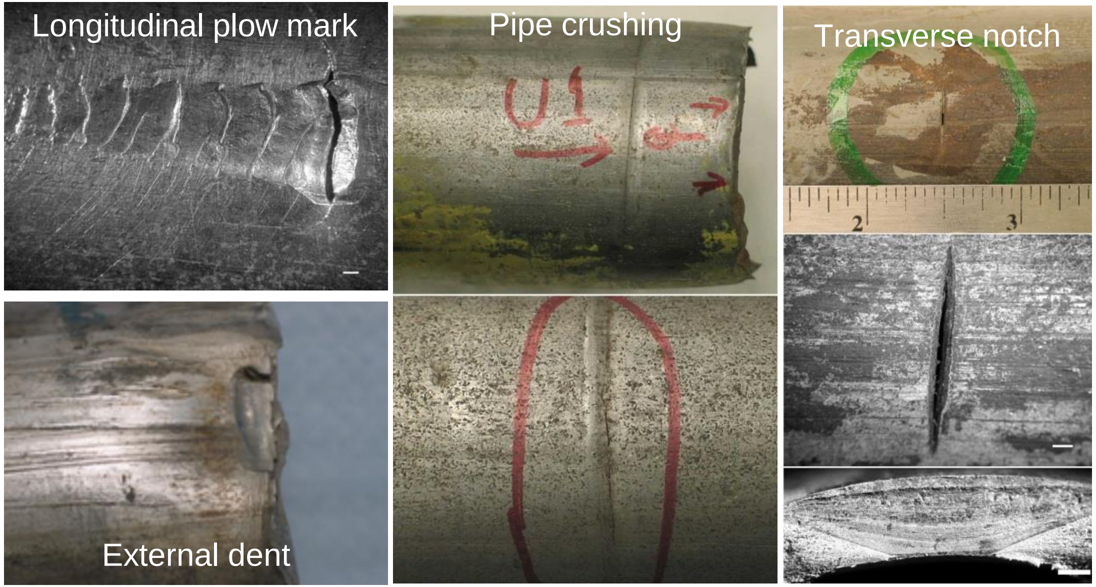




CT string failure analysis process – Visual/Stereoscopic Examination

- One of the most important stages – In many cases gives good evidence on the cause of the failure – What to look for during this stage?:

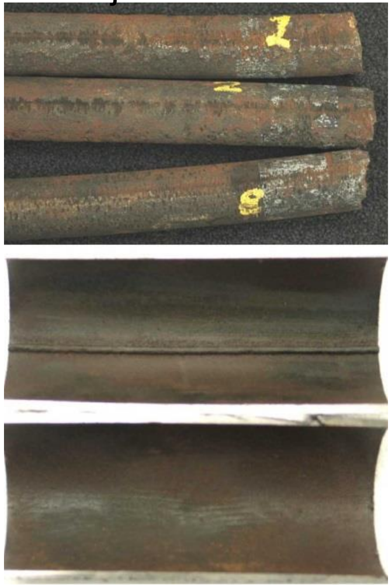
Mechanical damage



Visual/Stereoscopic Examination – What to look for?

External Corrosion

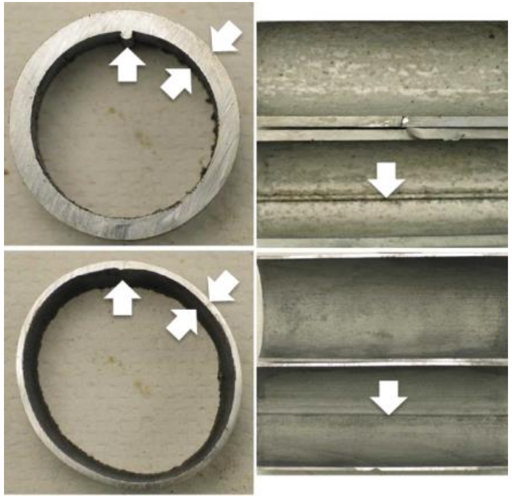
Acid job – 2” – CT80



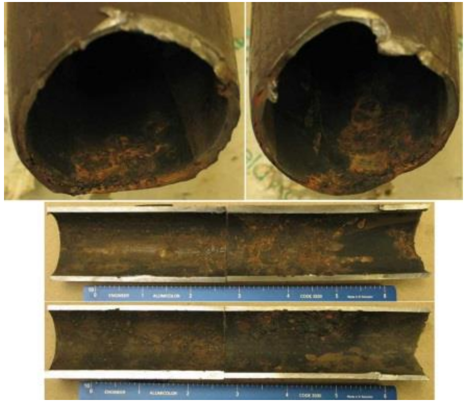
Pressure testing

1-3/4” – CT1300

Internal Corrosion



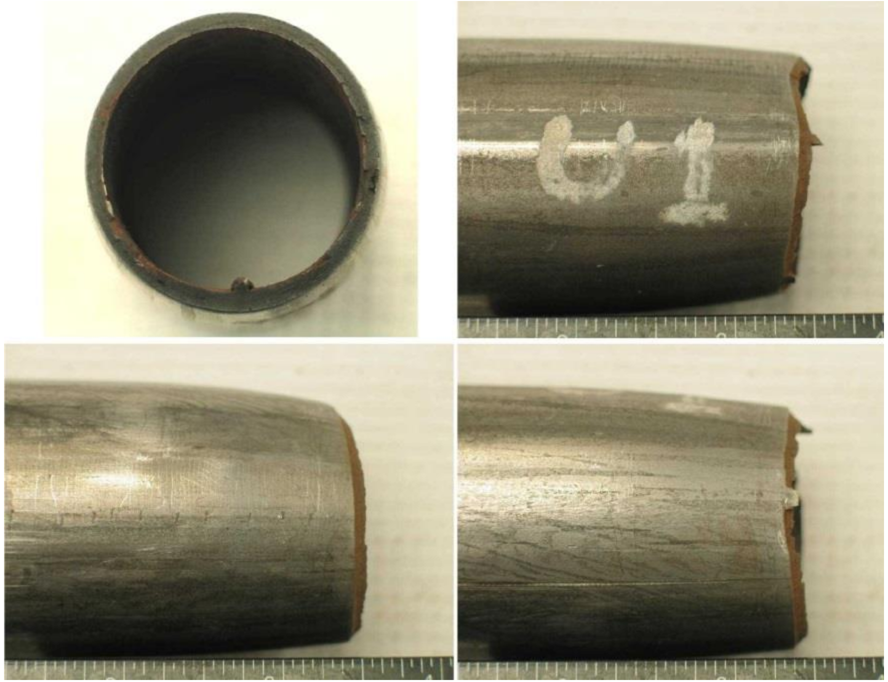
Acid job – 1-1/2” – CT80



N2 jetting – 1-1/2” – CT80

Visual/Stereoscopic Examination – What to look for?

Necking and 45° fracture propagation



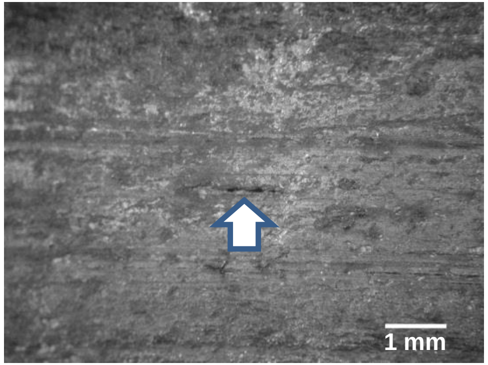
Fishing – 2” – CT90

Visual/Stereoscopic Examination – What to look for?

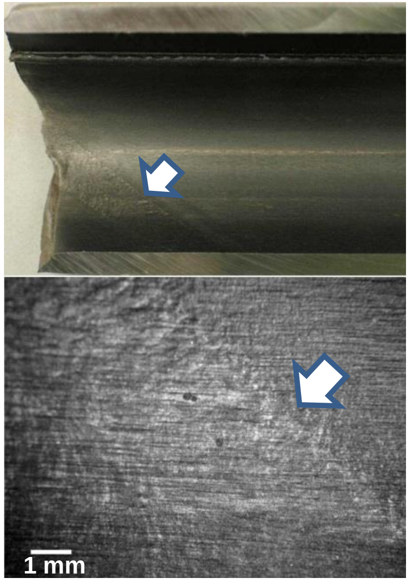
Small longitudinal splits

Pressure Testing 2-3/8" – CT100

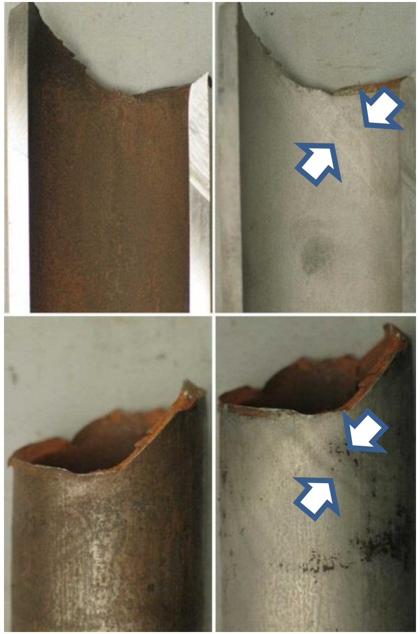
Optiport 2" – CT90



Confirm the presence of a bias weld



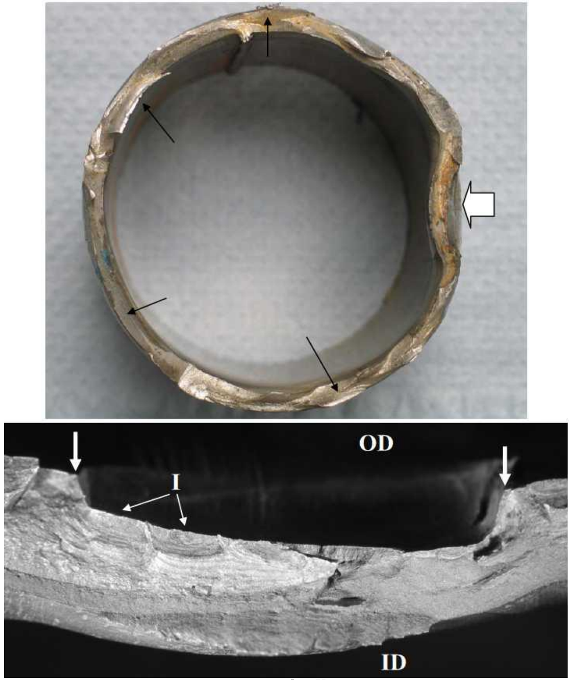
Milling – 2" – CT90



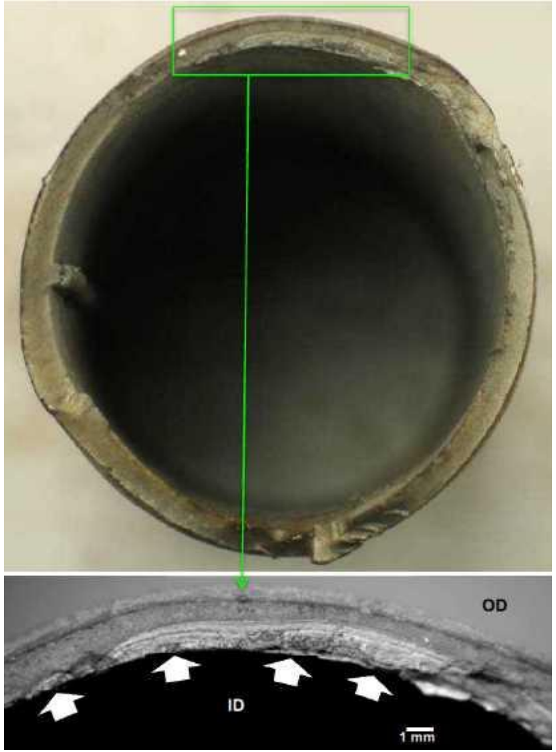
Milling – 2" – CT90

Visual/Stereoscopic Examination – What to look for?

Fracture origin



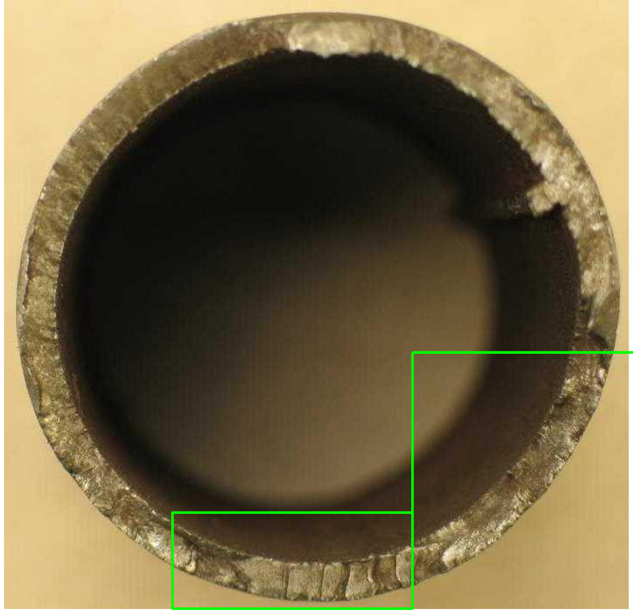
Frac – 2-7/8" – CT70



Milling – 1-1/2" – CT90

Visual/Stereoscopic Examination – What to look for?

Fracture origin



Fishing – 1-3/4” – CT90

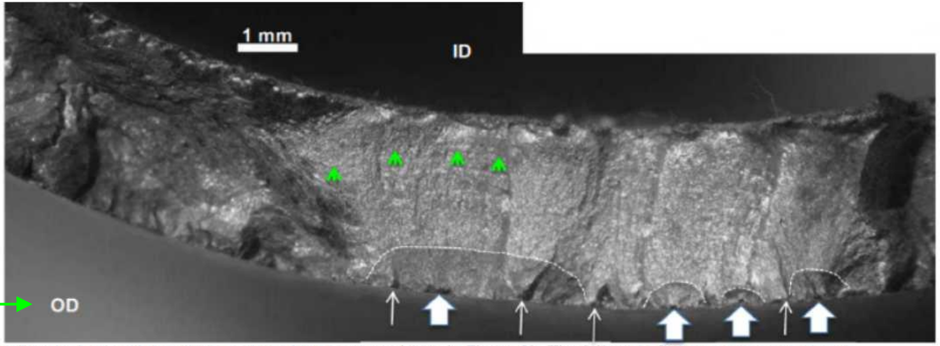


Figure 4. Detailed view of the “flat” portion of the fracture shown in Figure 3b. *The following features can be observed:*

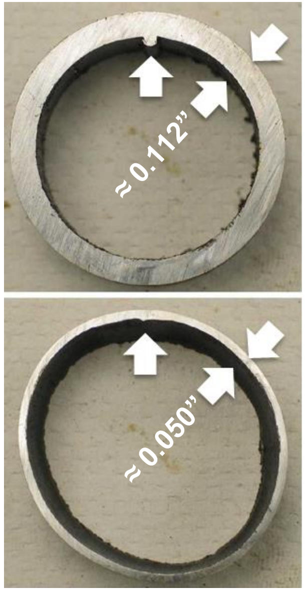
- Ratchet marks at the outside diameter (small white arrows), indicative of multiple fatigue cracks starting at the outside diameter.
- Thumbnail cracks starting from external pits (darker areas enclosed by dotted lines and block arrows).
- Some light marks concentric towards the OD can be observed (small green arrows), indicating propagation by fatigue from the OD.

All these features indicate that the fracture started at this location (fracture origin) from multiple fatigue cracks that propagated from the outside diameter at external pits.

CT string failure analysis process – Dimensional inspection

Verify the pipe condition regarding OD, ovality, wall thickness.

Acid corrosion



Acid job – 1-1/2” – CT80

External abrasion

Location	Down-hole end (1)	1	2	3	4	5	6	7	8	9	10	11	12	Up-hole end (1)
Thickness measured (in.)	0.121”	0.111	0.107	0.101	0.083	0.068	0.056	0.056	0.082	0.087	0.105	0.120	0.120	0.133

(1) Measured at approximately 12” from the central portion on each side

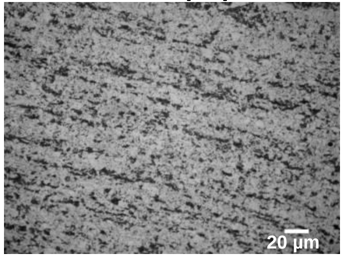
Cleanout – 1-3/4” – CT90

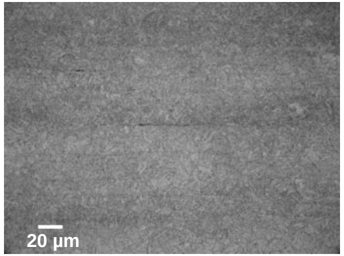
CT string failure analysis process – Metallographic analysis

- With the information gathered from the previous stages normally there is a good idea of what caused the failure.

- Check pipe microstructure is OK:

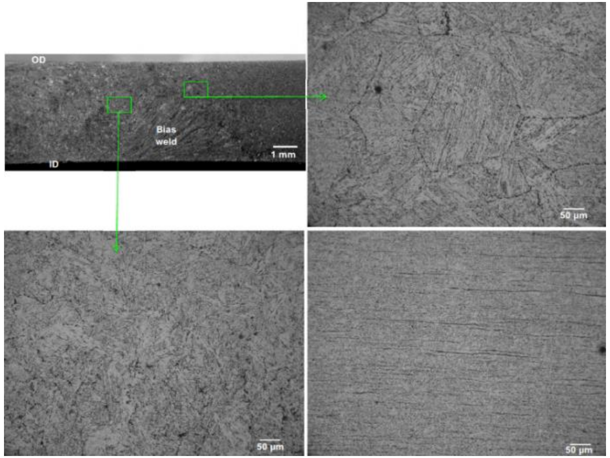
HSLA





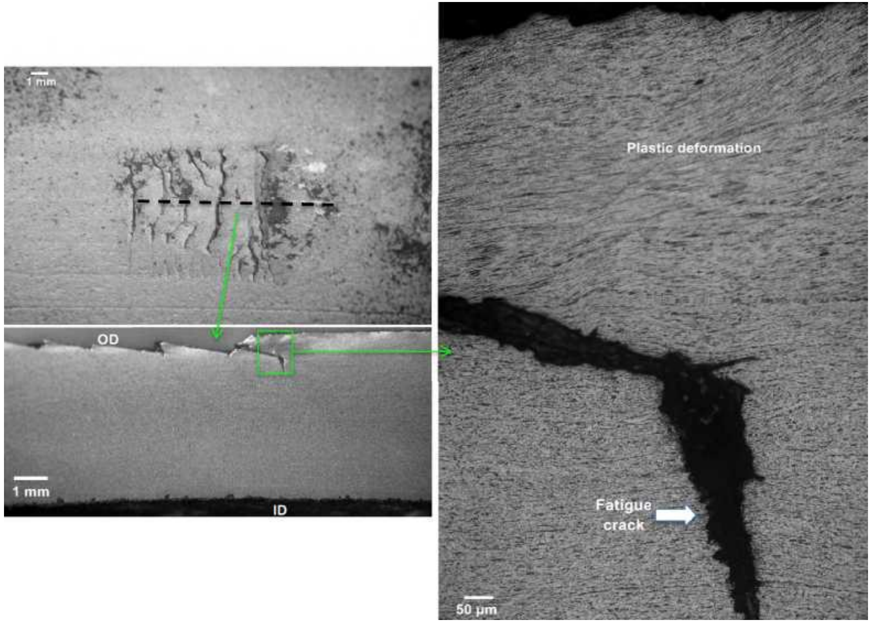
Q&T

Bias Weld

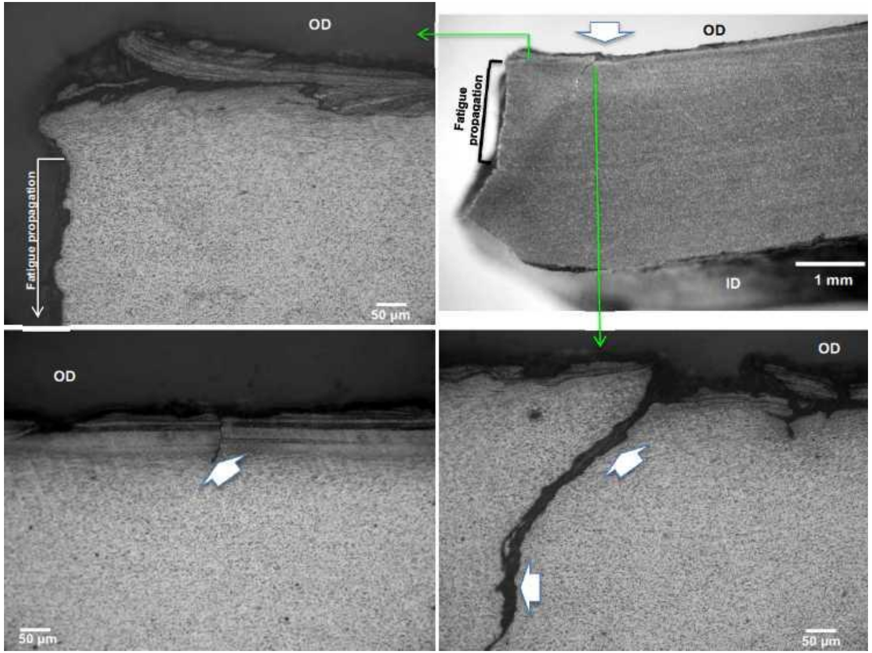


CT string failure analysis process – Metallographic analysis

- Mechanical damage: confirm plastic deformation at damage:



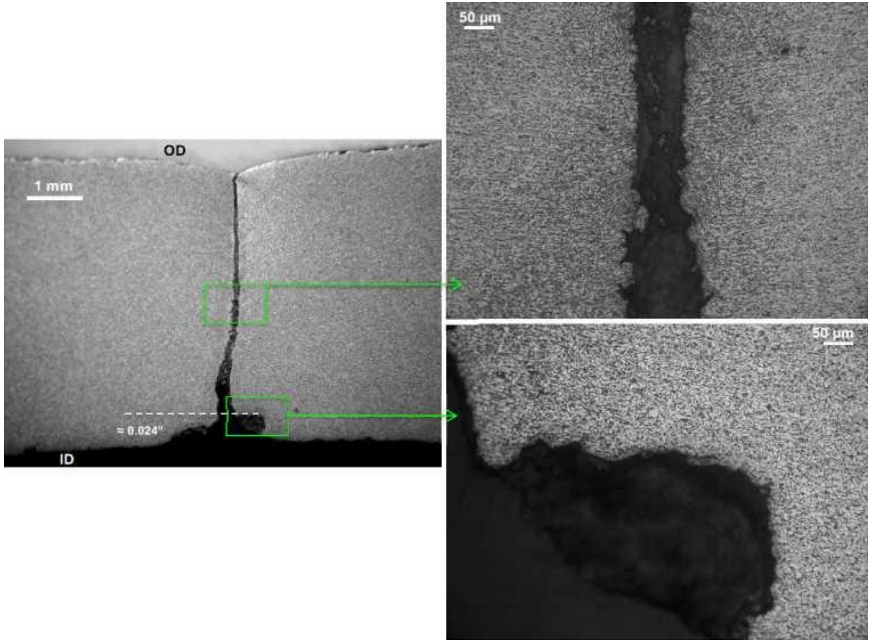
Longitudinal plow mark



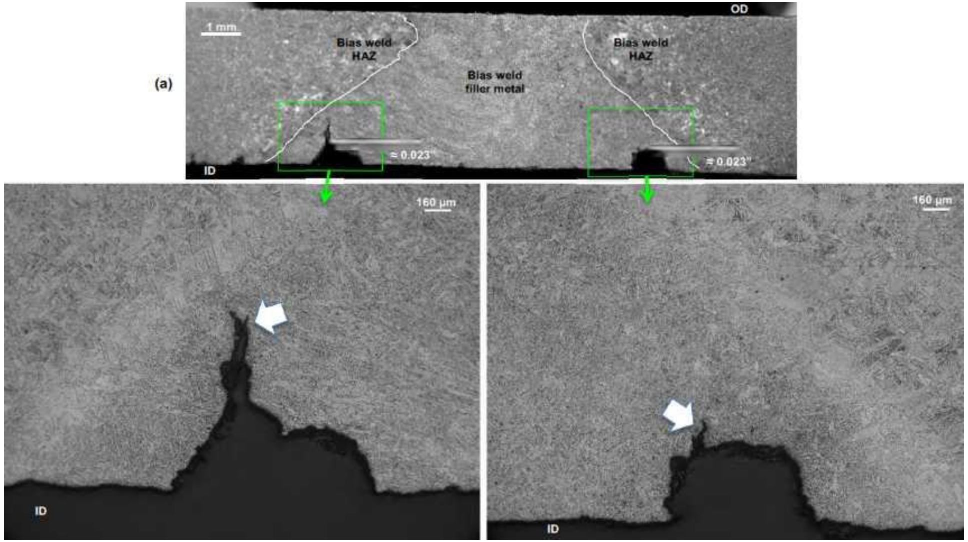
Pipe crushing

CT string failure analysis process – Metallographic analysis

- Corrosion: corrosion depth / metallurgy at corrosion:



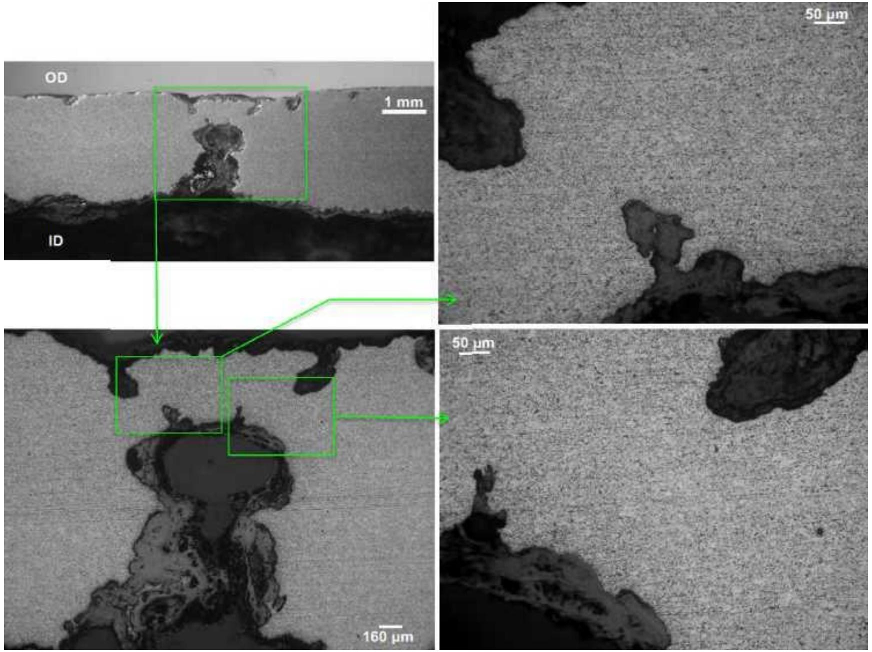
Internal pit

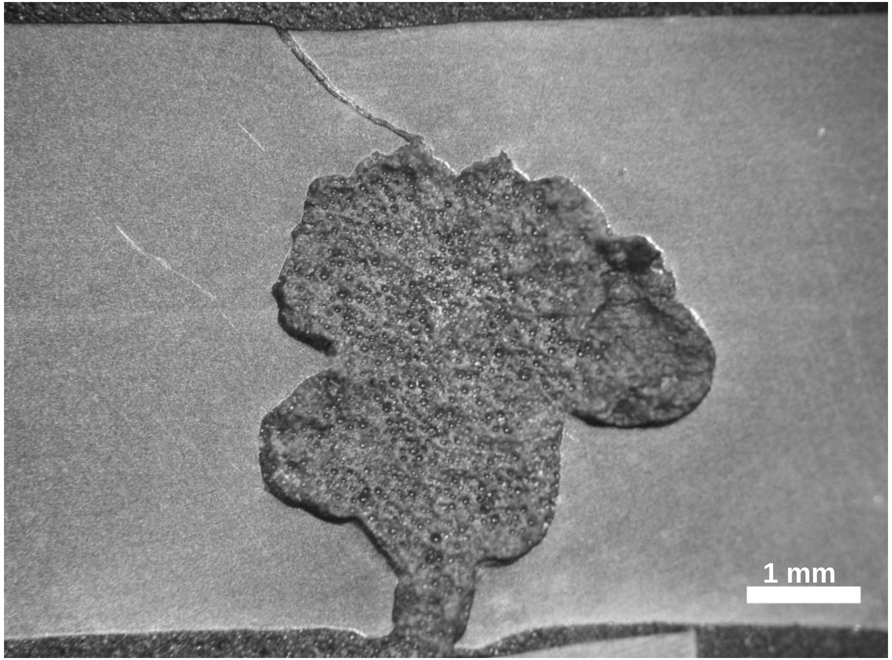


Internal pitting at bias weld

CT string failure analysis process – Metallographic analysis

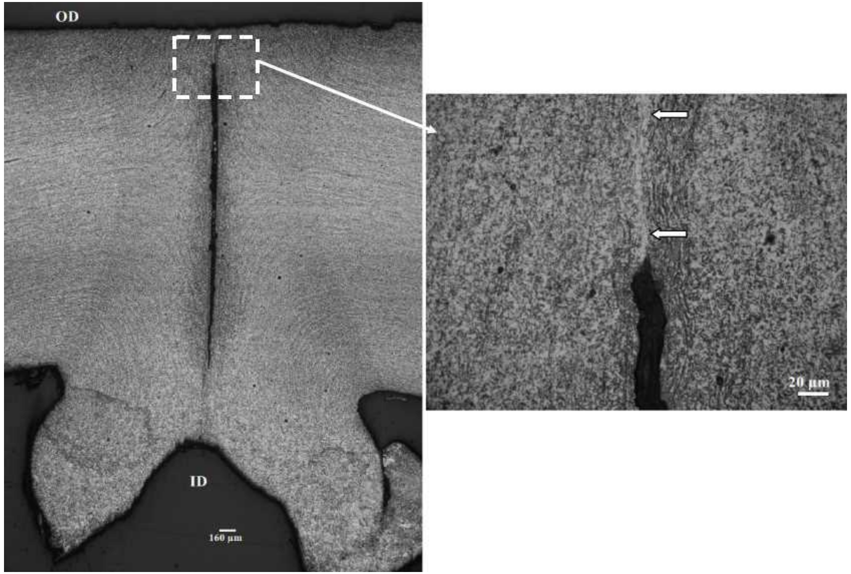
- MIC: pitting shape: normally "cavernous", deep, and very aggressive:





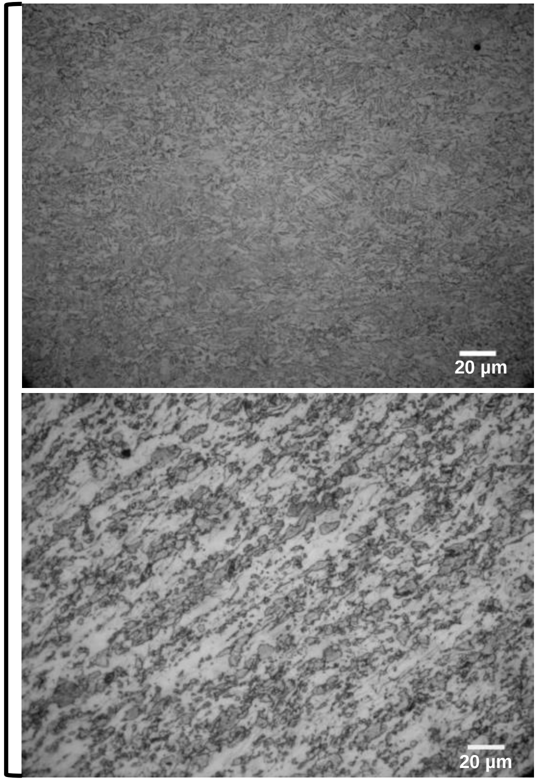
CT string failure analysis process – Metallographic analysis

- Manufacturing flaw:



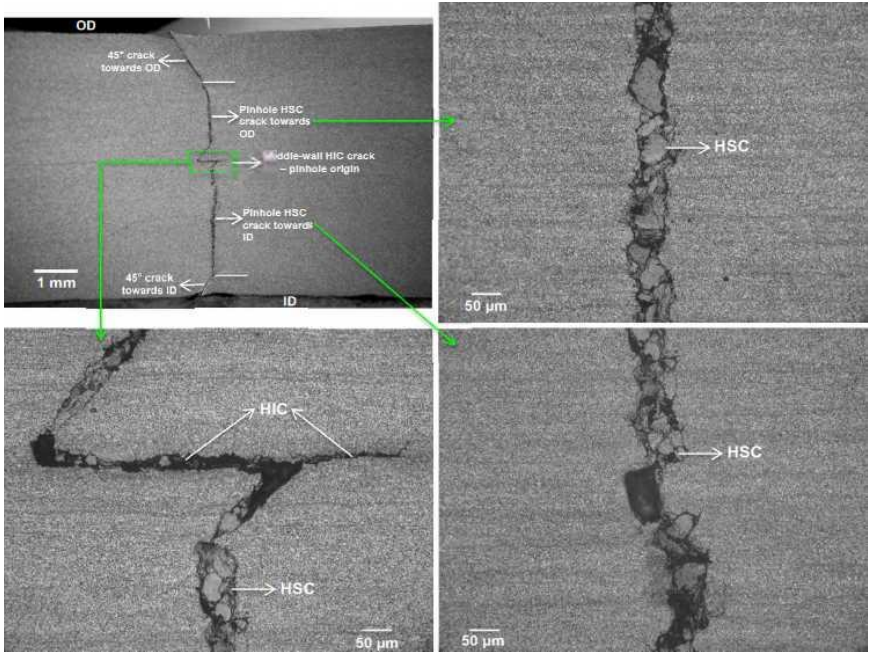
"Cold weld"

Abnormal microstructures

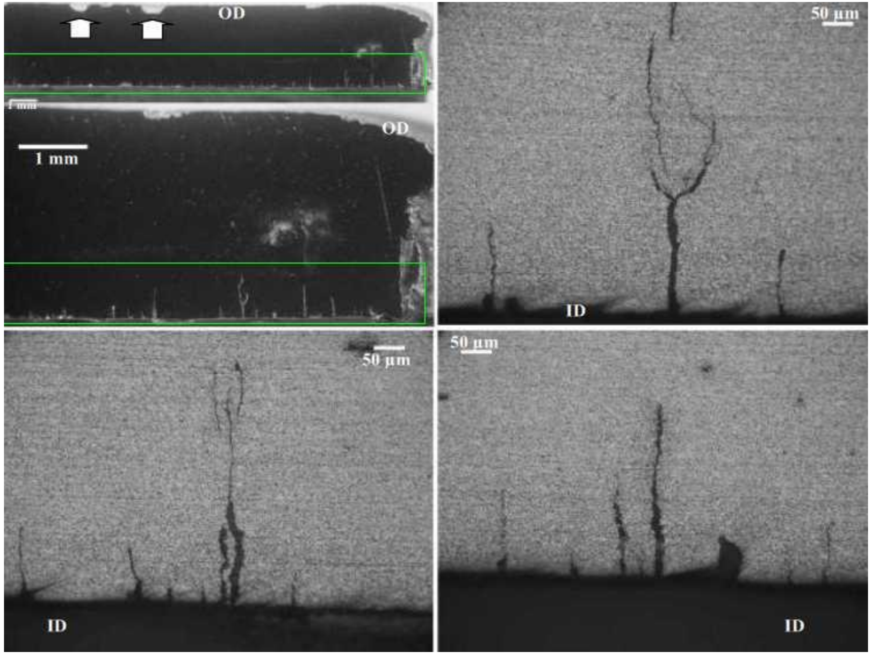


CT string failure analysis process – Metallographic analysis

- Environmental cracking:



H2S cracking



Caustic cracking

CT string failure analysis process – EDS

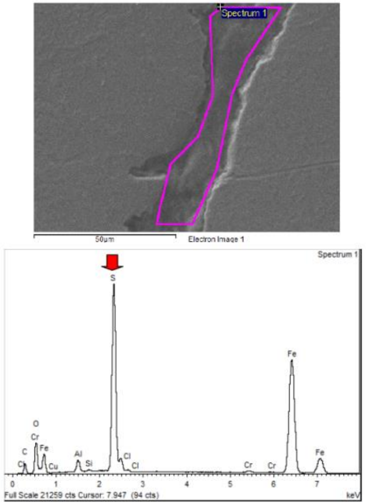
- EDS: corrosion products / foreign particles

Spectrum processing :
Peak possibly omitted : 7.466 keV

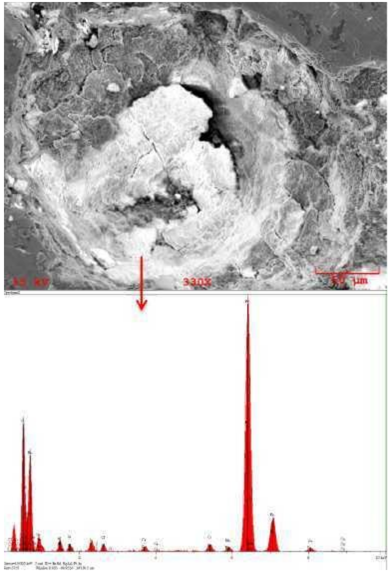
Processing option : All elements analyzed (Normalised)
Number of iterations = 4

Standard :
C CaCO3 1-Jun-1999 12:00 AM
O SiO2 Pella 9-Mar-2017 11:49 AM
Al Al Pella 9-Mar-2017 12:05 PM
Si SiO2 Pella 9-Mar-2017 11:49 AM
S FeS2 1-Jun-1999 12:00 AM
Cl KCl 1-Jun-1999 12:00 AM
Cr Cr 1-Jun-1999 12:00 AM
Fe Fe 1-Jun-1999 12:00 AM
Cu Cu 1-Jun-1999 12:00 AM

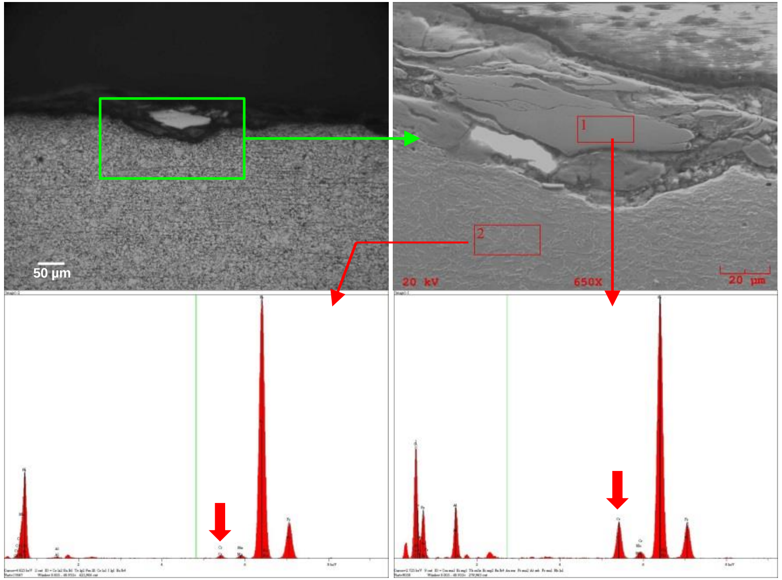
Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C K	3.91	0.2217	24.62	0.49	48.35
O K	5.43	0.6534	11.60	0.17	17.11
Al K	0.46	0.6367	1.01	0.03	0.88
Si K	0.06	0.7480	0.11	0.02	0.09
S K	13.99	0.8712	22.39	0.17	16.48
Cl K	0.13	0.6274	0.29	0.03	0.19
Cr K	0.27	0.9672	0.39	0.03	0.18
Fe K	24.82	0.8782	39.43	0.28	16.66
Cu K	0.09	0.7967	0.16	0.05	0.06
Totals			100.00		



EDS within a crack – (S)



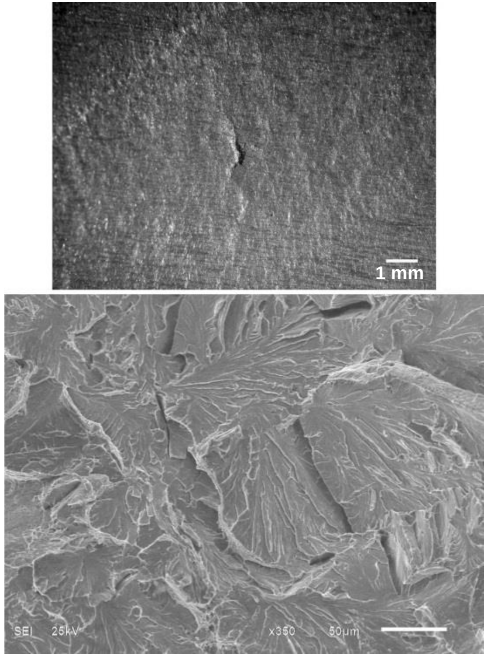
EDS within external pit – (Fe, O)



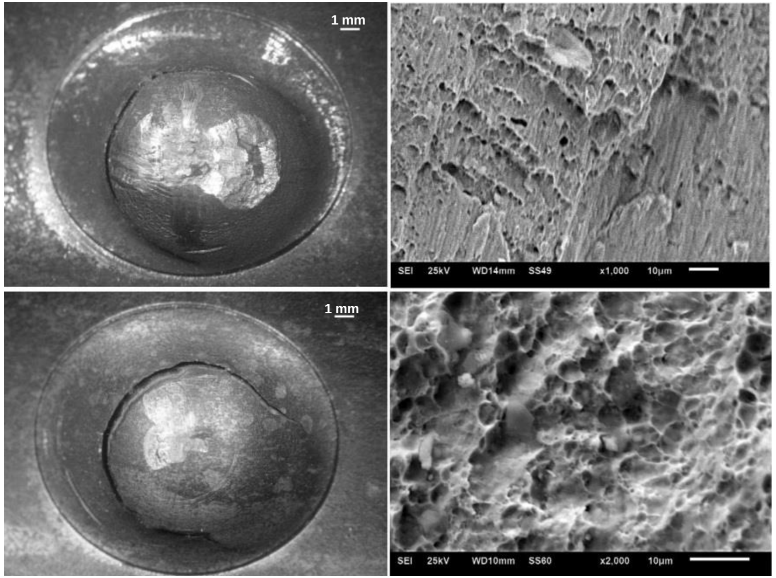
EDS on particle – Higher Cr than base metal

CT string failure analysis process – SEM Fractography

- SEM fractography: confirming fracture propagation mode: brittle (cleavage/intergranular) or ductile (dimples).



Cleavage on secondary crack (after opening) – MIC failure



Cracks on dimple on connection – Elongated dimples (shear) on cracks

CT string failure analysis process – Tension test

SPE 38412

Determining the M
A. Crabtree, SPE, BJ Se

SPE 38412

3.d. Conduct one unloading and reloading cycle at approximately 0.8% of strain to obtain the elasticity modulus as schematically shown in Figure 11.

4.b. Determine the Yield Strength by intercept of the tensile curve with the 1% offset line drawn at the angle of the elastic reloading line obtained in step 3d.

length.

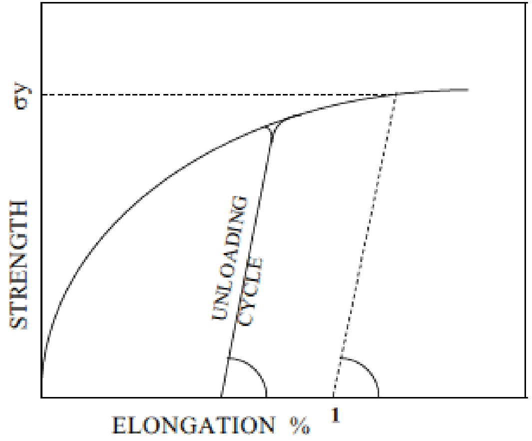
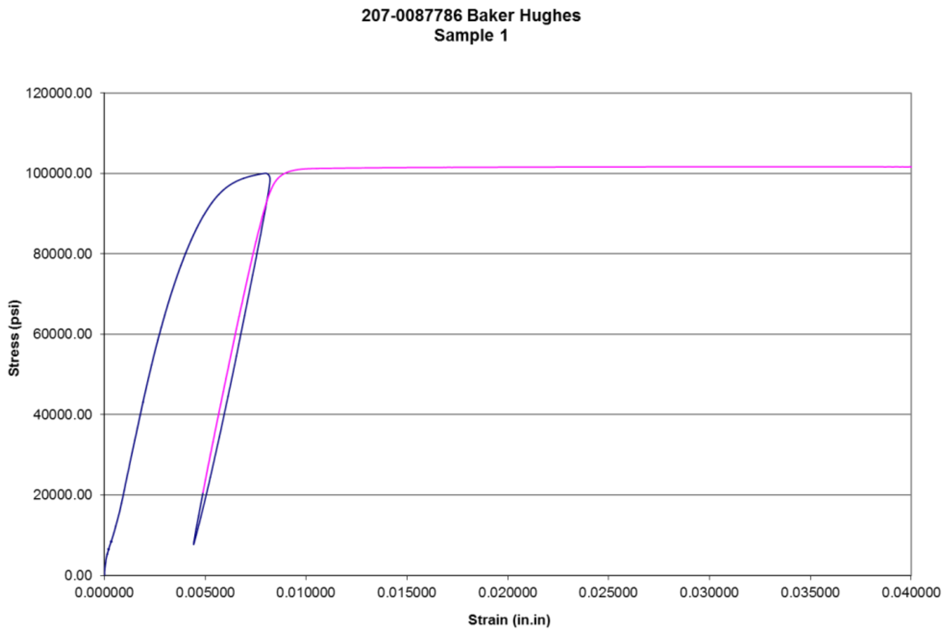


Figure 11. Schematic showing a full body tensile test procedure for determining Yield Strength and modulus of elasticity of bent pipe.

CT string failure analysis process – Tension test



TENSILE TEST

Client: Baker Hughes Canada Company
Address: 6620-36 St. SE
Calgary, AB
T2C 2G4

Attention: Tomas Padron

Sample Description: **1-3/4 in. OD x 0.125 in. WT Nominal Coiled Tubing,**

Specimen Type & Preparation: As received tube
Test Procedure: ASTM A370 / SPE 38412 Appendix III
Governing Specification: No governing specification stipulated

Test Result: **As reported below**

Acuren Specimen ID : 861	Test Results		Gov. Spec. Requirements	
	Imperial (ksi)	Metric (MPa)	Imperial (ksi)	Metric (MPa)
Yield Strength (1% Offset Method) *	102	700	N/S	N/S
Ultimate Tensile Strength *	102	700	N/S	N/S
Elongation (%)	20		N/S	

Acuren Specimen ID : 862	Test Results		Gov. Spec. Requirements	
	Imperial (ksi)	Metric (MPa)	Imperial (ksi)	Metric (MPa)
Yield Strength (1% Offset Method) *	101	700	N/S	N/S
Ultimate Tensile Strength *	102	705	N/S	N/S
Elongation (%)	24		N/S	

N/S = Not Specified

* Calculated values are based on nominal tubing dimensions.

Reviewed By: Tested By:

Specimens will be disposed of 60 days after test date.

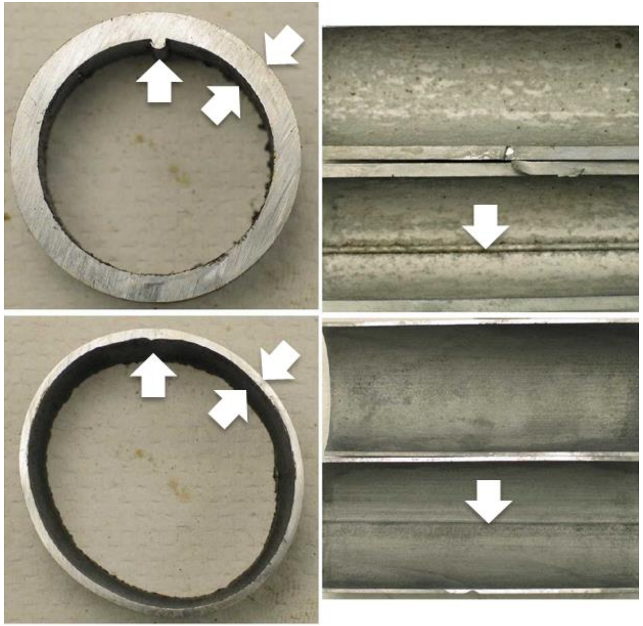
Page 2 of 2

CT Failures Statistics – Terminology

Storage-corrosion: corrosion damage caused by the accumulation of corrosive fluids (within or outside the string) while it remains in storage for long periods.

Internal storage-corrosion example

Acid internal-corrosion example

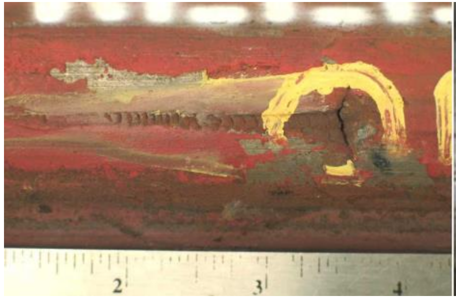


Corrosion-operations: corrosion damage caused by the action of fluids pumped or the well environment during operations

CT Failures Statistics – Terminology

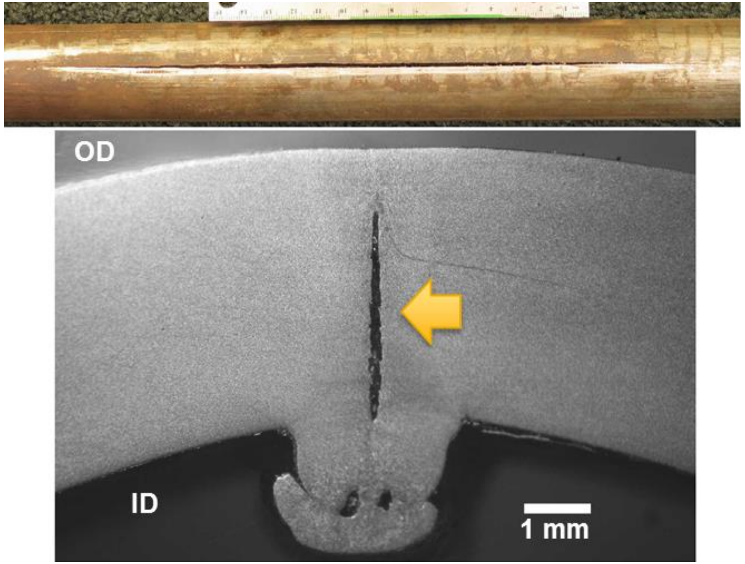
Manufacturing flaw: premature failure associated with issues originated during the manufacturing process

Longitudinal plow mark



External dent

Mechanical damage: premature fatigue failure that starts at external damage caused by mechanical means.



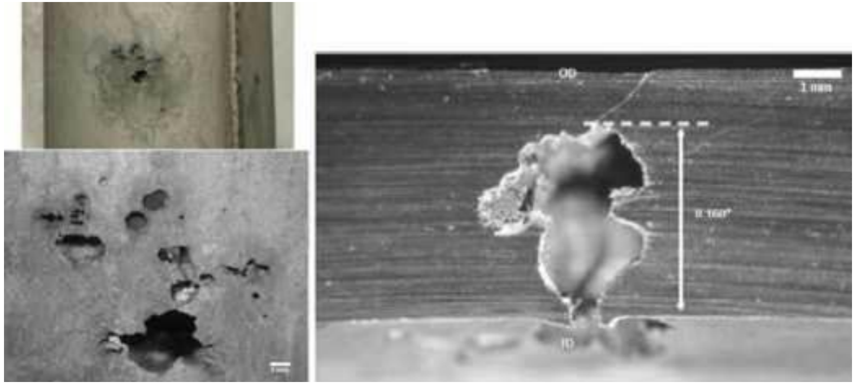
“Cold weld” example

CT Failures Statistics – Terminology

Human error: failure associated with errors during the string operation.

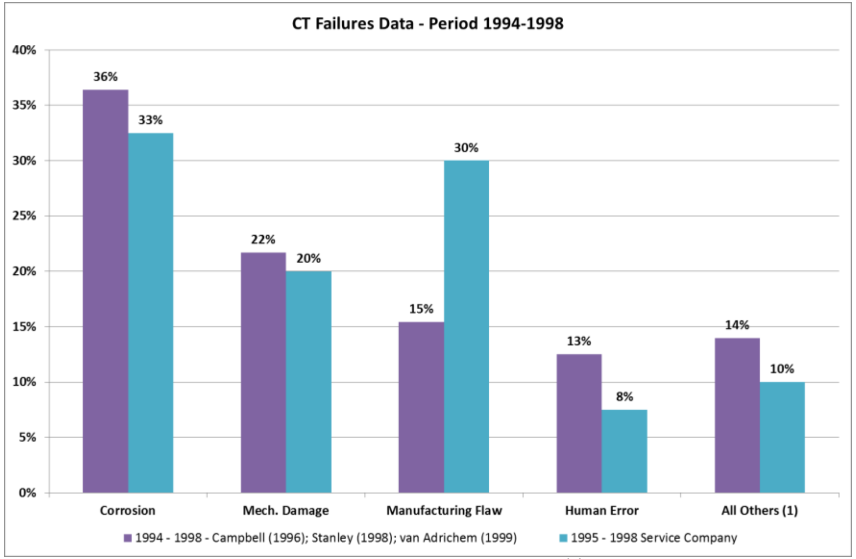
Buckling　　　　Overload

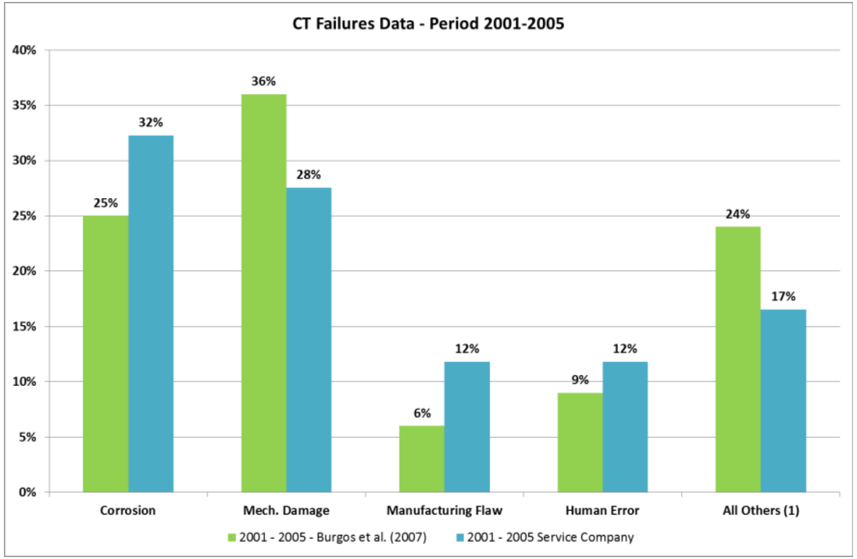
Internal MIC



MIC (Microbiological influenced corrosion): corrosion failure due to the presence of certain specific type of bacteria within the fluid in contact with the pipe.

CT Failures Statistics – Period 1994-2005

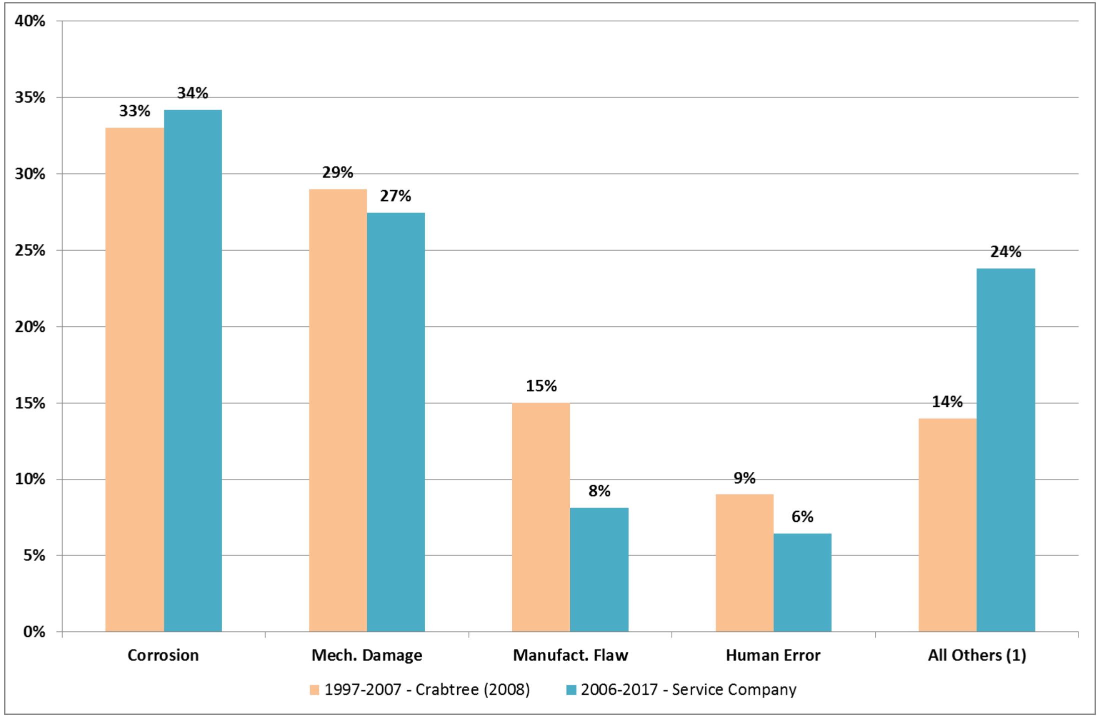




(1) All Others includes: fatigue, erosion, H2S failure, field welding, ext. abrasion, unknown

- CT Failures trend is similar for the CT industry
- Main causes: Corrosion / Mechanical damage / Manufacturing flaw / Human error
- These causes represent around 80% to 90% of CT failures

CT Failures Statistics – Period 2006-2017 vs. Previous Periods

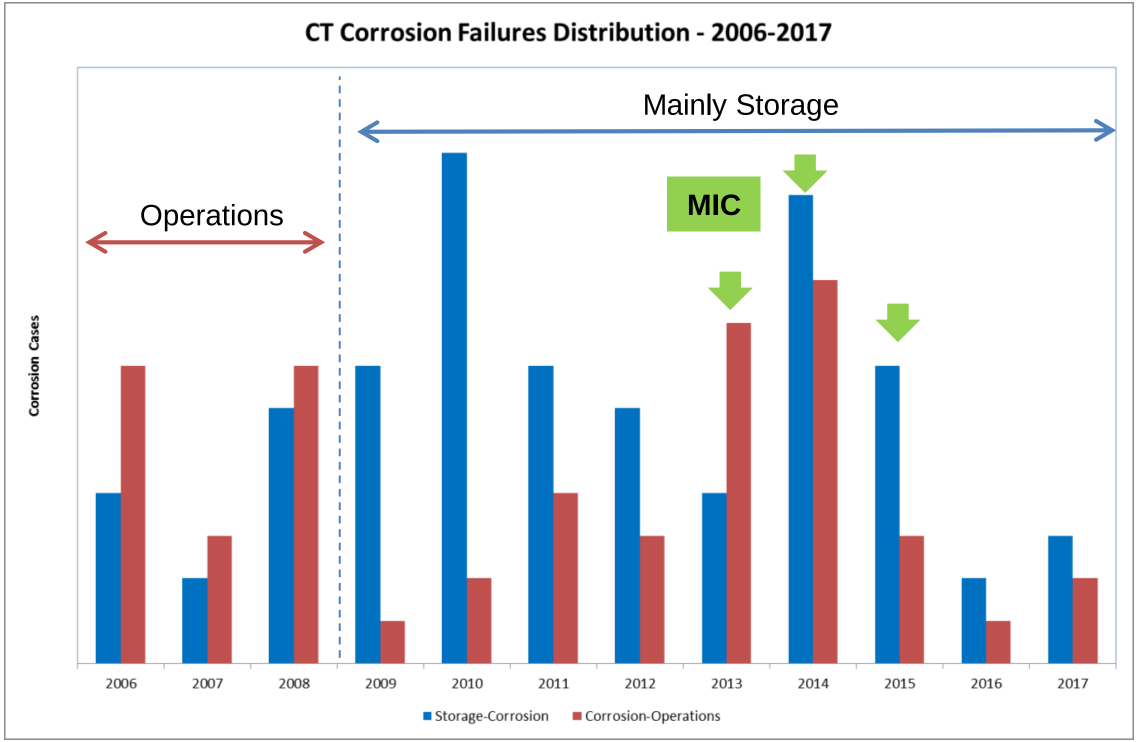


(1) All Others includes: fatigue, erosion, H2S failure, field welding, ext. abrasion, unknown

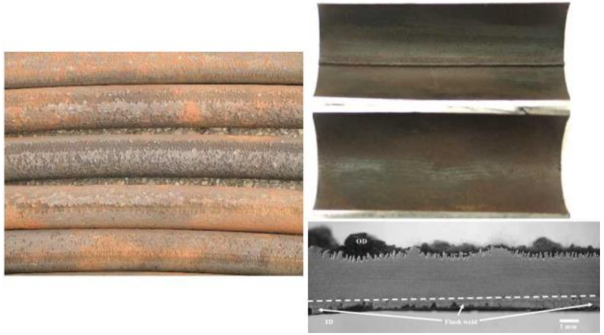
4 main CT failures causes have remained the same:

- Corrosion (≈ 30%)
- Mechanical damage (≈ 30%)
- Manufacturing flaw
- Human error

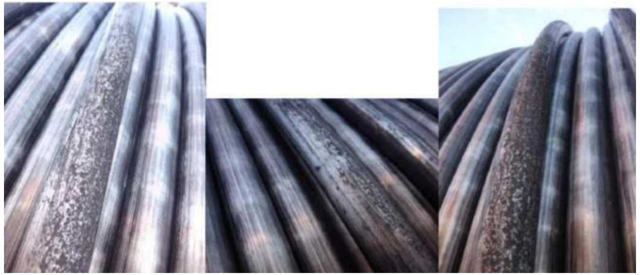
Main Failures Causes Review: Corrosion (≈30%)



Corrosion-Operations

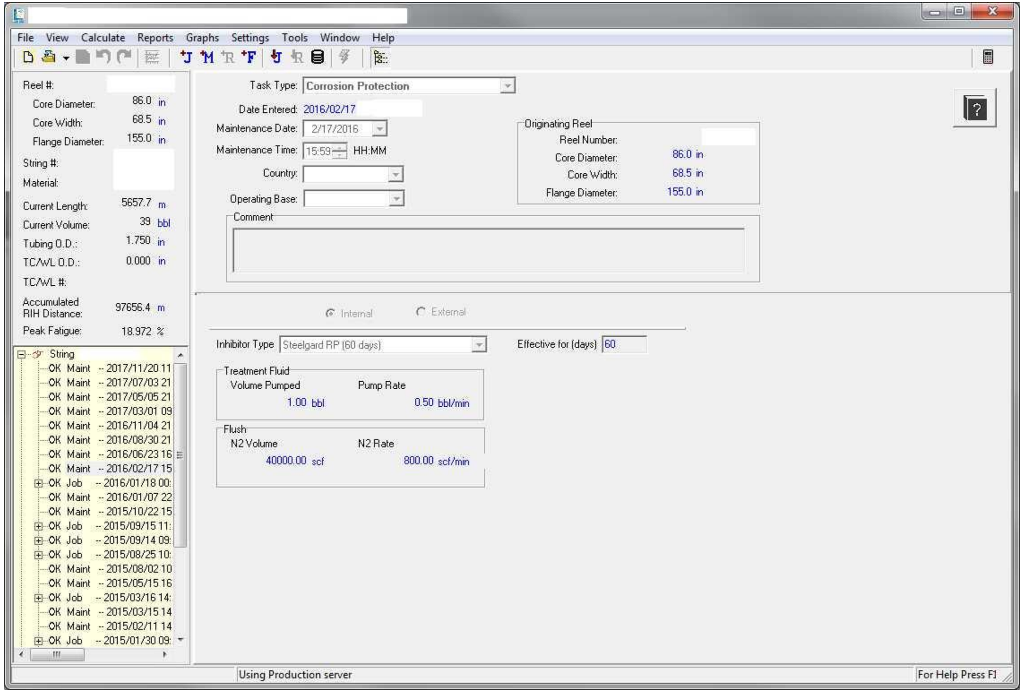


Storage-Corrosion



Main Failures Causes Review: Corrosion (≈30%)

- Mitigation measures - Storage-corrosion:
  - Eliminating residual fluids
  - Application of corrosion inhibitors (internally/externally)
  - Records kept within the string management system

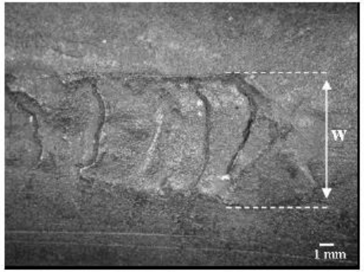
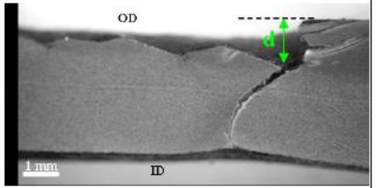


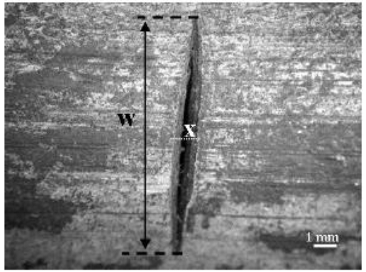
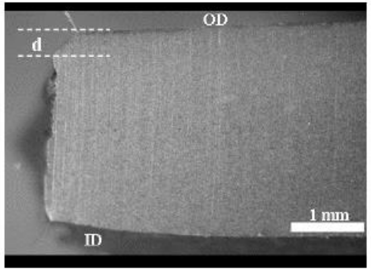
Main Failures Causes Review: Mechanical Damage (≈30%)

- Normally caused by the action of the surface equipment.
- Can be very diverse.
- Stress/strain concentration point

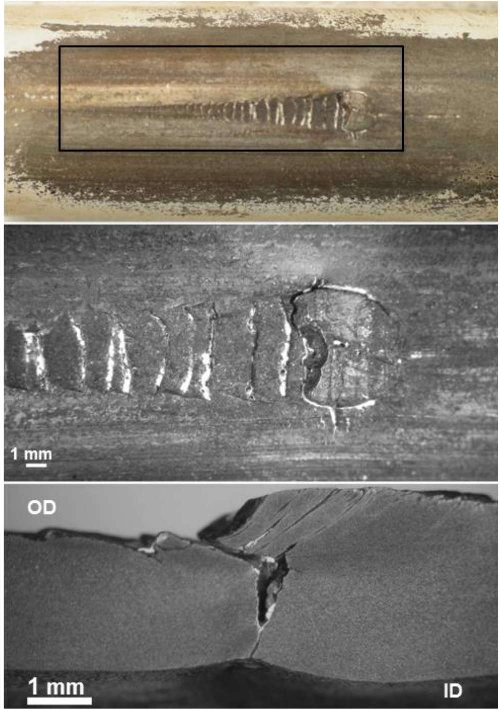
Main Failures Causes Review: Mechanical Damage (≈30%)

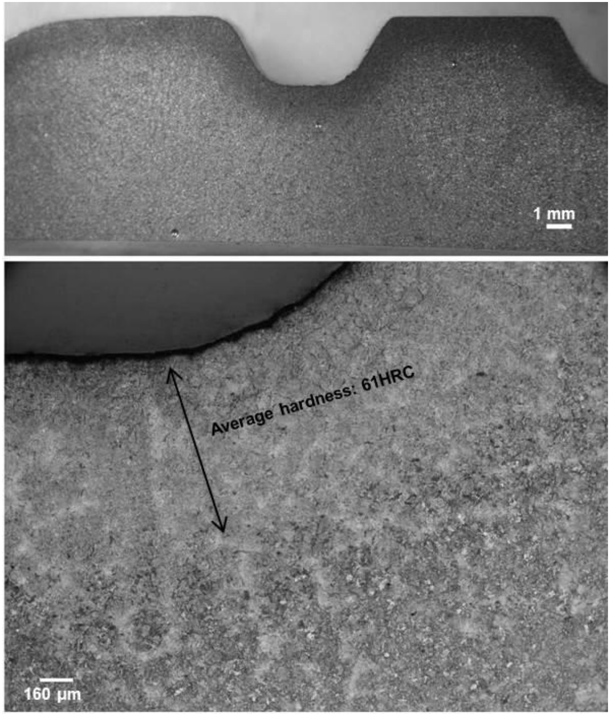
Most frequent types of mechanical damage (2006-2017):

Damage: Longitudinal Plowing Mark (LPM); Frequency: 46%		
General Appearance	Detailed view	Longitudinal Section
		

Damage: Transverse Notch; Frequency: 30%		
General Appearance	Detailed view	Longitudinal Section
		

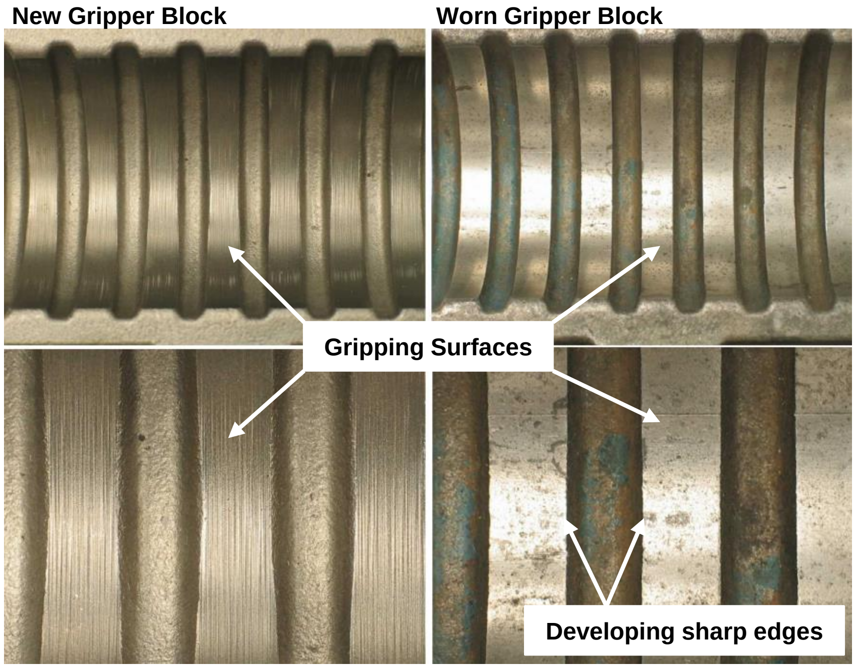
Main Failures Causes Review: Longitudinal Plowing Marks (LPM)



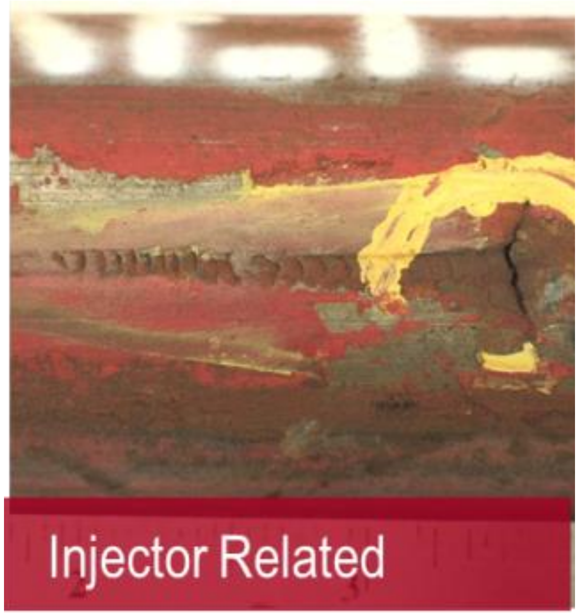


Main Failures Causes Review: Longitudinal Plowing Marks (LPM)

Frequently associated with worn gripper blocks



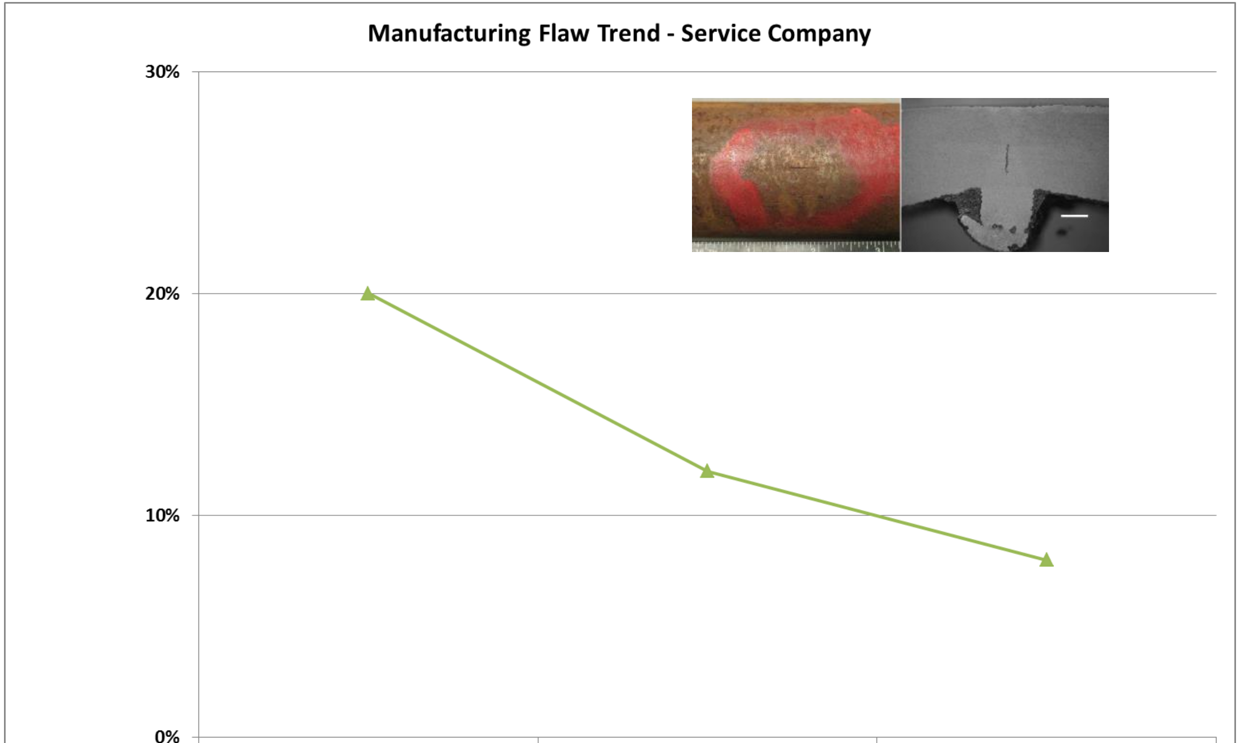
Main Failures Causes Review: Longitudinal Plowing Marks (LPM)



Some mitigation actions for LPM:

- Replacing “smooth” gripper blocks based on OEM recommendations
- Coating gripper blocks with tungsten carbide
- Inspect gripper blocks prior mobilization for the presence of debris in the grooved gripper blocks

Main Failures Causes Review: Manufacturing Flaw



	1995-2000	2001 – 2005	2006 - 2017
Manufac. Flaw	20%	12%	8%

Main Ideas

- CT Failures occur and in many cases it is worthy to perform failure analyses to establish the cause(s) based on data/evidence

Main Ideas

CT failure analysis:

Logical process of examination to establish the failure cause(s) based on evidence collected and the use of engineering principles.

- Most common CT failure analyses include the following stages:
  - Sample(s) collection/preservation
  - Collection of data regarding failure/CT string
  - Visual/stereoscopic examination
  - Dimensional inspection
  - Metallographic analysis
  - Results analysis and report preparation



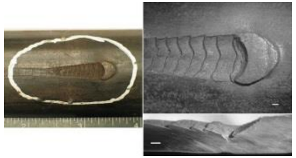


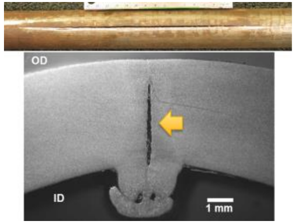
Main Ideas

- Data allow inferring that the main CT Failures causes are similar for the CT industry.

- No significant change was observed on the CT failures causes for the periods 1994-2005 and 2006-2017:
  - Corrosion
  - Mechanical damage
  - Manufacturing flaw
  - Human error

- These causes represented around 80% - 90% of the CT failures





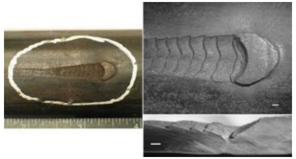
Acknowledgements

ICoTA Canada
Baker Hughes a GE Company
Steven Craig

Thank you

Questions?

Corrosion



Mech. Damage