GL Noble Denton

Review of Stress Corrosion Cracking

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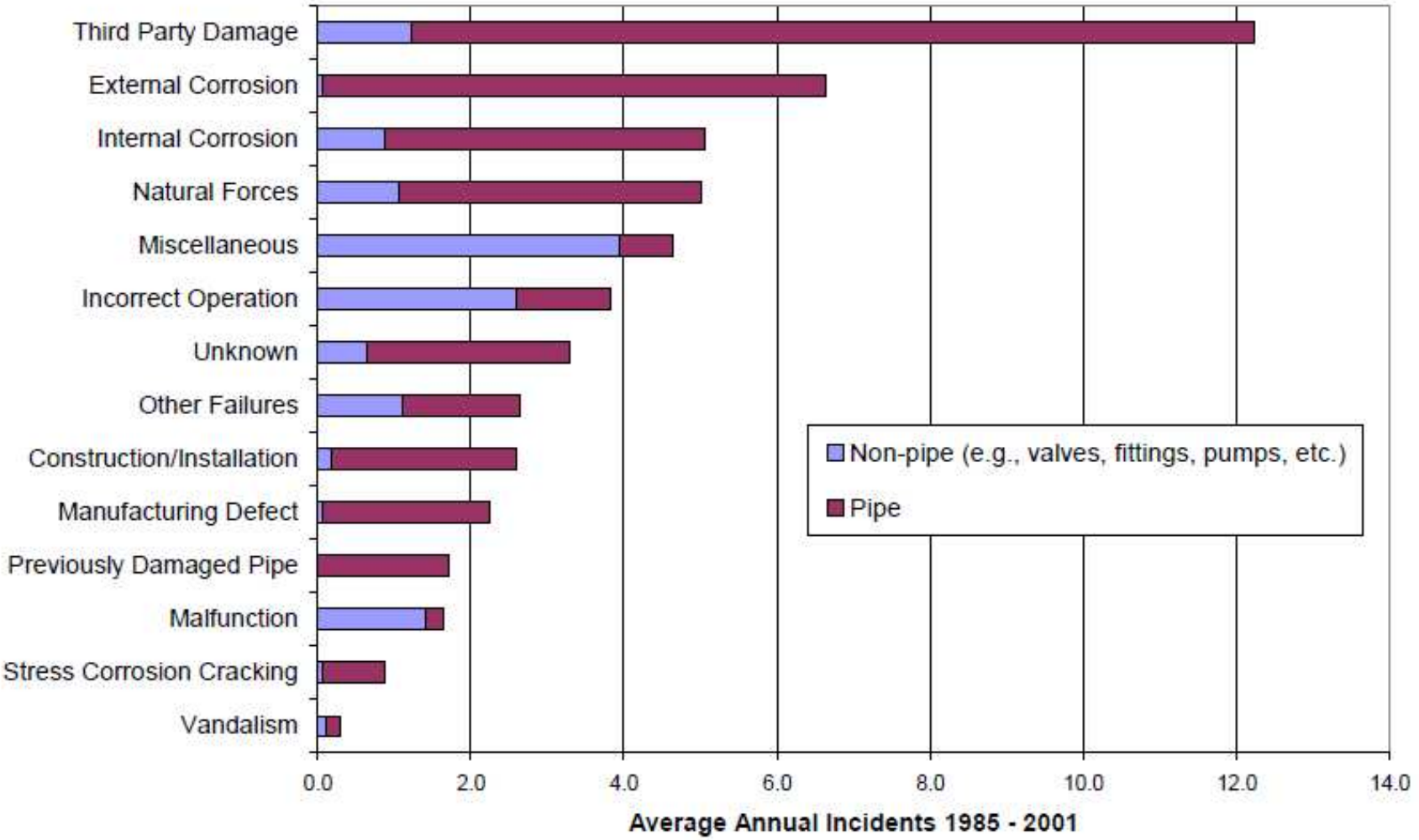
High Level Review of SCC

- Threat Level
- Characteristics of SCC
- Requirements for SCC
- High pH SCC
- Near Neutral pH SCC
  - Longitudinal
  - Circumferential
- Experience (American, Canadian & European)
- Examples
  - Near neutral (Longitudinal)
  - Near neutral (Circumferential)

Threats to Pipelines (OPS)

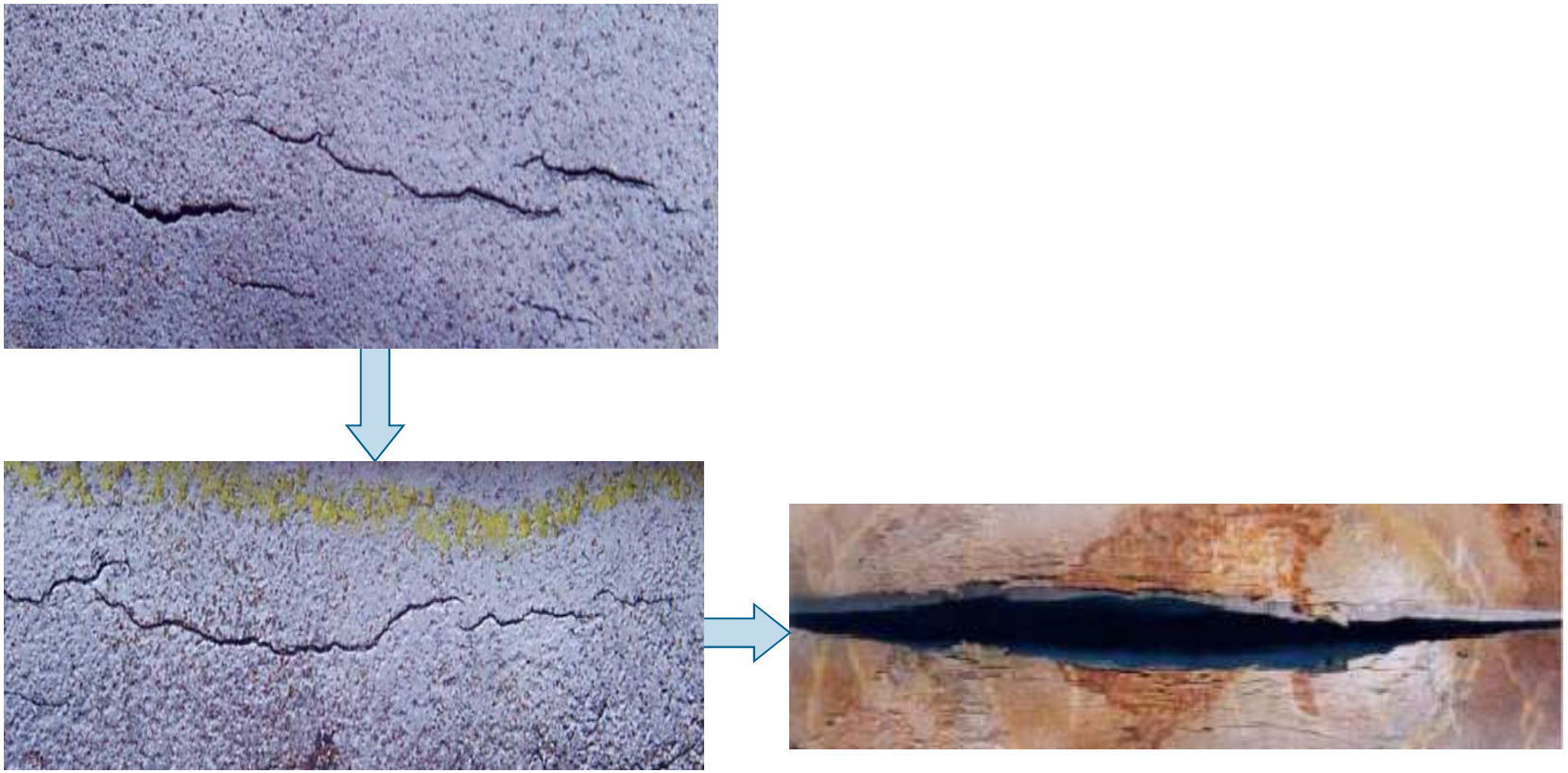


SCC in Pipelines

- SCC in pipelines is characterised as “High pH SCC” or “Near neutral pH SCC. The ‘pH’ relates to the environment at the crack location not the soil pH.
- The most obvious characteristic of SCC in pipelines, irrespective of type, is the presence of colonies of parallel cracks on the external surface.
- The cracks are closely spaced, are of varying length and depth and are perpendicular to the direction of the highest stress (generally the hoop stress) on the external surface.

SCC in Pipelines

• The cracks tend to coalesce to form longer and deeper cracks, which in some cases can lead to a rupture. Cracks do not need to fully penetrate the wall for a rupture to occur.



• If cracks are sparsely spaced they might grow through wall and leak before they reach a length that is sufficient to cause a rupture.

Requirements for SCC to occur

For SCC to occur three conditions must be satisfied simultaneously:

- A tensile stress higher than the threshold stress; frequently including some dynamic or cyclic component to the stress.
- A material that is susceptible to SCC
- A potent cracking environment

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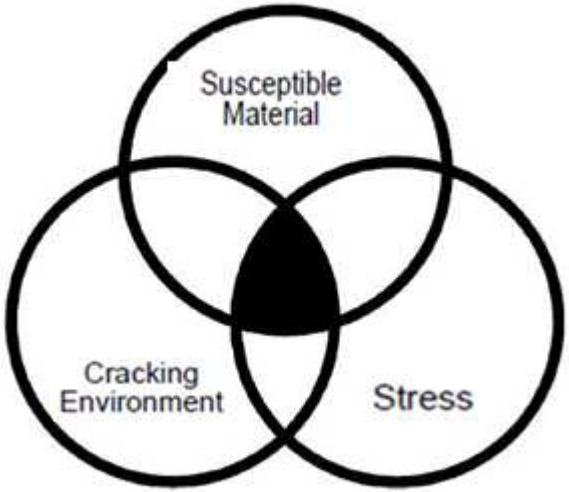

* In the majority of cases SCC occurs under a disbonded coating

High pH (classical) SCC

•High pH SCC cracking is caused by the dissolution of grain boundaries in a stressed metal in contact with aqueous solution.

•It is most frequently observed as intergranular cracking.

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• It is generally experienced on pipe coated with field-applied CTE, tape and asphalt.

Conditions required for High pH SCC to occur

The following condition must exist for high pH SCC to occur:

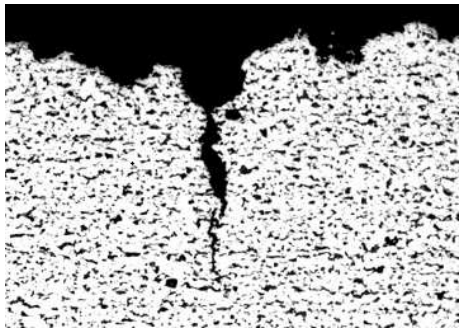
- A stress level in excess of the threshold stress; the threshold stress for crack initiation decreases if the pipeline is undergoing pressure cycling.
- The pipe surface must be in contact with an alkaline solution containing carbonate/bicarbonate at a pH within the range 8 – 12.
- The pipe's potential must be within the range -625mV to -825mV ($Cu/CuSO_4$ reference electrode)

  -If the pipeline operating temperature increases this can widen the range of critical pipe-to-soil potentials over which crack initiation can take place; temperature also increases the crack growth rate.

High pH SCC has been predominantly found downstream of compressor stations where higher operating temperature exist in conjunction with pressure cycling.

Near Neutral pH SCC (NNSCC)

- Near neutral pH SCC is a form of transgranular cracking which occurs under near neutral conditions (pH 5 – 7.5) when dilute bicarbonbate/carbonic acid solutions are present at the metal's surface.



- NNSCC was first recognized in Canada in 1985 and and has subsequently been found elsewhere in the world.
- It is predominantly associated with disbonded tape, CTE and asphalt coatings.

Conditions for Near Neutral SCC (NNSCC) to occur

The following conditions must exist for NNSCC to occur:

- Stress levels above 40% SMYS.
  Fluctuating stresses are important in terms of the crack growth mechanism.
- The surface of the pipe must be in contact with low conductivity, near neutral pH (5 – 7.5) groundwater containing dissolved carbon dioxide.
- Little if any CP current must be reaching the pipe surface either because of CP shielding by high dielectric coatings or due to the presence of high resistivity soils.

NNSCC generally occurs under a disbonded coating, which is shielding the pipe from CP, and where general or pitting corrosion is already occurring.

Design Considerations for SCC

Pipeline Steel - All steels have been found to be susceptible to some extent.

Cyclic Stress Range – The frequency and the range of cyclic stresses strongly influence the initiation and growth rate of both forms of SCC.

Coating Type – Coatings that are prone to cathodic disbonding and which shield CP are more susceptible to SCC, in particular wrapping tapes.

Age of Pipeline – All factors being equal, older pipelines are at greatest risk.

Soil – SCC tends to occur in expansive clay soils which damage coatings that are susceptible to soil stressing thereby exposing the metal's surface.

Surface Preparation – Grit blasting

- removes contaminants that would otherwise accelerate disbonding
- it removes mill-scale that can hold potentials in the cracking range for high pH SCC
- it distorts the grain structure making crack growth more torturous for mechanisms that rely on intergranular crack growth

Temperature – Crack initiation and the growth of high pH SCC is controlled by temperature. Increasing temperature will reduce crack initiation times and increase crack growth rate.

Operator Experience with SCC (USA and Canada)

The table below shows the in-service failures due to SCC experienced by eight operators in the USA collectively responsible for 160,000 miles of high pressure gas pipelines.

Failures in the USA

Year	65/70	71/75	76/80	81/85	86/90	91/95	96/00	01/05	06/10	Totals
High pH SCC	7	12	2	9	8	10	7	4	0	59
Near-neutral SCC	1	2	2	1	1	5	6	5	3	26

Failures in Canada

22 failures within the period 1977 – 2005 (mostly Near Neutral SCC)

Operator Experience with SCC (USA)

In the USA many operators manage their SCC problem by performing repeat hydrostatic tests.

Occurrences of in-service and hydrostatic failures due to high pH SCC

Year	65/70	71/75	76/80	81/85	86/90	91/95	96/00	01/05	06/10	Totals
In-service failures	7	12	2	9	8	10	7	4	0	59
Hydrostatic test failures	52	71	8	10	45	49	31	19	13	298

Occurrences of in-service and hydrostatic failures due to near-neutral pH SCC

Year	65/70	71/75	76/80	81/85	86/90	91/95	96/00	01/05	06/10	Totals
In-service failures	1	2	2	1	1	5	6	5	3	26
Hydrostatic test failures	32	18	0	0	10	18	7	11	63	159

Operator Experience with SCC in Europe

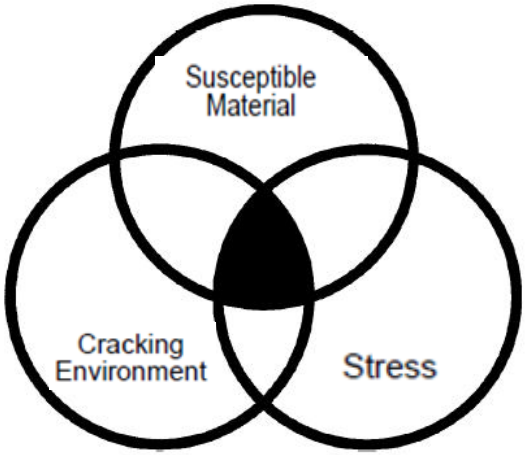
- It is extremely difficult to obtain information related to SCC on the European pipeline network; this may be due to the fact that there have been few if any high profile incidents.
- GL is unaware of any evidence of the high pH form of SCC within Europe
- Leaks and ruptures are known to have occurred due to the circumferential form of NNSCC
- GL is aware of pipelines in Europe which contain very extensive longitudinal NNSCC at tape coated field joints.

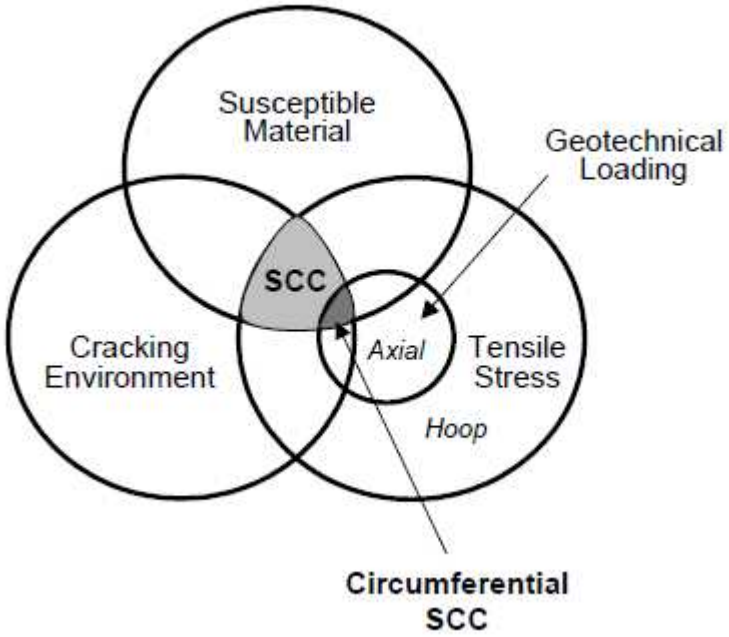
Near-neutral SCC on Tape Coated Field Joints

Diameter (mm)	WT (mm)	Strength	SMYS (Mpa)	UTS (Mpa)	Mainline Coating	Field Joint Coating	Pressure MOP (bar)	Commisioned
954	12.6	X60	415	550	Asphalt	Tape	67.5	1974

Circumferential Near-neutral pH SCC

- Circumferential SCC is a subset of transgranular SCC in which the principle stress acting on the pipe is a bending stress
    - Soil creep
    - Slope movement
    - External loading





Circumferential Near-neutral pH SCC

- Circumferential SCC accounts for approximately 10% of SCC failures
- Since 1985 at least 9 circumferential SCC failures have been documented
  - 6 were leaks, 3 were ruptures
  - 7 were associated with tapes and 2 with HSSs
  - 2 were on liquid lines and 7 gas lines

Heat Shrink Sleeve under which Circumferential Near-neutral pH SCC occurred on an Indonesian Pipeline