The Challenges of Coiled Tubing Failure Analyses

Presented by

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Coiled Tubing

Coiled tubing is a well completion and intervention tool for the upstream oil and gas industry.

- **10,000 to 25,000 ft long (3 to 7.5 km)**
- **3/4 to 4-1/2 in OD (19 to 114 mm)**
- **0.090 to 0.250 in wall (2.3 to 6.4 mm)**
- **70 to 140 ksi SMYS (480 to 960 MPa)**

A minimum of three cycles of fully reversed plastic bending each trip into and out of the well.

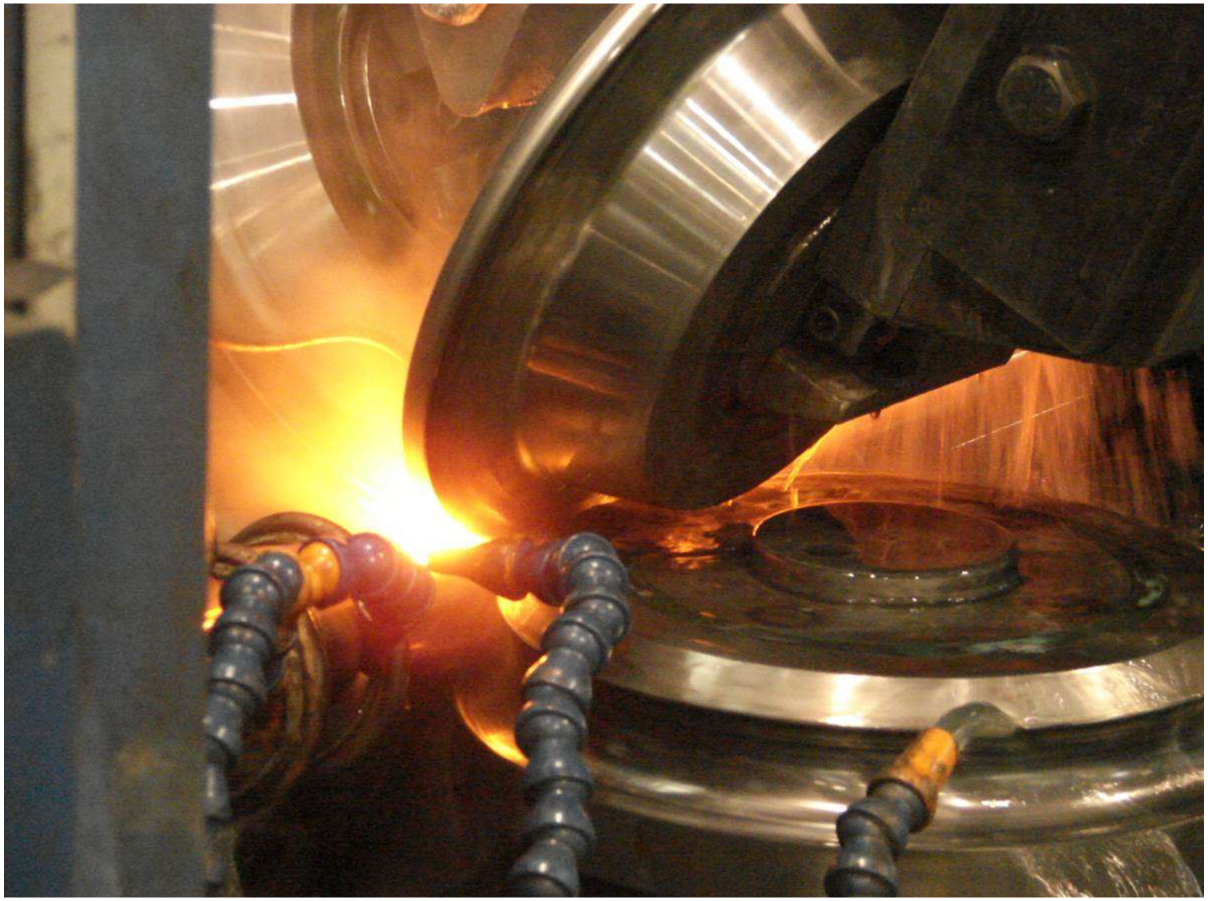
Manufacture of Coiled Tubing

High quality steel strip is slit to the desired width, based on pi x dia.

Strips are welded end to end. To improve fatigue performance of the weld, the ends are cut on a bias before joining. The "bias welds" are ground smooth and carefully inspected using digital radiography.

Most strings are fabricated using strip of different wall thicknesses to reduce the weight on the string at the top of the well. Specially rolled strip with continuously varying wall thickness may be used as transition pieces.

- The assembled strip is wound onto a large reel and fed into a high-frequency induction welding pipe mill.



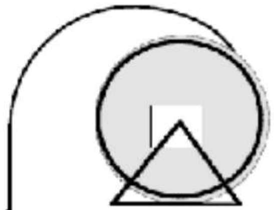
- The flash is removed from the outside surface, but usually not from the inside surface. (The variation in wall thickness creates a variable inside diameter, which complicates the design of an internal trimming tool.)
- The weld is seam annealed and the tubing is stress-relieved.
- The tubing is cooled before being coiled onto a large reel.
- An end fitting is welded to the “uphole” or “reel” end and a bottom hole assembly is welded to the “downhole” or “free” end.
- Hydrostatic testing is performed with inhibited water. A wiper ball is run through the tubing to remove residual water and the string is purged with nitrogen.

QTI Form No. 57
3/9/2010:1247

WELD LOCATION RECORD and MATERIAL CERTIFICATE

[redacted]

CUSTOMER [redacted]
PO#
QTI# 62795
STRING# 441560000
DIAMETER 2.000 INCH
WALL .156 - .203
GRADE QT900
HYDROTESTED TO 10900 PSI
SHIPPED ON 17732
Spool/Reel #MS1580950966N
SHIP TO NEW COLUMBIA, PA 17856



	Strip#	Wall	Length	Weld Loc	Weld Type	COIL Number	HEAT Number	Yield Strength psi (0.2%)	Tensile Strength psi	Tensile to Yield ratio %	Elong %	Rockwell Hardness Mat'l		Rockwell Hardness Weld		C	Mn	P	S	Si	Cr	Cu	Ni	Mo
0	1500099446	.156 - .156	993	993	BIAS	8212199	426926	93500	101500	1.09	29.0	97	HRB	21	HRC	0.132	0.786	0.015	0.0010	0.337	0.579	0.261	0.165	0.108
1	1500099445	.156 - .156	1854	2847	BIAS	8212199	426926	93500	101500	1.09	29.0	97	HRB	21	HRC	0.132	0.786	0.015	0.0010	0.337	0.579	0.261	0.165	0.108
2	1500099457	.175 - .156	1543	4390	BIAS	8212204	417805	97000	103000	1.06	28.5	99	HRB	21	HRC	0.128	0.787	0.016	0.0010	0.328	0.600	0.263	0.165	0.109
3	1500099129	.203 - .175	1417	5807	BIAS	7711088	425600	91500	101000	1.1	30.0	97	HRB	20	HRC	0.133	0.797	0.014	0.0020	0.340	0.586	0.284	0.166	0.104
4	1500099356	.203 - .203	1153	6960	BIAS	8817083	428223	93500	102500	1.1	37.5	96	HRB	99	HRB	0.134	0.789	0.012	0.0020	0.330	0.573	0.262	0.165	0.110
5	1500099350	.203 - .203	1301	8261	BIAS	8817079	428223	93500	102500	1.1	37.5	96	HRB	99	HRB	0.134	0.789	0.012	0.0020	0.330	0.573	0.262	0.165	0.110
6	1500098712	.203 - .203	1340	9601	BIAS	8405132	427657	93000	102500	1.1	29.0	99	HRB	20	HRC	0.133	0.777	0.014	0.0010	0.325	0.572	0.255	0.164	0.110
7	1500098455	.203 - .203	1386	10987	BIAS	8212164	426482	98000	107000	1.09	32.5	21	HRC	21	HRC	0.133	0.792	0.015	0.0010	0.366	0.591	0.281	0.169	0.112
8	1500098454	.203 - .203	1369	12356	BIAS	8212164	426482	98000	107000	1.09	32.5	21	HRC	21	HRC	0.133	0.792	0.015	0.0010	0.366	0.591	0.281	0.169	0.112
9	1500099236	.203 - .203	1309	13665	BIAS	8817084	410059	98000	106000	1.08	29.0	98	HRB	21	HRC	0.140	0.815	0.016	0.0020	0.329	0.572	0.266	0.004	0.106
10	1500099205	.175 - .203	1518	15183	BIAS	7703079	425253	93000	103000	1.11	31.0	99	HRB	20	HRC	0.137	0.804	0.011	0.0030	0.342	0.562	0.279	0.162	0.110
11	1500099362	.175 - .175	1567	16750	BIAS	7142044	425254	95000	103500	1.09	34.0	96	HRB	98	HRB	0.133	0.799	0.012	0.0020	0.331	0.567	0.276	0.164	0.109
12	1500098441	.175 - .175	927	17677	BIAS	7733092	426485	94000	102500	1.09	29.5	99	HRB	21	HRC	0.140	0.792	0.016	0.0020	0.329	0.583	0.277	0.169	0.112
13	1500097440	.175 - .175	367	18044	END	7434100	425252	94000	103000	1.1	28.0	98	HRB	99	HRB	0.126	0.784	0.012	0.0020	0.336	0.573	0.258	0.163	0.109

Total String: 18044 FT

By [redacted]

String Manufactured: 3/31/2015

Date 4/1/2015

ORIENTATION X BED

Material Specification: **ASTM A606 Type 4, Modified**
N.D.E. Tested ASTM E-309 **Mechanical Test Method per ASTM A370**
Customer Specification: **Quality Tubing Specification**
Weld Location Notes: **Hour Glass Design**

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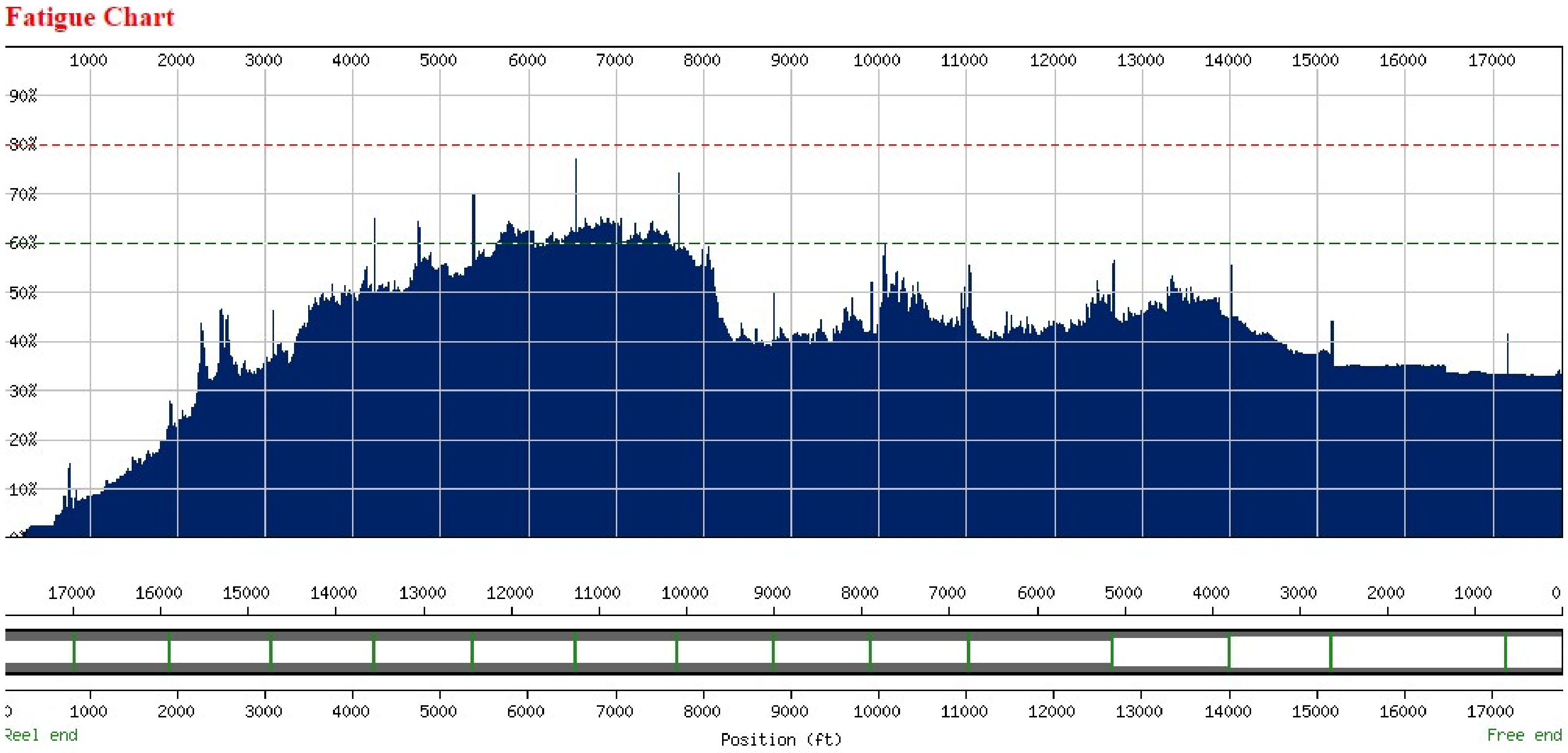
Performance of Coiled Tubing

- Controlled by fatigue
- Sophisticated instrumentation has been developed to track the deformation experienced by the tubing at each point along its length and computer models predict remaining fatigue life based on those assessments.
- Premature failures are expensive.

Fatigue Monitoring Data



Consequences of Use

- Plastic deformation
- Yield strength drops due to Bauschinger effect
- Diameter growth
- Localized plastic deformation of bias weld HAZ, termed "striping"

Modes of Failure

Fatigue due to mechanical damage	Any mechanical damage to the surface will reduce fatigue life. • Improperly sized or aligned surface equipment • Cutting debris in the well • Mishandling
Corrosion fatigue	Corrosion pits initiate fatigue cracks • Acidic well treatment chemicals • Dissolved oxygen • Microbiologically influenced corrosion • Corrosive formation fluids • Improper storage—ponding of residual water
Sulfide Stress Cracking	Coiled tubing generally sees a controlled (non-sour) environment and at most short-term exposure to hydrogen sulfide. Nonetheless, the most commonly used grades are susceptible to hydrogen stress cracking if exposed to sour conditions and failures can occur.

Modes of Failure

Overload	Unusual, but can happen. Slanted fracture, local through-thickness necking Uniform deformation before localized necking may be extensive, reducing wall thickness and increasing yield strength for some distance from the point of failure. Often occurs at a bias weld marking a change in wall thickness. Dynamic loading may be an issue.
Wear	Sliding (axial) wear in horizontal wells thins one side of the tubing, resulting in a tensile fracture or burst. Circumferential wear is extremely unusual, but can occur.
Brittle bias weld failures	Bias welds, esp. in some high-strength grades, can become brittle after use, and become more sensitive to corrosion pits and other surface irregularities.

Modes of Failure

Seam Weld Defects	Because coiled tubing is made using a standard high frequency electric welding process, the same defects occur in it as can occur in other electric-welded pipe. Often related to interrupted electrical power or strip edge condition. Usually detected during hydrostatic testing. Unusual irregularities in the internal flash may provide confirmation.
Ice plugs	Water freezing in the coils can cause ruptures. Usually splits along the longitudinal weld seam.
Overpressure	Although used at pressures as high as 15,000 psi, pressure-related failures are extremely rare. Swelling would prevent passage through pressure control equipment at the surface.

Fatigue at mechanical damage

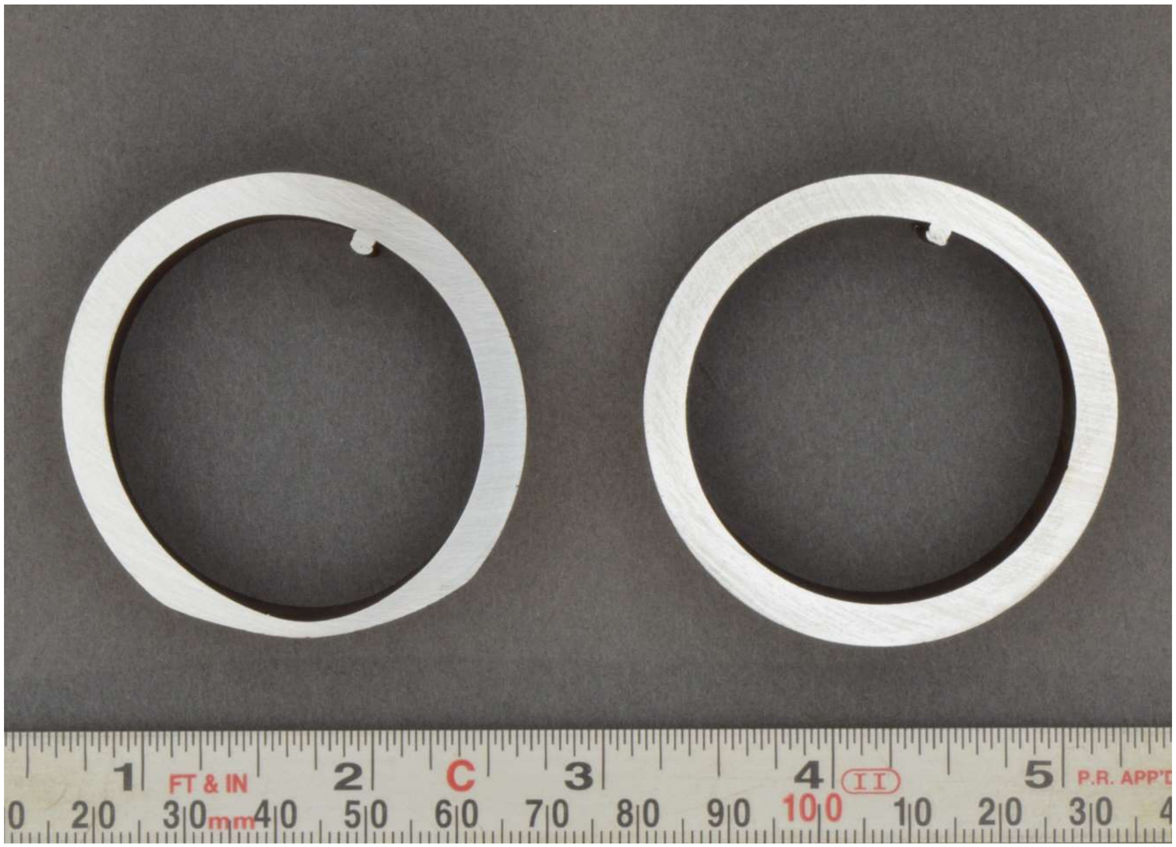
Corrosion Fatigue

- Note internal pitting and small cracks extending from pits.

Sour Corrosion and SSC

- Note angular corrosion, termed "trenching" on outside surface (near crack). This is a form of incipient sulfide stress cracking.

Wear Failures



Seam weld defect

- Note variation in internal flash adjoining eroded hole.

Peculiarities of Coiled Tubing Failure Investigations

Ordinary features	Noteworthy features
Yield strength below SMYS	Corrosion pits
Oversize OD	Internal corrosion pits in parallel lines or oval pattern
Below-spec wall thickness on overload failures	External mechanical damage, especially small surface tears
Axial scoring	Wear damage
Fatigue features on fracture surface	Fatigue features on fracture surface
Internal weld flash	Interruptions in the internal weld flash
Shallow impressions alongside bias weld (striping)	

Acknowledgements

This presentation is based on the article, "The Challenges of Coiled Tubing Failure Analysis," by

- Michael Burns, Stress Engineering Services, Inc.
- Kevin Elliott, NOV Quality Tubing
- Travis Graham-Wright, NOV Quality Tubing
- Austin Sutch, NOV Quality Tubing
- Pankaj Kumar, Stress Engineering Services, Inc.

The article will be published in the proceedings of MS&T 2016 and will be available on request after October 27, 2016.

Questions?