Department of Metallurgical and Materials Engineering

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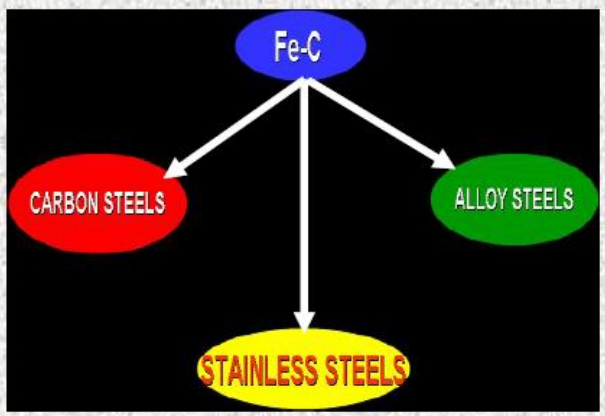
MSE 4941
Advanced Structural Steels
Lecture 3

Dr. Alptekin KISASÖZ

Table 1. Use of stainless steel in the industrialised world, divided into various product forms and application categories.

PRODUCT FORMS		APPLICATION CATEGORIES		
Cold rolled sheet	60 %	**Consumer items**		26 %
Bar and wire	20 %	Washing machines and dishwashers	8 %	
Hot rolled plate	10 %	Pans, cutlery, etc.	9 %	
Tube	6 %	Sinks and kitchen equipment	4 %	
Castings and other	4 %	Other	5 %	
		Industrial equipment		74 %
		Food industry and breweries	25 %	
		Chemical, oil and gas industry	20 %	
		Transport	8 %	
		Energy production	7 %	
		Pulp and paper, textile industry	6 %	
		Building and general construction	5 %	
		Other	5 %	

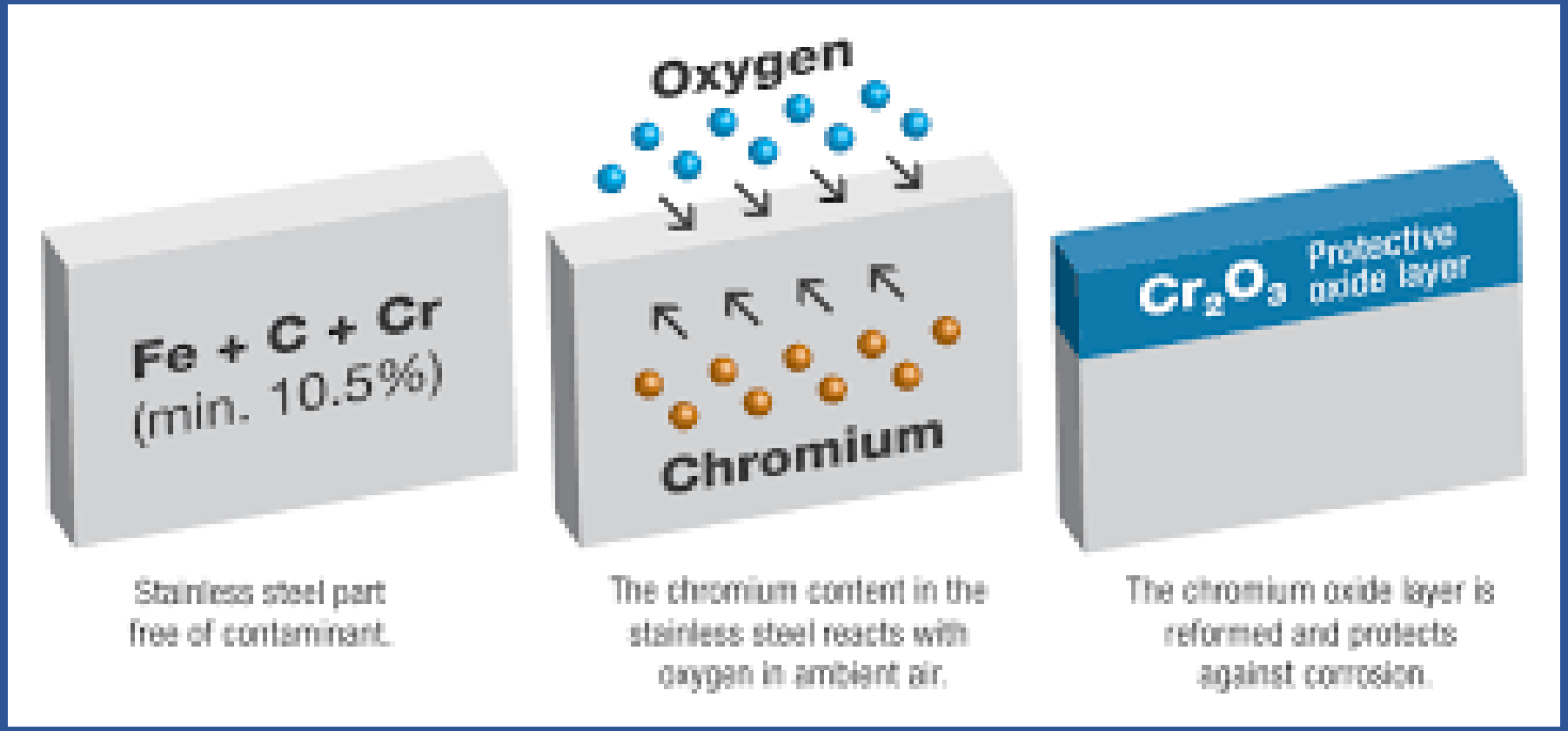
"Steel Family"

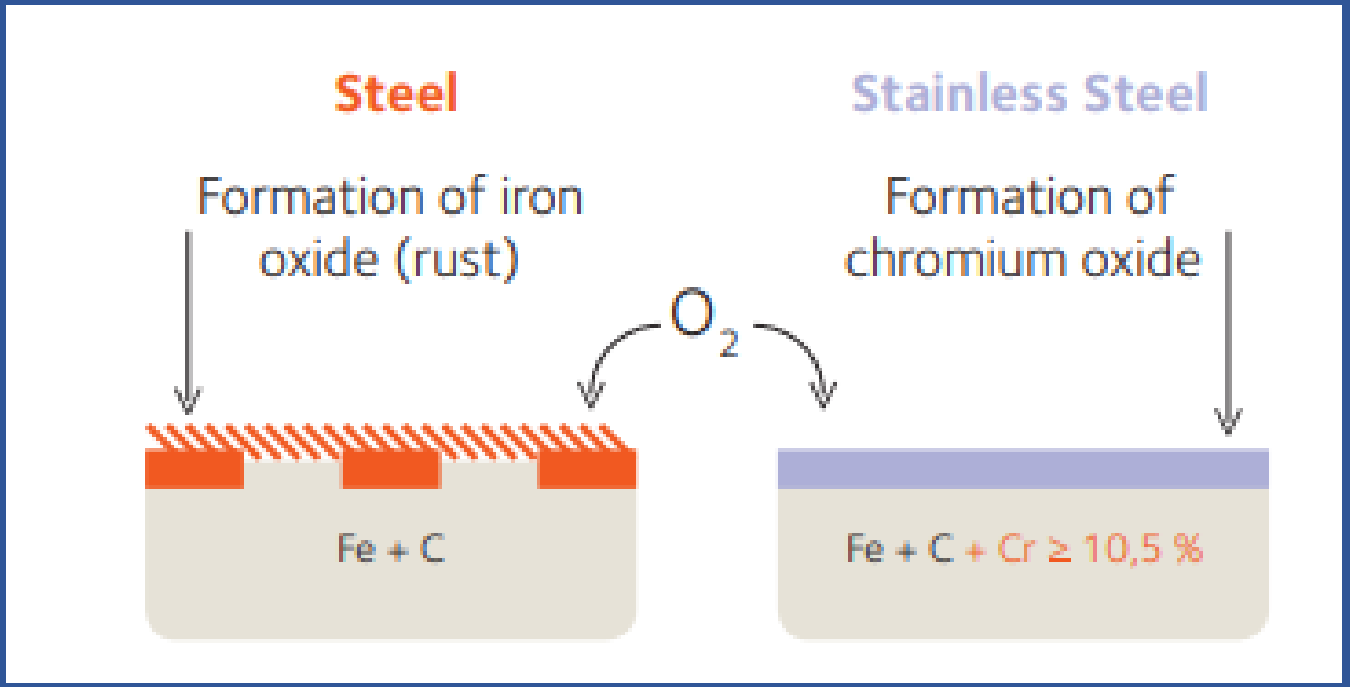


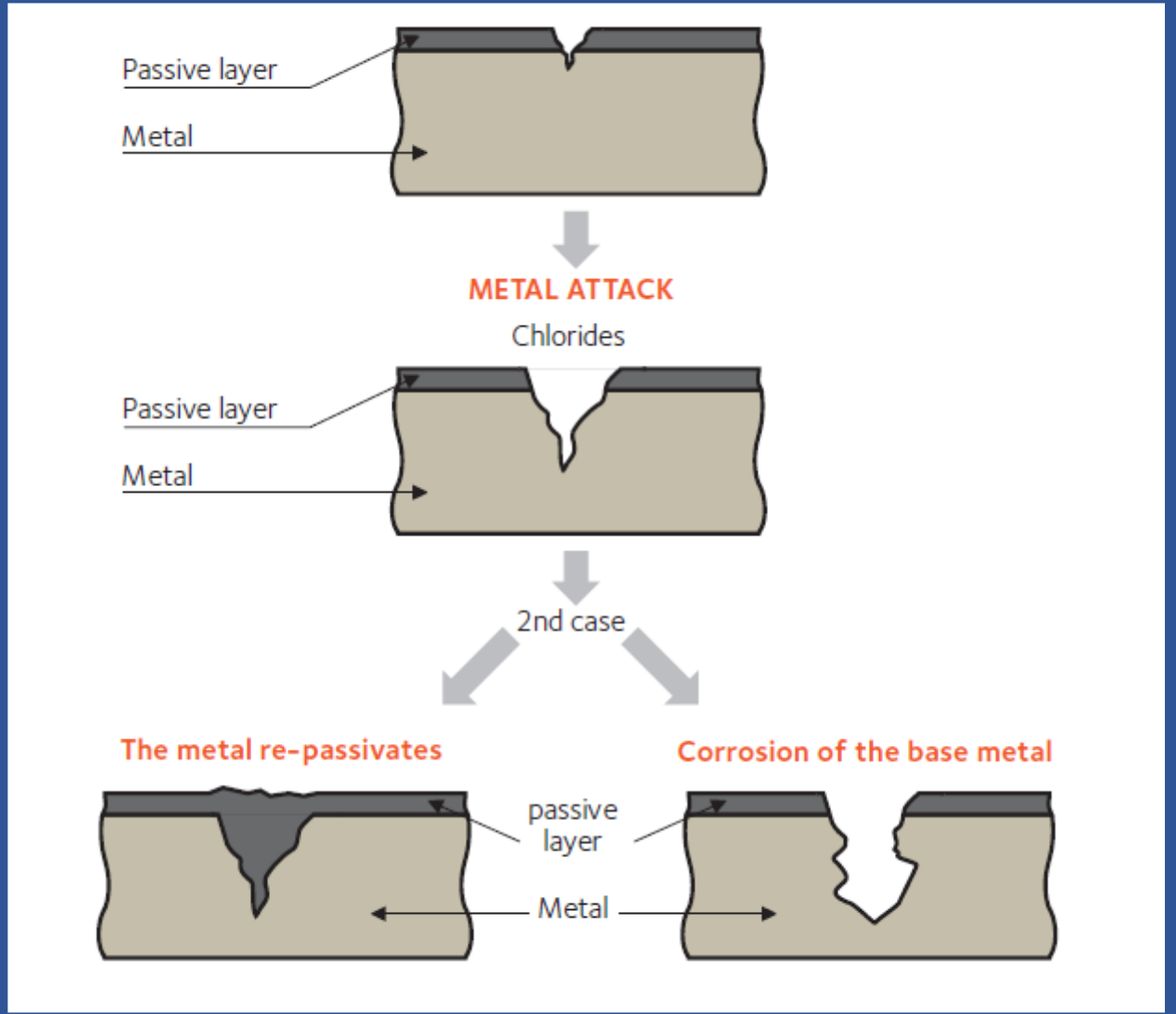
Harry Brearley

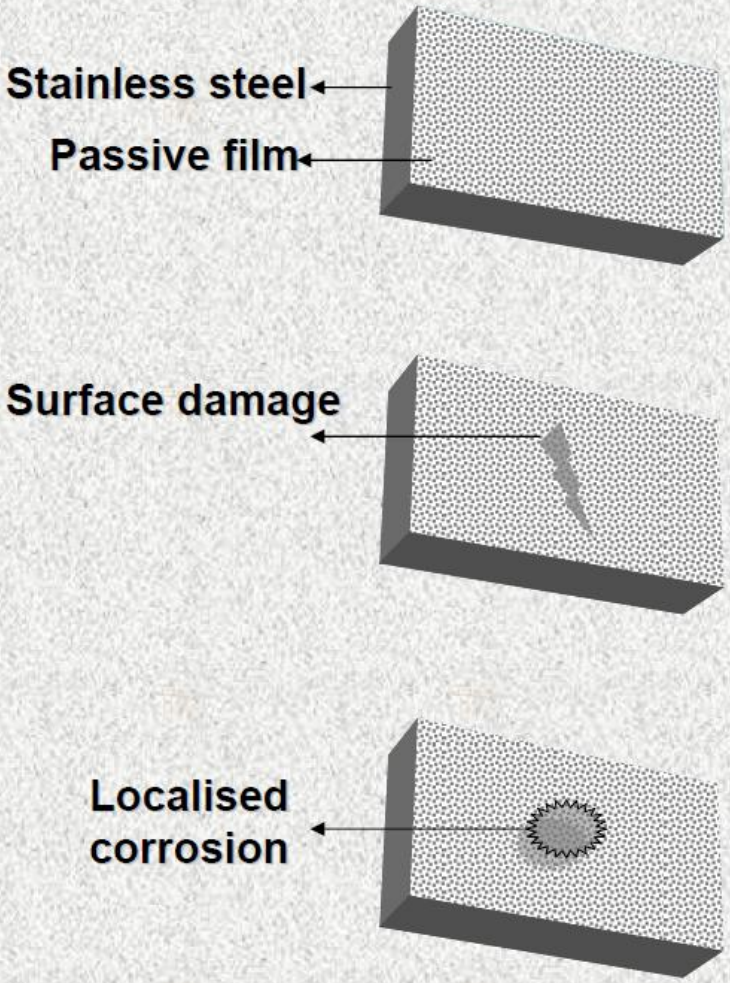
Developments.....

'Iron Alloys'	'Alloy Steels'	'Stainless Steels'
Fe-Carbon Steels	Fe-Low Carbon (< 0.15%)-High Cr Alloy, Brustlein, France,1875	E.Haynes, USA & Becket & Dantsizen, USA, 1911-14
Fe-C, P, S, Mn Alloys	Fe-high C-30-35%Cr-2%W Alloy, First Patent Woods & Clark, UK, 1872	Austenitic steel with <1% C, <20% Ni and 15-40% Cr, E.Maurer and B.Strauss, FRG, 1912-1914
Delhi Iron Pillar 400 A.D	Fe-high C-low Cr Alloy M. Faraday, UK, P. Berthier, France (1820-21)	Martensitic steel with 12.8% Cr and 0.24% C, Harry Brearley, UK, 1913 E. Stuart – 'stainless' **First ever 'stainless steel'**
PreHistoric Iron		Minimum Cr – 10.5% & Mo effect, P.Monnartz and W.Borchers, FRG, 1911
		Fe-Ni-Cr Alloys, L.Guillet, France, 1904-06
		Aluminothermic Reduction process for Carbon-free Cr, H. Goldschmidt, FRG, 1895

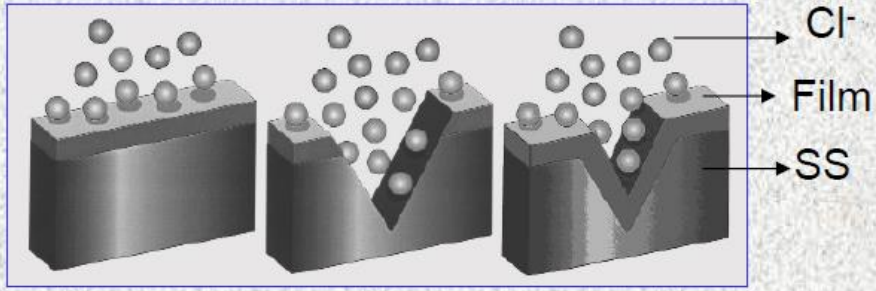

Oxygen
Fe + C + Cr
(min. 10.5%)
Chromium
Cr_2O_3 Protective oxide layer
Stainless steel part free of contaminant.
The chromium content in the stainless steel reacts with oxygen in ambient air.
The chromium oxide layer is reformed and protects against corrosion.


Steel
Stainless Steel
Formation of iron oxide (rust)
Formation of chromium oxide
O_2
Fe + C
Fe + C + Cr ≥ 10,5 %


Passive layer
Metal
METAL ATTACK
Chlorides
Passive layer
Metal
2nd case
The metal re-passivates
Corrosion of the base metal
passive layer
Metal

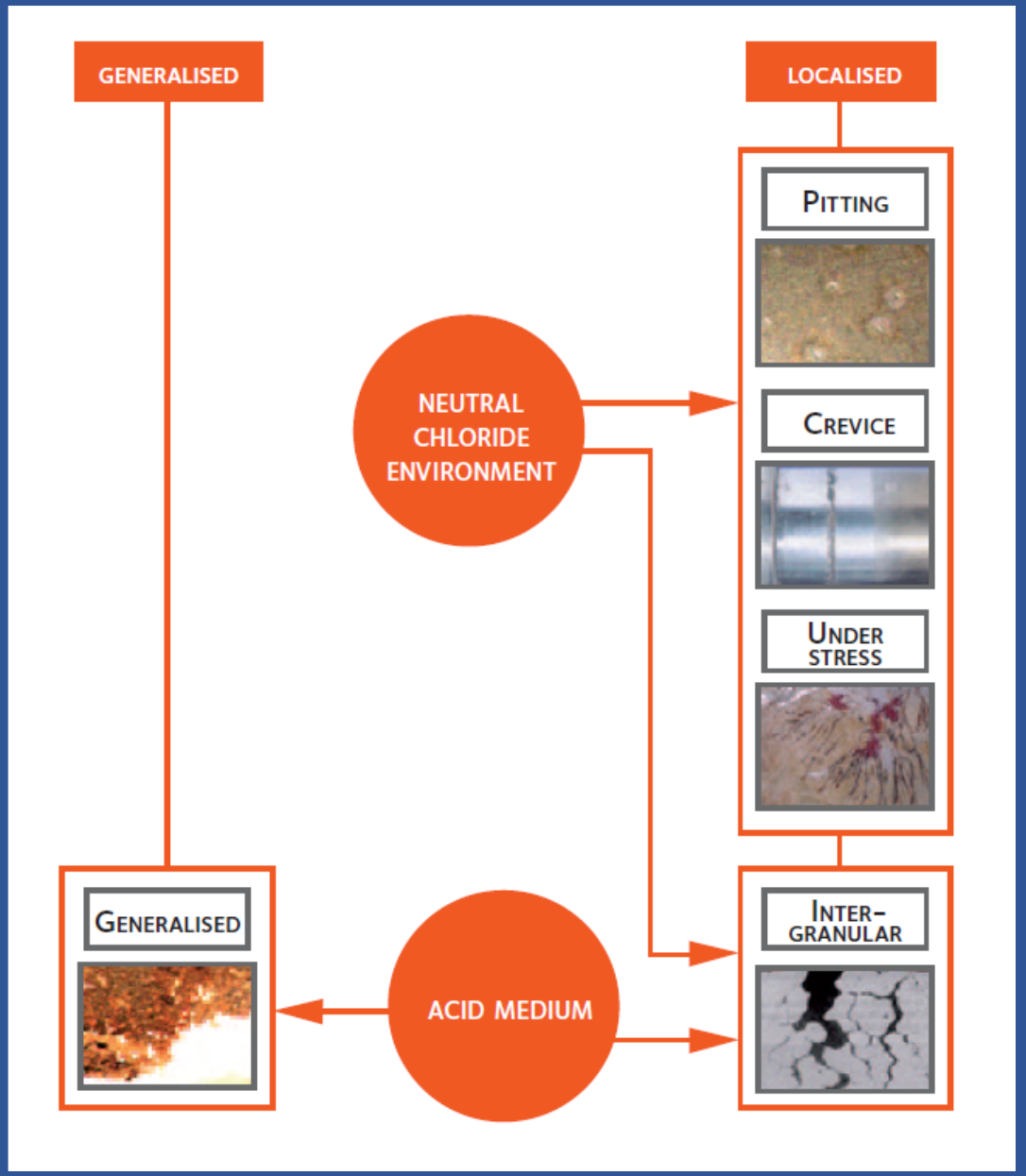


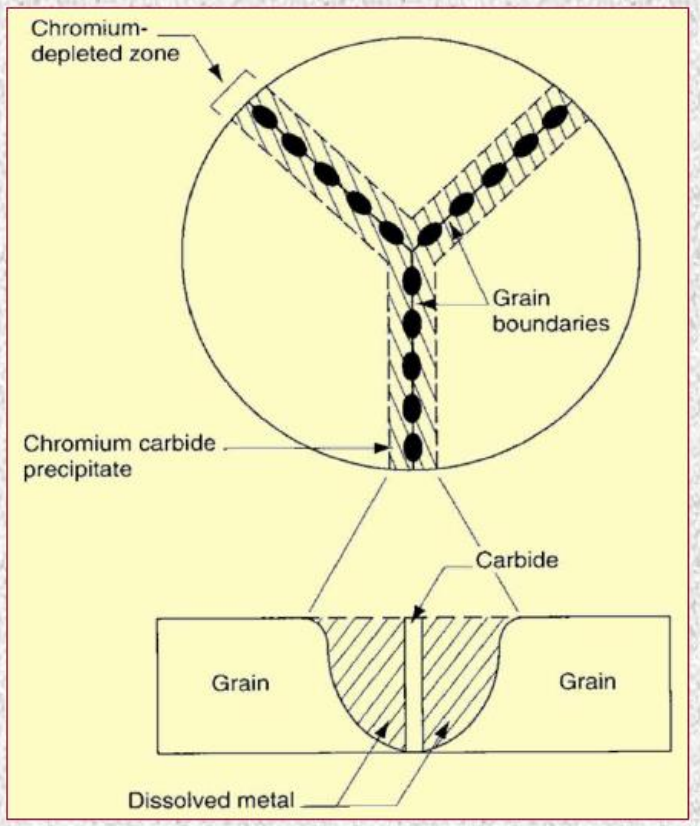
Thin, adherent and self-healing passive films offer protection against halide ions by quickly reforming the passive film.

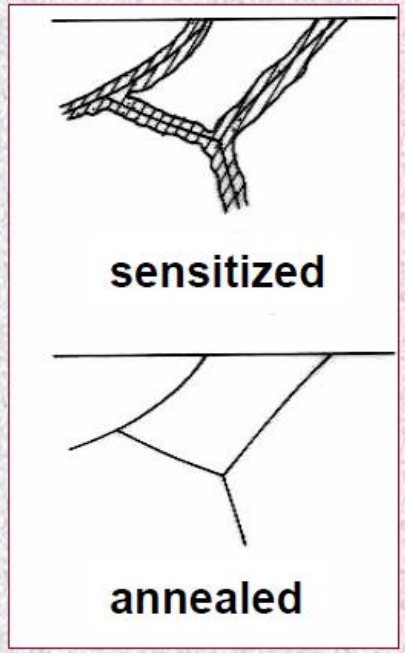


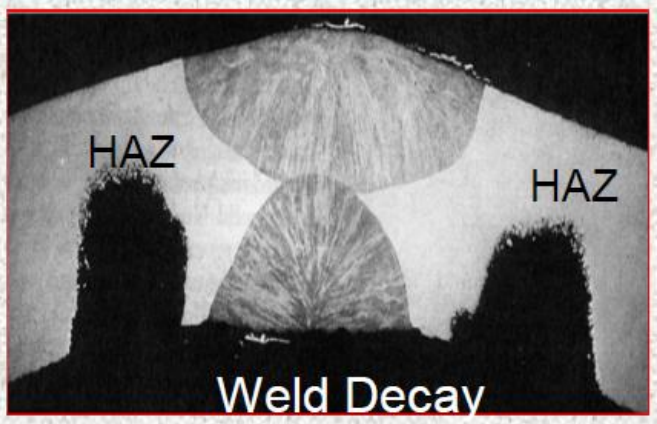
However, localised damage is caused to the film by chloride ions at weak sites leading to 'localized corrosion'.

'Localised Corrosion' like pitting, crevice corrosion, intergarnular corrosion, stress corrosion cracking, corrosion fatigue etc. caused due to the destruction of passive films are the root cause of failure of SS components in industrial service.


GENERALISED
LOCALISED
PITTING
NEUTRAL CHLORIDE ENVIRONMENT
CREVICE
UNDER STRESS
GENERALISED
ACID MEDIUM
INTER-GRANULAR

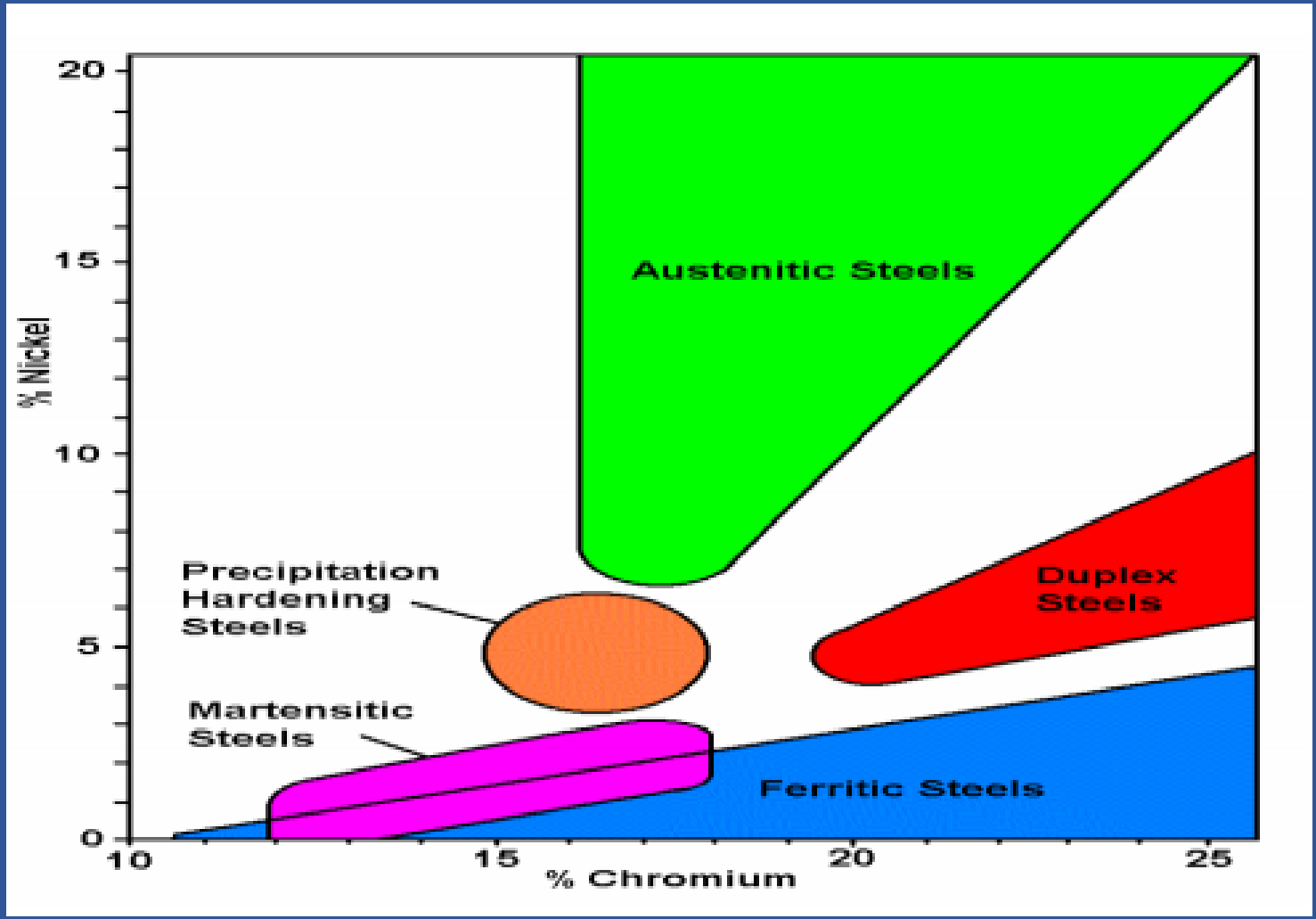






Formation of chromium-rich $M_{23}C_6$ carbides at grain boundaries during slow heating/cooling of austenitic stainless steels between 400-750°C leads to development of chromium-depleted zones (< 9% Cr) along the grain boundaries. This is known as Sensitisation

Any sensitised microstructure will undergo selective localised corrosion along grain boundaries leading to Intergranular Corrosion

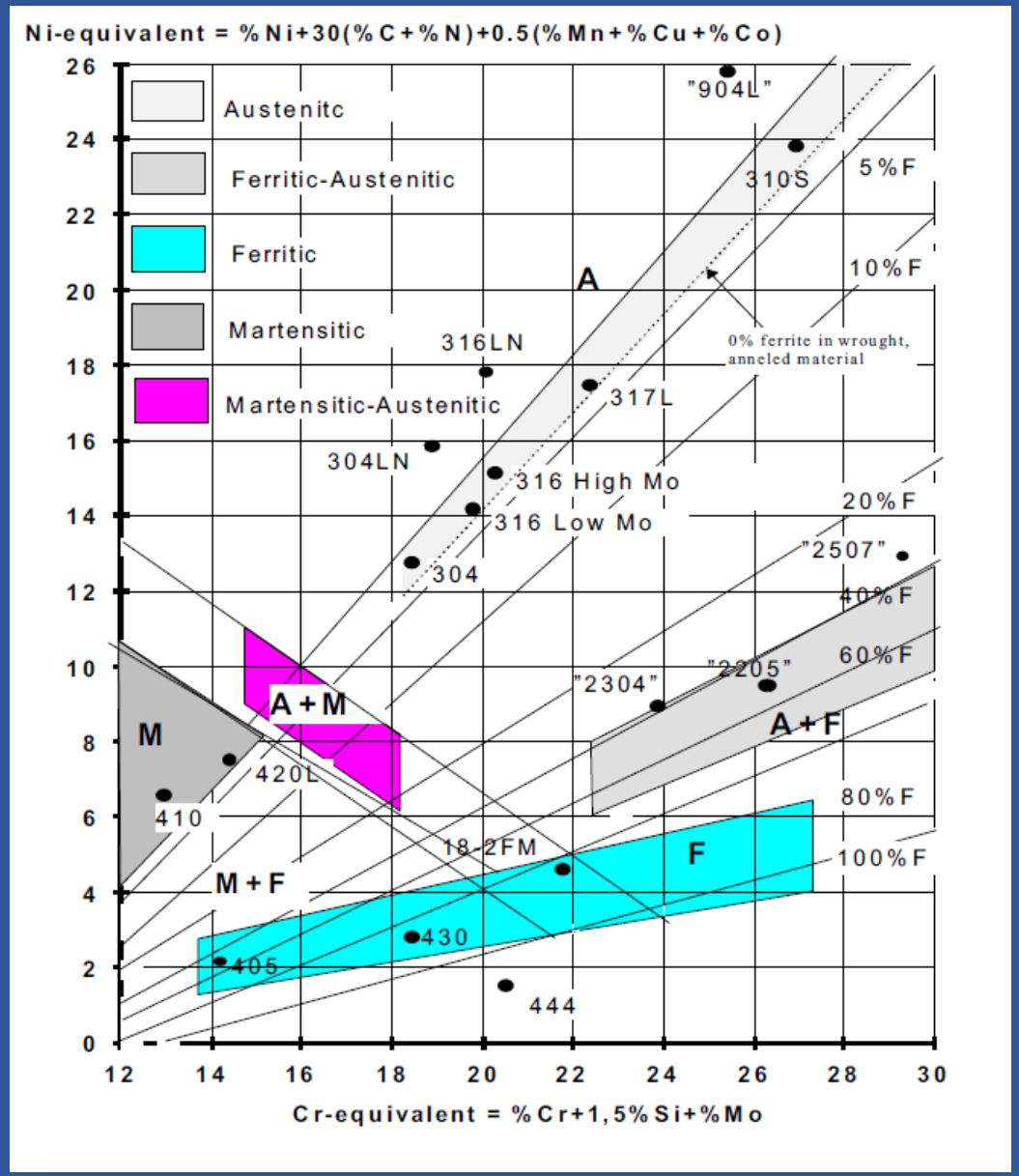

Austenitic Steels
Duplex Steels
Precipitation Hardening Steels
Martensitic Steels
Ferritic Steels
% Nickel
% Chromium
0
5
10
15
20
10
15
20
25

Steel category	Composition (wt%)					Hardenable	Ferro-magnetism
	C	Cr	Ni	Mo	Others		
Martensitic	›0.10 ›0.17	11-14 16-18	0-1 0-2	- 0-2	V	Hardenable	Magnetic
Martensitic-austenitic	‹0.10	12-18	4-6	1-2		Hardenable	Magnetic
Precipitation hardening		15-17 12-17	7-8 4-8	0-2 0-2	Al, Al,Cu,Ti,Nb	Hardenable	Magnetic
Ferritic	‹0.08 ‹0.25	12-19 24-28	0-5 -	‹5 -	Ti	Not hardenable	Magnetic
Ferritic-austenitic (duplex)	‹0.05	18-27	4-7	1-4	N, W	Not hardenable	Magnetic
Austenitic	‹0.08	16-30	8-35	0-7	N,Cu,Ti,Nb	Not hardenable	Non-magnetic

The effect of the alloying elements on the structure of stainless steels is summarised in the Schaeffler-Delong diagram. The diagram is based on the fact that the alloying elements can be divided into ferrite-stabilisers and austenite-stabilisers. This means that they favour the formation of either ferrite or austenite in the structure. If the austenite-stabilisers ability to promote the formation of austenite is related to that for nickel, and the ferrite-stabilisers likewise compared to chromium, it becomes possible to calculate the total ferrite and austenite stabilising effect of the alloying elements in the steel. This gives the so-called chromium and nickel equivalents in the Schaeffler-Delong diagram:

Chromium equivalent = %Cr + 1.5 x %Si + %Mo

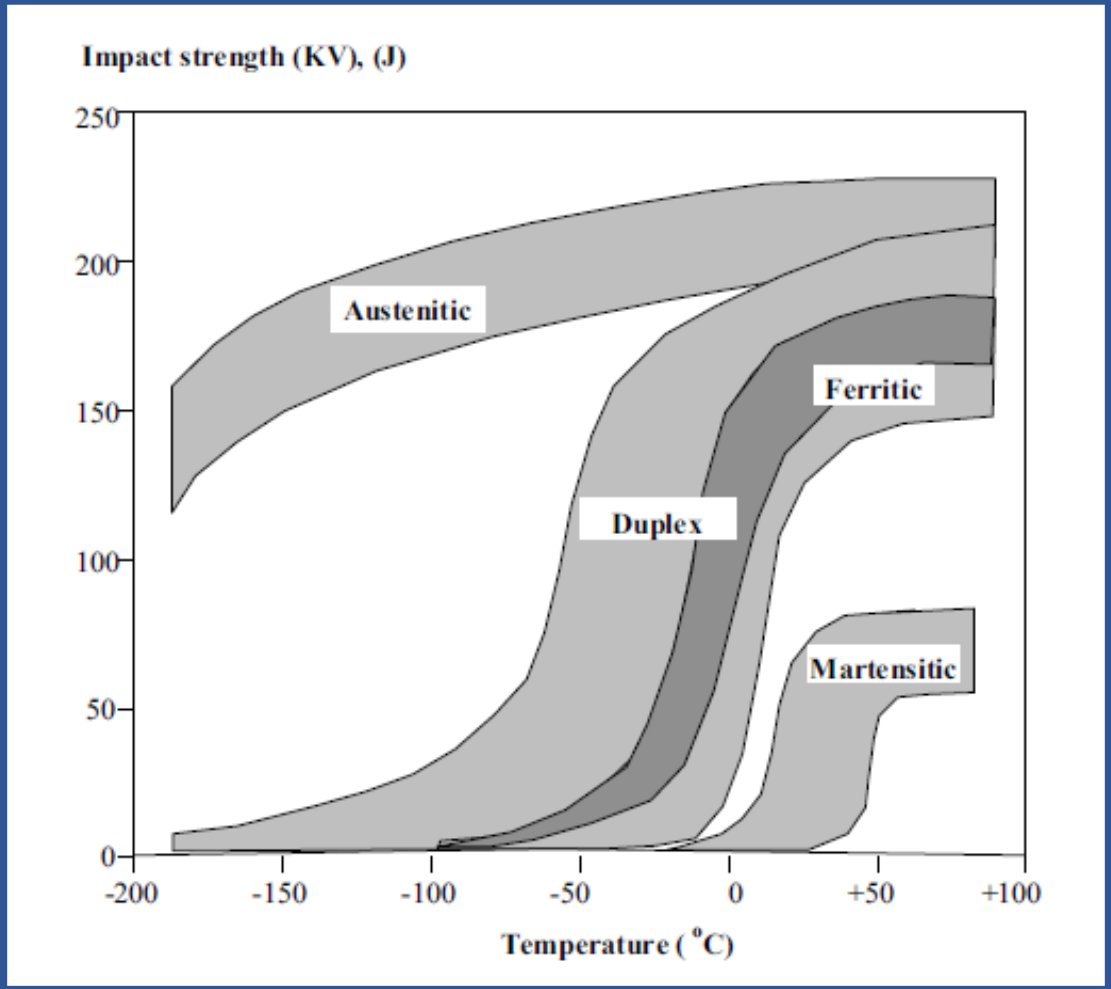
Nickel equivalent = %Ni + 30 x (%C + %N) + 0.5 x (%Mn + %Cu + %Co)

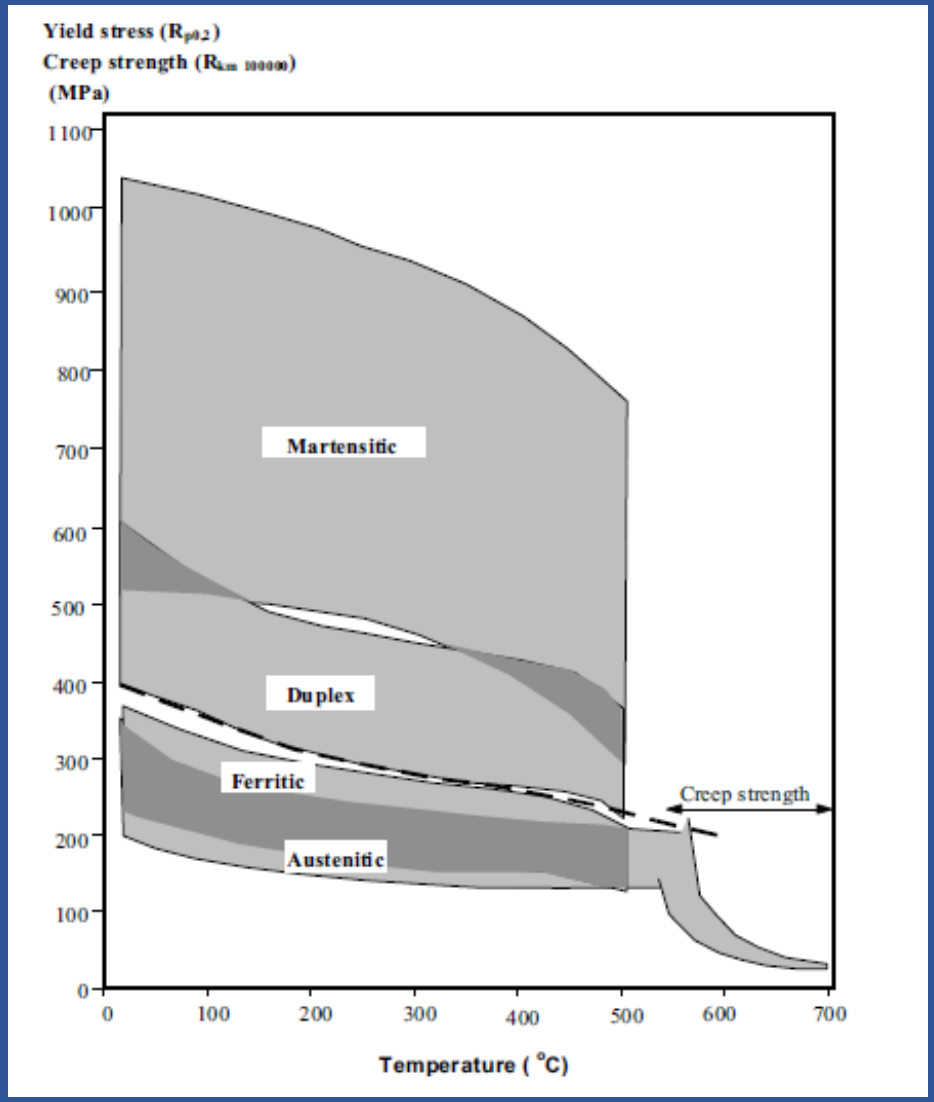


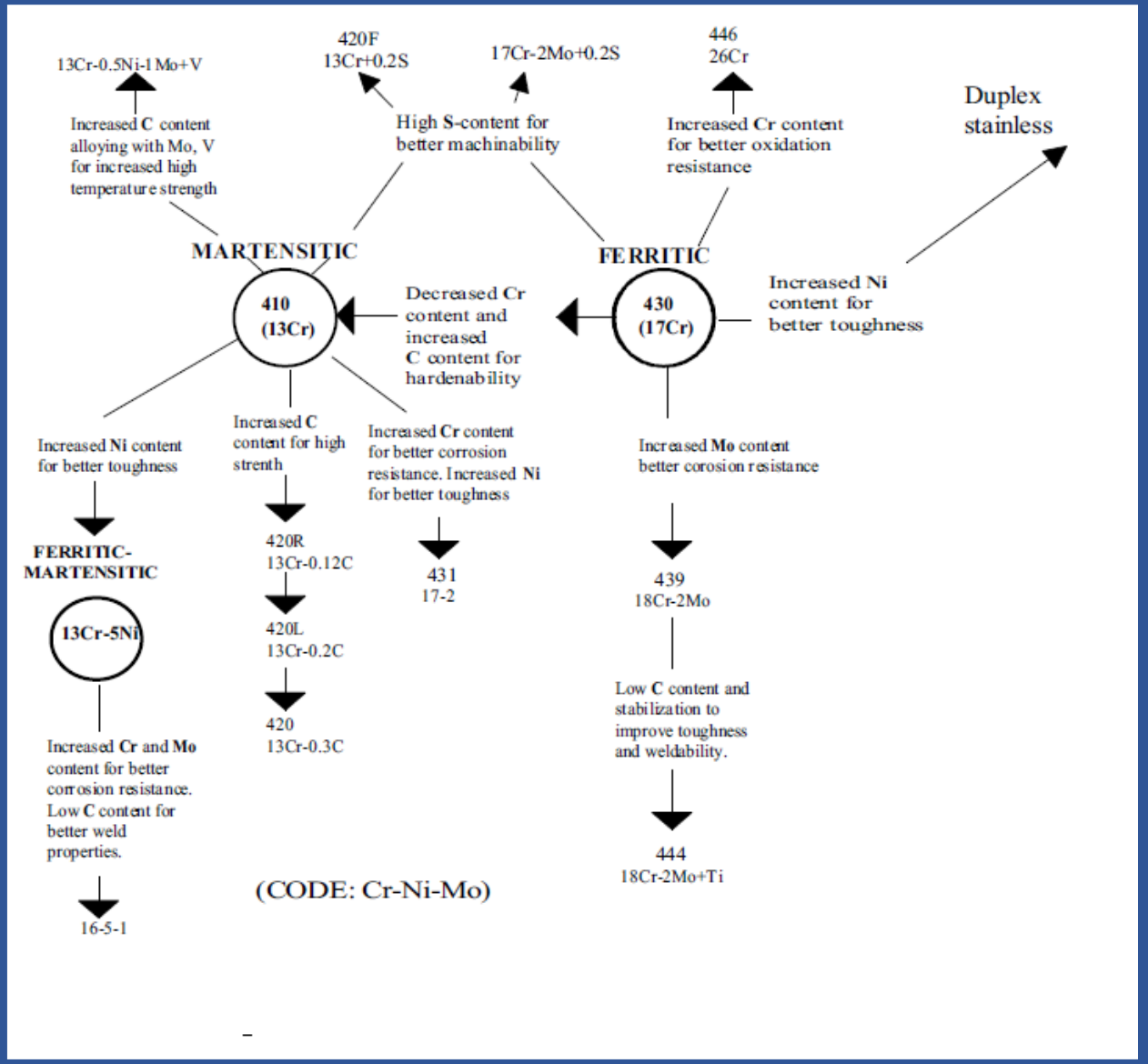
The Schaeffler-Delong diagram

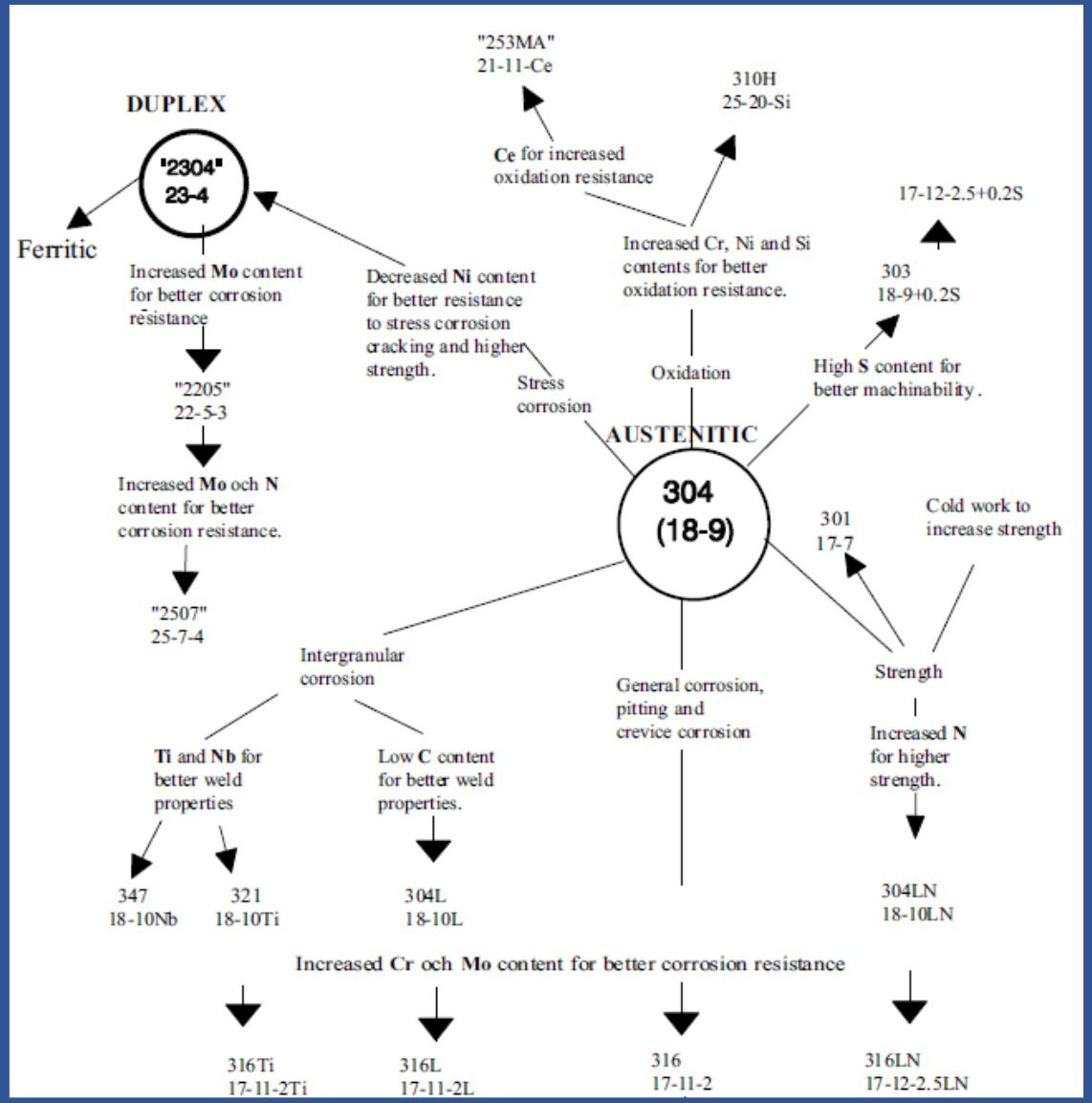
Mechanical Properties of Stainless Steels

Steel grade		$R_{p0.2}$	$R_{p1.0}$	R_m	A_5
ASTM	AvestaPolarit	(MPa)	(MPa)	(MPa)	(%)
Martensitic					
410S		540		690	20
"420L"		780		980	16
431		690		900	16
Ferritic-martensitic					
-	248 SV	790	840	930	18
446	-	340		540	25
444	Elit 18-2	390		560	30
Ferritic-austenitic (Duplex)					
S32304	SAF2304	470	540	730	36
S31803	2205	500	590	770	36
S32750	SAF2507	600	670	850	35
Austenitic					
304	18-9	310	350	620	57
304L	18-10L	290	340	590	56
304LN	18-9LN	340	380	650	52
304N	18-8N	350	400	670	54
321	18-10Ti	280	320	590	54
316L	17-11-2L	310	350	600	54
316Ti	17-11-2Ti	290	330	580	54
316	17-12-2.5	320	360	620	54
316L	17-12-2.5L	300	340	590	54
317L	18-13-3L	300	350	610	53
S31726	17-14-4LN	320	360	650	52
N08904	904L	260	310	600	49
S31254	254 SMO	340	380	690	50
S32654	654 SMO	520	560	890	55
Austenitic (heat resistant steels)					
310S	25-20	290	330	620	50
S30415	153 MA	380	410	700	50
S30815	253 MA	410	440	720	52
S35315	353 MA	360	400	720	50


Impact strength (KV), (J)
250
200
150
100
50
0
Austenitic
Ferritic
Duplex
Martensitic
-200
-150
-100
-50
0
+50
+100
Temperature (°C)


Yield stress ($R_{p0.2}$)
Creep strength ($R_{k/m\ 100000}$)
(MPa)
1100
1000
900
800
700
600
500
400
300
200
100
0
Martensitic
Duplex
Ferritic
Austenitic
Creep strength
0
100
200
300
400
500
600
700
Temperature (°C)


13Cr-0.5Ni-1Mo+V
420F
13Cr+0.2S
17Cr-2Mo+0.2S
446
26Cr
Duplex stainless
Increased C content alloying with Mo, V for increased high temperature strength
High S-content for better machinability
Increased Cr content for better oxidation resistance
MARTENSITIC
FERRITIC
410 (13Cr)
430 (17Cr)
Decreased Cr content and increased C content for hardenability
Increased Ni content for better toughness
Increased Ni content for better toughness
Increased C content for high strenth
Increased Cr content for better corrosion resistance. Increased Ni for better toughness
Increased Mo content better corosion resistance
FERRITIC-MARTENSITIC
13Cr-5Ni
420R
13Cr-0.12C
420L
13Cr-0.2C
420
13Cr-0.3C
431
17-2
439
18Cr-2Mo
Low C content and stabilization to improve toughness and weldability.
444
18Cr-2Mo+Ti
Increased Cr and Mo content for better corrosion resistance. Low C content for better weld properties.
16-5-1
(CODE: Cr-Ni-Mo)


"253MA"
21-11-Ce
310H
25-20-Si
DUPLEX
"2304"
23-4
Ce for increased
oxidation resistance
17-12-2.5+0.2S
Ferritic
Increased Mo content
for better corrosion
resistance
Decreased Ni content
for better resistance
to stress corrosion
cracking and higher
strength.
Increased Cr, Ni and Si
contents for better
oxidation resistance.
303
18-9+0.2S
"2205"
22-5-3
Stress
corrosion
Oxidation
High S content for
better machinability.
AUSTENITIC
304
(18-9)
Increased Mo och N
content for better
corrosion resistance.
301
17-7
Cold work to
increase strength
"2507"
25-7-4
Intergranular
corrosion
General corrosion,
pitting and
crevice corrosion
Strength
Ti and Nb for
better weld
properties
Low C content
for better weld
properties.
Increased N
for higher
strength.
347
18-10Nb
321
18-10Ti
304L
18-10L
304LN
18-10LN
Increased Cr och Mo content for better corrosion resistance
316Ti
17-11-2Ti
316L
17-11-2L
316
17-11-2
316LN
17-12-2.5LN

References

https://www.nickelinstitute.org/~/media/Files/TechnicalLiterature/StainlessSteels_AnIntroductiontotheirMetallurgyandCorrosionResistance_14056_.ashx

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