General concepts about pipe properties - API Standards -

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Contents

Contents

- Video
- Range of casing and tubing
- Pipe OD
- Mandrel drift
- Pipe properties according to API 5CT
- Anisotropy

Casing

Definition

Casing is defined as a pipe with an outside diameter range of between 4 ½" and 20".

The API has adopted a designation which correlates to the grade of steel.

This designation consists of a letter arbitrarily selected by API followed by a number which represents the minimum yield strength of the steel in thousands of $lb/inch^2$ or psi.

Casing

Example

Casing in steel grade N-80 has a yield strength of 80,000 lb/inch^2

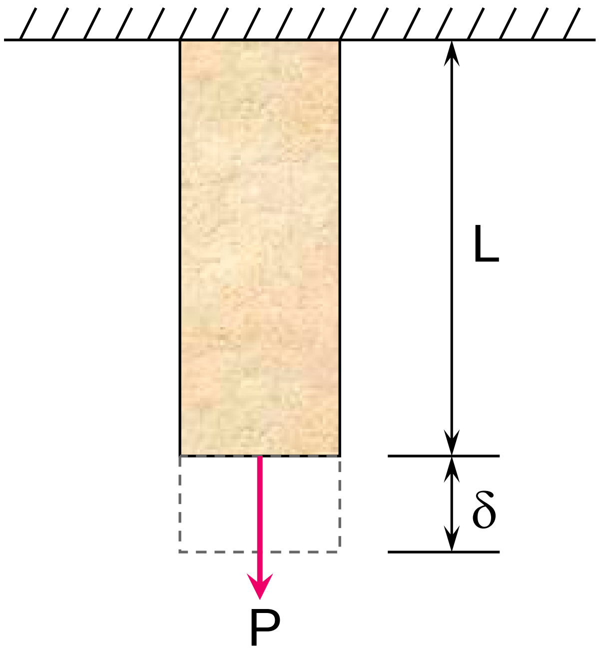
N-80 = 80,000 lb/inch^2 or psi

The yield strength defined by the API is the minimum tensile strength required to produce an elongation of 0.005 per length unit on a laboratory test specimen near its elastic limit.

Hook’s Law

Concept

If a bar of length “L” is subjected to a tensile force “P”, a longitudinal deformation will be observed that is proportional to the applied force “P” and inversely proportional to the area of the transverse section of said bar.

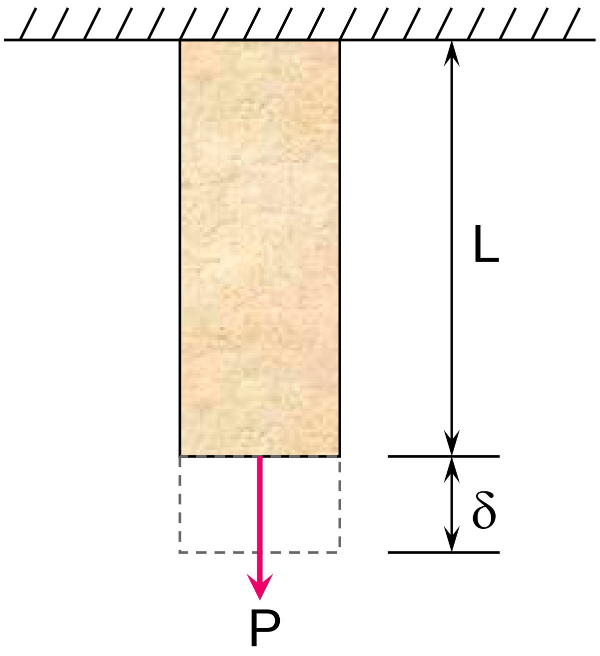


$$\delta \propto \frac{P\,L}{A}$$

Hook's Law

Concept

Introducing a constant of proportionality "E" , a characteristic of each material, called the elastic module or Young's modulus, we have:



$$\delta = \frac{P\,L}{E\,A}$$

Back out the Young's modulus value :

$$E = \frac{P\,L}{\delta\,A}$$

Hook's Law

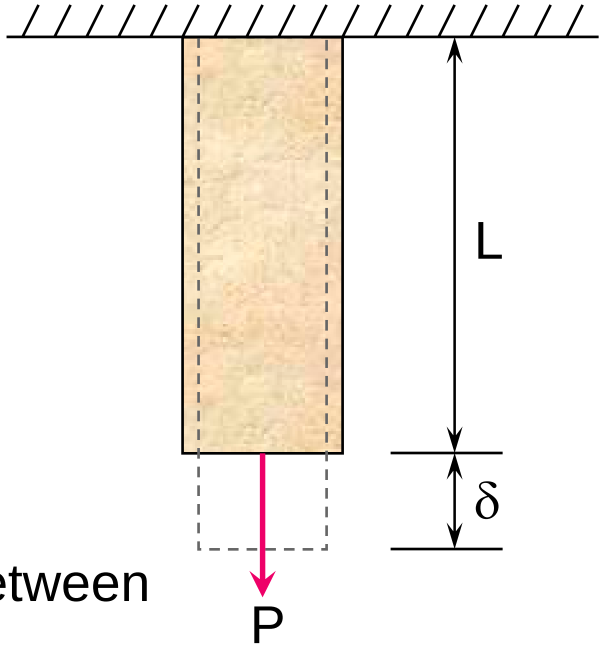
Concept

The unitary axial stress is:

$$\sigma = \frac{P}{A}$$

The unitary axial strain is defined as:

$$\varepsilon = \frac{\sigma}{L}$$

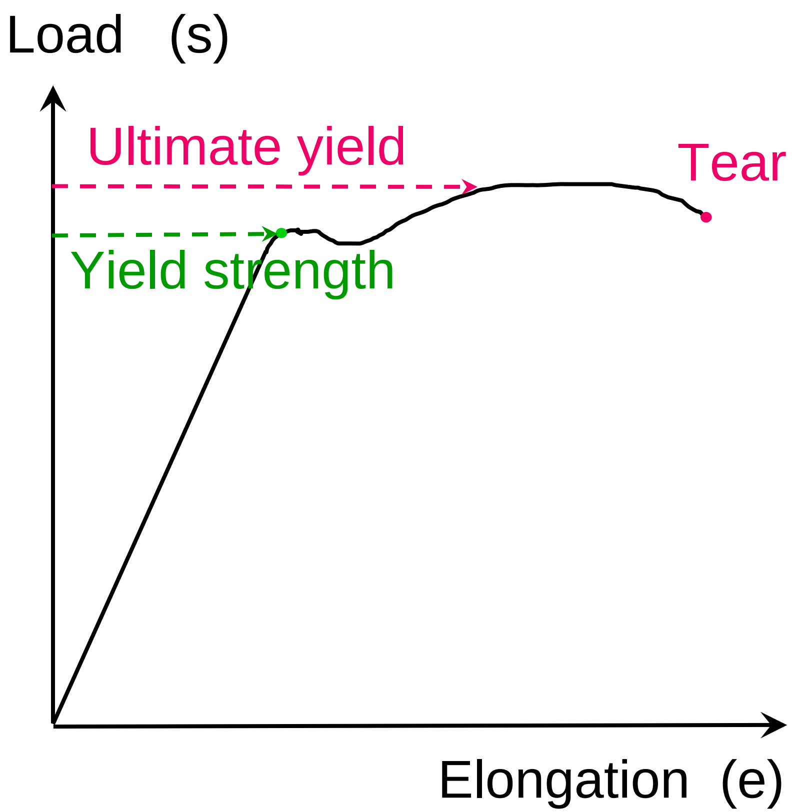


Young's modulus is, therefore, the ratio between axial stress and strain

$$E = \frac{\sigma}{\varepsilon}$$

Hook’s Law

Load versus elongation chart



Any increase in tensile force is accompanied by an increase in length, which is why Hook’s Law is only applicable in the plastic region.

Yield Strength

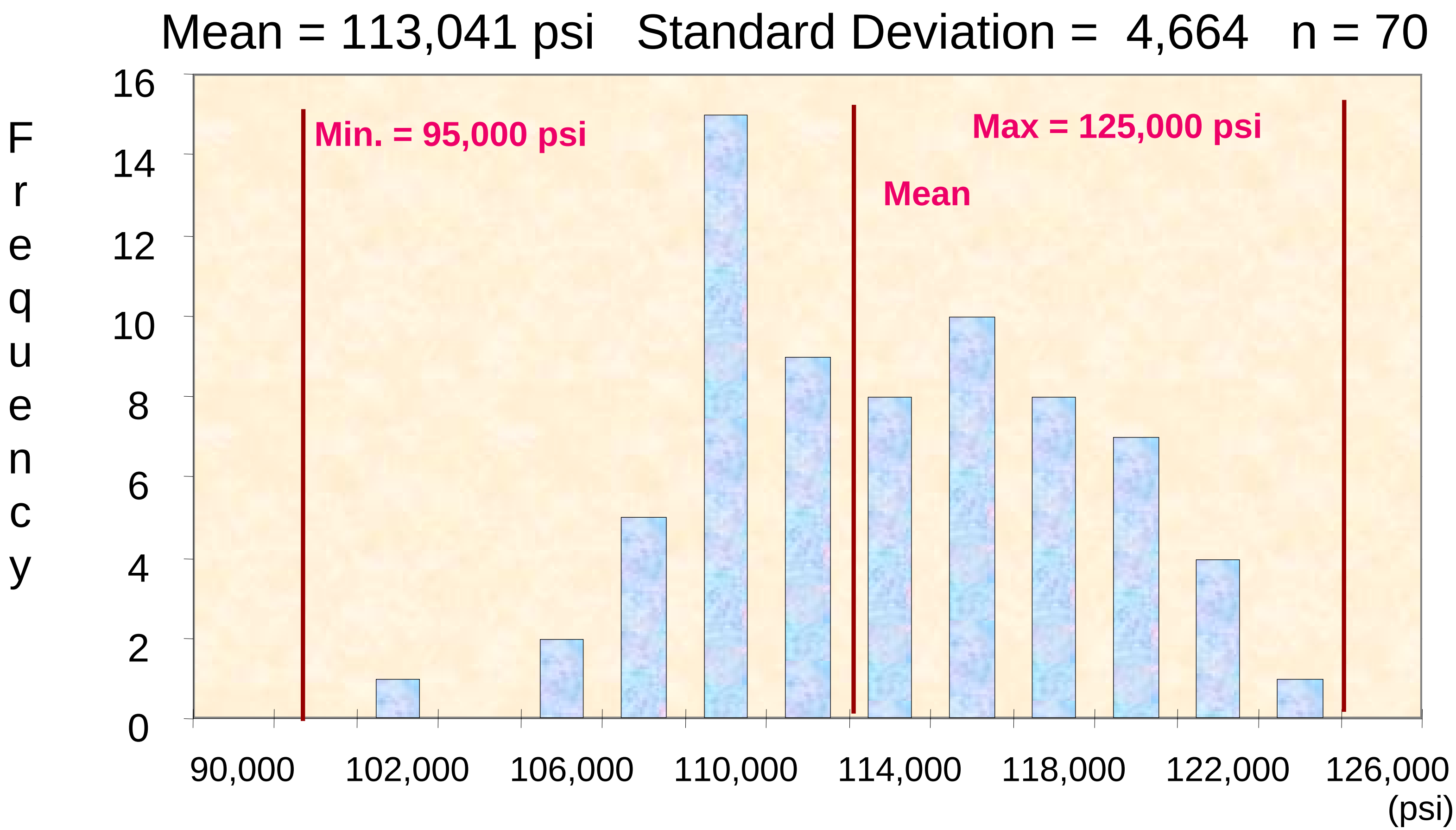
Example of Tensile Tests

Test conducted on a length of 16” N-80 84 lb/ft casing from different heats used in the Zaap 7D well.

Heat No.	Nominal wall (inch) (0.495)	Min. yield strength (psi) min. = 80,000	Tensile strength (psi) min.=110,000
96650	0.484	84,348	122,042
96995	0.523	87,478	125,029
97893	0.508	81,077	119,766
96503	0.547	86,197	121,615
96535	0.539	84,064	116,068
96570	0.583	86,197	125,029
96621	0.547	83,068	120,619
96881	0.524	85,628	118,628

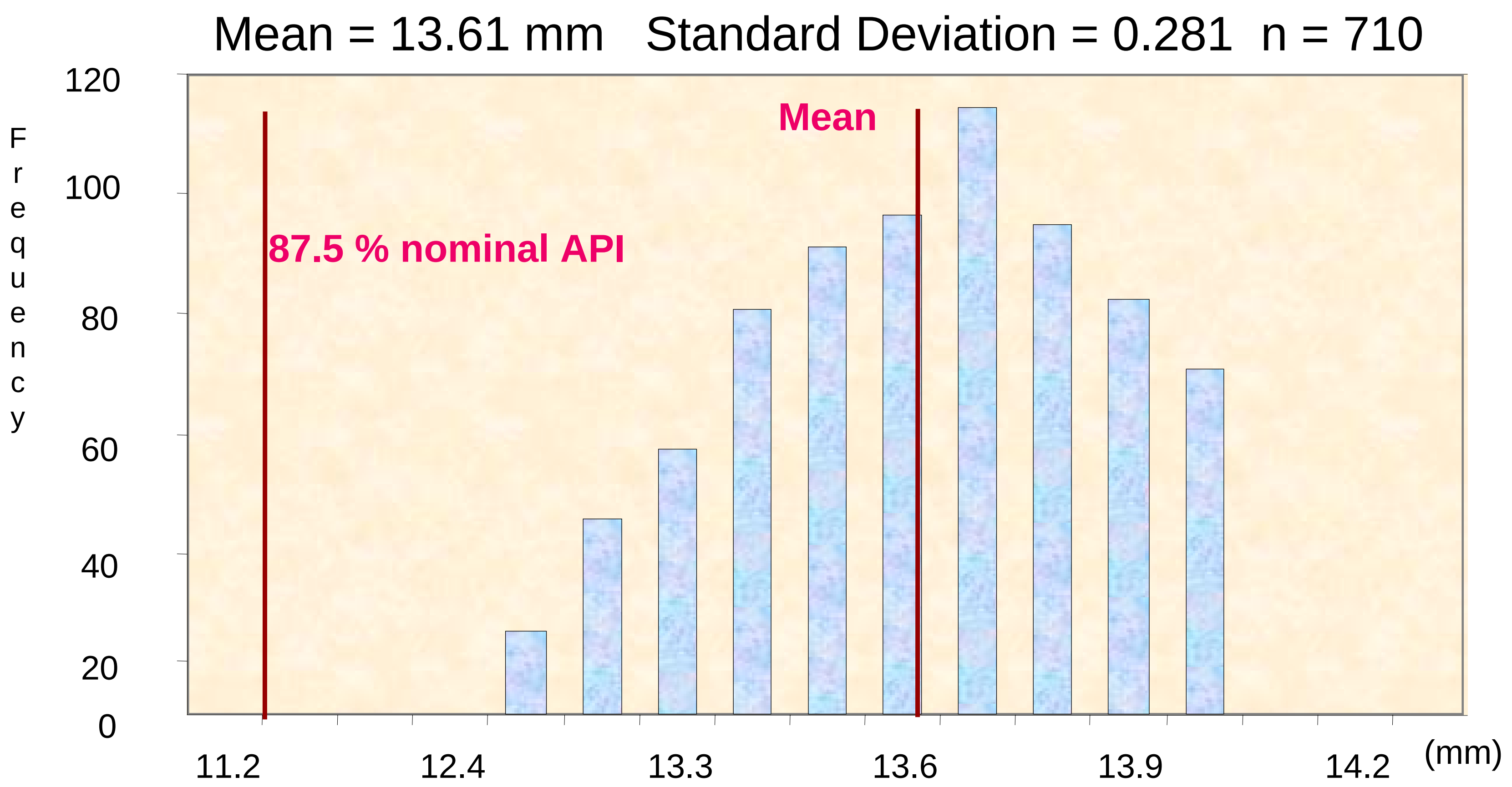
Yield Strength

Example: 13 3/8” TAC-95 72 lb/ft casing

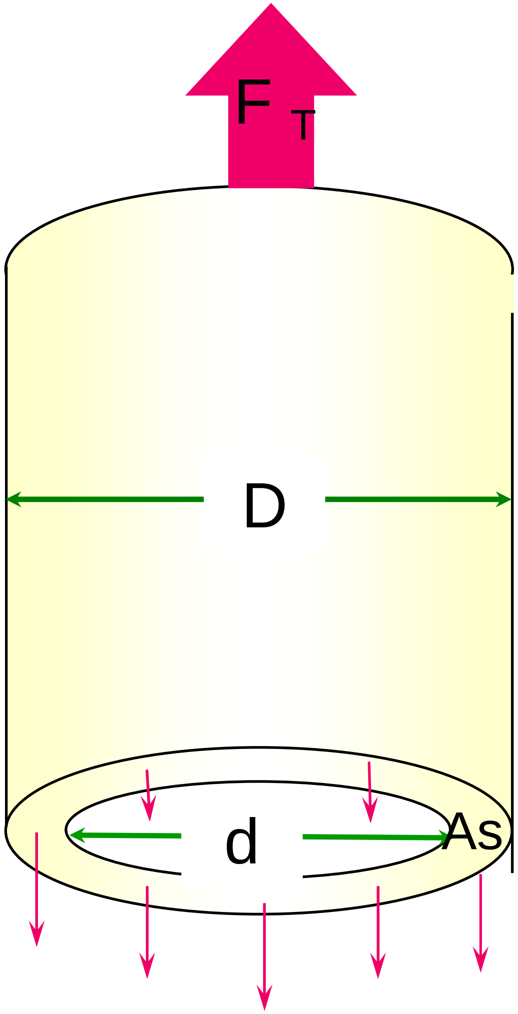


Pipe Body Wall Thickness

Example: 13 3/8” casing TAC-95 72 lb/ft



Tension



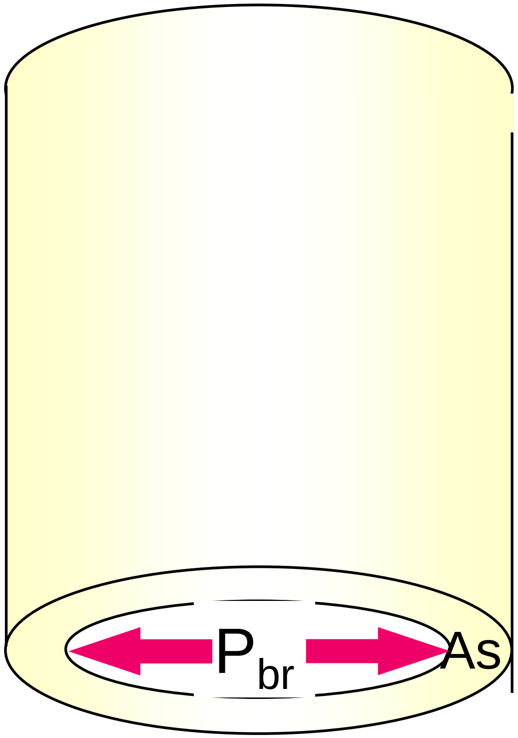
The tension force “Ft” pulls on part of the pipe and is resisted by the force of the wall thickness of the pipe itself, which produces a counterforce:

$$F_T = \sigma_y \; A_s$$

$$F_T = 0.7854 \; \sigma_y \; (D^2 - d^2)$$

$$F_T = \pi \; \sigma_y \; (Dt - t^2)$$

Internal Pressure



The burst pressure given by API is based on the Barlow's equation, where 87.5% is used as the minimum permissible wall thickness value.

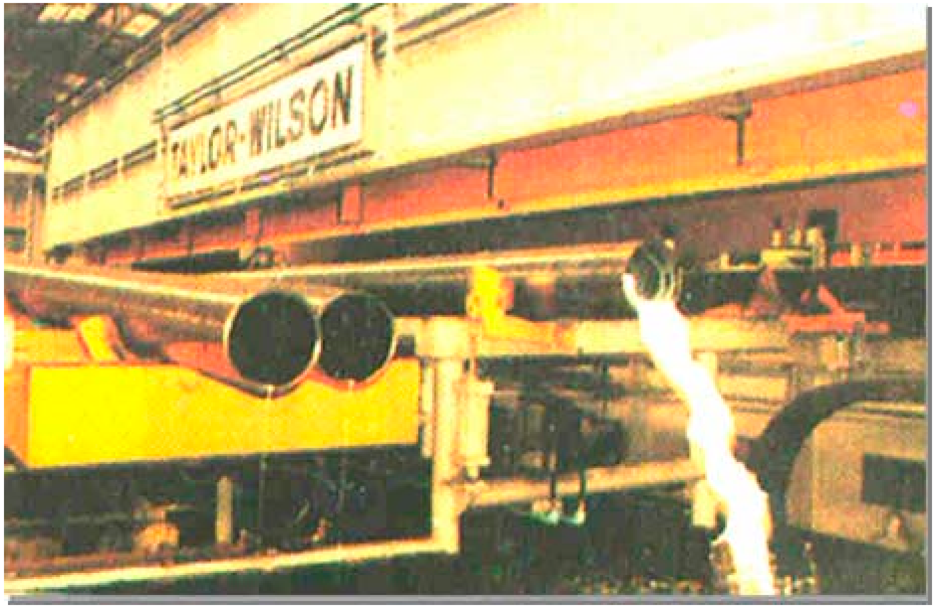
$$P_{br} = 0.875 \frac{2 \sigma_y t}{D}$$

The API allows for a maximum permissible tolerance of pipe body wall thickness of less than 12.5%

Internal Pressure

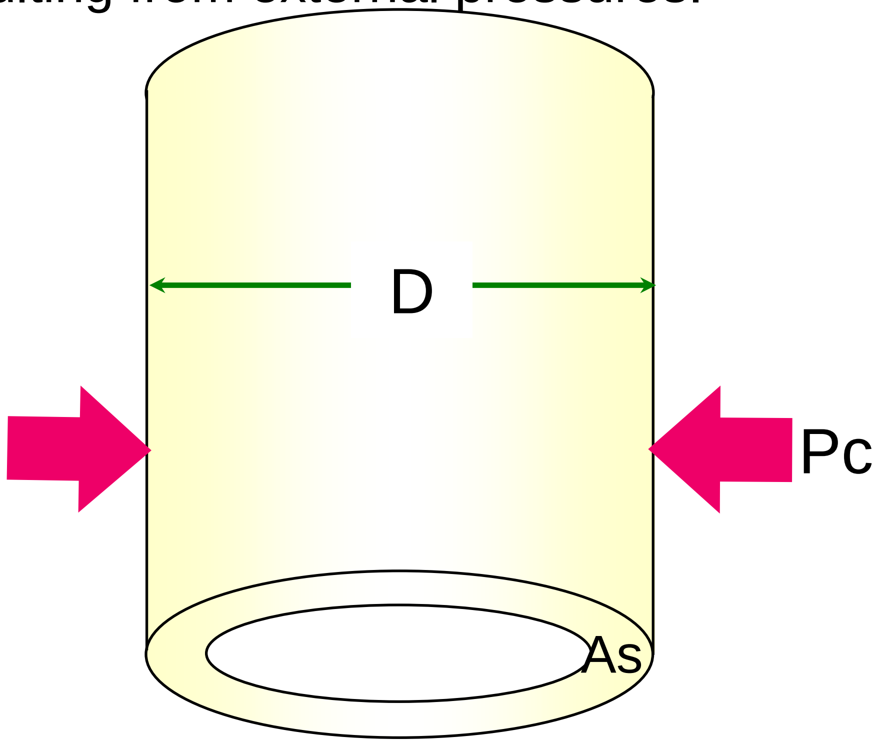
On-line hydraulic testing for all pipe

The hydraulic test is conducted on all pipes as per API standards. The test is 80% of the mechanical capacity of the internal pressure held for a five seconds.



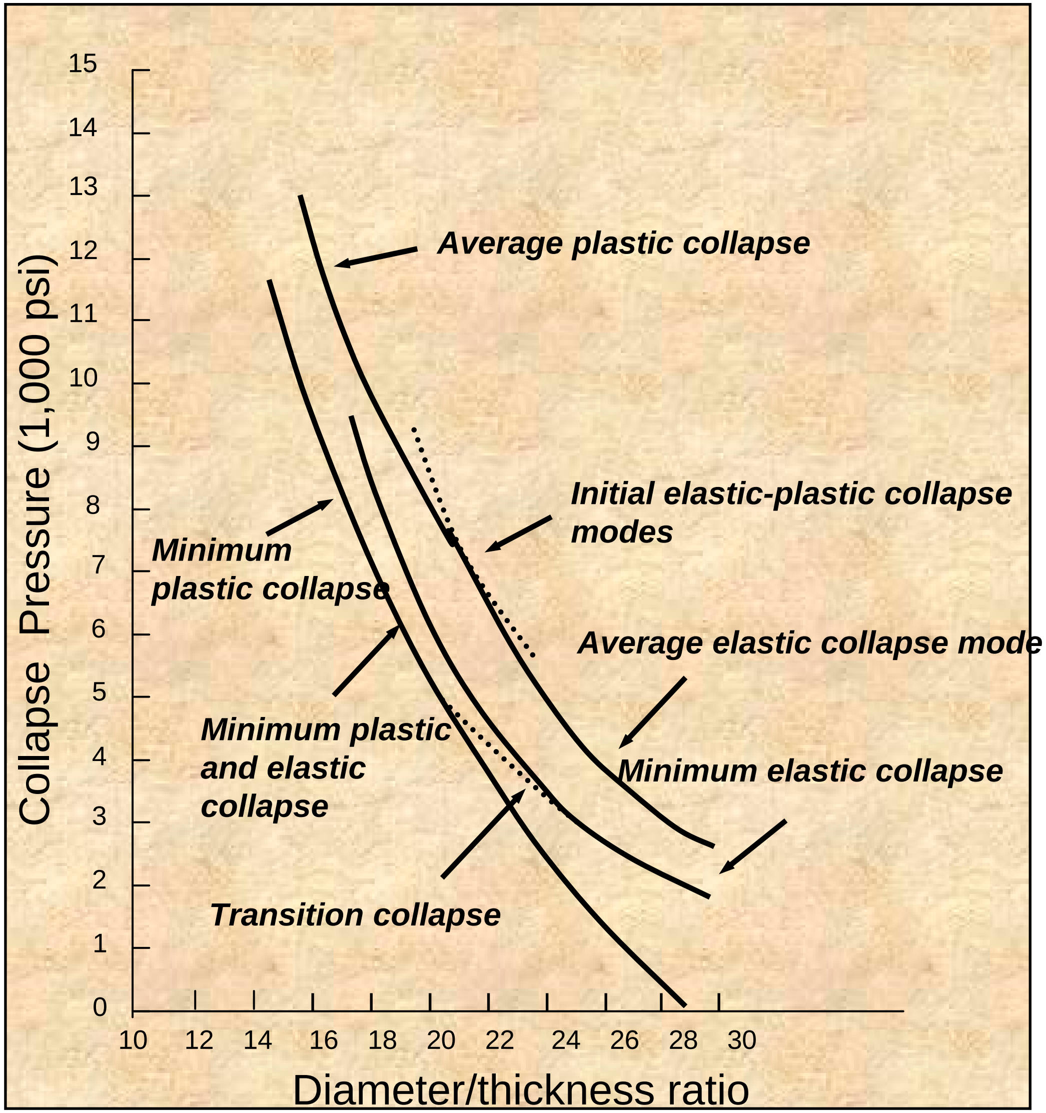
Collapse

Mechanical force capable of deforming a pipe due to the effect resulting from external pressures.



Collapse

The API 5C3 provides four formulas which predict the material's minimum collapse resistance value depending on the type of failure: elastic, transition, plastic and yield.



Collapse

The four equations

For elastic collapse

$$P_c = \frac{2E}{1-\nu^2}\left[\frac{1}{\left(\frac{D}{t}\right)\left[\left(\frac{D}{t}\right)-1\right]^2}\right]$$

For transition collapse

$$P_c = \sigma_y\left[\frac{F}{\left(\frac{D}{t}\right)} - G\right]$$

For plastic collapse

$$P_c = \sigma_y\left[\frac{A}{\left(\frac{D}{t}\right)} - B\right] - C$$

For yield collapse

$$P_c = 2\sigma_y\left[\frac{\left(\frac{D}{t}\right)-1}{\left(\frac{D}{t}\right)^2}\right]$$

Collapse

The variables (polynomial)

$$A = 2.8762 + 0.10679X10^{-5}\sigma_y + 0.21301X10^{-10}\sigma_y^{\,2} - 0.53132X10^{-16}\sigma_y^{\,3}$$

$$B = 0.026233 + 0.50609X10^{-6}\sigma_y$$

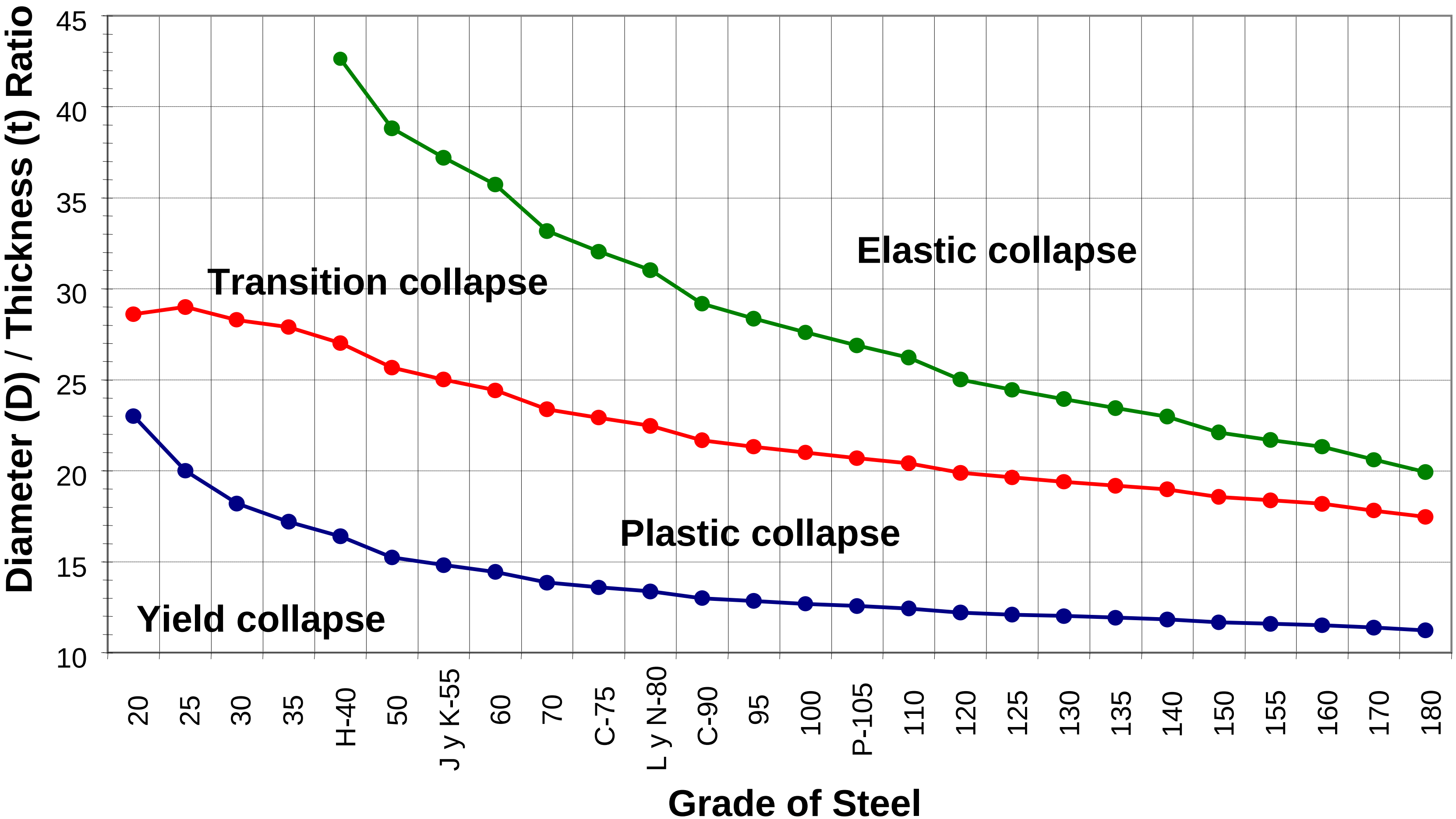
$$C = -465.30 + 0.030867\sigma_y - 0.10483X10^{-7}\sigma_y^{\,2} + 0.36989X10^{-13}\sigma_y^{\,3}$$

$$F = \frac{\left\{46.96X10^{6}\left[\dfrac{3\left(\dfrac{B}{A}\right)}{2+\left(\dfrac{B}{A}\right)}\right]^{3}\right\}}{\sigma_y\left[\dfrac{3\left(\dfrac{B}{A}\right)}{2+\left(\dfrac{B}{A}\right)}\right]\left[1-\dfrac{3\left(\dfrac{B}{A}\right)}{2+\left(\dfrac{B}{A}\right)}\right]^{2}}$$

$$G = \frac{FB}{A}$$

Collapse

Diameter / Thickness Ratio



Collapse

Elastic Collapse

Grade	range D/t
H-40	42.64 and larger
H-50	38.83 and larger
J-K-55 and D	37.21 and larger
-60	35.73 and larger
-70	33.17 and larger
C-75 and E	32.05 and larger
L-80 and N-80	31.02 and larger
-90	29.18 and larger
C-95	28.36 and larger
-100	27.60 and larger
P-105	26.89 and larger
P-110	26.22 and larger
-120	25.01 and larger
-125	24.46 and larger
-130	23.94 and larger
-135	23.44 and larger
-140	22.98 and larger
-150	22.11 and larger
-155	21.70 and larger
-160	21.32 and larger
-170	20.60 and larger
-180	19.93 and larger

Transition Collapse

Grade	range D/t
H-40	27.01 - 42.64
H-50	25.63 - 38.83
J-K-55 and D	25.01 - 37.21
-60	24.42 - 35.73
-70	23.38 - 33.17
C-75 and E	22.91 - 32.05
L-80 and N-80	22.47 - 31.02
-90	21.69 - 29.18
C-95	21.33 - 28.36
-100	21.00 - 27.60
P-105	20.70 - 26.89
P-110	20.41 - 26.22
-120	19.88 - 25.01
-125	19.63 - 24.46
-130	19.40 - 23.94
-135	19.18 - 23.44
-140	18.97 - 22.98
-150	18.57 - 22.11
-155	18.37 - 21.70
-160	18.19 - 21.32
-170	17.82 - 20.60
-180	17.47 - 19.93

Collapse

Plastic Collapse

Grade	range D/t
H-40	16.40 – 27.01
H-50	15.24 – 25.63
J-K-55 and D	14.81 – 25.01
-60	14.44 – 24.42
-70	13.85 – 23.38
C-75 and E	13.60 – 22.91
L-80 and N-80	13.38 – 22.47
-90	13.01 – 21.69
C-95	12.85 – 21.33
-100	12.70 – 21.00
P-105	12.57 – 20.70
P-110	12.44 – 20.41
-120	12.21 – 19.88
-125	12.11 – 19.63
-130	12.02 – 19.40
-135	11.94 – 19.18
-140	11.84 – 18.97
-150	11.67 – 18.57
-155	11.59 – 18.37
-160	11.52 – 18.19
-170	11.37 – 17.82
-180	11.23 – 17.47

Yield Collapse

Grade	range D/t
H-40	16.40 and lower
H-50	15.24 and lower
J-K-55 and D	14.81 and lower
-60	14.44 and lower
-70	13.85 and lower
C-75 and E	13.60 and lower
L-80 and N-80	13.38 and lower
-90	13.01 and lower
C-95	12.85 and lower
-100	12.70 and lower
P-105	12.57 and lower
P-110	12.44 and lower
-120	12.21 and lower
-125	12.11 and lower
-130	12.02 and lower
-135	11.94 and lower
-140	11.84 and lower
-150	11.67 and lower
-155	11.59 and lower
-160	11.52 and lower
-170	11.37 and lower
-180	11.23 and lower

High Collapse Pipe

Factors to be considered for high collapse pipe

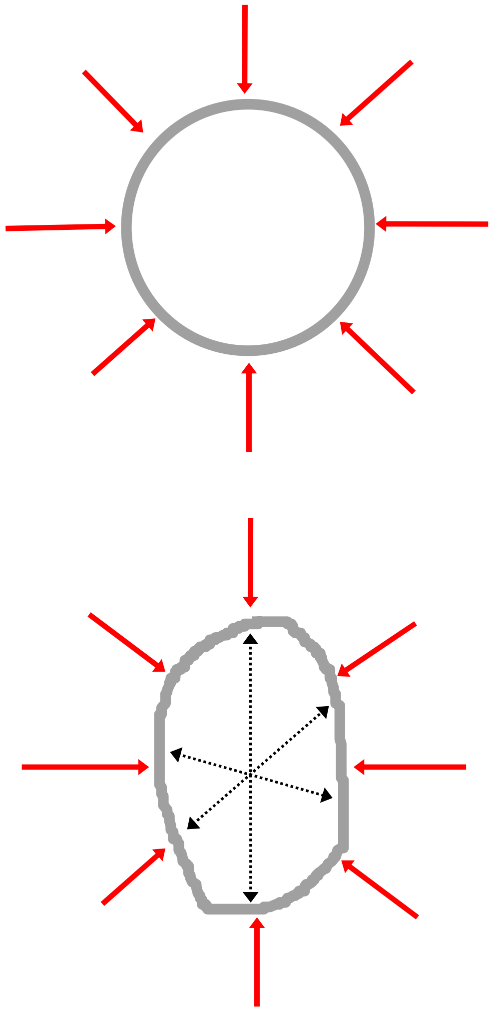
- Geometric Aspect
- Chemical and Mechanical Properties

The pipe's geometry must meet the same requirements as those for an API pipe, especially for pipe that has an OD greater than 13" with a high D/t ratio. The wall body thickness plays an important roll in this direct relationship between the pipe's mechanical capacity and its collapse resistance. That is why, when this type of pipe is being manufactured, it is rolled to have at least the nominal wall thickness up to the maximum allowed wall thickness.

High Collapse Pipe

Ovality

Ovality does not refer to an oval shape of a transverse section, rather what it means is the irregularity of the diameter in this section. The rounder a transverse section is, the more uniform will be the distribution of the applied external forces (arc effect), thereby providing a greater balance of forces which in turn makes for better mechanical resistance of the pipe.



High Collapse Pipe

Ovality

Ovality is the difference between the maximum outside diameter and the minimum outside diameter measured around the same transverse section expressed in percentage in terms of the average outside diameter (relative value).

$$0 = \frac{D_{maximum.} - D_{minimum.}}{D_{average.}} \quad X\ 100$$

$$0 = \frac{9.724 - 9.709}{9.717} \quad X\ 100 = 0.15\ \%$$

High Collapse Pipe

Ovality

High collapse pipe is rolled with minimum ovality, while taking continuous on-line outside diameter measurements by both section and length, in addition to roundness measurements (maximum and minimum) using an automatic laser X-ray emission at the sizing mill exit. The rate of physical measurements taken is also increased.

High Collapse Pipe

Pipe Eccentricity

Pipe eccentricity is the difference between maximum and minimum wall thickness measured around the same transverse section expressed in a percentage in terms of average wall thickness (relative value).

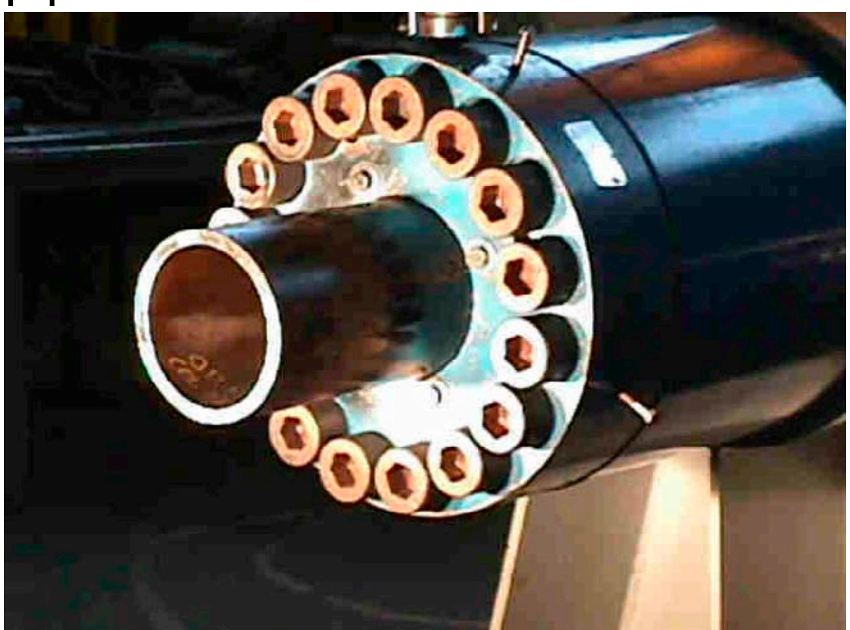
$$e = \frac{T_{\text{maximum.}} - t_{\text{minimum.}}}{T_{\text{average.}}} \text{ X } 100$$

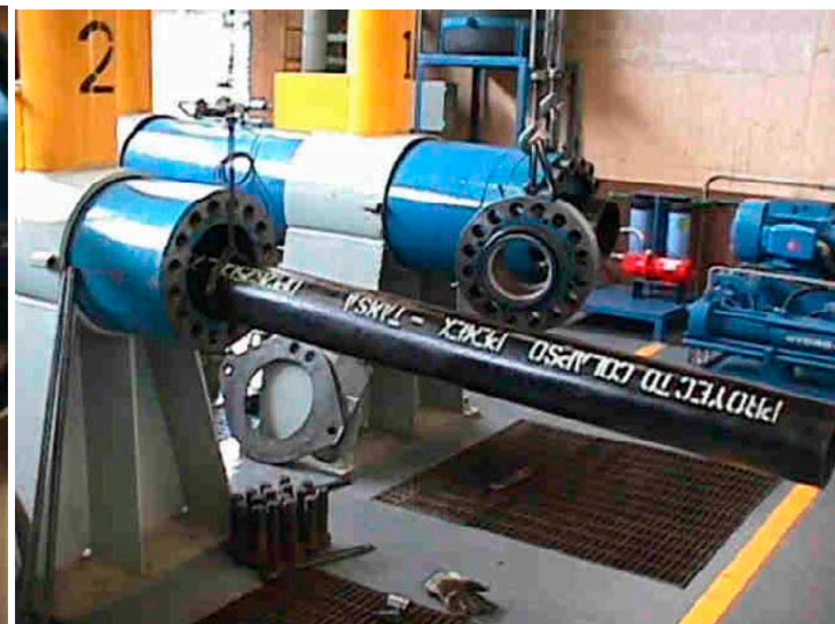
$$e = \frac{0.558 - 0.542}{0.546} \text{ X } 100 = 2.93\ \%$$

Collapse Tests

Mill Collapse Testing Equipment

Two or three collapse test are performed per heat. The testing range is from 13 3/8” to 5”. The sample must be of a length of eight times the pipe diameter.





Collapse Tests

V I D E O

Range of Casing

Length ranges permitted by API

Range three is the most commonly used for casing.

Range	Length (feet)	Length (m)
1	16 - 25	4.88 - 7.62
2	25 - 34	7.62 - 10.36
3	34 - 48	10.36 – 14.63

Range of Tubing

Length ranges permitted by API

Range two is the most commonly used for tuning.

Range	Length (feet)	Length (m)
1	20 - 24	6.10 - 7.32
2	28 - 32	8.53 – 9.75
3	38 - 42	11.58 – 12.80

Pipe Outside Diameter

Outside diameter tolerance permitted by API

Outside Diameter	Tolerance
Diameter equal to or greater than 4 ½" (casing)	Above 1% Below -0.5%
Diameter less than 4 ½" (tubing)	+ ó – 0.031 pg

Mandrel Drift

Diameter	Unit weight (lb/ft)	Mandrel length	Mandrel Diameter
13 3/8”	72.0	12”	12.250”
11 3/4”	42.0	12”	11.000”
11 3/4”	60.0	12”	10.625”
11 3/4”	65.0	12”	10.625”
11 7/8”	71.8	12”	10.625”
10 3/4”	45.5	12”	9.875”
10 3/4”	55.5	12”	9.625”
9 5/8”	40.0	12”	8.750”
9 5/8”	48.4	12”	8.375”
9 5/8”	53.5	12”	8.500”
9 7/8”	62.80	12”	8.500”
8 5/8”	32.0	6”	7.875”
8 5/8”	40.0	6”	7.625”
7 3/4”	46.1	6”	6.500”
7”	23.0	6”	6.250”
7”	32.0	6”	6.000”

Pipe Properties

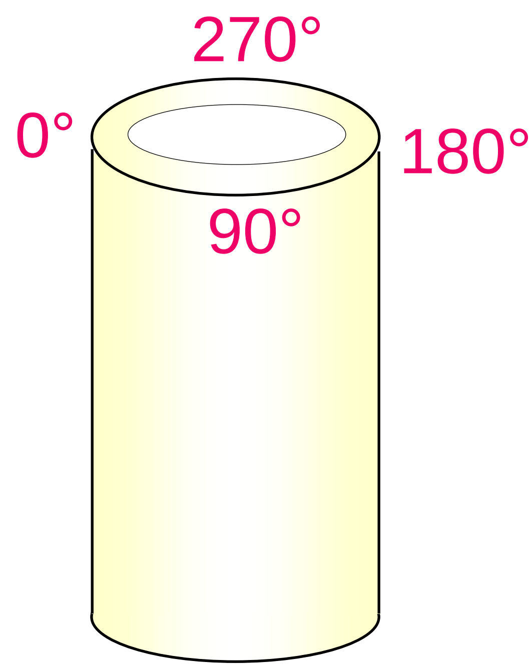
API 5CT standard

Group	Grade	Type	Yield strength (psi) Minimum	Yield strength (psi) Maximum	Strength (psi)	Hardness HRC	Wall Thickness (inch)	Hardness Var HRC
1	H-40		40,000	80,000	60,000	-		
	J-55		55,000	80,000	75,000	-		
	K-55		55,000	80,000	95,000	-		
	N-80		80,000	110,000	100,000	-		
2	M-65		65,000	85,000	85,000	22		
	L-80	1	80,000	95,000	95,000	23		
	L-80	9Cr	80,000	95,000	95,000	23		
	L-80	13Cr	80,000	95,000	95,000	23		
	C-90	1, 2	90,000	105,000	100,000	25.4	0.500 or less	3.0
	C-90	1, 2	90,000	105,000	100,000	25.4	0.501 – 0.749	4.0
	C-90	1, 2	90,000	105,000	100,000	25.4	0.750 – 0.999	5.0
	C-90	1, 2	90,000	105,000	100,000	25.4	1.000 or greater	6.0
	C-95		95,000	110,000	105,000	-		
	T-95	1, 2	95,000	110,000	105,000	25.4	0.500 or less	3.0
	T-95	1, 2	95,000	110,000	105,000	25.4	0.501 – 0.749	4.0
	T-95	1, 2	95,000	110,000	105,000	25.4	0.750 – 0.999	5.0
3	P-110		110,000	140,000	125,000	-		-
4	Q-125	1-4	125,000	150,000	135,000	-	0.5000 or less	3.0
	Q-125	1-4	125,000	150,000	135,000	-	0.501 – 0.749	4.0
	Q-125	1-4	125,000	150,000	135,000	-	0.750 or greater	5.0

Anisotropy

Concept

The anisotropy of a body means that not all parts of the body possess the same mechanical properties in every direction.



Anisotropy

Example: 11 ¾” casing TRC-95 from an offshore well

Heat No.	Position	Yield Strength (psi) min.=95,000	Tensile strength (psi) min.=105,000
98366	0°	101,480	116,865
	90°	100,740	115,782
	180°	98,395	115,376
	270°	101,408	116,291
98369	0°	96,505	110,277
	90°	95,421	112,364
	180°	97,424	112,235
	270°	95,269	106,609