Stress Corrosion Cracking of Carbon and Low alloy Steels

LECTURE 05

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SCC of Steels,

- *containing less than approximately 5% total alloying elements,*
- *having yield strengths of less than about 1241 MPa(180ksi)*
- microstructural types :
  - *Ferritic-Pearlitic*
  - tempered martensite (with yield strengths greater than about 620 MPa (90 ksi)

Typical Compositions and Mechanical Properties of Common Carbon and Low-Alloy Steels

UNS	ASTM	Composition, wt %	Yield strength MPa	Yield strength ksi	Tensile strength MPa	Tensile strength ksi	Elongation, %
K01700	A285A	0.17 C, 0.9 Mn	165	24	310–380	45–55	30
K03005	A53B	0.3 C, 1.2 Mn	241	35	415	60	...
K03006	A106B	0.3 C, 0.3–1.1 Mn, 0.1 Si (min)	241	35	415	60	...
G41300	4130 (AISI)	0.3C, 1 Mn, 0.25 Si, 1 Cr, 0.2 Mo	615–1358	89–197	676–1613	98–234	12–28
G43400	4340 (AISI)	0.4 C, 0.7 MN, 0.25 Si, 0.8 Cr, 1.8 Ni, 0.25 Mo	896–1572	130–228	979–1958	142–284	11–21
K21590	A387 (22)	0.15 C, 0.45 Mn, 0.5 Si, 2.25 Cr, 1 Mo	205–310	30–45	415–690	60–100	18

For carbon and low-alloy steels

At least two mechanisms are thought to be operative:

- *anodic (active-path) SCC and*
- *cathodic (hydrogen-embrittlement) SCC*

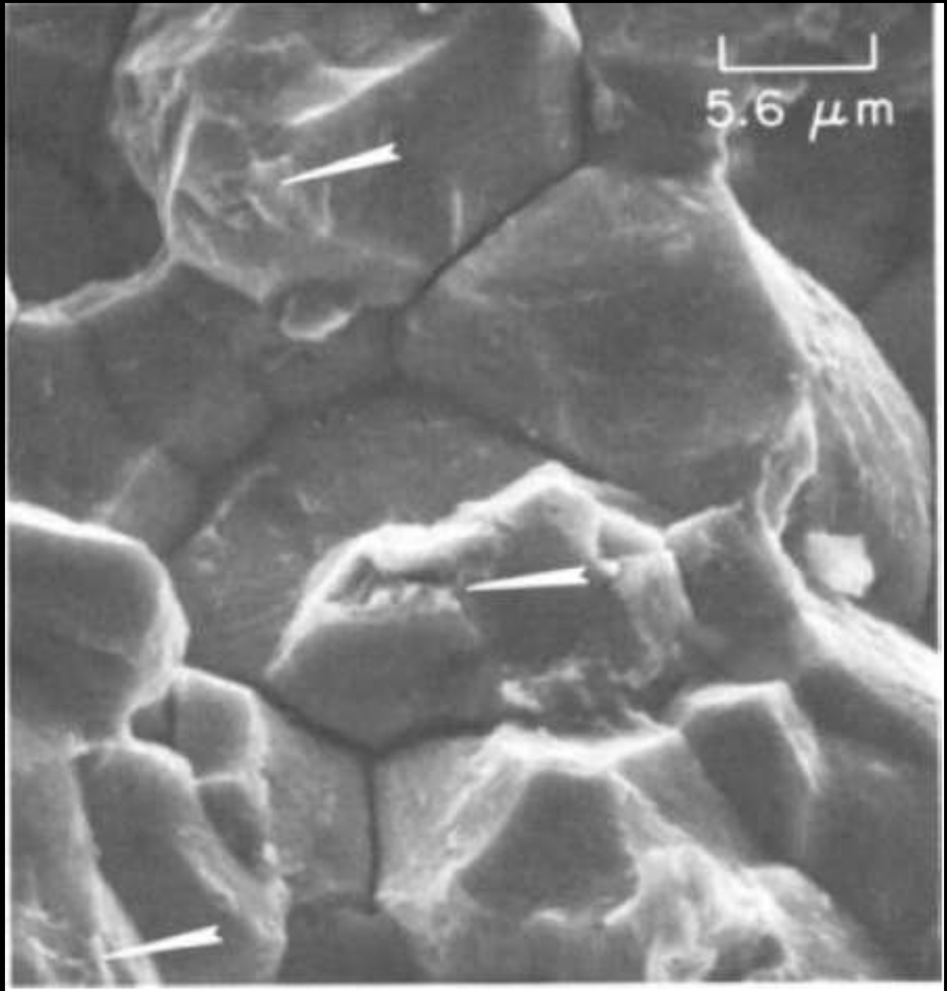
When more negative potentials, lower pH values, and lower temperatures promote SCC, a hydrogen-embrittlement mechanism is generally thought to be active

Fracture Modes

- *Intergranular cracking:*

along prior-austenite grain boundaries for quenched and tempered steels) , in neutral or acidic environments (for example, aqueous chloride solutions)

In hydroxide-containing environments, aqueous nitrates, ammoniacal solutions, carbonates, and alkanolamine solutions

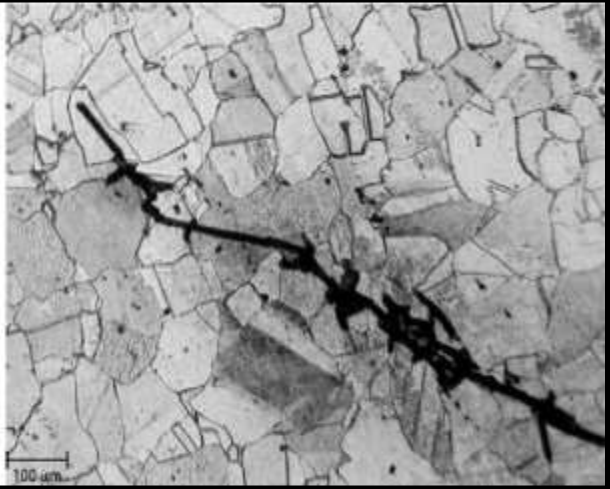


SEM fractograph 1800×

Fracture Modes

- *Transgranular fracture,*

sometimes described as "cleavage-like" because of its brittle appearance, is often observed for SCC in environments that contain hydrogen sulfide, but intergranular cracking is also common


100 µm

Environmental Aspects

Aqueous Chlorides:

SCC in aqueous chlorides is observed less frequently in steels with lower strength levels.

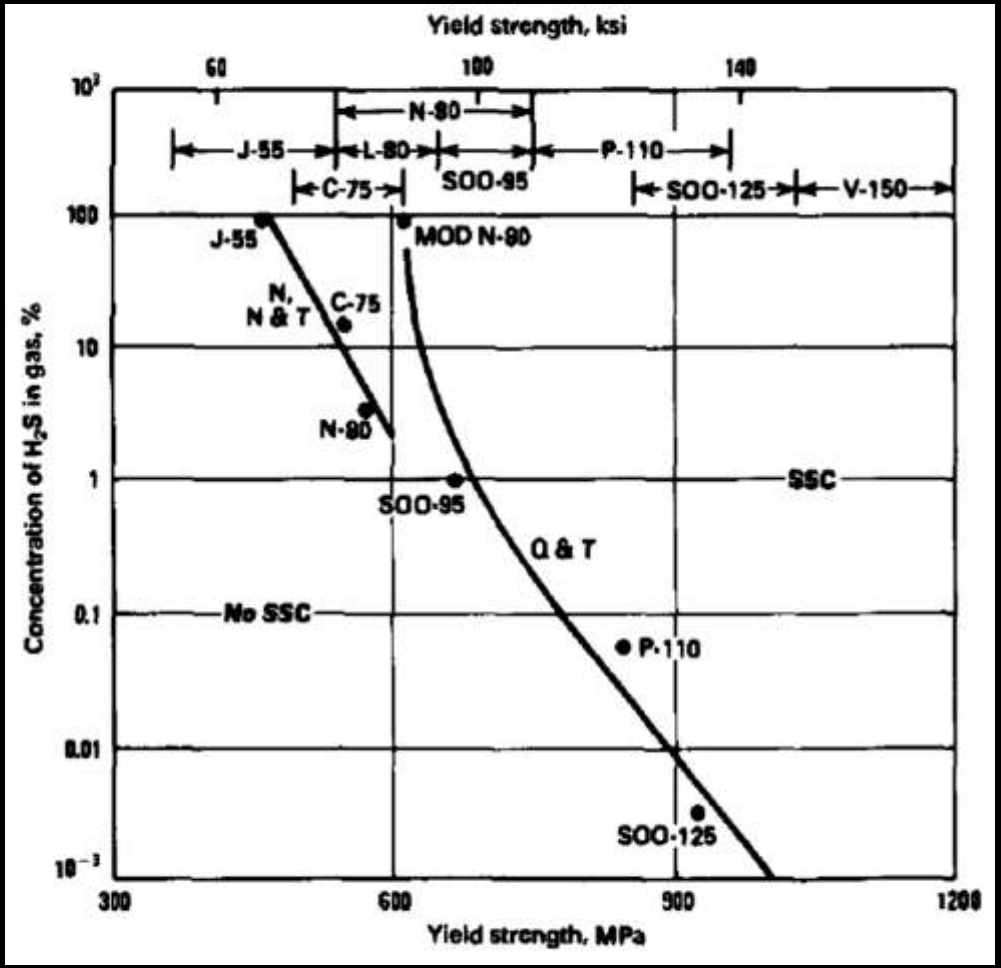
Stress-corrosion cracking of steels is most often associated with an aqueous phase.

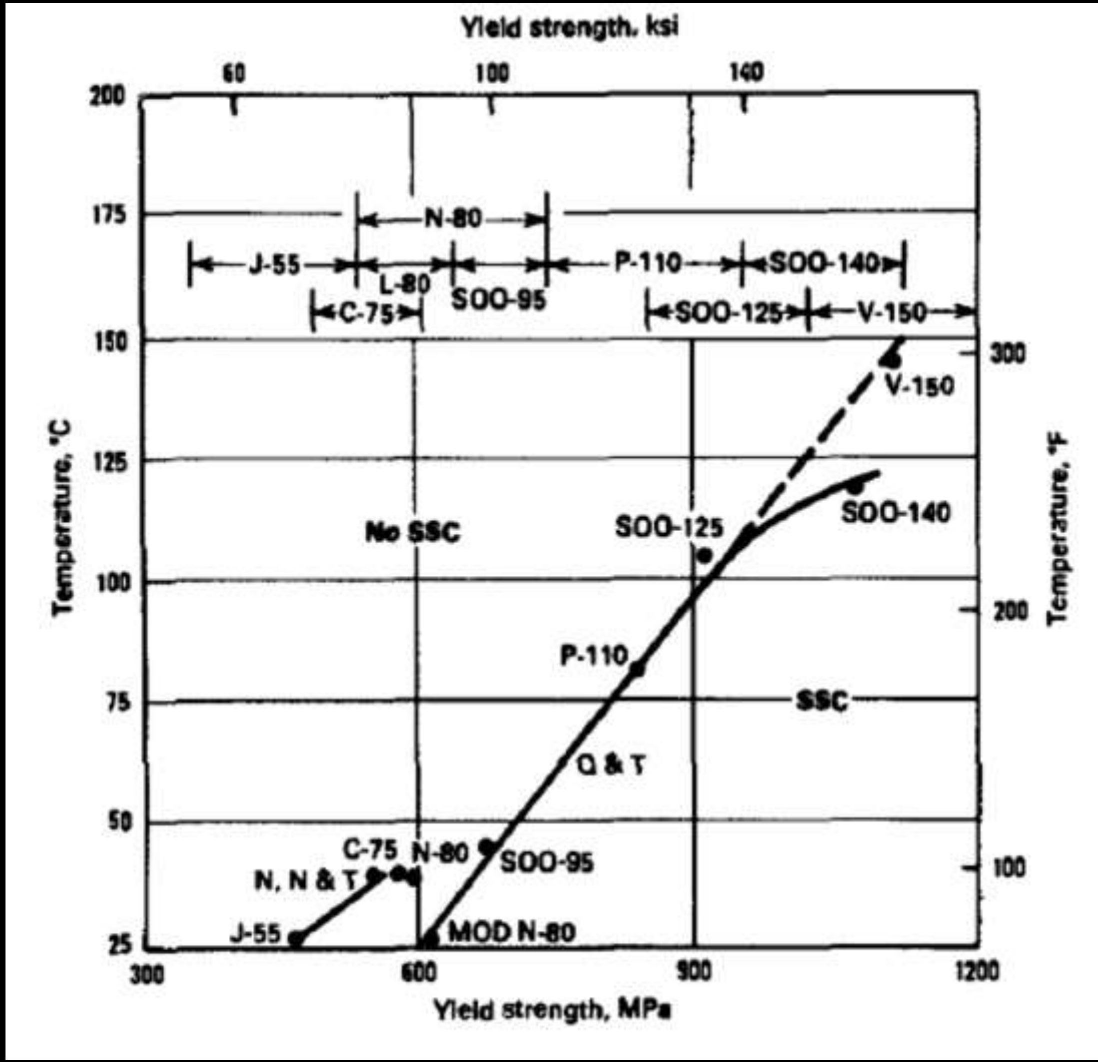
SCC has been reported in water vapor, but crack-growth rates increase dramatically with relative humidity.

At about 60% relative humidity, crack growth rates are comparable to those observed in water, suggesting the presence of a condensed phase at the crack tip.

Hydrogen Sulfide

SCC problems in hydrogen sulfide are more prevalent for steels with higher strength levels and are often associated with hard zones caused by cold working or welding.




Yield strength, ksi
60
100
140
200
175
150
125
100
75
50
25
N-80
J-55
L-80
P-110
SOO-140
C-75
SOO-95
SOO-125
V-150
300
200
100
Temperature, °C
Temperature, °F
V-150
SOO-140
SOO-125
No SSC
P-110
SSC
Q & T
C-75
N-80
SOO-95
N, N & T
J-55
MOD N-80
300
600
900
1200
Yield strength, MPa

Metallurgical Aspects / Resistance to SCC

Element	AISI 4120 (Yield strength = 1034 MPa, or 150 ksi)	AISI 4340 (Yield strength = 1172–1448 MPa, or 170–210 ksi)
Carbon	Decrease	Decrease
Manganese	No effect	Decrease
Nickel	Increase	No effect
Chromium	Increase	No effect
Molybdenum	Increase	No effect
Vanadium	Increase	...
Niobium	Increase	...
Titanium	Increase	...
Zirconium	Increase	...
Boron	No effect	...
Copper	No effect	...
Silicon	No effect	...
Sulfur	Beneficial	No effect
Phosphorus	Decrease	No effect
Oxygen	Decrease	...
Nitrogen	Decrease	No effect

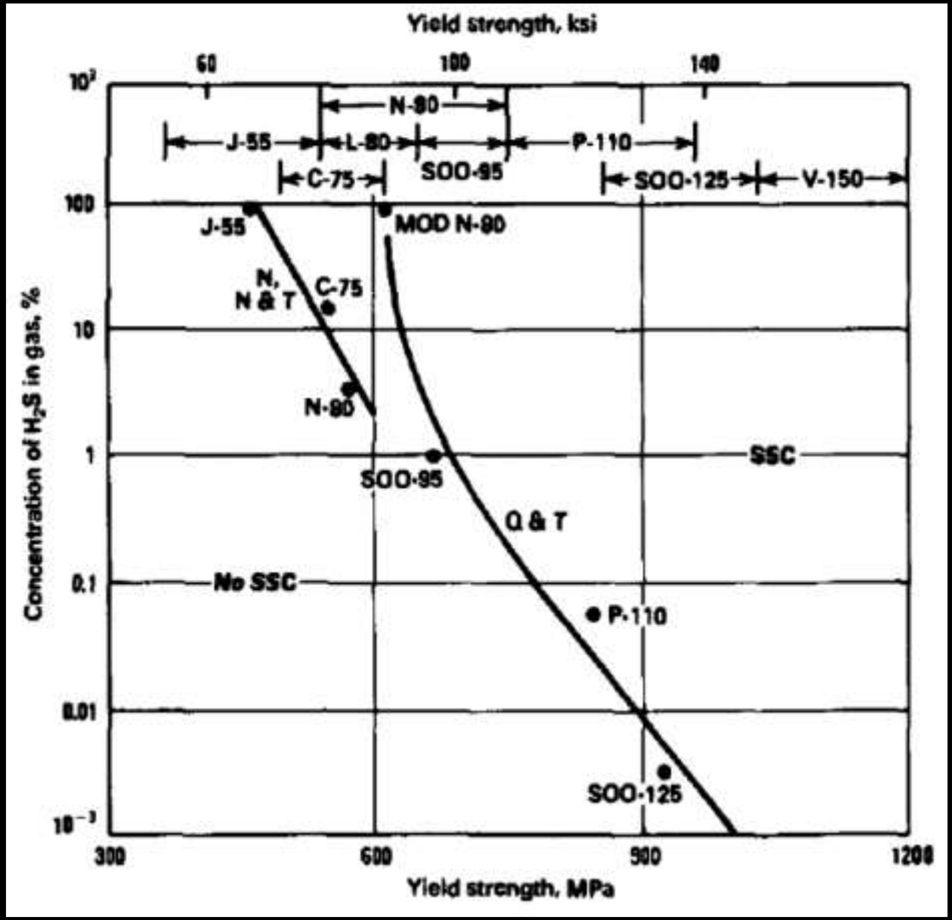
Effects of Microstructure and Heat Treatment

- *Fine grain size has been shown to increase the SCC resistance of quenched and tempered steels in hydrogen sulfide solutions.*
- *For quenched and tempered steels, the presence of twinned martensite is thought to reduce SCC resistance as it does fracture toughness and hydrogen-embrittlement resistance*
- *Manganese segregation in tempered steels can produce localized regions of increased hardness. This results in a preferential path for SCC in aqueous hydrogen sulfide and a corresponding drop in SCC resistance.*
- *Inclusions in steels act as SCC initiation sites and accelerate crack propagation in the major axis direction of elongated inclusions such as sulfides*

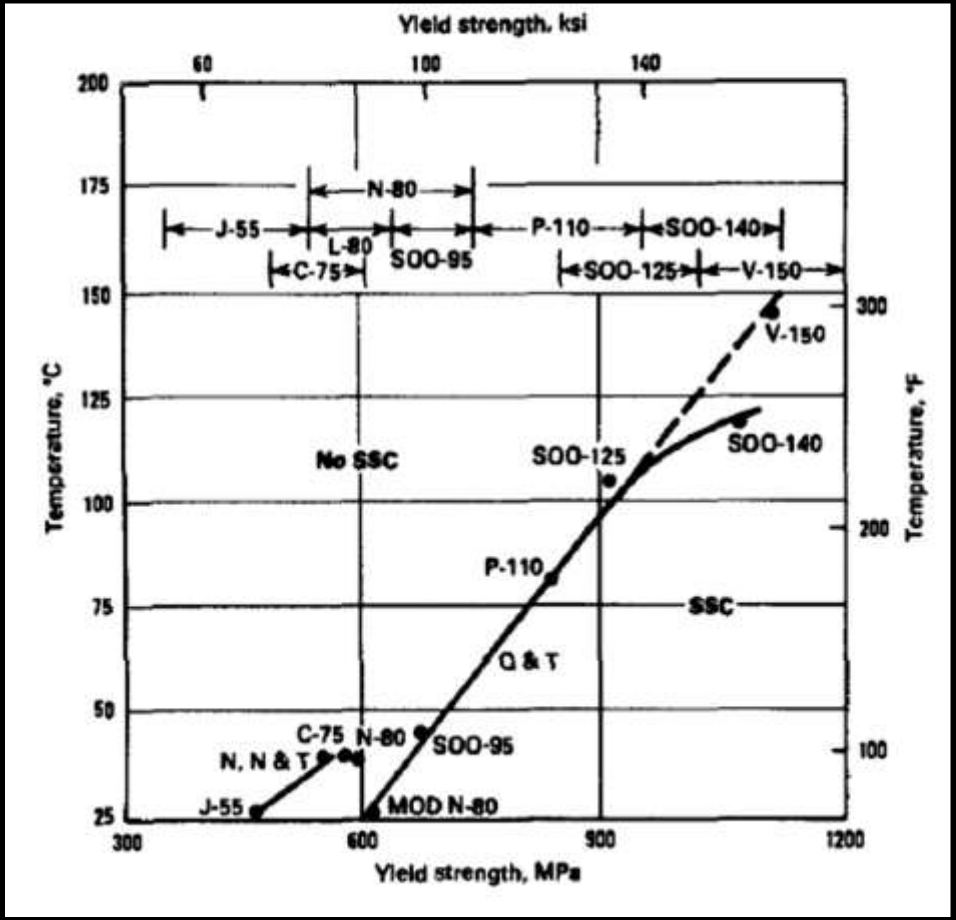
Effects of Mechanical Properties

- *Strength level is perhaps the greatest influence on the SCC resistance of steels under a variety of conditions, with resistance decreasing as strength is increased*

Yield strength		Threshold stress intensity			
		Water/3.5% NaCl		Seawater	
MPa	ksi	MPa√m	ksi√in.	MPa√m	ksi√in.
862	125	55	60	64	70
1034	150	48	53	54	59
1207	175	25	28	35	39
1379	200	9	10	12	13



Yield strength, ksi
60
100
140
N-80
J-55
L-80
P-110
C-75
SOO-95
SOO-125
V-150
J-55
MOD N-80
N, N & T
C-75
N-80
SOO-95
SSC
Q & T
No SSC
P-110
SOO-125
Concentration of H_2S in gas, %
300
600
900
1200
Yield strength, MPa



Yield strength, ksi
60
100
140
N-80
J-55
L-80
P-110
SOO-140
C-75
SOO-95
SOO-125
V-150
V-150
SOO-140
No SSC
SOO-125
P-110
SSC
Q & T
C-75
N-80
N, N & T
SOO-95
J-55
MOD N-80
Temperature, °C
Temperature, °F
300
600
900
1200
Yield strength, MPa

Effects of Mechanical Properties

- *Although a clearly defined yield-strength threshold for SCC in aqueous chlorides is not apparent, it can be generalized that steels with yield strengths of less than 689 MPa (100 ksi) are resistant.*
- *Stress-corrosion cracking in aqueous hydrogen sulfide has been reported at yield-strength levels down to 296 to 414 MPa (43 to 60 ksi)*

Yield strength		Threshold stress intensity			
		Water/3.5% NaCl		Seawater	
MPa	ksi	MPa$\sqrt{m}$	ksi$\sqrt{in.}$	MPa$\sqrt{m}$	ksi$\sqrt{in.}$
862	125	55	60	64	70
1034	150	48	53	54	59
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Effects of Cold Work

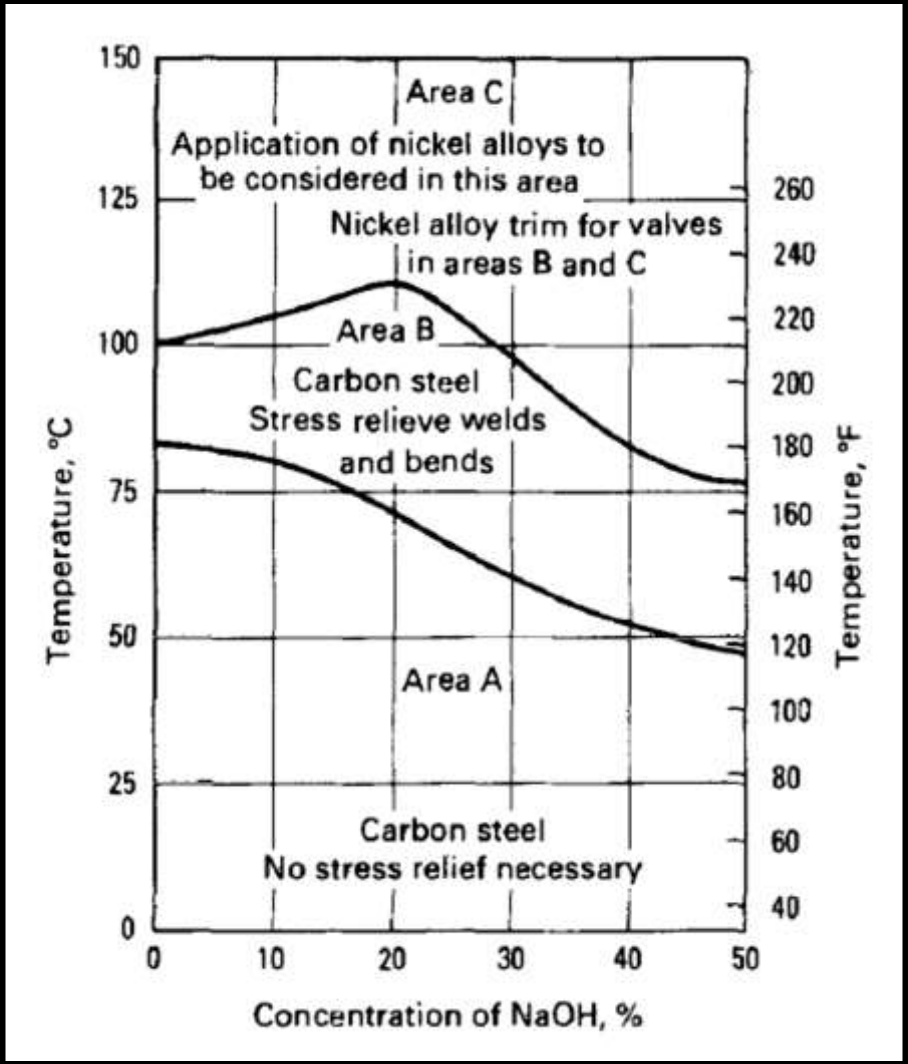
Prestress, (% elongation)	Applied stress (% yield strength) 130	80
0	No SCC	No SCC
1	No SCC	No SCC
2	No SCC	No SCC
3	SCC	No SCC
5	SCC	No SCC

- *In hydrogen sulfide environments, cold working as little as 1% has a strong detrimental effect on SCC resistance*
- *due to increases both in available sites for SCC initiation and in hydrogen solubility*

Prevention and Control

- *limiting the yield strength of steels used in aqueous chlorides to 689 MPa (100 ksi).*
- *Note that because of their simplicity and nondestructive nature, strength limitations are often accomplished in practice through hardness measurements and control*
- *the most comprehensive SCC prevention and control guidelines have been developed for hydrogen sulfide service (NACE MR 01-75)*
- ***For most steels, hardness is restricted to a maximum of 22 HRC.***
- *Additionally, MR-01-75 sets limits with respect to nickel content (1 % maximum) and degree of cold work and specifies required stress relief heat treatments*

- *NACE Standard MR-01-75 gives postweld heat-treatment guidelines for welded steels to be used in hydrogen sulfide service.*
- *For pressure vessel welds, a maximum hardness of 200 HB has been generally accepted.*
- *For refinery pressure vessels, it has now become accepted practice to stress relieve all welds in hydrogen sulfide service, not only to prevent SCC by lowering hardness but also to minimize chances of SOHIC*



- *What is SOHIC?*
- *Search about it.*