IBC Onshore Pipeline Engineering
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Line pipe specifications and properties

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Specification scope

Linepipe specifications give requirements for:

- Linepipe grades
- manufacturing processes
- mechanical properties
  - strength
  - toughness
- chemical composition
- metallurgical supply condition
- weldability
- optional requirements based on service criteria
- dimensions
- Tolerances on dimensions
- inspection and testing methods and acceptance criteria
- marking

Linepipe for oil and gas transmission lines is generally specified to ISO 3183:2012 / API 5L 45th edition – harmonised standards

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- manufacturing processes
- mechanical properties
  - strength
  - toughness
- chemical composition
- metallurgical supply condition
- weldability
- optional requirements based on service criteria
  - Requirements for H_2S service
- dimensions
- Tolerances on dimensions
- inspection and testing methods and acceptance criteria
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ISO 3183 allows only

- Seamless
- Submerged arc welded (SAW)
- Combination welding (GMAW and SAW)
- High frequency induction welded

Pressure calculations

$$P = \frac{2t.f_y}{D} x(S.F)$$

f_y	=	Specification minimum yield stress (SMYS)
t	=	nominal wall thickness
D	=	nominal outside diameter of pipe
S.F.	=	safety factor

This formula shows the following, if you increase the SMYS of the pipe:

- The wall thickness is decreased for a given maximum design pressure.
- The maximum design pressure is increased for a given wall thickness.

API 5L grades

API 5L: Specification for Line Pipe

- First published in 1920s
- the last independent API edition was published in 2004.

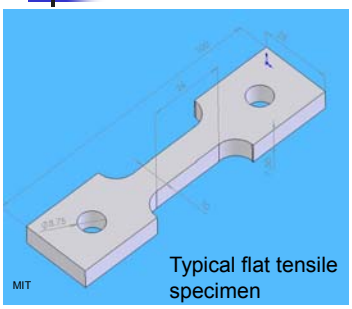
Grade	Date of Introduction (Approx)	Minimum Yield Strength	
		PSI	N/mm²
X42	1948	42,000	(289)
X52	1957	52,000	(358)
X56	1959	56,000	(386)
X60	1964	60,000	(413)
X65	1968	65,000	(448)
X70	1970	70,000	(482)
X80	1985-6 (first use 1992)	80,000	(551)
(X100)	1985 & 1996 (both trial production)	100,00	(688)

Line pipe to ISO 3183 / API 5L

- combined ISO/API standard: 2007
- ISO 3183 3rd edition: 2012/API 5L 45th edition
- Incorporates previous API 5L grades
- Has two Product Specification levels for oil and gas pipeline service
  - PSL 1
  - PSL 2
- PSL 1
  - limited to maximum grade L485
  - May be any metallurgical condition
- PSL 2 higher quality
  - Tighter chemical composition limits than PSL 1
  - Restrictions on manufacturing process for pipe
  - Charpy V toughness requirements are specified (at 0°C)
  - Restrictions on metallurgical condition of pipe

ISO grade	API 5L grade	Yield strength $R_{t0.5}$ N/mm²	UTS (min.) N/mm²
L245	B	245 - 450	415
L290	X42	290 - 495	415
L360	X52	360 - 530	460
L415	X60	415 - 565	520
L450	X65	450 – 600	535
L485	X70	485 - 635	570
L555	X80	555 - 705	625
L690	X100	690 - 840	760
L830	X120	830 - 1050	915

Tensile tests



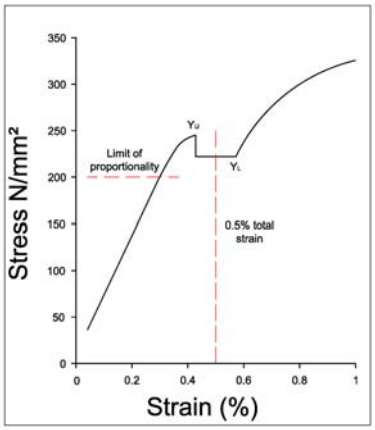
Typical flat tensile specimen

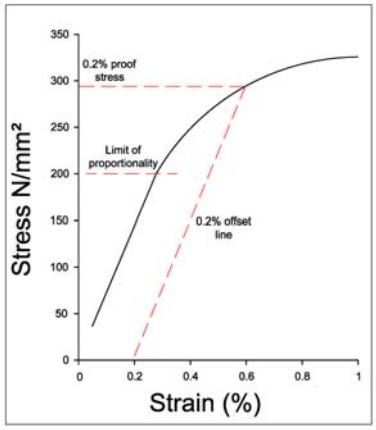
Tensile test machine

Necking and fracture

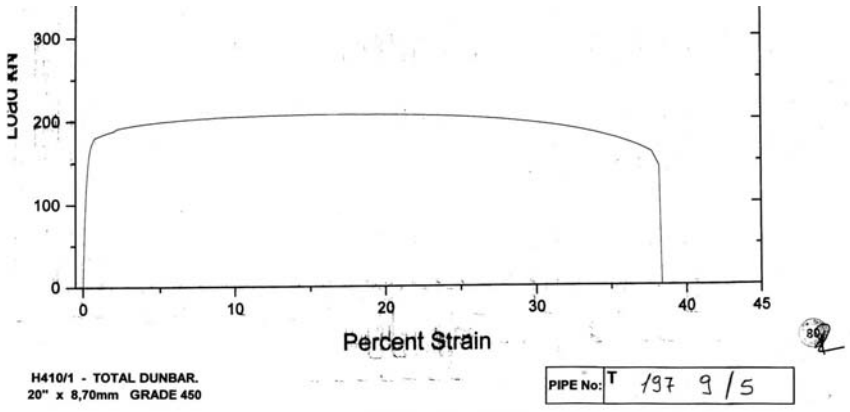
Extensometer

Yield behaviour





Linepipe - ductility



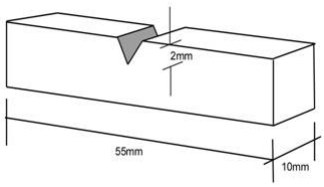
Examples of brittle materials

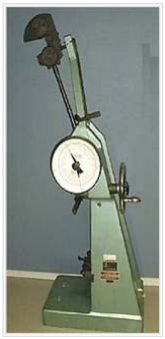
Steel

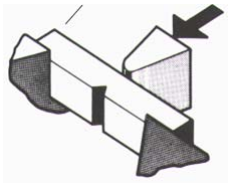
Glass

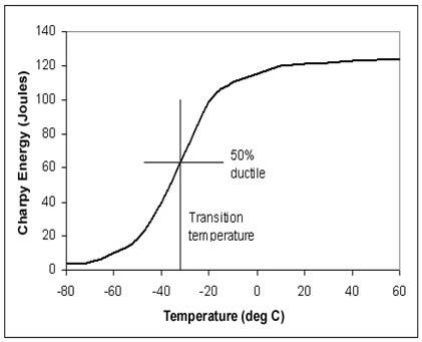
Jelly

Transition behaviour – the Charpy V-notch test









Fracture in pipelines

Brittle fracture requires:-

- an initiator (i.e. a defect or notch),
- stress
- susceptible material

A crack, once initiated can propagate with a mix of brittle and ductile failure modes.

Brittle initiation area and ductile arrest in a pipe fracture test

Unstable crack propagation

It can occur over long distances at constant speed.

- Distance and speed of travel is dependent on the rate of decay of the pipeline pressure compared with the velocity of crack propagation
- It is a significant risk in gas pipelines because of the stored energy.

ISO 3183:2012 Annex G: PSL 2 pipe with resistance to ductile fracture propagation

Avoiding crack initiation and propagation

The speed of propagation of the fracture depends on:-

- the fracture mode
- material fracture properties

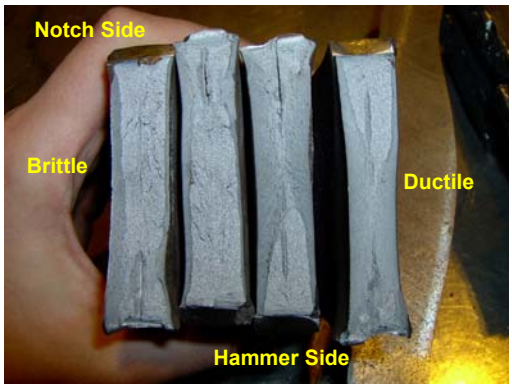
The more brittle mode (cleavage), then the faster the fracture.

- To avoid crack *initiation* the linepipe has to be tough enough to prevent initiation from large flaws under the acting stresses
- To avoid crack *propagation* the linepipe has to be tough enough to arrest (stop) a running crack once it has initiated
- the toughness of the linepipe necessary to arrest a running *(propagating)* crack is much greater than that to prevent a crack *initiating.*

The Drop Weight Tear Test (DWTT)

The (DWTT) is carried out to API 5L3

- Specimens have a punched sharp notch (0.0005 to 0.001 inch tip radius)
- It is carried out on full pipe wall thickness
- The notch is oriented so the crack will run in the longitudinal direction of the pipe
- One test consists of two specimens tested at minimum design temperature



Propagation and correlation with DWTT

American Gas Association found a correlation between

- the occurrence of running fractures in full scale pipe tests
- the results of the Drop Weight Tear Test (DWTT) carried out at the minimum design temperature.

The assessment criterion was the percentage of ductile texture (shear area) on the fracture face

It is required to show high shear (ductile) behaviour.

Current specifications require 85% shear area.

Toughness requirements – summary

The requirements for linepipe steel include:-

- Adequate Charpy V toughness at or below the minimum operating temperature to prevent fracture initiation by brittle fracture.

For gas transmission lines the requirements to reduce the risk of fracture propagation are:-

- As above plus….
- Adequate shear area in a full thickness DWTT at the minimum operating temperature – to resist running ductile brittle cracks.

Role of the elements in carbon-manganese steels

The fundamental elements
Carbon (C)
Manganese (Mn)
Silicon
Aluminium (Al)
The impurity elements
Sulphur (S)
Phosphorus (P)
The solid solution hardening elements
Copper (Cu)
Nickel (Ni)
Chromium (Cr)
Molybdenum (Mo)
The micro-alloying elements
Niobium (Nb)
Vanadium (V)
Titanium (Ti)
The sulphide shape control elements
Calcium (Ca)
Cerium (Ce).

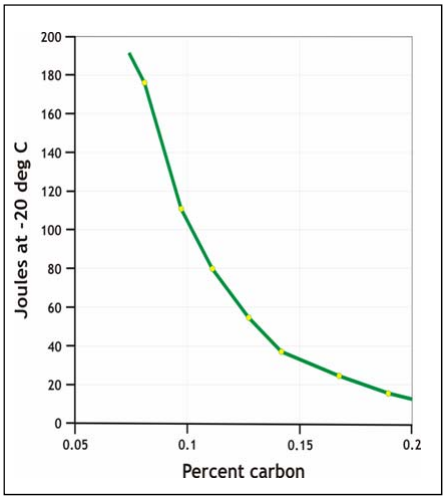
Comparison: chemical analysis of PSL 1 and PSL 2

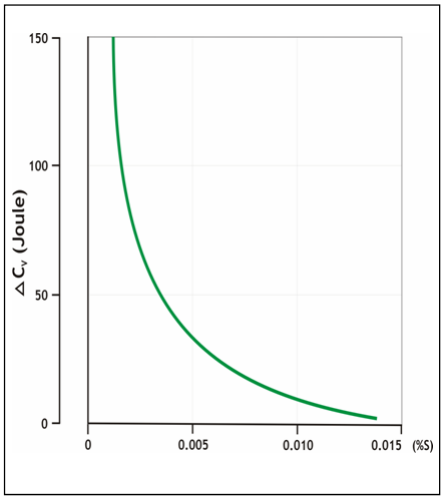
- PSL 2 has lower carbon and sulphur contents than PSL 1
- Mn content may be higher to balance the reduction in carbon

What is the significance of composition?

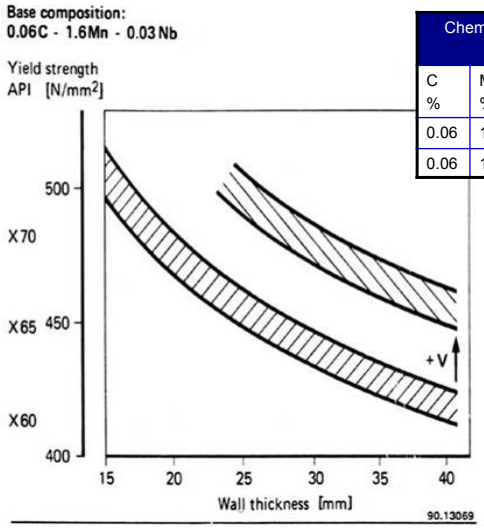
Grade	PSL	C max.	Mn max.	P max.	S max.
L360 X52	PSL 2	0.22	1.40	0.025	0.015
	PSL 1	0.26	1.40	0.030	0.030
L415 X60	PSL 2	0.12	1.60	0.025	0.015
	PSL 1	0.26	1.40	0.030	0.030
L450 X65	PSL 2	0.12	1.60	0.025	0.015
	PSL 1	0.26	1.45	0.030	0.030
L485 X70	PSL 2	0.12	1.70	0.025	0.015
	PSL 1	0.26	1.65	0.030	0.030
L555 X80	PSL 2	0.12	1.85	0.025	0.015
	-	-	-	-	-
L690 X100	PSL2	0.10	2.10	0.020	0.010
	-	-	-	-	-

Effect of carbon and sulphur on toughness





Effect of micro-alloying



Chemical composition				CE	Wall Thickn.	Grade
C %	Mn %	Nb %	V %	IIW	mm	API
0.06	1.60	0.03	-	0.32	30	X60
0.06	1.60	0.03	0.06	0.33	30	X70

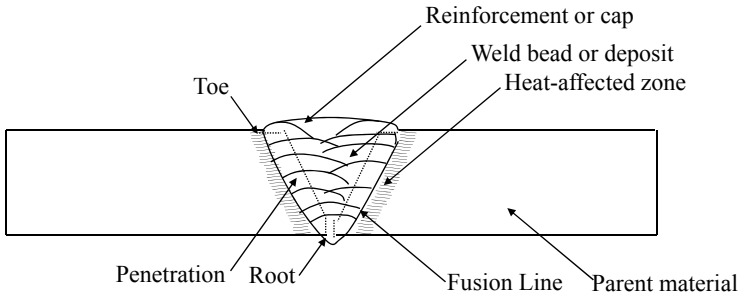
Weldability 1

A practical definition of a weldable steel is that it can be welded without excessive heat affected zone hardening or heat affected zone cracking.

Welding is used for:-

- Pipe production
- Making up multiple joints
- Girth welding as part of pipelay
- The welding of fittings (flanges, tees, manifolds, etc)
- The welding of buckle arrestors
- Modification to the pipeline in service including hot tapping.

Fusion weld definitions



Weldability 2

Hardening and cracking in the heat affected zone is controlled by the following:-

- The chemical composition of the steel
- Control of weld metal hydrogen content
- Pre-heat and interpass temperature control.

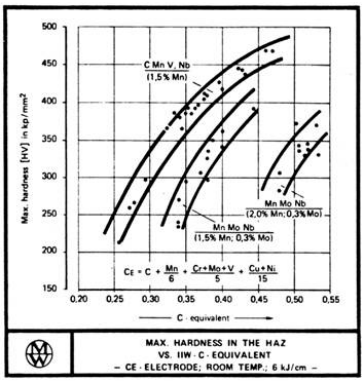
Cold cracking is a particular risk in welding older pipeline steels, high tensile steels and when welding with stick electrodes (particularly cellulosic electrodes).

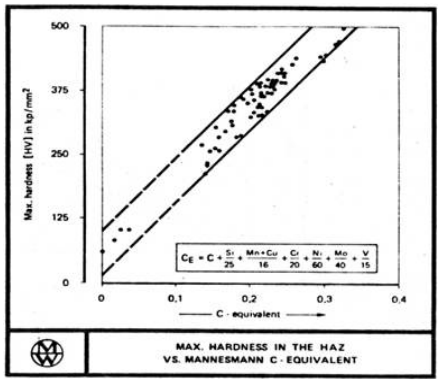
Weldability is assessed by an index:-

$$Carbon\ equivalent_{IIW} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

Letters represent the percentages of the elements in the steel.

Weldability – but the IIW formula is not valid for modern steels





The Pcm formula is now widely used for modern steels:-

$$P_{CM} = C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + 5B$$

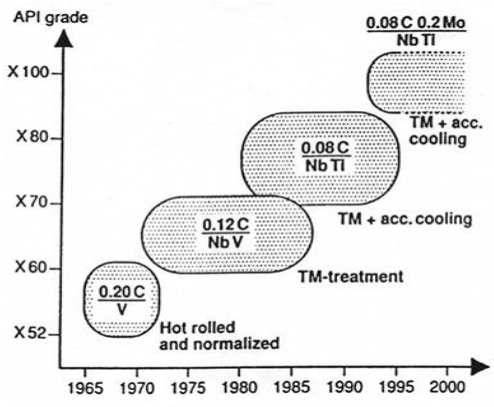
CEq and Pcm for PSL 1 and PSL 2

Grade	PSL	C max.	Mn max.	P max.	S max.	CE max	Pcm max
L360 X52	PSL 2	0.22	1.40	0.025	0.015	0.43	0.25
	PSL 1	0.26	1.40	0.030	0.030	-	-
L415 X60	PSL 2	0.12	1.60	0.025	0.015	0.43	0.25
	PSL 1	0.26	1.40	0.030	0.030	-	-
L450 X65	PSL 2	0.12	1.60	0.025	0.015	0.43	0.25
	PSL 1	0.26	1.45	0.030	0.030	-	-
L485 X70	PSL 2	0.12	1.70	0.025	0.015	0.43	0.25
	PSL 1	0.26	1.65	0.030	0.030	-	-
L555 X80	PSL 2	0.12	1.85	0.025	0.015	0.43	0.25
	-	-	-	-	-	-	-
L690 X100	PSL2	0.10	2.10	0.020	0.010	-	0.25
	-	-	-	-	-	-	-

Development of grades

Abbreviations used in standards
R = hot rolled
N = normalised
Q = quenched and tempered
M = thermo-mechanically treated

The following section of the presentation explains the meaning and significance of these terms



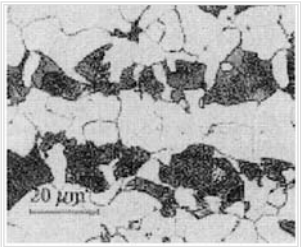
Improving the properties 1

The toughness and strength of linepipe are increased by:-

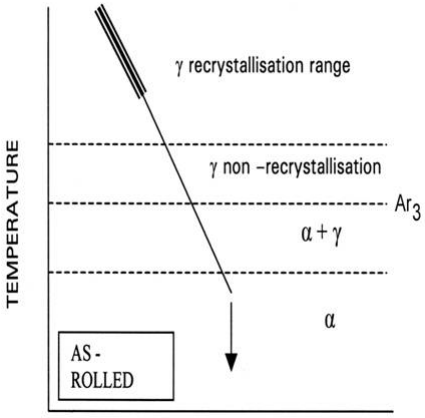
- The use of grain refining elements (micro-alloying)
- Addition of solid solution hardening elements
- Thermal treatments to alter microstructure (such as quenching and tempering)
- Thermo-mechanical rolling without or with accelerated cooling

The objective is to improve the steel microstructures from ferrite and pearlite

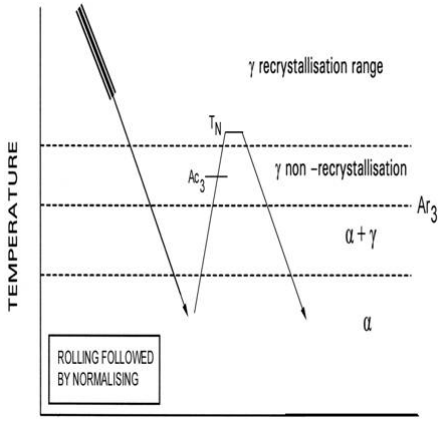
These are inadequate to meet the demands of high strength, adequate toughness and good weldability.



Hot rolled and normalised steel



Abbreviation: R



Abbreviation: N

Quenched and tempered steels

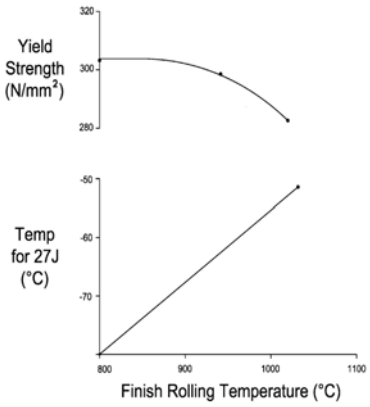
- It is the oldest method of hardening and strengthening steel
- Quenching is the rapid cooling of steel and involves the use of water or oil
  - High carbon phases transform to strong but brittle phases
- Tempering is reheating the steel to just below 723°C
  - This softens the steel; reducing strength and increasing toughness.

Abbreviation: Q

Thermo-mechanical treatments 1

In controlled rolled steels the steel is rolled right down to the temperature boundary where no recrystallisation occurs.

Effect of finish rolling temperature on yield strength and impact transition temperature on a simple steel
(0.08%C, 0.30%Si, 1.45%Mn, 0.07%Al steel)

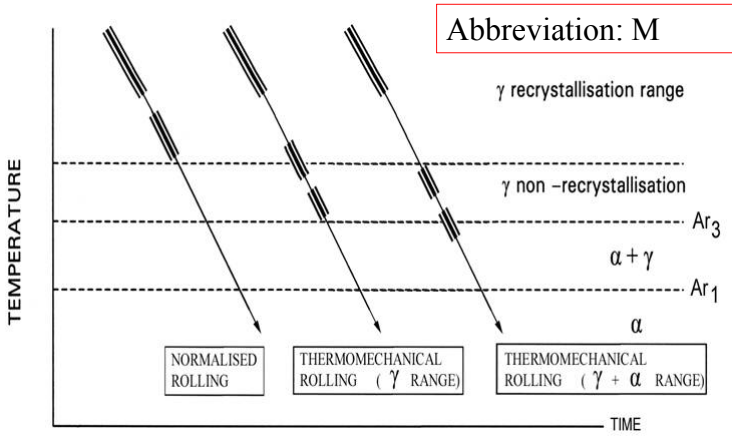


rolling practice has developed much further for steel plate used to make welded pipe

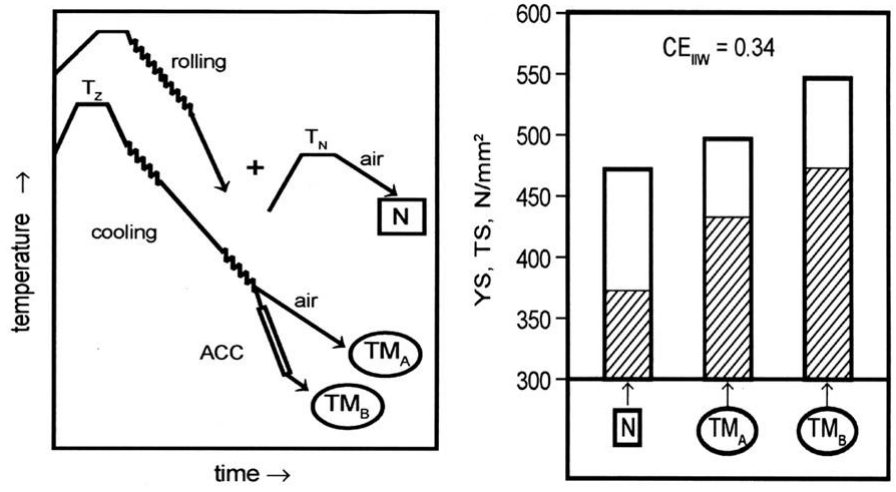
Thermo-mechanical treatments 2

The fundamental aim in thermo-mechanical treatments is to work the steel at a series of temperatures where successive re-crystallisation occur to give finer and finer grain structure.

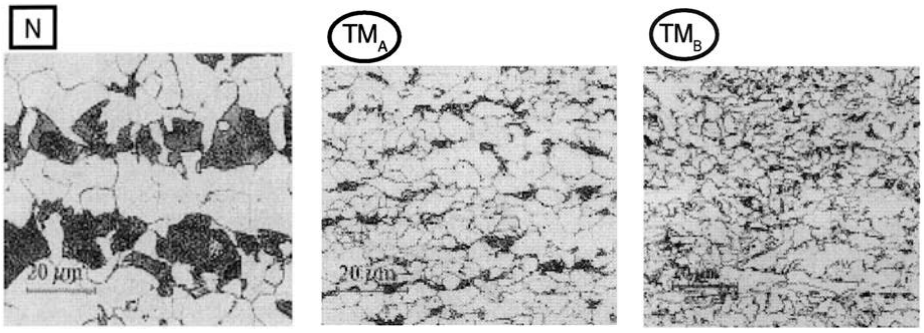
Abbreviation: M



Thermo-mechanical treatments plus accelerated cooling 1



Thermo-mechanical treatments plus accelerated cooling 2



What are the key temperatures in TMCP plate rolling

- Slab reheating temperature
  - Example 1050°C ± 30°C
- Finish rolling temperature
  - Example 760°C ± 25°C
- Start accelerated cooling temperature
  - Example 750°C ± 30°C
- Stop accelerated cooling temperature
  - Example 330 °C ± 45°C

The detail for any particular order is proprietary steelmaker know-how

Permitted supply conditions for PSL 2

ISO grade	API 5L grade	Yield strength $R_{t0.5}$ N/mm²	UTS (min.) N/mm²	PSL2 supply Condition
L245	B	245 - 450	415	R N Q M
L290	X42	290 - 495	415	R N Q M
L360	X52	360 - 530	460	N Q M
L415	X60	415 - 565	520	N Q M
L450	X65	450 – 600	535	Q M
L485	X70	485 - 635	570	Q M
L555	X80	555 - 705	625	Q M
L690	X100	690 - 840	760	M
L830	X120	830 - 1050	915	M

R = hot rolled
N = normalised
Q = quenched and tempered
M = thermo-mechanically treated

Additional/optional requirements

Client specifications frequently state additional requirements

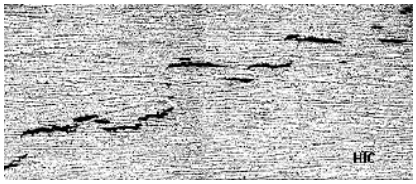
- Restrictions on the manufacturing process.
- Restrictions on chemical composition
- weldability testing requirements
- Improved fracture toughness (Charpy V-notch or DWTT)
- H_2S (sour) service testing requirements
- Additional non-destructive testing requirements
- Tighter tolerances: on pipe wall thickness, diameter and out-of-roundness
- Alternative weld preparations
- Alternative marking requirements
- Material traceability requirements.

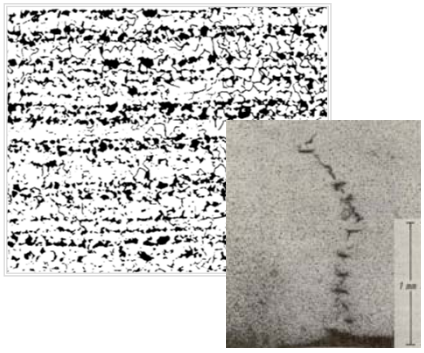
ISO 3183:2012 Annex H: PSL 2 pipe ordered for sour service

Hydrogen induced crack (HIC) and susceptible microstructure

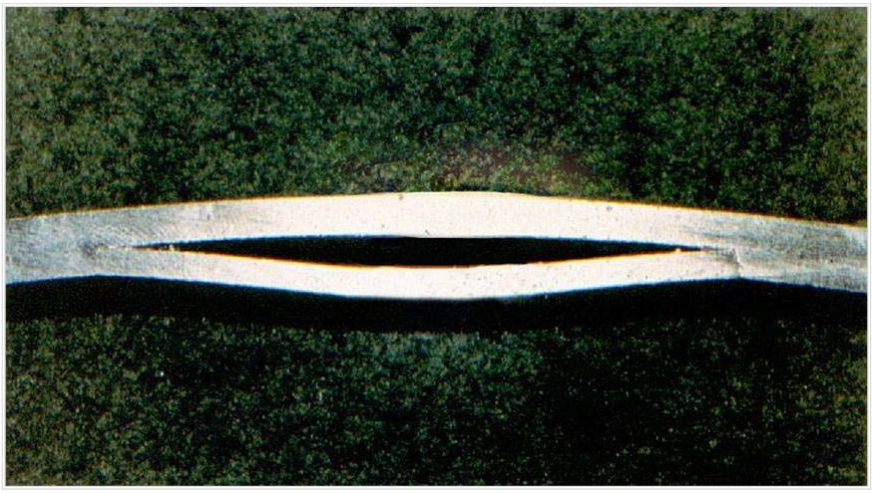
- Cracks are along the rolling direction and stepped
- Surface blisters occur
- No externally applied stress is necessary
- It occurs in steels of all strength levels
- It is associated with non-metallic inclusions
- Associated with plate produced by controlled rolling
- Strong correlation between HIC, laminations and hydrogen blisters that cause rupture.

SOHIC are staggered small cracks in a "ladder-like" crack array.





Blister due to HIC



Improvement of steels for HIC resistance

- Improvement is by reducing the number of inclusions (e.g. by reducing the sulphur content) and/or modifying inclusion shape.
- Addition of small amounts of cerium or calcium prevents the MnS particles from elongating
- Linepipe is tested for susceptibility to HIC using tests to NACE TM0284 in a suitable solution

NACE TM0284-2003 test method

- Coupons measure 100 mm by 20 mm
- Test solutions
  - synthetic sea water saturated with H_2S (solution B)
  - NaCl, acetic acid solution saturated with H_2S (solution A)
- Tested at ambient temperature and pressure immersed for ninety-six hours
- They are sectioned, polished and etched and crack lengths measured

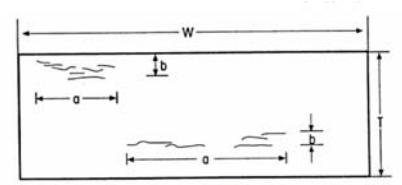
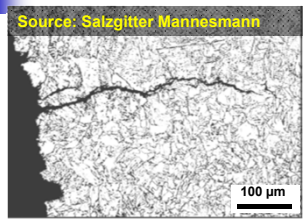


FIGURE 11
Test specimen and crack dimensions to be used in calculating CSR, CLR, and CTR

Courtesy: NACE International

Evaluation is based upon the following ratios:-
Crack Length Ratio (CLR)
Crack Sensitivity Ratio (CSR)
Crack Thickness Ratio (CTR)

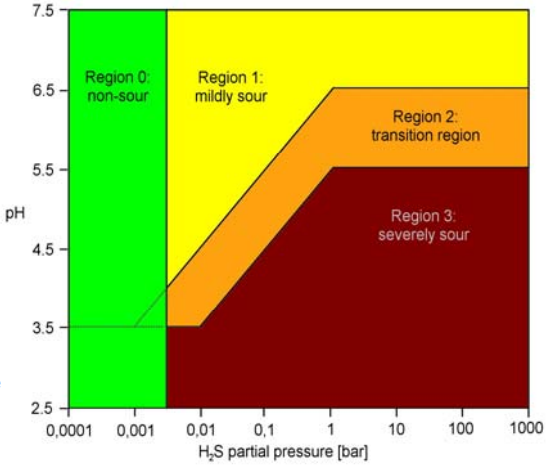
Sulphide stress cracking (SSC) domains



Sour service is where the fluids contain hydrogen sulphide above a critical level.

Specific guidance on sulphide stress cracking and its avoidance is given in ISO 15156-2/NACE MR0175
SSC depends on both pH and partial pressure

Region 0: Non-sour
Region 1: Mildly sour
Region 2: transition zone - some judgement has to be made
Region 3: SSC is likely to occur and materials resistant to SSC should be selected.



Testing for susceptibility to SSCC

- Commonly done using 4 point bend specimen to ASTM G39 and NACE TM0177-2005
- The specimen will generally contain a weld, either longitudinal or circumferential
- Weld and surface not machined

- It is conducted at different H_2S partial pressures in the range 0.001 to 1 bar, to simulate service environments of interest.

Guidelines to avoid sulphide stress cracking

- Limiting the strength can eliminate sensitive microstructures
- Surface hardness measurements are commonly used as a means of assessing the microstructures
- Welds are tested by taking sections and doing micro-hardness determinations particularly in the HAZ
- For pipelines, distinction can be made between the internal process side and the external side. Weld roots Hv10 250, weld cap 275
- Nickel containing consumables can be used with up to 2.2% nickel providing hardness is controlled in accordance with the standard.

- Materials should be purchased tested (or with test pedigree) for susceptibility (tests to ASTM G38 or ISO 7539 Part 5)

Summary - linepipe materials

- Continuous line pipe product development has resulted from market needs.
- There are many critical requirements when specifying line pipe
- Fracture resistance is important, with special requirements for gas pipelines.
- Weldability is a vital requirement for line pipe.
- Modern specifications restrict the steel chemistry to optimise strength, toughness and weldability
- Client specifications select options from the standard and state further restrictions on manufacturing, analysis and properties
- There has been a progressive move from as-rolled or normalised steels to quenched and tempered and increasing sophisticated TMCP steels.
- Even small percentages of H_2S in the fluids are critical to steelmaking.

Manufacturing methods and property requirements are mutually interdependent, as the next presentation illustrates.

The end