Lec. (3)

Prosthetics and orthotics
Materials Science

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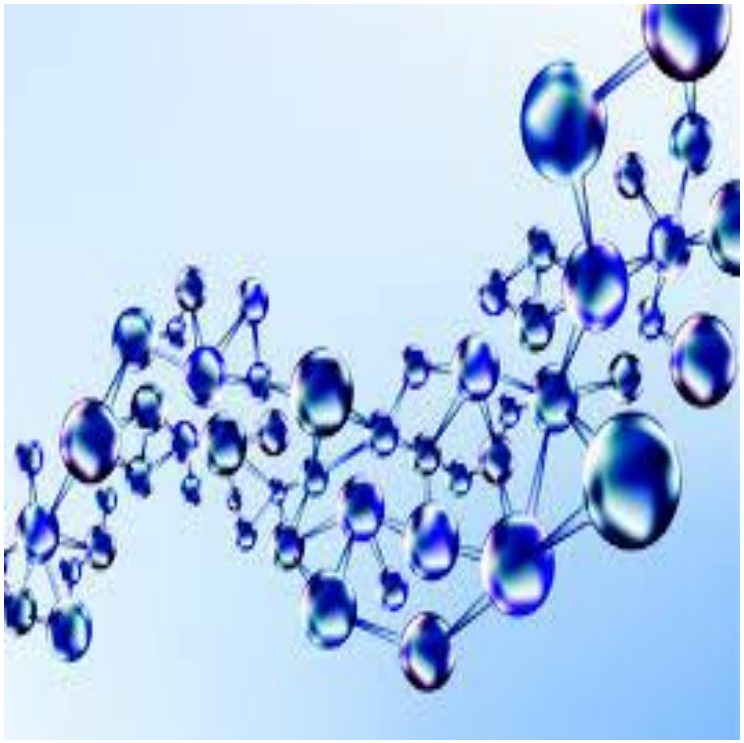

Lecture 3

Stainless Steel

(Fe-Cr alloys, min 10-12 w-% Cr)

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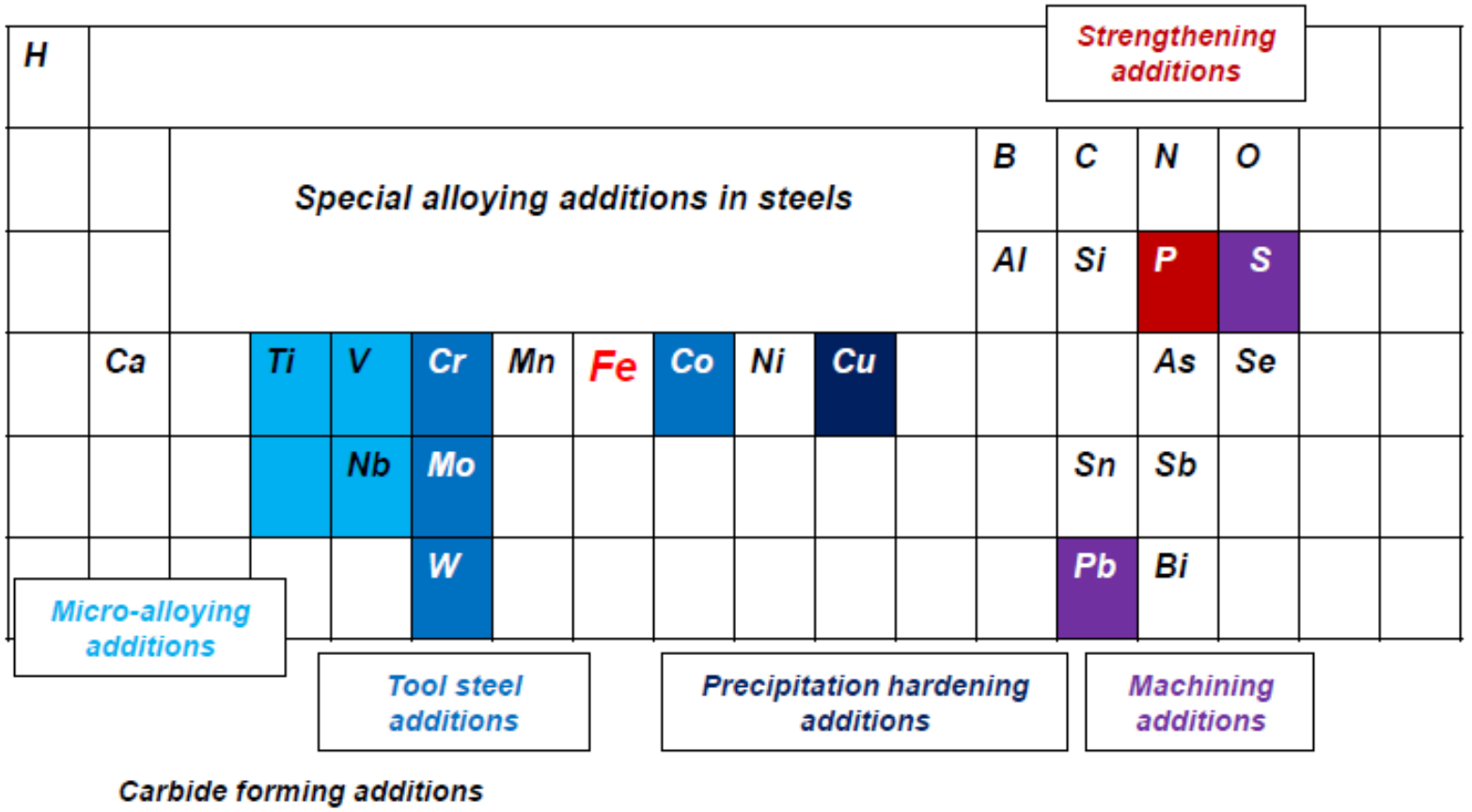
Steel: Alloying



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Microstructure of stainless steels

Review of the properties of alloying elements in stainless steels

Chromium: Corrosion protection, ferrite stabilizer, carbide former ($M_{23}C_6$), nitride former (Cr_2N)

Nickel: austenite stabilizer, toughness improving element in ferrite-martensite

Manganese: always present in steels (1-2% in stainless steels), austenite stabilizer, sulfide former (MnS), increases N-solubility in austenite

Silicon: always present in steels (0.3-0.6% in stainless steels, de-oxidation of steel), improves heat resistance (4-5%)

Molybdenum: improves corrosion resistance, high temperature strength

Nb, Ti, V: MC carbide forming elements

Al, Ti, Cu: promote precipitation hardening by Ni_3Ti, Ni_3Al, or Cu precipitates

C: solid solution strengthening, austenite stabilizer, critical in martensitic grades

N: solid solution strengthening, austenite stabilizer, increases corrosion resistance

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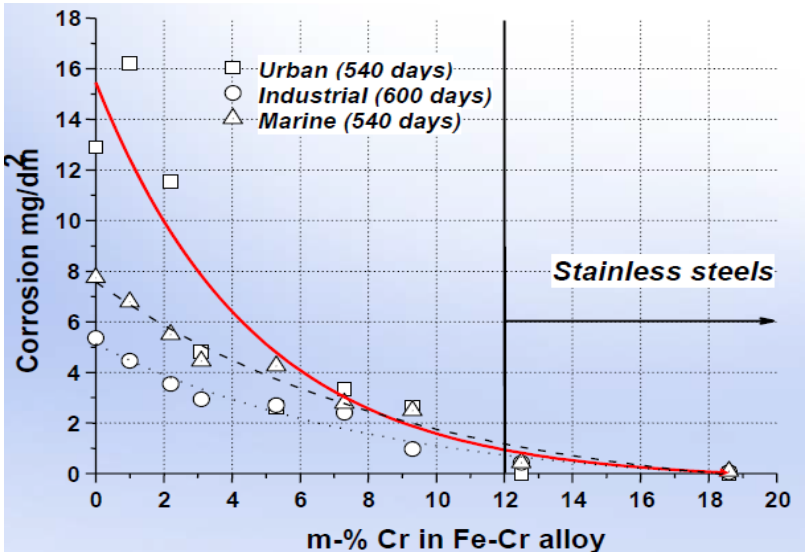
Stainless Steel

- Stainless Steel is a common name for metal alloys that consist of 10 % or more Cr. Although it is called "stainless", a better term for it is "highly stain resistant".



- Stainless steel differs from carbon steel by the amount of chromium present. Carbon steel rusts when exposed to air and moisture. This iron oxide film is active and accelerates corrosion by forming more iron oxide.
- Stainless steels have sufficient amounts of chromium present so that a passive film of chromium oxide forms which prevents further surface corrosion and blocks corrosion from spreading into the metal's internal structure.

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Properties of Stainless Steel

1. Corrosion resistance (process and food products industries)

- High oxidation-resistance in air at ambient temperature are normally achieved with additions of a minimum of 13% (by weight) chromium, and up to 26% is used for harsh environments.
- The chromium forms a passivation layer of chromium-oxide (Cr_2O_3) when exposed to oxygen. The layer is too thin to be visible, and the metal remains lustrous.
- It is impervious to water and air, protecting the metal beneath. Also, **this layer quickly reforms when the surface is scratched.** This phenomenon is called **passivation** and is seen in other metals, such as **aluminium** and **titanium**

2. Hygienic properties

- The clean-ability of stainless steel makes it the first choice in hospitals, kitchens, food and pharmaceutical processing facilities.

Properties of Stainless Steel

3. High and Low Temperature Resistance

- Some grades will resist scaling and maintain high strength at very high temperatures, while others show exceptional toughness at cryogenic temperatures.

4. Ease of fabrication

- The majority of stainless steels can be cut, welded, formed, machined and fabricated readily

5. Strength (Structural material)

- The cold work hardening properties of many stainless steels can be used in design to reduce material thickness and reduce weight and costs.
- Other stainless steels may be heat treated to make very high strength components
- Excellent dimensional tolerances

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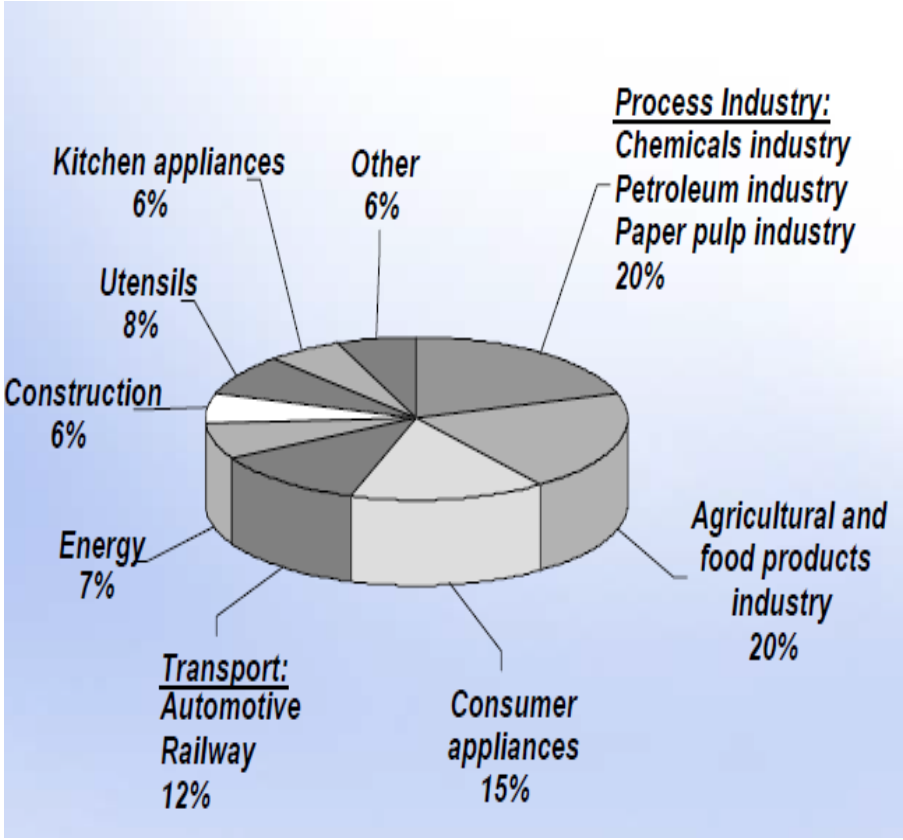
Applications Of Stainless Steel

- Medical and pharmaceutical industries
- Chemical industry
- Food processing and beverage industry
- General building and construction industries
- General architecture
- External building applications
- Internal building applications
- Nuclear industry



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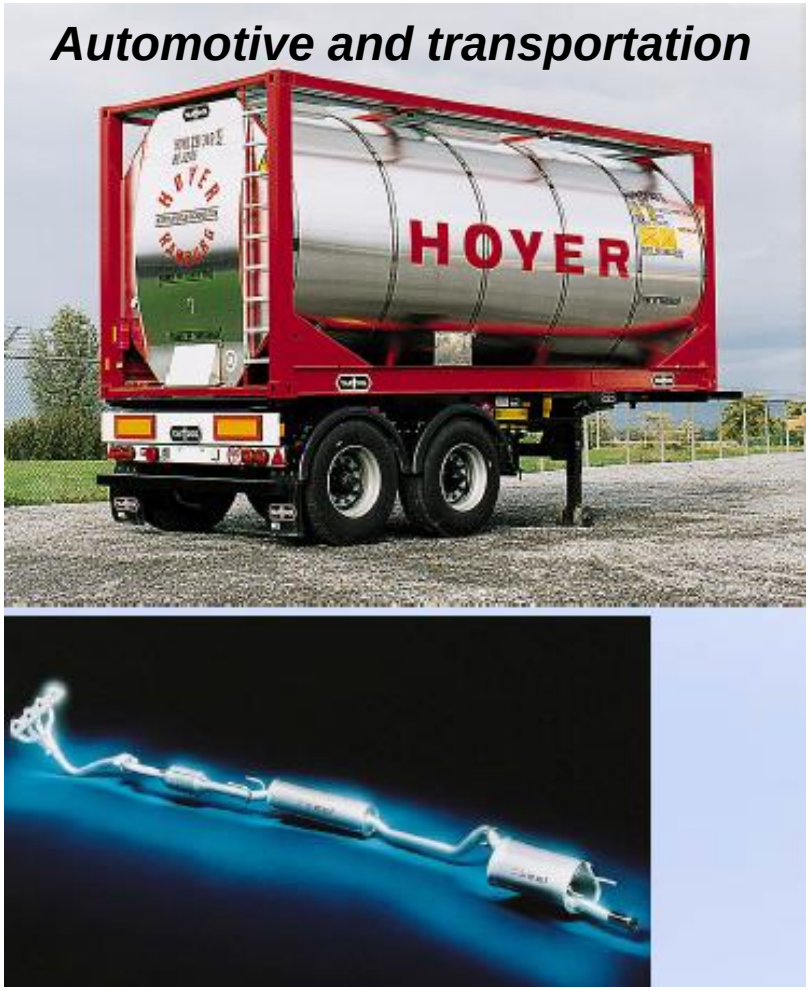
Common Applications Of Stainless Steel



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Common Applications Of Stainless Steel

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Common Applications Of Stainless Steel in Prosthetics and orthotics Materials Science

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Types of Stainless Steel

- In addition to **chromium**, **nickel**, **molybdenum**, **titanium**, **niobium** and other elements may also be added to stainless steels in varying quantities to produce a range of stainless steel grades, each with different properties.
- There are a number of grades to chose from, but all stainless steels can be divided into five basic categories as follow:
    1. **Ferritic**
    2. **Austenitic**
    3. **Martensitic**
    4. **Duplex**
    5. **Precipitation hardening (P-H)**
- These are named according to the microstructure inherent in each steel group. Austenitic and ferritic grades account for approximately 95% of stainless steel applications.

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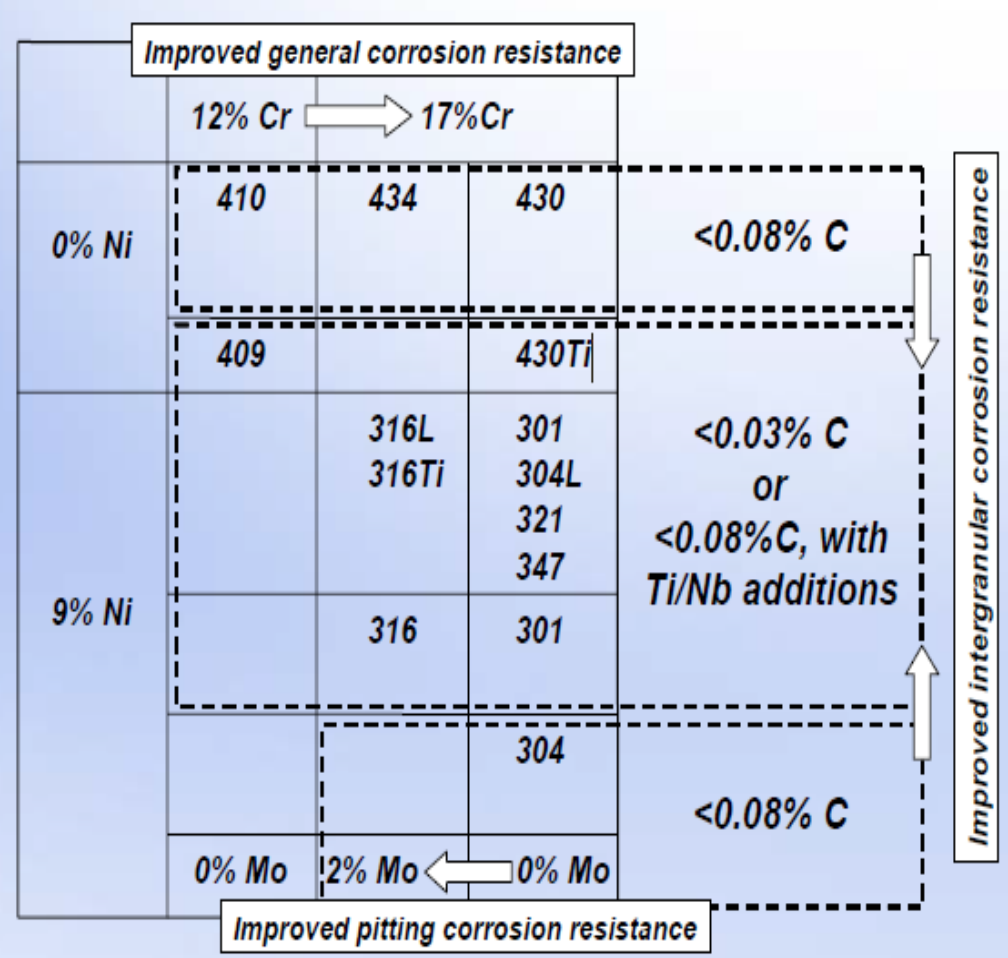
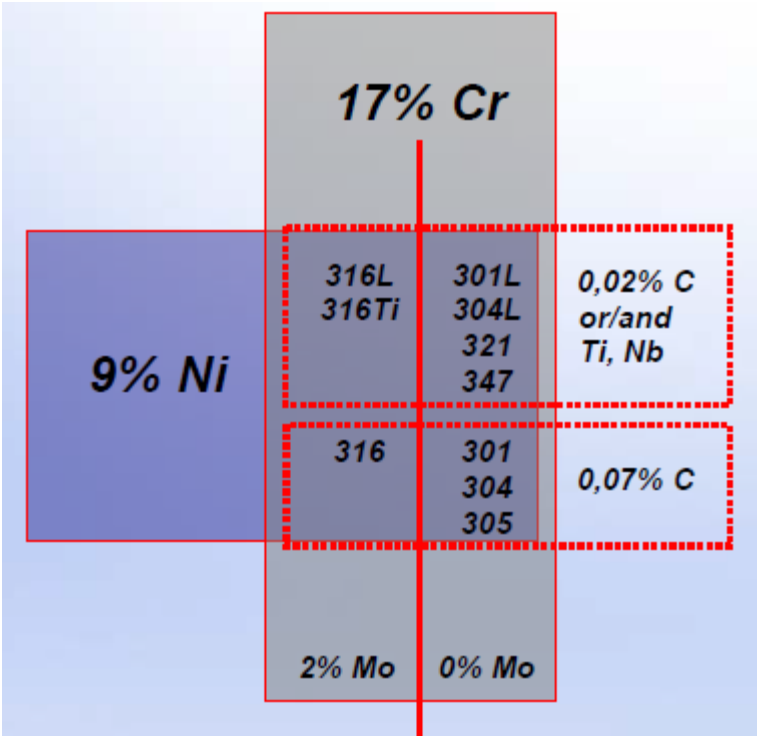
Types of Stainless Steel





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Types of Stainless Steel

	C	Si max	Mn Max	Cr	Mo max	Ni	Cu max	Nb	Ti	Al	V	N	S
Ferritic	≤ 1	1	1	15-18	2.0	< 1		+	+	+			
Martensitic	0.1-0.2	1	1.5	12-18	1.2	≤ 2.5					+		+
Austenitic	≤ 0.1	1	2	17-26	5.0	7-26	2.2	+	+			+	+
Duplex	≤ 0.1	1	2	24-28	2.0	4-7.5		+					

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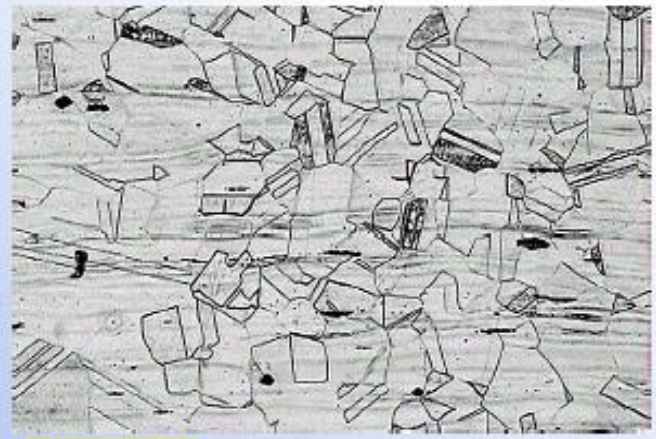
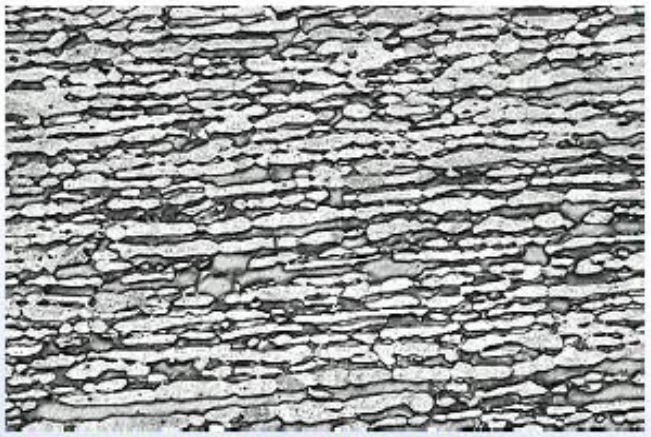
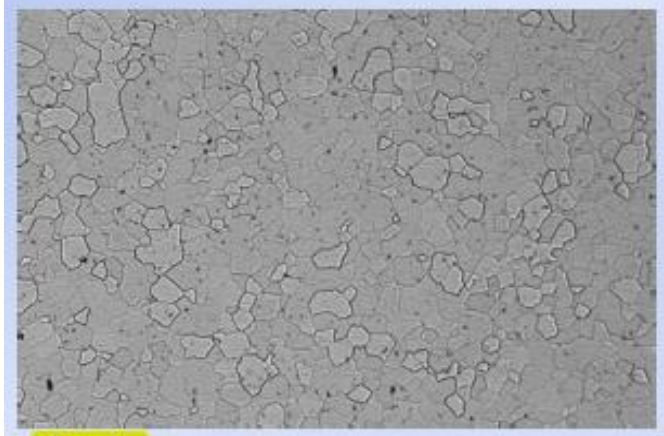
Types of Stainless Steel



Austenite



Duplex: ferrite + austenite



Ferrite

Martensite

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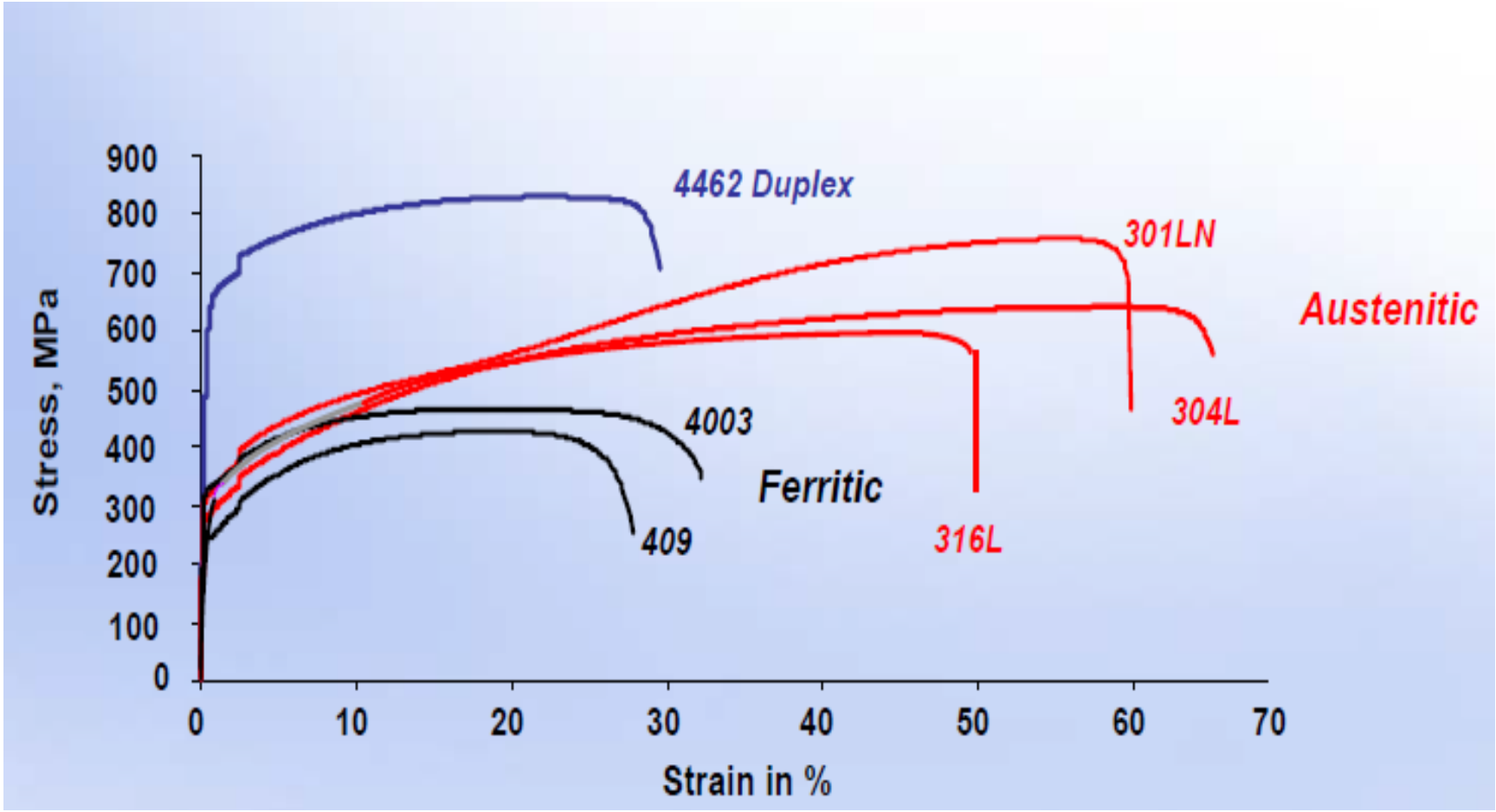
Types of Stainless Steel



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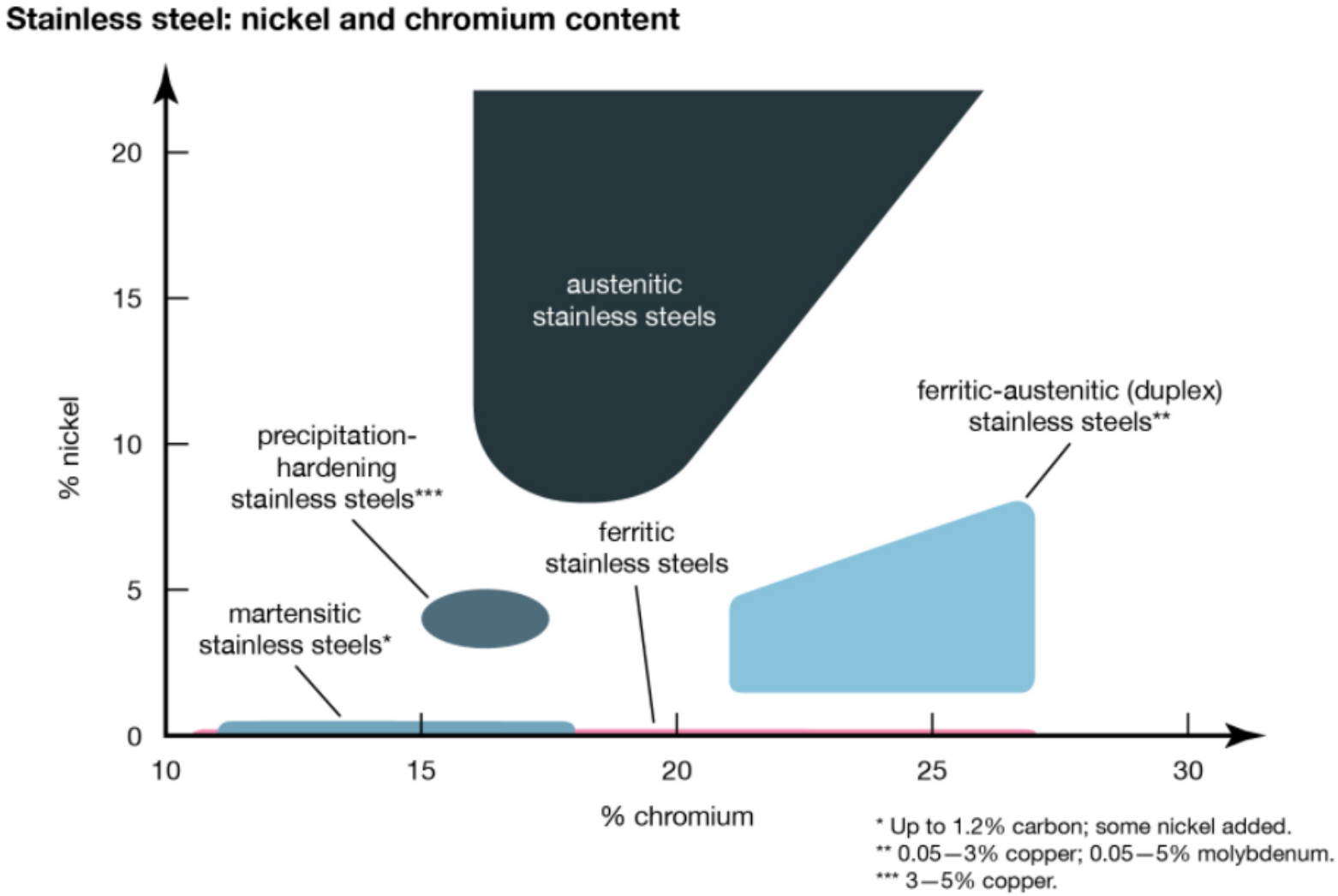
Types of Stainless Steel



Ferritic Stainless steel

Ferritic stainless steels are essentially chromium containing alloys with BCC crystal structures.

Chromium content is usually in the range of **10.5 to 30%**. Some grades may contain molybdenum, silicon, aluminum, titanium, and niobium to confer particular characteristics.

Sulfur may be added to improve machinability.

The ferritic alloys:

- Ferromagnetic,
- Have good ductility and formability,
- High-temperature strengths are relatively poor compared to the austenitic grades.
- Toughness may be limited at low temperatures and in heavy sections.

Ferritic Stainless steel

Ferritic stainless steel are typically used in:

- Vehicle exhausts
- Fuel lines
- Cooking utensils
- Architectural trim
- Domestic appliances

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Austenitic Stainless steel
(16-26 % Cr; up to about 14%Ni)

Austenitic stainless steels have a face-centered cubic structure. This structure is attained through the liberal use of austenitizing elements such as nickel, manganese, and nitrogen.

These steels are essentially

- Excellent corrosion resistance in organic acid, industrial and marine environments
- Nonmagnetic in the annealed condition
- Can be hardened only by cold working.
- Have excellent cryogenic properties
- Good high-temperature strength.
- Excellent weldability and formability

Austenitic Stainless steel
(16-26 % Cr; up to about 14%Ni)

The 2xx series steels contain nitrogen, 4 to 15.5% Mn, and up to 7% Ni.

The 3xx types contain larger amounts of nickel and up to 2% Mn.

Molybdenum, copper, silicon, aluminum, titanium, and niobium may be added to confer certain characteristics such as halide pitting resistance or oxidation resistance.

Sulfur or selenium may be added to certain grades to improve machinability

Austenitic Stainless steel (16-26 % Cr; up to about 14%Ni)

Austenitic stainless steel are typically used in:

- Kitchen sinks
- Architectural applications such as roofing and cladding
- Roofing and gutters
- Doors and Windows
- Balustrading
- Benches and food preparation areas
- Food processing equipment
- Heat exchangers
- Ovens
- Chemical tanks

Martensitic Stainless steel

Martensitic stainless steels are essentially alloys of chromium and carbon that possess a distorted body-centered cubic crystal structure (martensitic) in the hardened condition.

They are:

- Ferromagnetic,
- Hardenable by heat treatments, and
- Resistant to corrosion only to relatively mild environments.
- High strength and hardness levels
- Poor weldability

Chromium content is generally in the range of **10.5 to 18%,** and carbon content may exceed **1.2%**.

Martensitic Stainless steel

The chromium and carbon contents are balanced to ensure a martensitic structure after hardening.

Excess carbides may be present to increase wear resistance or to maintain cutting edges, as in the case of knife blades.

Elements such as niobium, silicon, tungsten, and vanadium may be added to modify the tempering response after hardening.

Small amounts of nickel may be added to improve corrosion resistance in some media and to improve toughness. Sulfur or selenium is added to some grades to improve machinability

Martensitic Stainless steel

Martensitic stainless steel are typically used in:

- Knife blades
- Cutlery
- Surgical instruments
- Fasteners
- Shafts
- Springs

Duplex Stainless steel

Duplex stainless steels have a mixed structure of BCC ferrite and FCC austenite.

The exact amount of each phase is a function of composition and heat treatment . Most alloys are designed to contain about equal amounts of each phase in the annealed condition.

The principal alloying elements are chromium and nickel, but nitrogen, molybdenum, copper, silicon, and tungsten may be added to control structural balance and to impart certain corrosion-resistance characteristics

Duplex Stainless steel

The corrosion resistance of duplex stainless steels is like that of austenitic stainless steels with similar alloying contents.

However, duplex stainless steels possess higher tensile and yield strengths and improved resistance to stress-corrosion cracking than their austenitic counterparts.

The toughness of duplex stainless steels is between that of austenitic and ferritic stainless steels

Duplex Stainless steel

Duplex Stainless steel are typically used in:

- Heat exchangers
- Marine applications
- Desalination plants
- Food pickling plants
- Off-shore oil & gas installations
- Chemical & petrochemical plant

Precipitation-Hardening Stainless steel

Precipitation-hardening stainless steels are chromium-nickel alloys containing precipitation-hardening elements such as copper, aluminum, or titanium.

Precipitation-hardening stainless steels may be either austenitic or martensitic in the annealed condition.

Those that are austenitic in the annealed condition are frequently transformable to martensite through conditioning heat treatments, sometimes with a subzero treatment.

In most cases, these stainless steels attain high strength by precipitation hardening of the martensitic structure

Precipitation-Hardening Stainless steel

Precipitation-Hardening Stainless steel are typically used in:

- Pulp and paper industry equipment
- Aerospace applications
- Turbine blades
- Nuclear waste casks
- Mechanical components

Classification of Stainless Steel

Classification of stainless steels according to AISI and UNS

(AISI: American Iron and Steel Institute), (UNS: Universal Numbering System)

1. Type 400: Ferritic stainless steels
2. Type 300: Austenitic stainless steels
3. Type 200: Austenitic stainless steels with Mn
4. Type 400: Martensitic stainless steels
5. UNS: Duplex stainless steels
6. UNS: Precipitation-hardened stainless steels

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Classification of Stainless Steel

AISI stainless steel classification scheme.

AISI: American Iron and Steel Type Number	Commonly used Type AISI 300 grades and type numbers
Type 200: Cr-Ni/Mn(N) austenitic	
Type 300: Cr-Ni austenitic	302: 18Cr-8Ni 303: free-machining 18Cr-8Ni, with min 0.07% Se, P or S 304: 18Cr-10Ni (C<0.08%) 316: Mo-additions 321: Ti-additions 347: Nb-additions
Type 400: Cr ferritic Cr-C martensitic	409: ferritic stainless steel 437: ferritic stainless steel 410: martensitic stainless steel

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Classification of Stainless Steel

Type	UNS number	Composition (wt %)[a] C	Mn	Si	Cr	Ni	Mo	Cu	Al
Austenitic Types									
201[b]	S20100	0.15	5.5–7.5	1.00	16.0–18.0	3.5–5.5			
304	S30400	0.08	2.00	1.00	18.0–20.0	8.0–10.5			
310	S31000	0.25	2.00	1.50	24.0–26.0	19.0–22.0			
316	S31600	0.08	2.00	1.00	16.0–18.0	10.0–14.0	2.0–3.0		
347[c]	S34700	0.08	2.00	1.00	17.0–19.0	9.0–13.0			
Ferritic Types									
405	S40500	0.08	1.00	1.00	11.5–14.5				0.10–0.30
430	S43000	0.12	1.00	1.00	16.0–18.0				
Martensitic Types									
410	S41000	0.15	1.00	1.00	11.5–13.0				
501	S50100	0.10 min	1.00	1.00	4.0–6.0		0.40–0.65		
Precipitation-Hardening Types									
17–4 PH[d]	S17400	0.07	1.00	1.00	15.5–17.5	3.0–5.0		3.0–5.0	
17–7 PH	S17700	0.09	1.00	1.00	16.0–18.0	6.5–7.75			0.75–1.5

Source: Data from *Metals Handbook*, 9th ed., Vol. 3, American Society for Metals, Metals Park, OH, 1980.

[a] Single values are maximum values unless otherwise indicated.

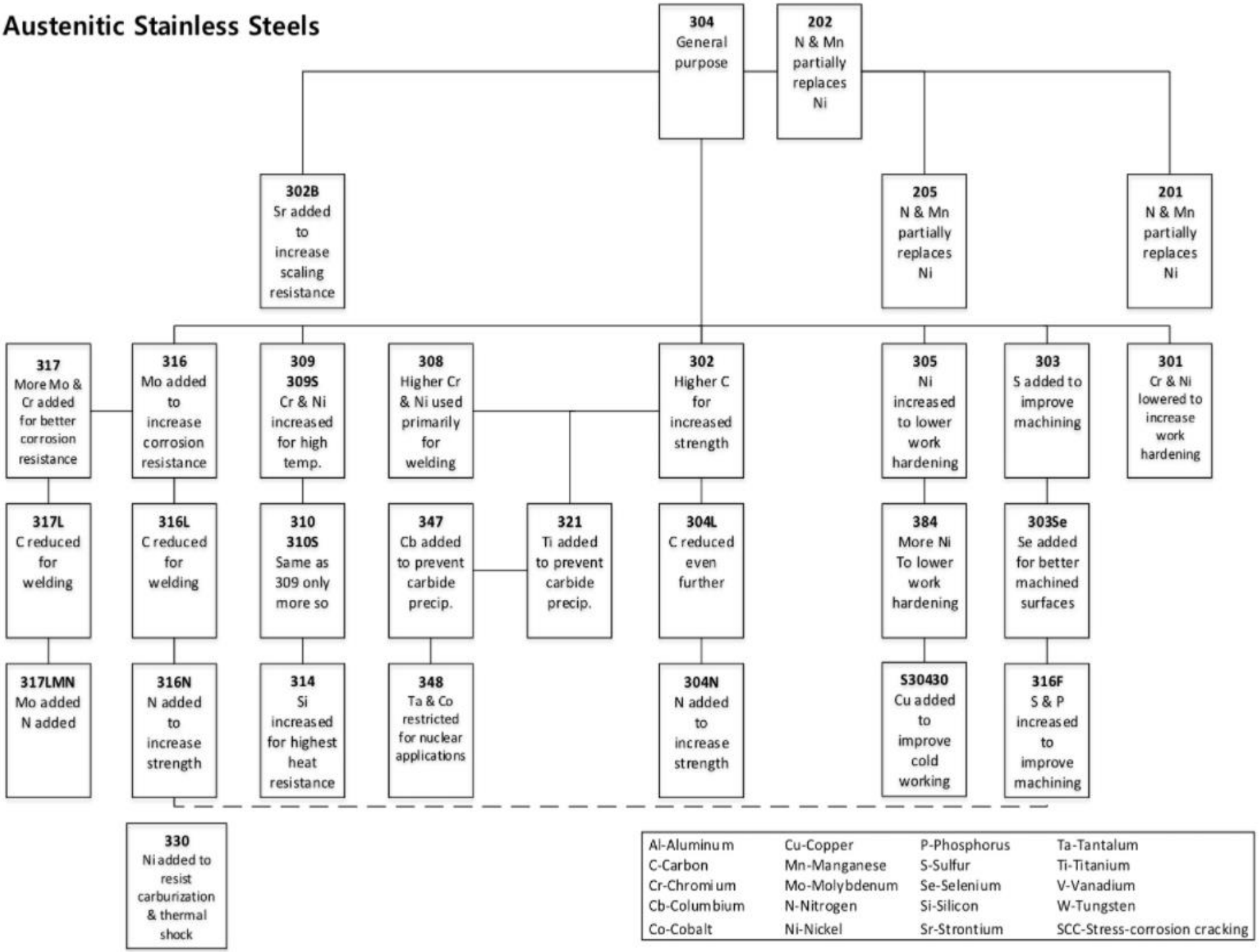
[b] 0.25 wt % N.

[c] $10 \times \%C = \min Nb + Ta$ (optional).

[d] 0.15 – 0.45wt % Nb+Ta.

Alloy Designations for Some Common Stainless Steels.

Austenitic Stainless Steels



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- Questions…