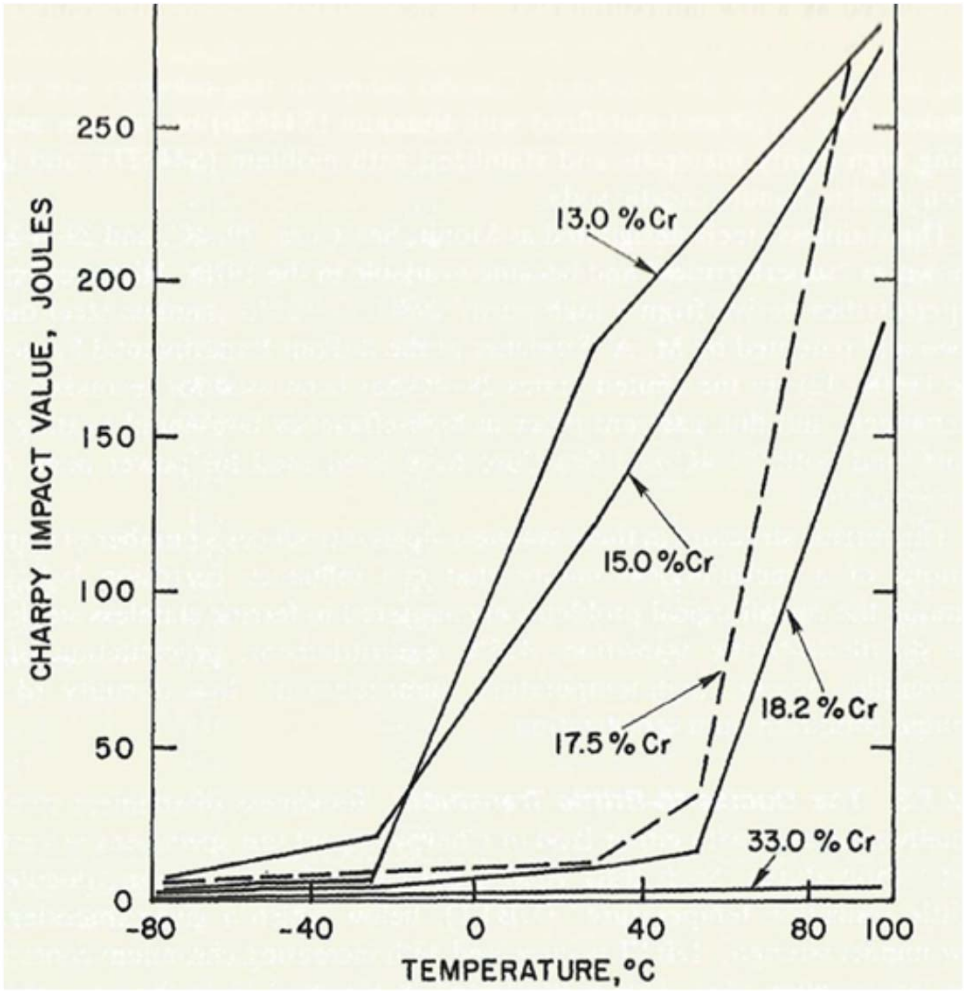
Ferritic Stainless Steels

- **Advantages**
  - Relatively Cheap
  - Low Corrosion rate – pitting & SCC
  - Low tendency of sensitization
- **Limitations**
  - High ductile to brittle transition temperature.
  - 475^{o}C Embrittlement
  - Formation of undesirable intermetallics such as Sigma, Chi and Laves phases.
  - Low Weld Ductility with increase in Cr Content
  - Sensitization
  - Limitation of Strength at higher temperature

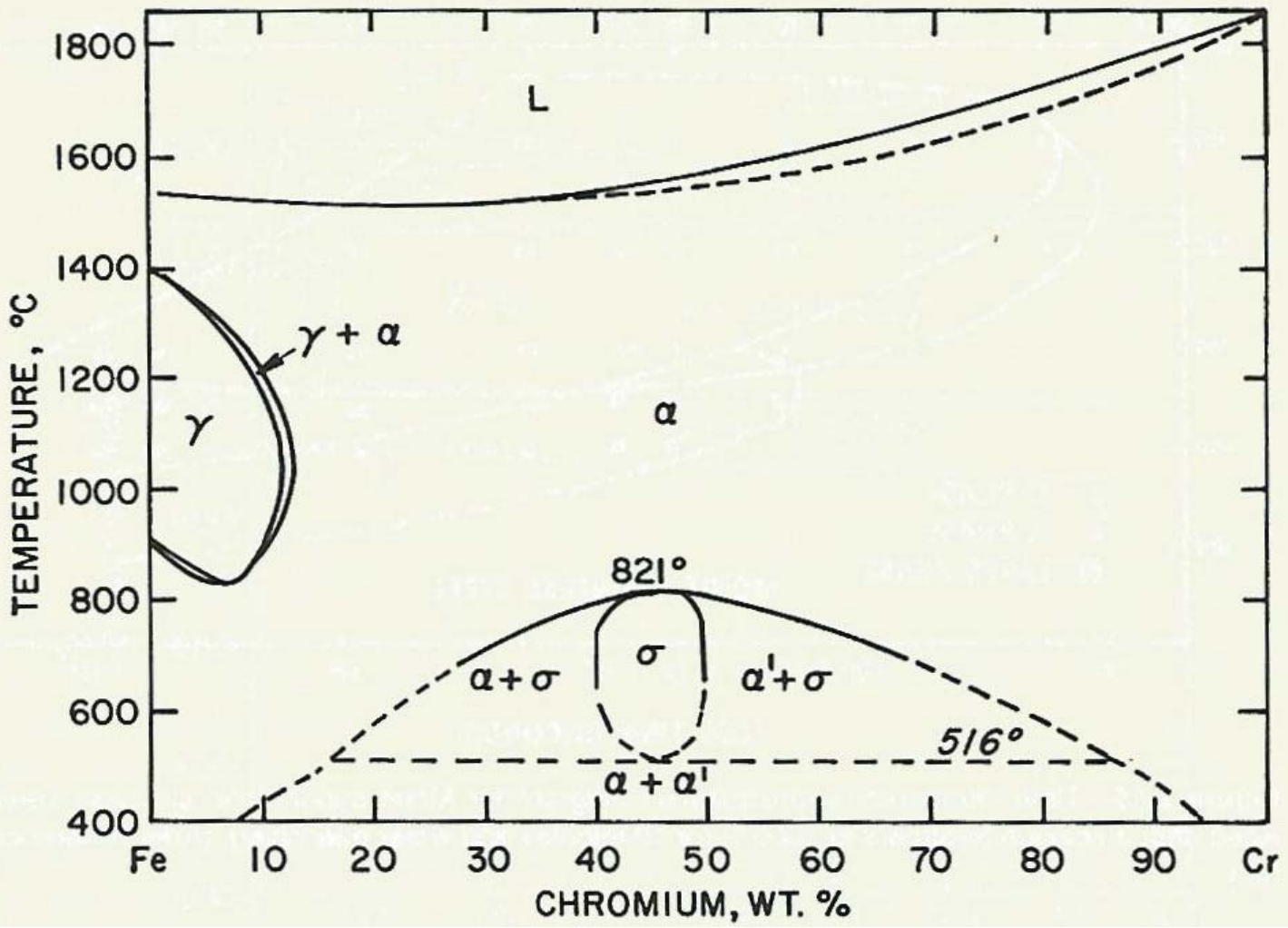
Composition of Important Ferritic Stainless steels

Grade	C	Mn	Si	Cr	Mo	P	S	Comments/Applications
405	0.08	1.0	1.0	11.5-14.5	-	0.04	0.03	0.1-0.3 Al
409	0.08	1.0	1.0	10.5-11.75	-	0.045	0.045	(6xC) Ti min
429	0.12	1.0	1.0	14.0-16.0	-	0.04	0.03	
430	0.12	1.0	1.0	16.0-18.0	-	0.04	0.03	
446	0.20	1.5	1.0	23.0-27.0	-	0.04	0.03	0.25 N

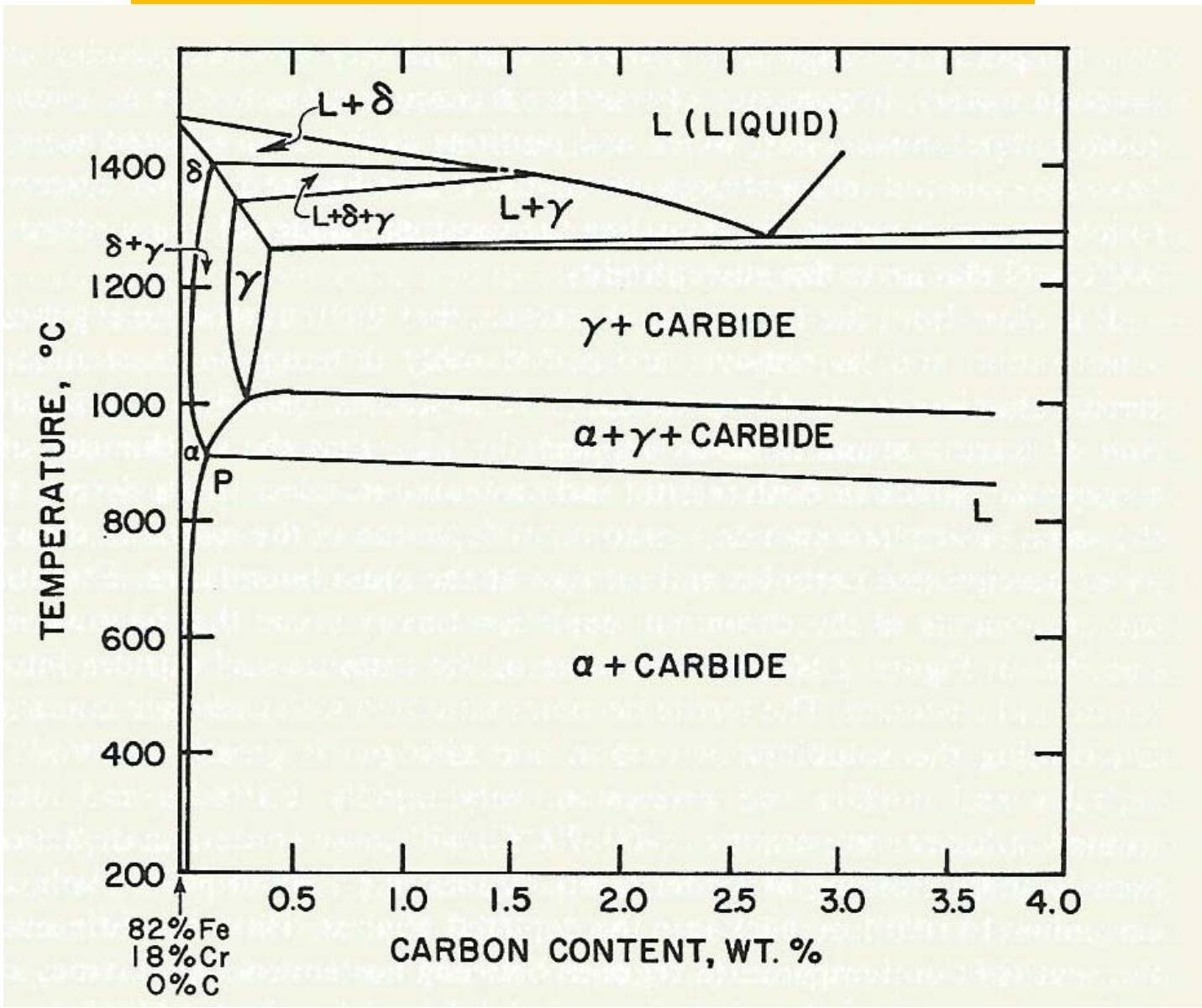
Effect of Cr Concentration on the impact properties of Fe-Cr Alloys



Fe-Cr equilibrium Diagram



Pseudo Binary Phase Diagram of Fe-18Cr Alloy



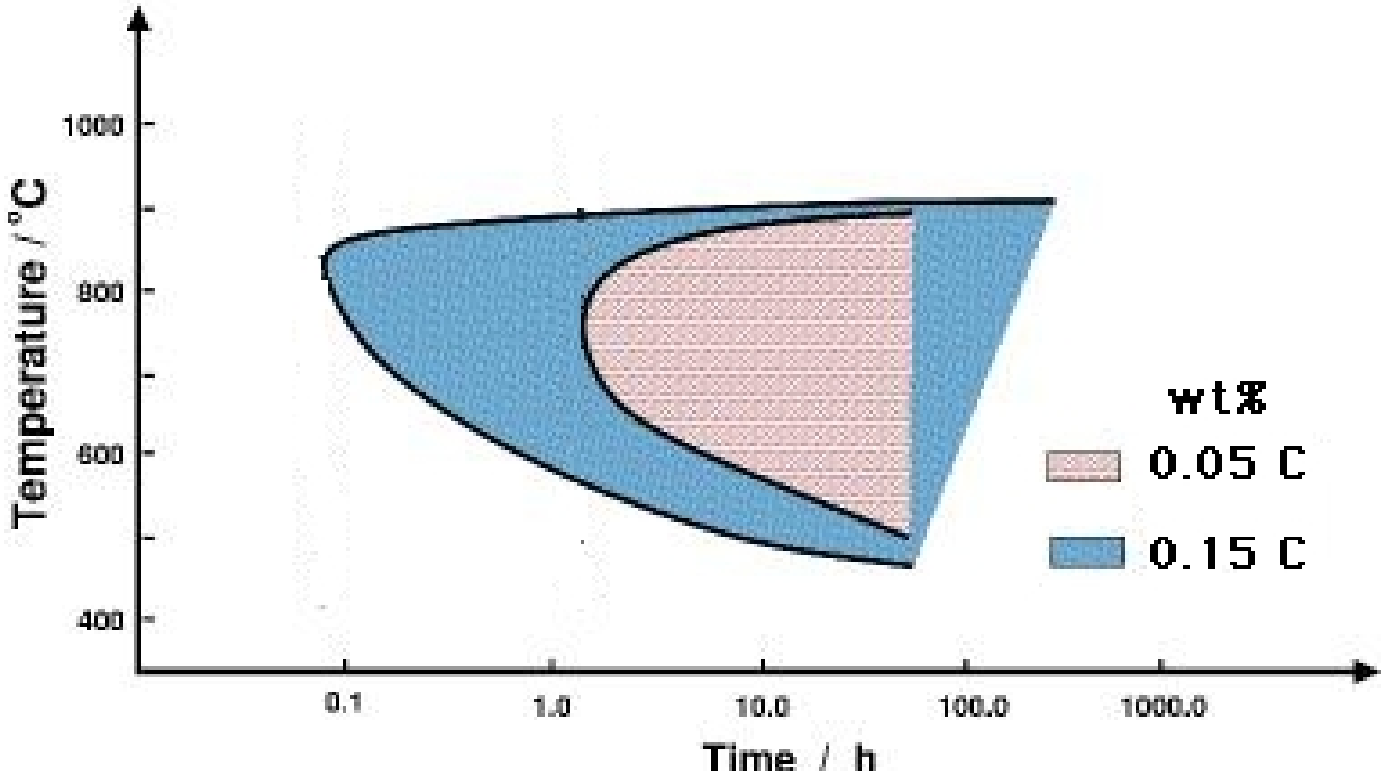
Austenitic Stainless Steel

- **Advantages**
  - Highly corrosion resistant
  - Useful for High Temperature Application
  - Various kinds of Verities
- **Limitations**
  - Sensitization – a major problem unless a right variety of SS is used.
  - Delta Ferrite formation during Welding – again a serious problem unless controlled way of weld pass is decided.
  - Deleterious phase formation when high Concentration of Mo, Cr are present.
  - High Temperature Strength Limit of 750^{o}C
  - Corrosion/oxidation limit of 900^{o}C

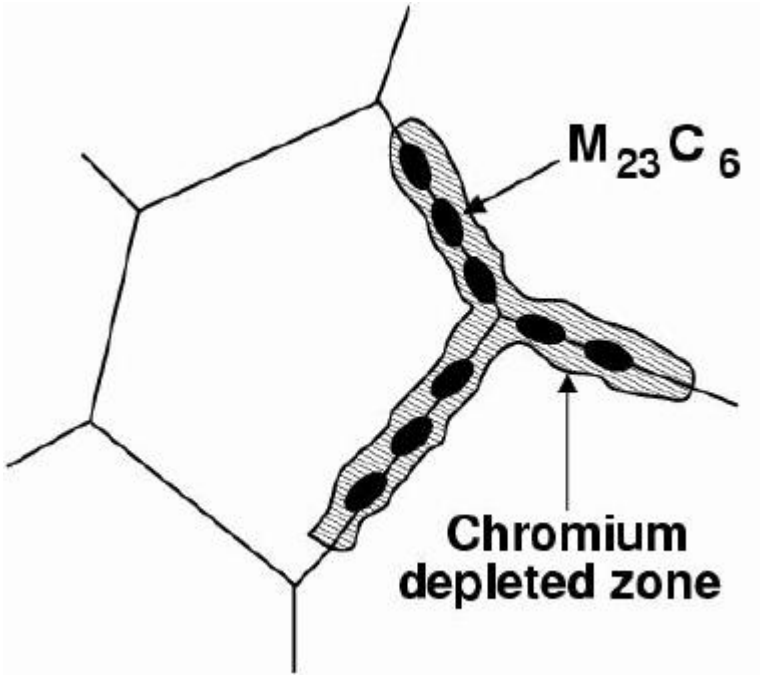
Composition of Austenitic Stainless Steels

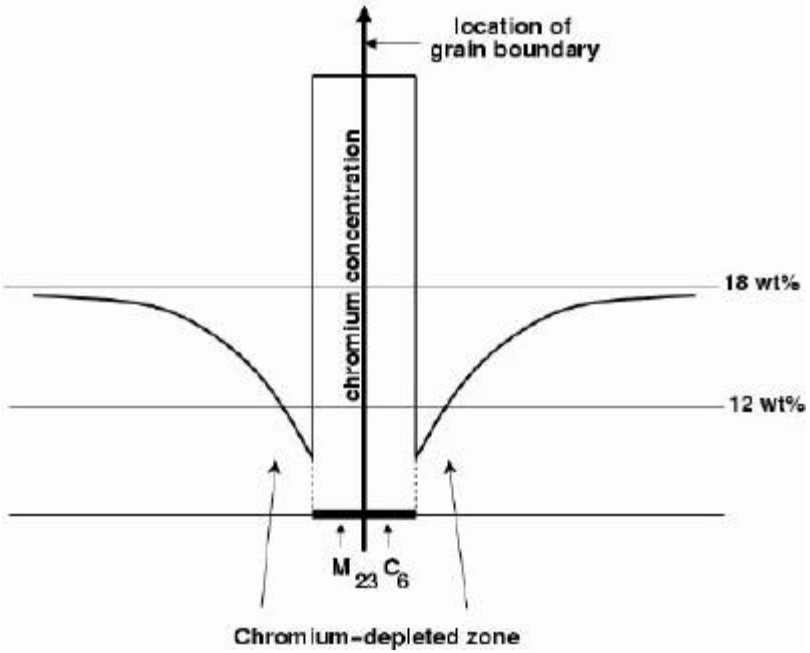
AISI grade	C max.	Si max.	Mn max.	Cr	Ni	Mo	Ti	Nb	Al	V
301	0.15	1.00	2.00	16-18	6-8					
302	0.15	1.00	2.00	17-19	8-10					
304	0.08	1.00	2.00	17.5-20	8-10.5					
310	0.25	1.50	2.00	24-26	19-22					
316	0.08	1.00	2.00	16-18	10-14	2.0-3.0				
321	0.08	1.00	2.00	17-19	9-12		5 x %C min.			
347	0.08	1.00	2.00	17-19	9-13			10 x %C min.		
E 1250	0.1	0.5	6.0	15.0	10.0					0.25
20/25-Nb	0.05	1.0	1.0	20.0	25.0			0.7		
A 286	0.05	1.0	1.0	15.0	26.0	1.2	~1.9	~0.18	~0.25	
254SMO	0.02	0.8	1.0	18.5-20.5	17.5-18.5	6-6.5	~1.9	~0.18	~0.25	
AL-6XN	0.03	1.0	2.0	20-22	23.5-25.5	6-7				

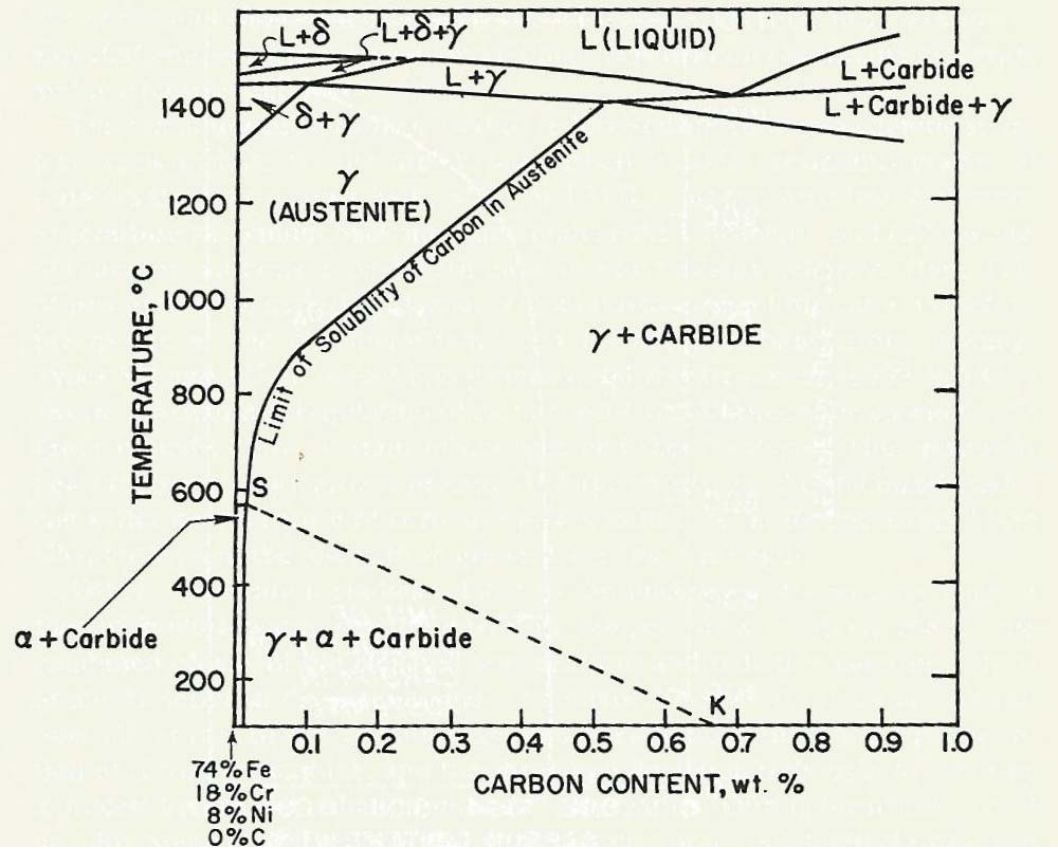
Sensitization of Austenitic SS



Mechanism of Sensitization

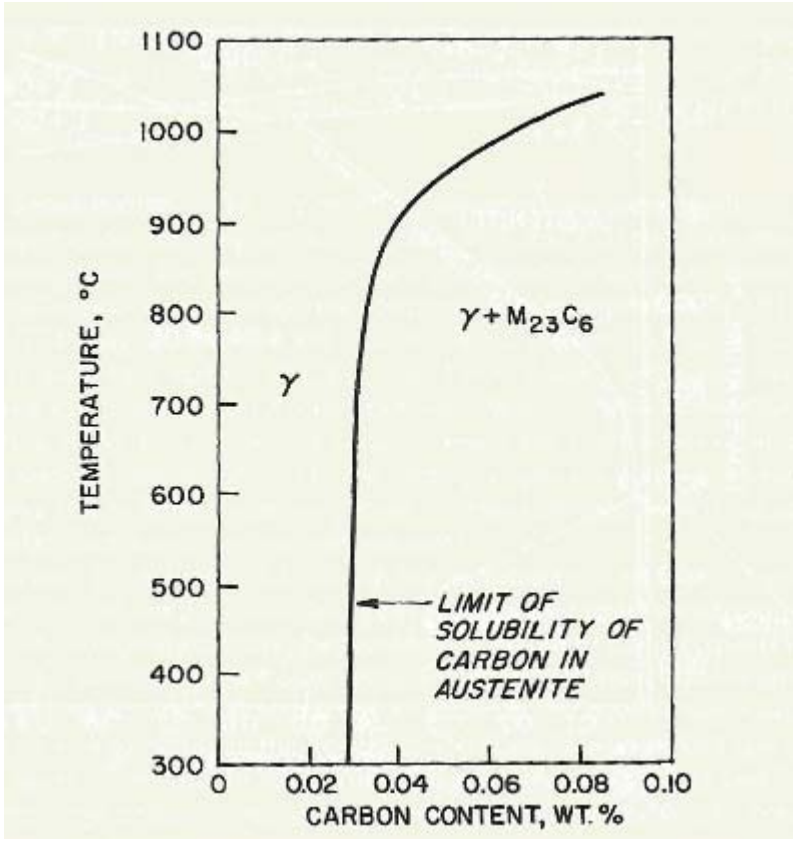




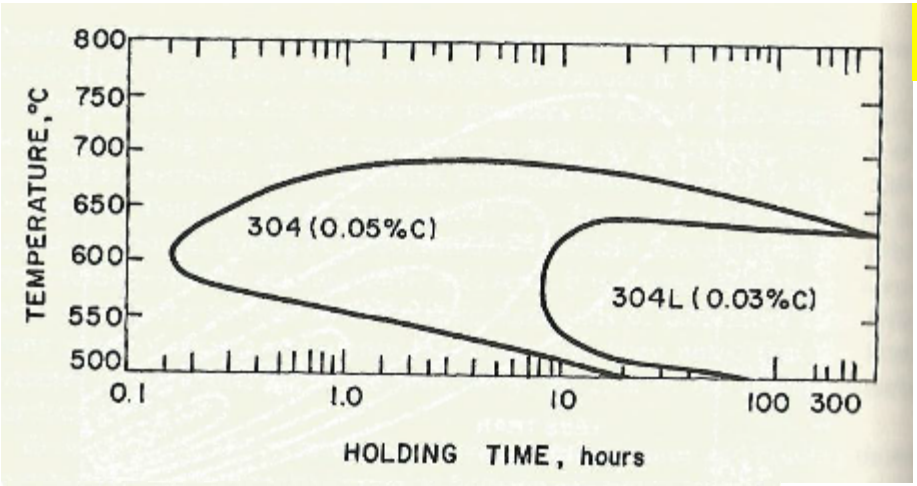


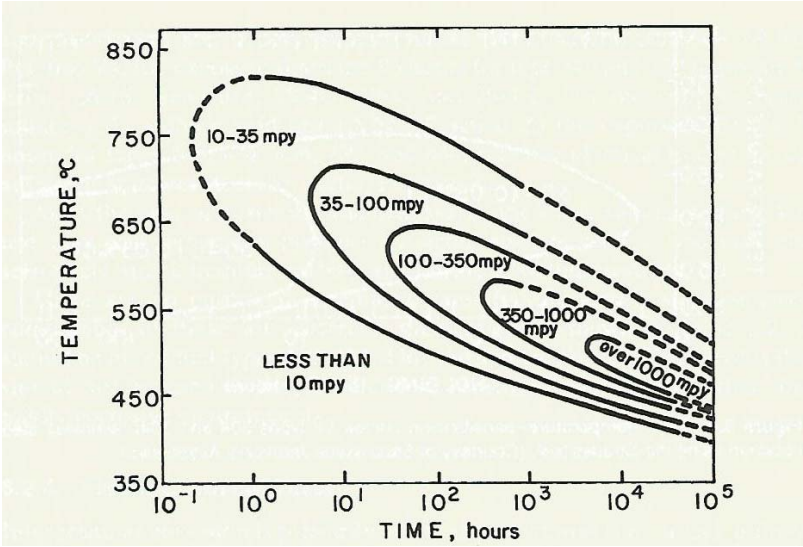
Pseudo binary Phase Digram Fe-18Cr-8Ni SS with C

C solubility limit in Fe-18Cr-8Ni SS

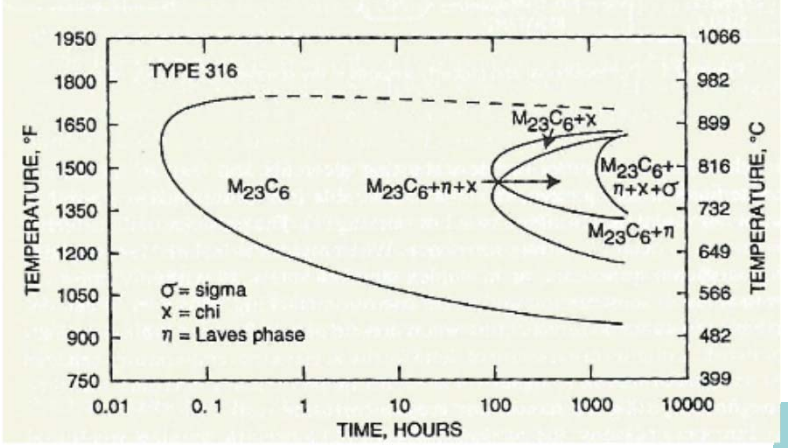


Sensitization Curves for 304 and 347 SS

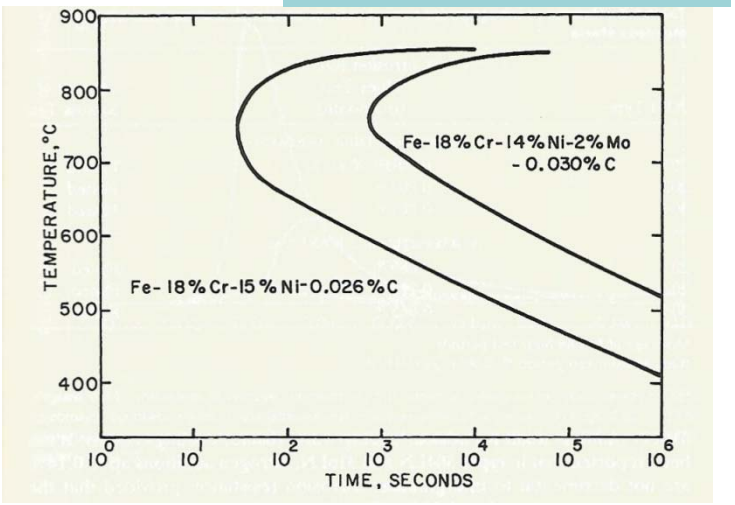




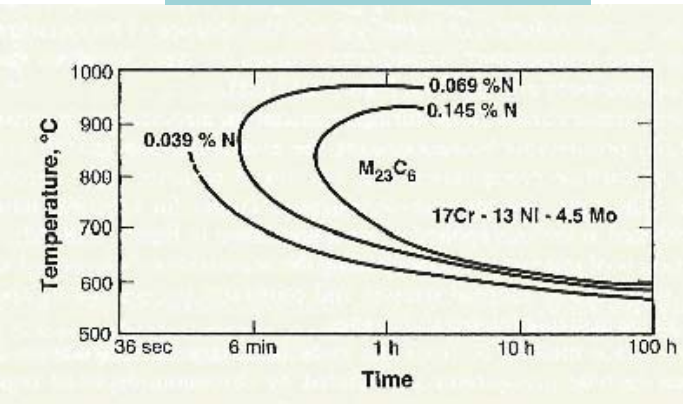
347 S



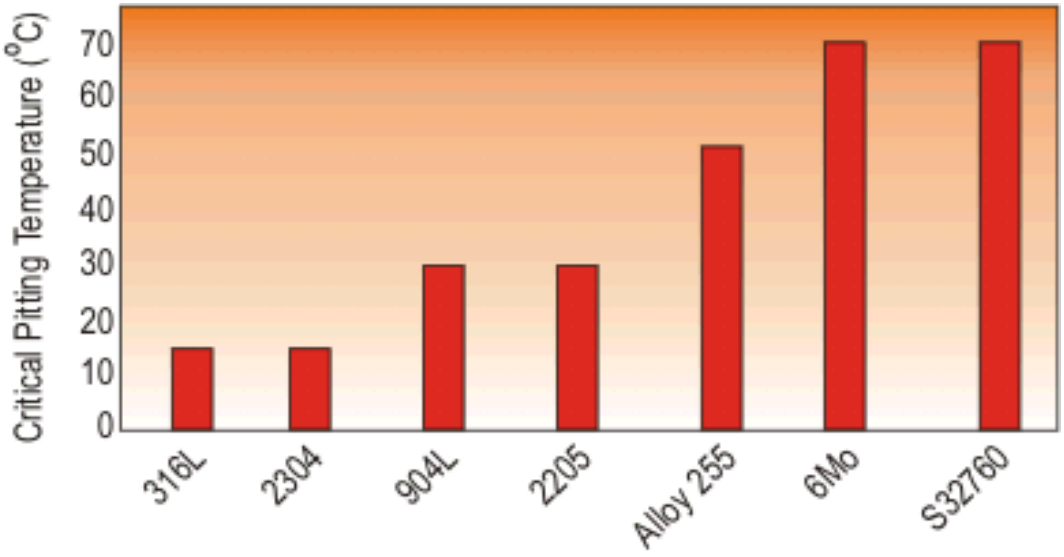
Effect of Mo on sensitization



Effect of N on Sensitization

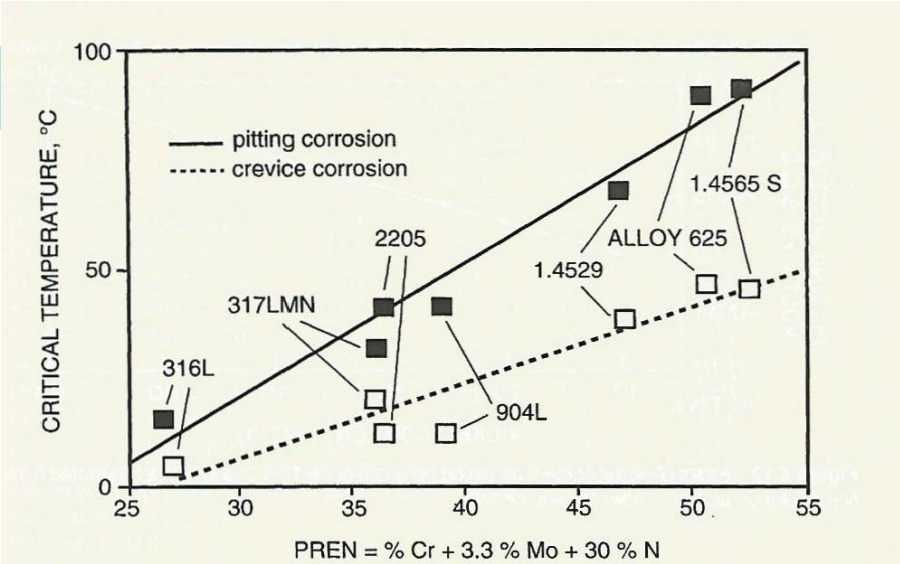


Pitting of Stainless Steels



Azom.com™

PRE = %Cr + 3.3 x %Mo + 16 x %N



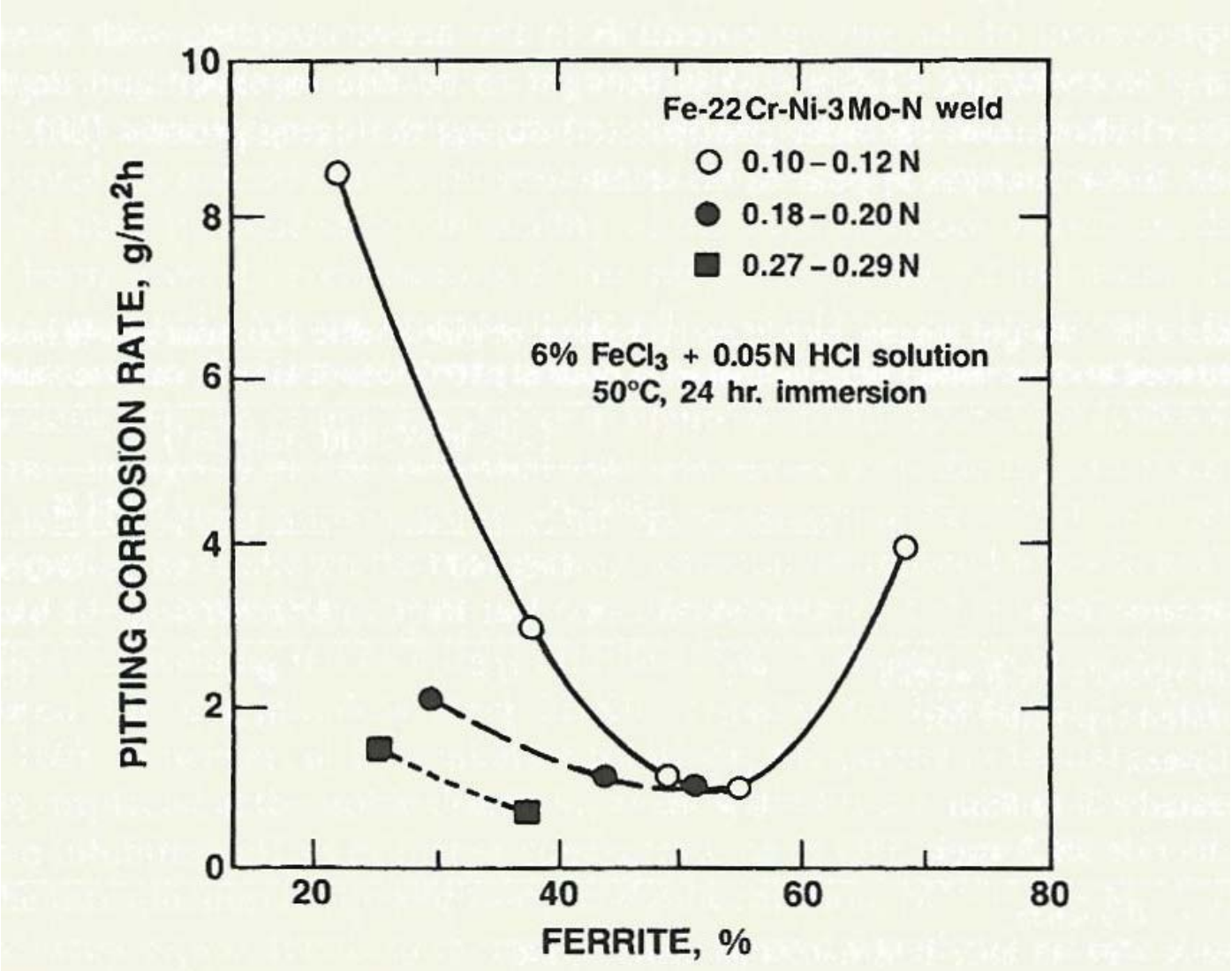
Super Ferritic/Austenitic Stainless Steels

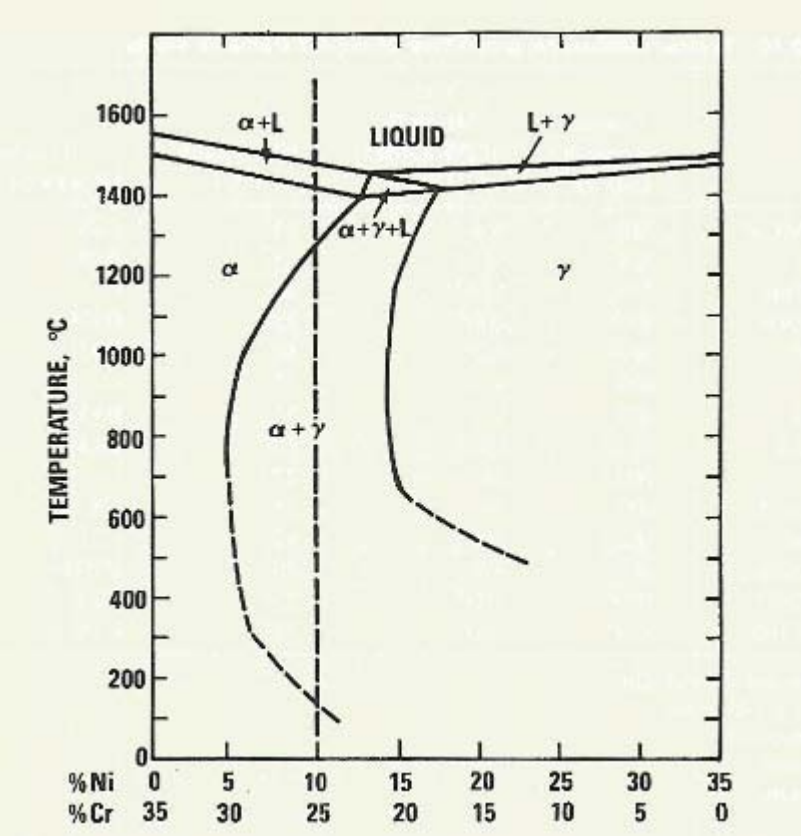
- To enhance further the Pitting corrosion, Chloride Stress Corrosion cracking, super ferritic, super-austentic Stainless Steels are made :
- They have Mo – upto 6%
- Nitrogen from 0.1-0.2%
- Mostly used in Offshore structure, ships and marine applications
- Very costly compared to conventional SS

Duplex stainless steels

Designation	Cr	Ni	C	Mn	Si	P	S	Other	UTS / MPa	Elongation / %
Type 329	28.0	6.0	0.10	2.0	1.0	0.04	0.03	1.5 Mo	724	25
Type 326	26.0	6.5	0.05	1.0	0.6	0.01	0.01	0.25 Ti	689	35
2RE60	18.5	4.5	0.02	1.5	1.6	0.01	0.01	2.5 Mo	717	48
IC378	21.8	5.5	0.03	1.38	0.40	0.03	0.01	3.0 Mo 0.18 Cu 0.07 V 0.14 N		
IC381	22.1	5.8	0.02	1.92	0.48	0.03	0.01	3.2 Mo 0.07 Cu 0.13 V 0.14 N		
A219	25.6	9.4	0.03	0.70	0.60	0.02	0.01	4.1 Mo 0.27 N		

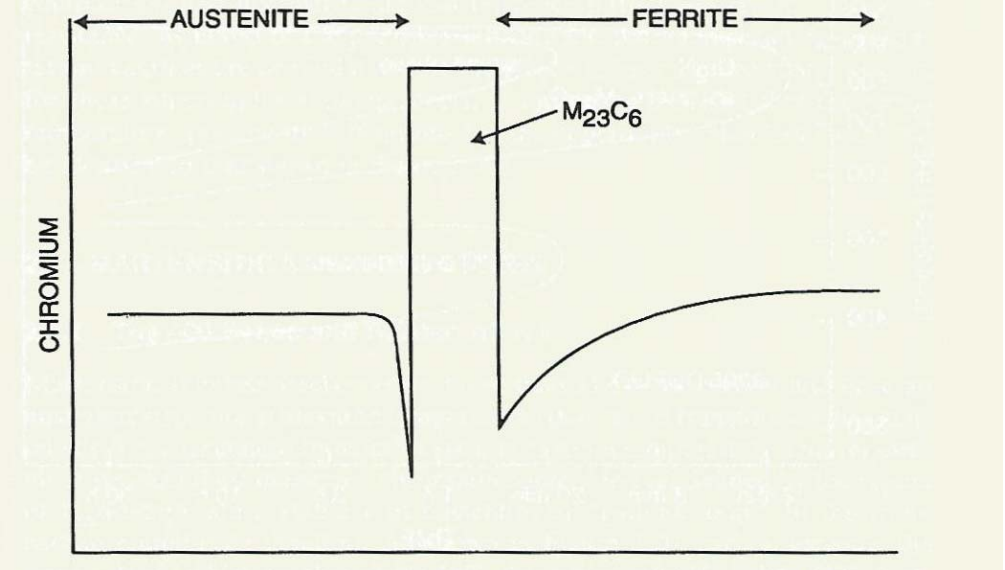
Effect of ferrite content on the pitting rate of duplex SS steel Welds of varying N levels – exposed to 6% FeCl3 + 0.05N HCl solution



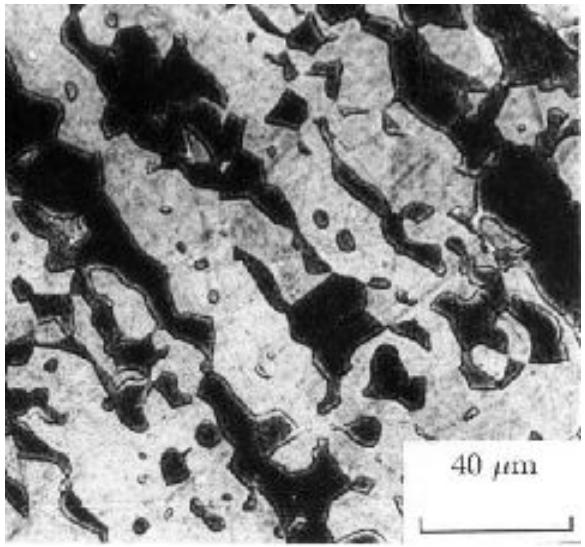


Pseudo binary phase diagram of 65Fe-Cr-Ni Alloy

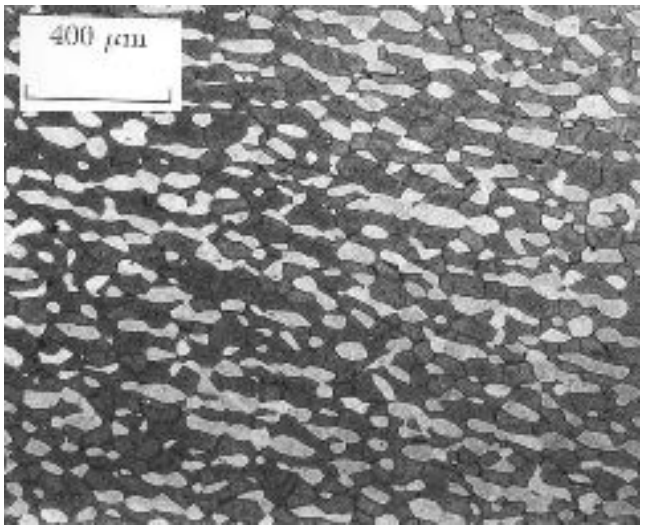
Cr concentration profile around austenitic-Ferrite interface
Containing M23C6 carbide



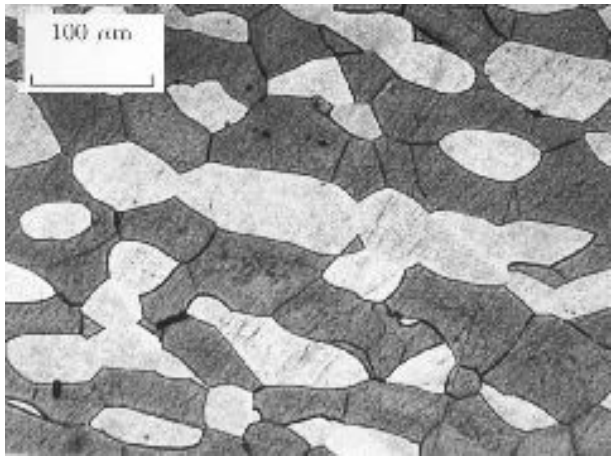
Microstructures of some Duplex SS



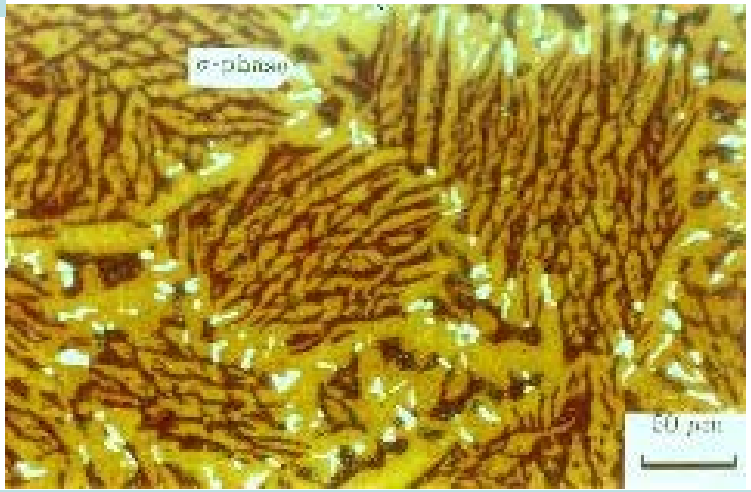
IC378 - The darker etching phase is ferrite and the remainder is austenite



IC381 (dark phase is ferrite).



IC381 (dark phase is ferrite



A219 The austenite is yellow and ferrite is dark brown, with the sigma phase white.

Duplex Stainless Steel

- **Advantages**
  - Very High Corrosion resistance especially pitting and SCC.
  - High Strength with high ductility.
  - Negligible Sensitization
- **Limitations**
  - Useful up to a temperature of 300^{o}C.
  - Problems of unwanted phase formation during welding.

11 Compositions of the 400 series martensitic stainless steels

Name	Composition[a]						
	Cr	C	Mn	Si	P	S	Other
403	11.5–13	0.15	1.0	0.5	0.040	0.030	—
410	11.5–13.5	0.15	1.0	1.0	0.040	0.030	—
410S	11.5–13.5	0.08	1.0	1.0	0.040	0.030	—
414	11.5–13.5	0.15	1.0	1.0	0.040	0.030	Ni 1.25–2.50
416	12–14	0.15	1.25	1.0	0.060	0.15[b]	Mo 0.60[c]
416Se	12–14	0.15	1.25	1.0	0.060	0.060	Se 0.15[b]
420	12–14	0.15[b]	1.0	1.0	0.040	0.030	—
420F	12–14	0.38	1.25	1.0	0.060	0.15[b]	Mo 0.60[c]
422	11–13	0.20–0.25	1.0	0.75	0.025	0.025	Ni 0.40–1.0, Mo 0.75–1.25 W 0.75–1.25, V 0.15–0.30
431	15–17	0.20	1.0	1.0	0.040	0.030	Ni 1.25–2.50
440A	16–18	0.60–0.75	1.0	1.0	0.040	0.030	Mo 0.75
440B	16–18	0.75–0.95	1.0	1.0	0.040	0.030	Mo 0.75
440C	16–18	0.95–1.20	1.0	1.0	0.040	0.030	Mo 0.75
440F	16–18	0.95–1.20	1.25	1.0	0.040	0.10–0.35	Mo 0.40–0.60
440FSe	16–18	0.95–1.20	1.25	1.0	0.040	0.030	Se 0.15[b], Mo 0.60

iron. Single values are maximum values unless otherwise noted.
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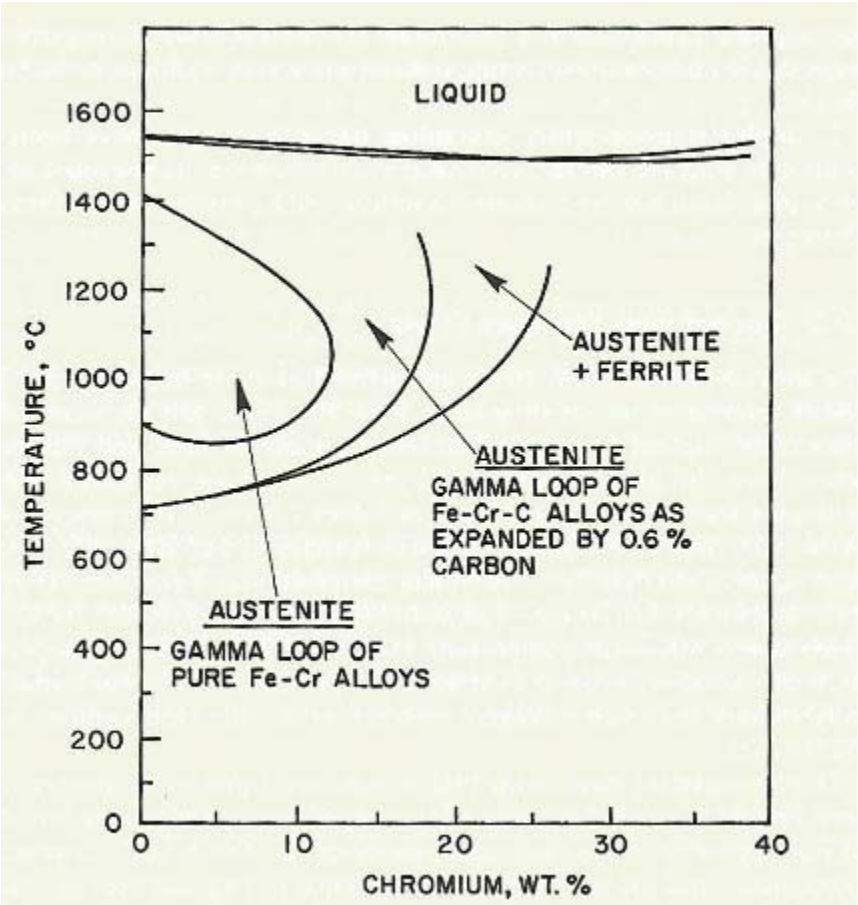
Effect of C addition on the gamma loop in Fe-Cr alloys



Composition of Martensitic Stainless Steels

Grade	C	Mn	Si	Cr	Ni	Mo	P	S	Comments/Applications
410	0.15	1.0	0.5	11.5-13.0	-	-	0.04	0.03	The basic composition. Used for cutlery, steam and gas turbine blades and buckets, bushings...
416	0.15	1.25	1.0	12.0-14.0	-	0.60	0.04	0.15	Addition of sulphur for machinability, used for screws, gears *etc.* 416 Se replaces suplhur by selenium.
420	0.15-0.40	1.0	1.0	12.0-14.0	-	-	0.04	0.03	Dental and surgical instruments, cutlery....
431	0.20	1.0	1.0	15.0-17.0	-	1.25-2.0	0.04	0.03	Enhanced corrosion resistance, high strength.
440A	0.60-0.75	1.0	1.0	16.0-18.0	-	0.75	0.04	0.03	Ball bearings and races, gauge blocks, molds and dies, cutlery.
440B	0.75-0.95	1.0	1.0	16.0-18.0	-	0.75	0.04	0.03	As 440A, higher hardness
440C	0.95-1.20	1.0	1.0	16.0-18.0	-	0.75	0.04	0.03	As 440B, higher hardness

Table 2.14 Typical mechanical properties of the martensitic precipitation-hardening stainless steels

Name	Condition	Tensile Strength (MPa)[a]	Yield Strength (0.2% Offset) (MPa)	Elongation (%)	Hardness (Rockwell C)
Stainless W	A[b]	827	517	7	30
	PH[c]	1344	1241	7	46
17–4 PH	A	1034	758	10	33
	PH	1379	1227	12	44
15–5 PH	A	862	586	10	27
	PH	1379	1275	14	44
CROLOY 16–6 PH	A	924	758	16	28
	PH	1303	1275	16	40
CUSTOM 450	A	972	814	13	28
	PH	1344	1282	14	43
CUSTOM 455	A	1000	739	14	31
	PH	1724	1689	10	49
PH13–8 Mo	A	896	586	12	28
	PH	1551	1379	13	48
ALMAR 362	A	827	724	13	25
	PH	1296	1276	15	41
IN-736	A	958	738	16	28
	PH	1310	1282	14	38

[a]1 MPa = 145.03 psi.
[b]A = solution annealed.
[c]PH = precipitation hardened, maximum values.

Source: Various.

Table 2.13 Typical compositions of the precipitation-hardening stainless steels

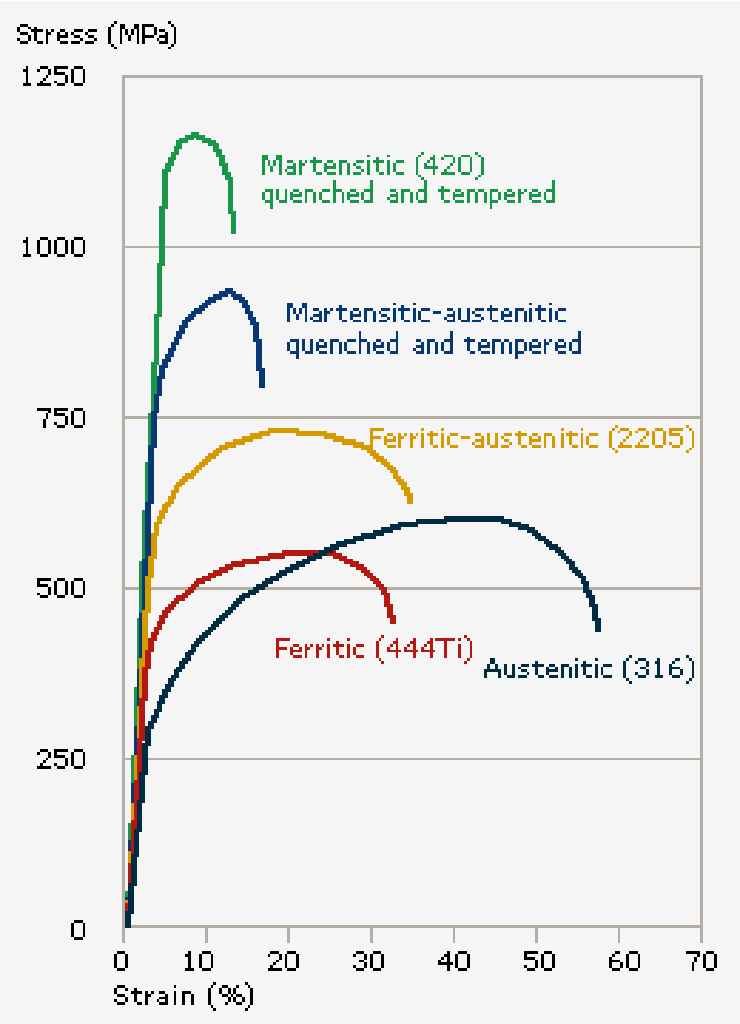
UNS Number	Name	Composition[a] (%)									
		Cr	Ni	C	Mn	Si	Cu	Mo	Ti	Al	Other
					Martensitic						
S17600	Stainless W[b]	16.75	6.75	0.07	0.50	0.50	—	—	0.80	0.20	—
S17400	17-4 PH	16.50	4.25	0.04	0.40	0.50	3.60	—	—	—	Nb + Ta 0.25
S15500	15–5 PH (XM-12)	15.00	4.60	0.04	0.25	0.40	3.50	—	—	—	Nb + Ta 0.35
S16600	Croloy 16–6 PH	15.75	7.50	0.03	0.80	0.45	—	—	0.60	0.40	—
S45000	Custom 450 (XM-25)	14.90	6.50	0.03	0.30	0.25	1.50	0.80	—	—	Nb + Ta 0.75
S45500	Custom 455 (XM-16)	11.75	8.50	0.03	0.20	0.20	2.25	—	1.20	—	Nb + Ta 0.30
S13800	PH 13–8 Mo (XM-13)	13.00	8.00	0.04	0.05	0.05	—	2.25	—	1.00	—
S36200	Almar 362 (XM-9)	14.50	6.50	0.30	0.30	0.20	—	—	0.80	—	—
—	IN-736	10.00	10.00	0.02	0.10	0.10	—	2.00	0.20	0.30	—
					Semiaustenitic						
S17700	17–7 PH	17.00	7.00	0.07	0.70	0.40	—	—	—	1.15	—
S15700	PH 15–7 Mo	15.00	7.00	0.07	0.70	0.40	—	2.25	—	1.15	—
S35000	AM-350	16.50	4.25	0.10	0.75	0.35	—	2.75	—	—	N 0.10
S35500	AM-355	15.50	4.25	0.13	0.85	0.35	—	2.75	—	—	N 0.12
S14800	PH 14–8 Mo[c] (XM-24)	15.50	8.75	0.05	0.10	0.10	—	2.50		1.35	—
					Austenitic						
—	17–10P	17.0	10.50	0.12	0.75	0.50	—	—	—	—	P 0.28
—	HNM	18.5	9.50	0.30	3.50	0.50	—	—	—	—	P 0.25
S66286	A-286	15.0	25.0	0.06	1.20	0.50	—	1.20	2.00	0.25	V 0.30

[a]Balance iron. Designations in parentheses are ASTM designations.
[b]Predominantly ferritic.
[c]Vacuum induction melted, maximum values.

Strengthening Mechanisms

- Ferritic – Heat treatment, carbide pption.
- Austenitic Structure – carbide precipittaion
- Duplex – 2 Phase Structure
- Martensitic – MS transformation
- PH SS – pption strengthening

Room Temperature Mechanical Properties of Stainless Steels



Elevated Temperature Mechanical Properties of Stainless Steels

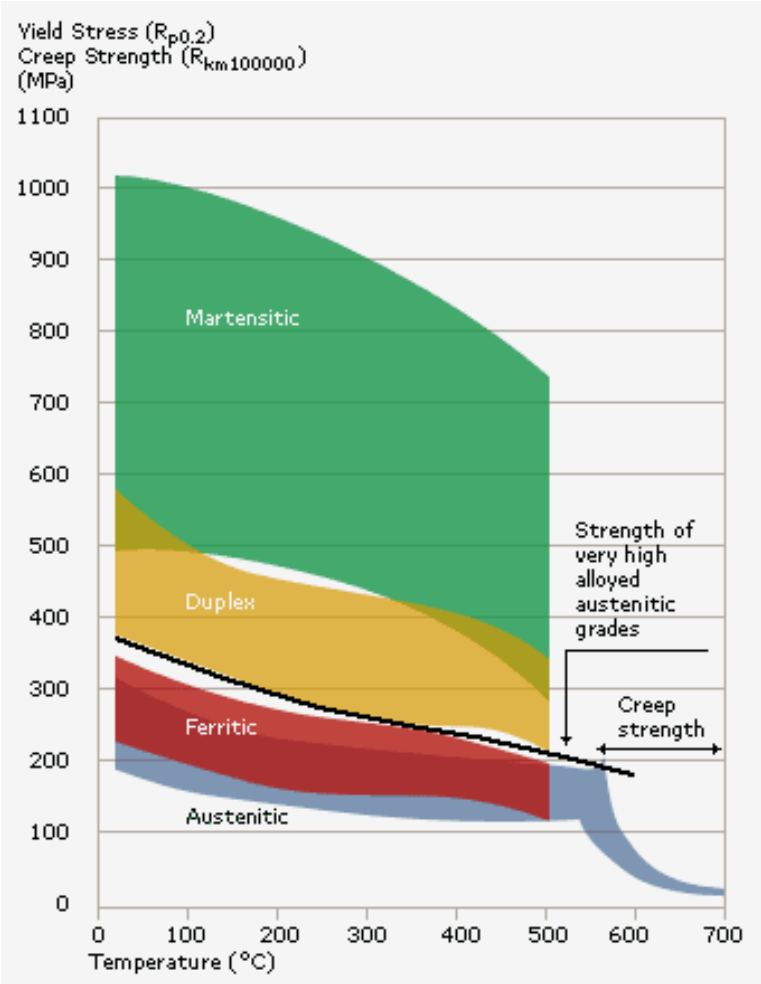


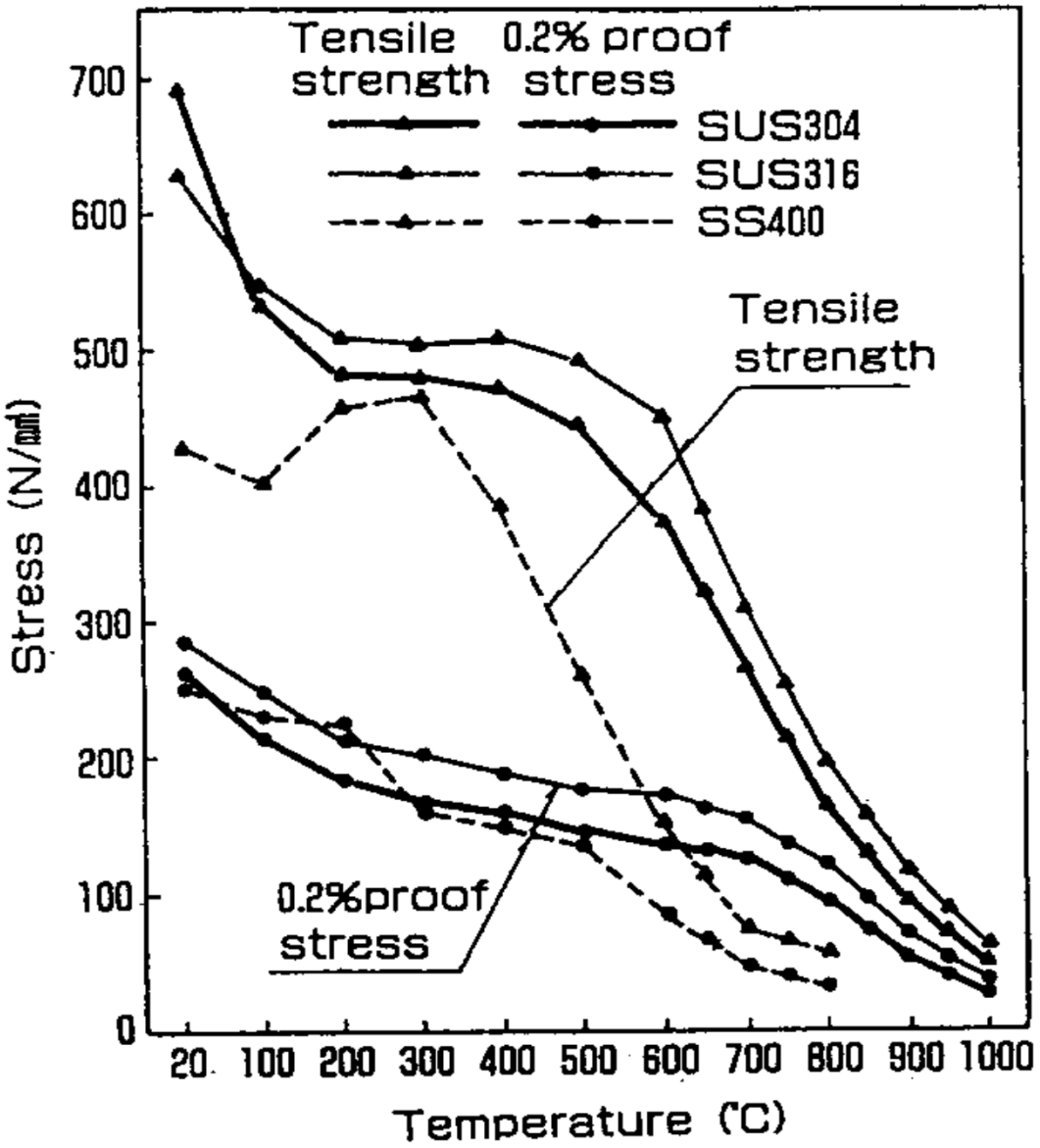
Table 1. Maximum service temperatures in dry air, based on scaling resistance (ref: ASM Metals Handbook)

Grade	Intermittent (°C)	Continuous (°C)
304	870	925
309	980	1095
310	1035	1150
316	870	925
321	870	925
410	815	705
416	760	675
420	735	620
430	870	815
2111HTR	1150	1150

TENSILE and YIELD STRENGTH AT TEMPERATURES SHOWN (ksi)

	24C		540C		650C	
Alloy	Tensile	Yield	Tensile	Yield	Tensile	Yield
304	87	39	55	18	44	16
309S	90	45	67	36	54	28
310	95	45	70	24	58	19
316	84	40	67.5	28	55	24
321	79	31	57.5	26	45	21
347	95	40	60	20.5	50.5	20
*403	110	75	65	52	87	n/a
*410	125	108	75	n/a	20	n/a

Tensile Strength of various SS at Elevated Temperatures



904L High Alloy Stainless Steel

904L is a non-stabilised low carbon high alloy austenitic stainless steel. The addition of copper to this grade gives it greatly improved resistance to strong reducing acids, particularly sulphuric acid. It is also highly resistant to chloride attack - both pitting / crevice corrosion and stress corrosion cracking.

Processing plant for sulphuric, phosphoric and acetic acids

- Pulp and paper processing
- Components in gas scrubbing plants
- Seawater cooling equipment
- Oil refinery components
- Wires in electrostatic precipitators

Grade		C	Mn	Si	P	S	Cr	Mo	Ni	Cu
904L	min.	-	-	-	-	-	19.0	4.0	23.0	1.0
	max.	0.020	2.00	1.00	0.045	0.035	23.0	5.0	28.0	2.0

Grade	Tensile Strength (MPa) min	Yield Strength 0.2% Proof (MPa) min	Elongation (% in 50mm) min	Hardness	
				Rockwell B (HR B)	Brinell (HB)
904L	490	220	35	70-90 typical	-

Rockwell Hardness value range is typical only; other values are specified limits.

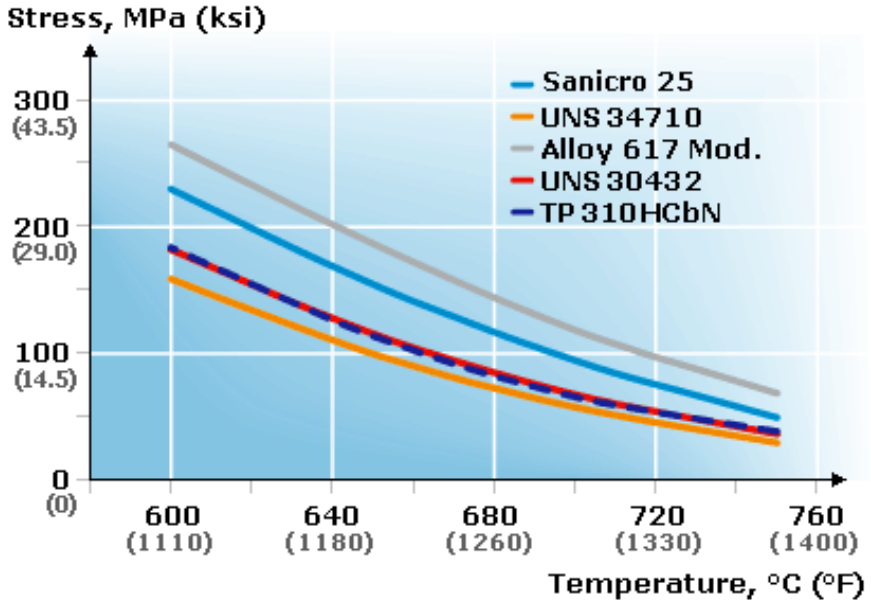
Sanicro 31HT

- An austenitic, nickel-iron-chromium stainless steel combining good resistance to high-temperature corrosion with high mechanical strength for severe, high-temperature environments, up to 1100°C in oxidizing atmospheres.
- Performs exceptionally well in different combustion and synthesis gases and also has good resistance to carburization and isothermal and cyclic oxidation. Typical applications include muffle tubes for wire annealing furnaces, furnace tubes and heat exchangers.
- **Excellent nitridation resistance – good for Ammonia**
- **Main characteristics of Sanicro 31HT**
  - High creep strength
  - Very good resistance to oxidation
  - Good resistance to combustion gases
  - Very good resistance to carburization
  - Excellent resistance to nitrogen absorption
  - Good structural stability at high temperatures
  - Good weldability

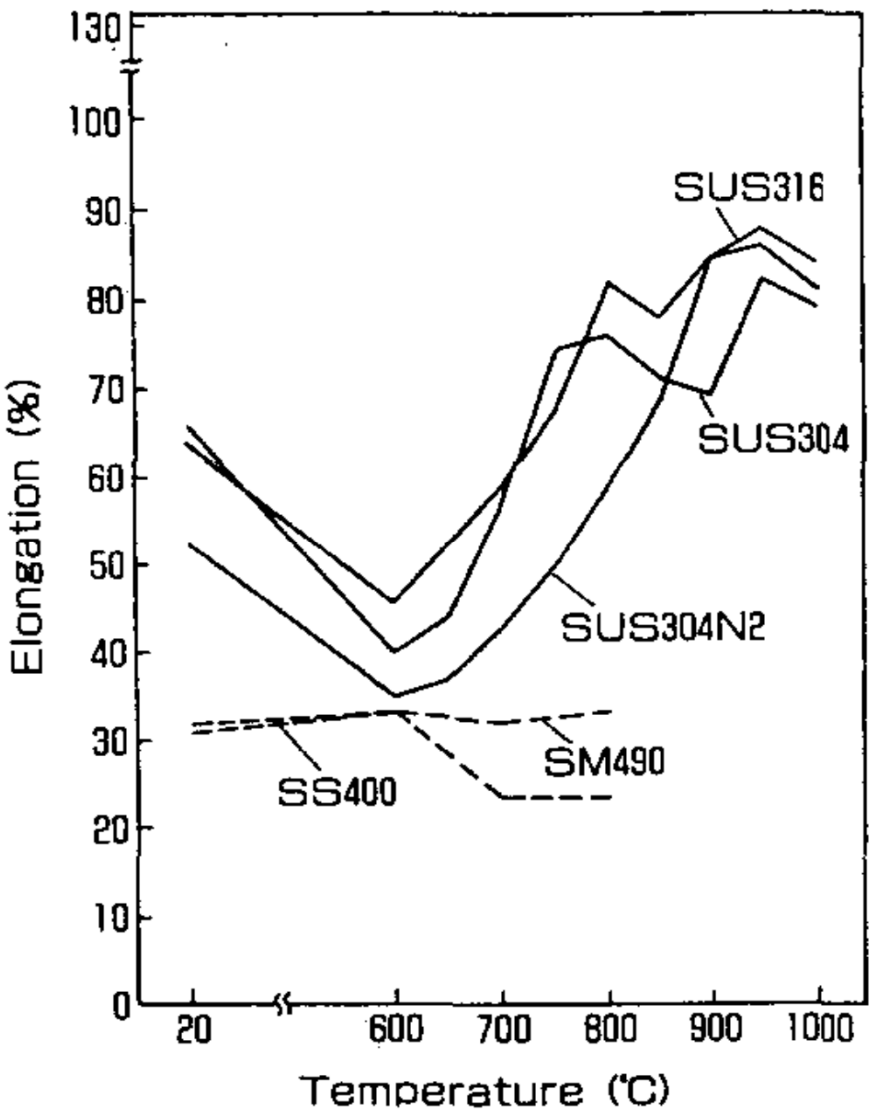
C	Si	Mn	P	S	Cr	Ni	Ti	Al	Fe
0.07	0.6	0.6	≤0.015	≤0.010	20.5	30.5	0.5	0.5	bal.

Sanicro 25 high-temperature stainless steel

- High-alloy austenitic stainless steel engineered for the next generation of coal-fired power boilers. It is ideal for reheater and superheater tubes, allowing for material temperatures of up to 700ºC significantly greater efficiency and sharply lower CO_2 emissions.
- **Superior creep strength**
- Will almost reach 100 MPa at 700°C after 100,000 hours. The latest proposed figure is 97 MPa (14.36 ksi).
- The below graph shows the creep strength of Sanicro 25 compared with other material.



% Elongation of various SS at Elevated Temperatures



Effect of Mo on the HT properties of Steels