

***Some notes on
metallic materials***

Artificial shoulder joint



Artificial dental root



Artificial elbow joint



Spinal fixation devices



Artificial hip joint



Artificial finger joint



Artificial ankle joint



Artificial knee joint



Osteosynthesis devices



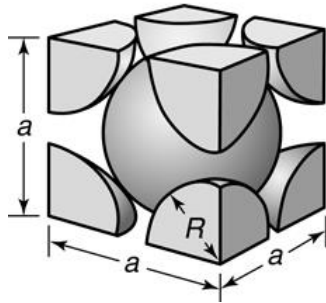
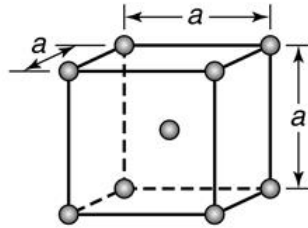
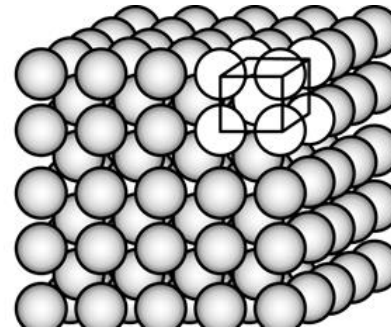
Metallic implants for orthopaedic surgery and dentistry

Clinical division	Medical device	Material
Orthopaedic surgery	Spinal fixation	316L stainless steel; Ti; Ti-6Al-4V; Ti-6Al-7Nb
	Bone fixation (bone plate, screw, wire, bone nail, mini-plate, etc.)	316L stainless steel; Ti; Ti-6Al-4V; Ti-6Al-7Nb
	Artificial joint; bone head	Co-Cr-Mo; Ti-6Al-4V; Ti-6Al-7Nb
	Spinal spacer	316L stainless steel; Ti-6Al-4; Ti-6Al-7Nb
Cardiovascular medicine and surgery	Implant-type artificial heart (housing)	Ti
	Pace maker (case)	Ti; Ti-6Al-4V
	(electric wire)	Ni-Co
	(electrode)	Ti; Pt-Ir
	(terminal)	Ti; 316L stainless steel; Pt
	Artificial valve (frame)	Ti-6Al-4V
	Stent	316L stainless steel; Ti-N; Ta; Co-Cr-Mo
	Guide-wire	316L stainless steel; Ti-Ni; Co-Cr
	Embolization wire	Pt
	Clip	Ti-6Al-4V; 630 stainless steel; Co-Cr
Otorhinology	Artificial inner ear (electrode)	Pt
	Artificial eardrum	316L stainless steel
Dentistry	Filling	Au foil; Ag-Sn(-Cu) amalgam
	Inlay, crown; bridge; clasp; denture base	Au-Cu-Ag; Au-Cu-Ag-Pt-Pd; Ti; Ti-6Al-7Nb; Co-Cr; 304 stainless steel; 316L stainless steel
	Thermosetting resin facing crown; porcelain-fused-to-metal	Au-Pt-Pd; Ni-Cr
	Solder	Au-Cu-Ag; Au-Pt-Pd
	Dental implant	Ti; Ti-6Al-4V; Ti-6Al-7Nb; Au
	Orthodontic wire	316L stainless steel; Co-Cr; Ti-Ni; Ti-Mo
	Magnetic attachment	Sm-C; Nd-Fe-B; Pt-Fe-Nb; 444 stainless steel; 447J1 stainless steel; 316L stainless steel
	Treatment device (bar, scaler, periodontal probe, dental tweezers, raspatory, etc.)	304 stainless steel
	Needle of syringe	304 stainless steel
	Scalpel	420J1 stainless steel
	Catheter	Ni-Ti; 304 stainless steel; 316L stainless steel; Co-Cr; Au; Pt-In
	Staple	630 stainless steel

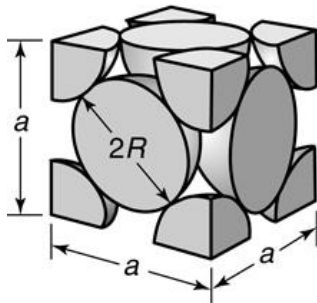
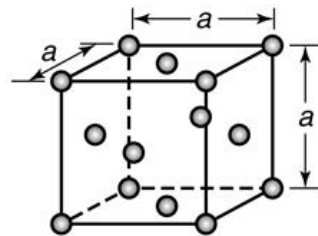
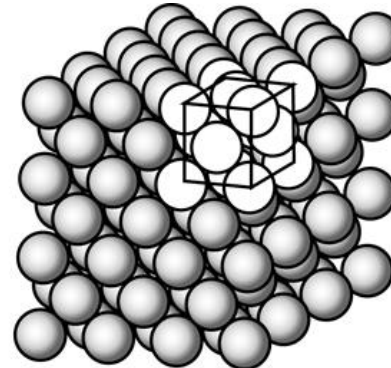
Metallic materials for biomedical applications

Materials		Mechanical property Tensile strength	Workability			Corrosion resistance
			Wear resistance	Plasticity	Machinability	Pitting
Stainless steel	Type 316L	Good	Excellent	Excellent	Excellent	Excellent
Co-Cr alloy	Cast Annealed	Good Excellent	Good Good	Poor Good	Poor Good	Good Fair
Ti; Ti alloy	CP Ti Ti-6Al-4V	Excellent Excellent	Excellent Excellent	Fair Fair	Fair Excellent	Excellent Excellent

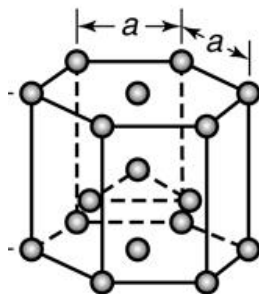
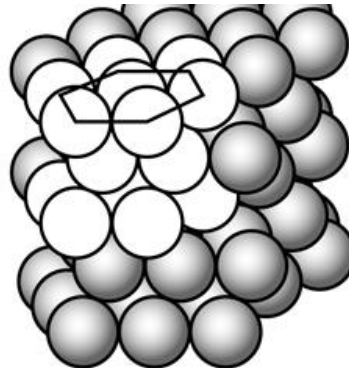
Crystallographic structure of metallic materials



Body-Centered
Cubic (BCC)
Structure

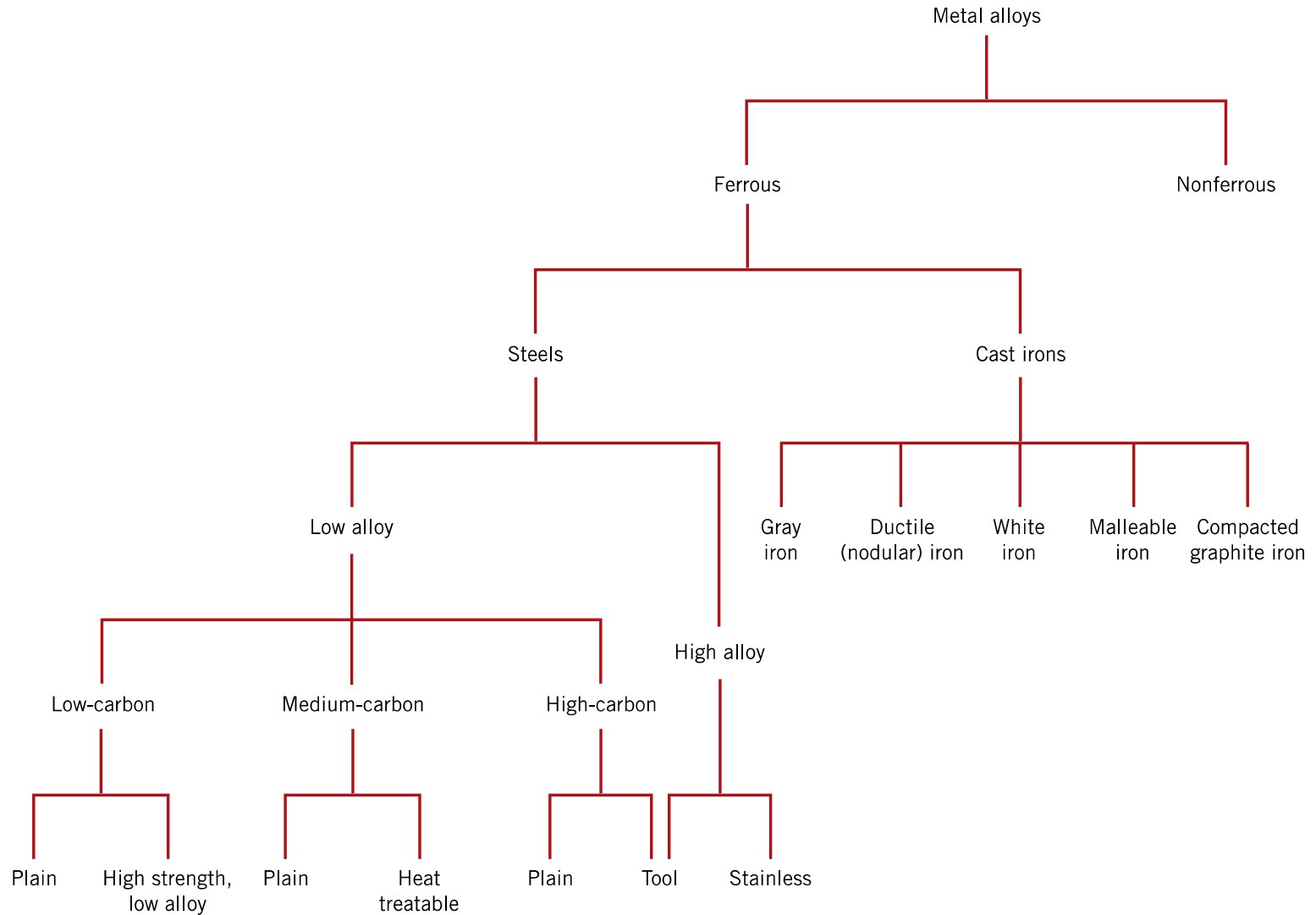


Face-Centered
Cubic (FCC)
Structure

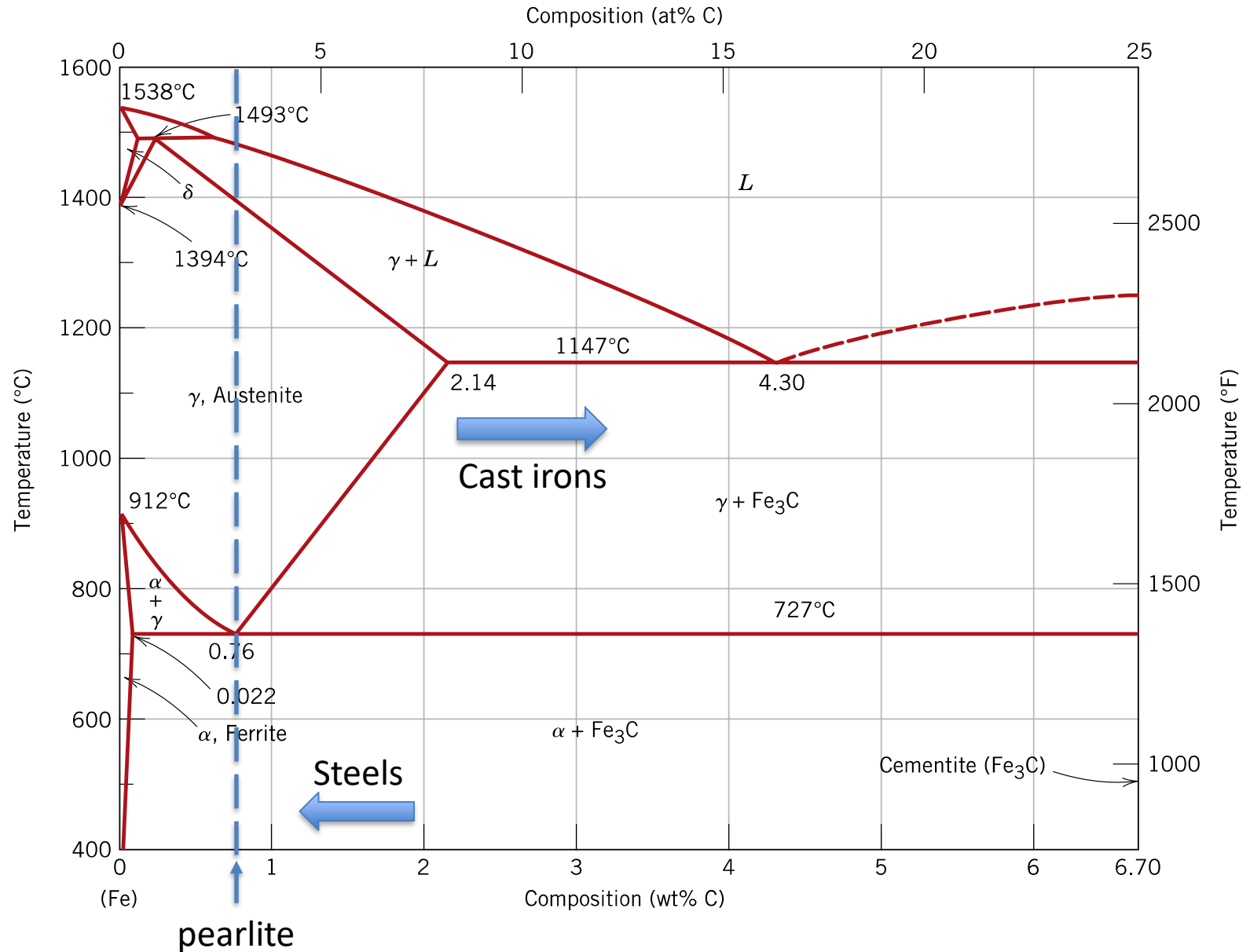


Hexagonal
Close Packed
(HCP) Structure

Classification of ferrous alloys



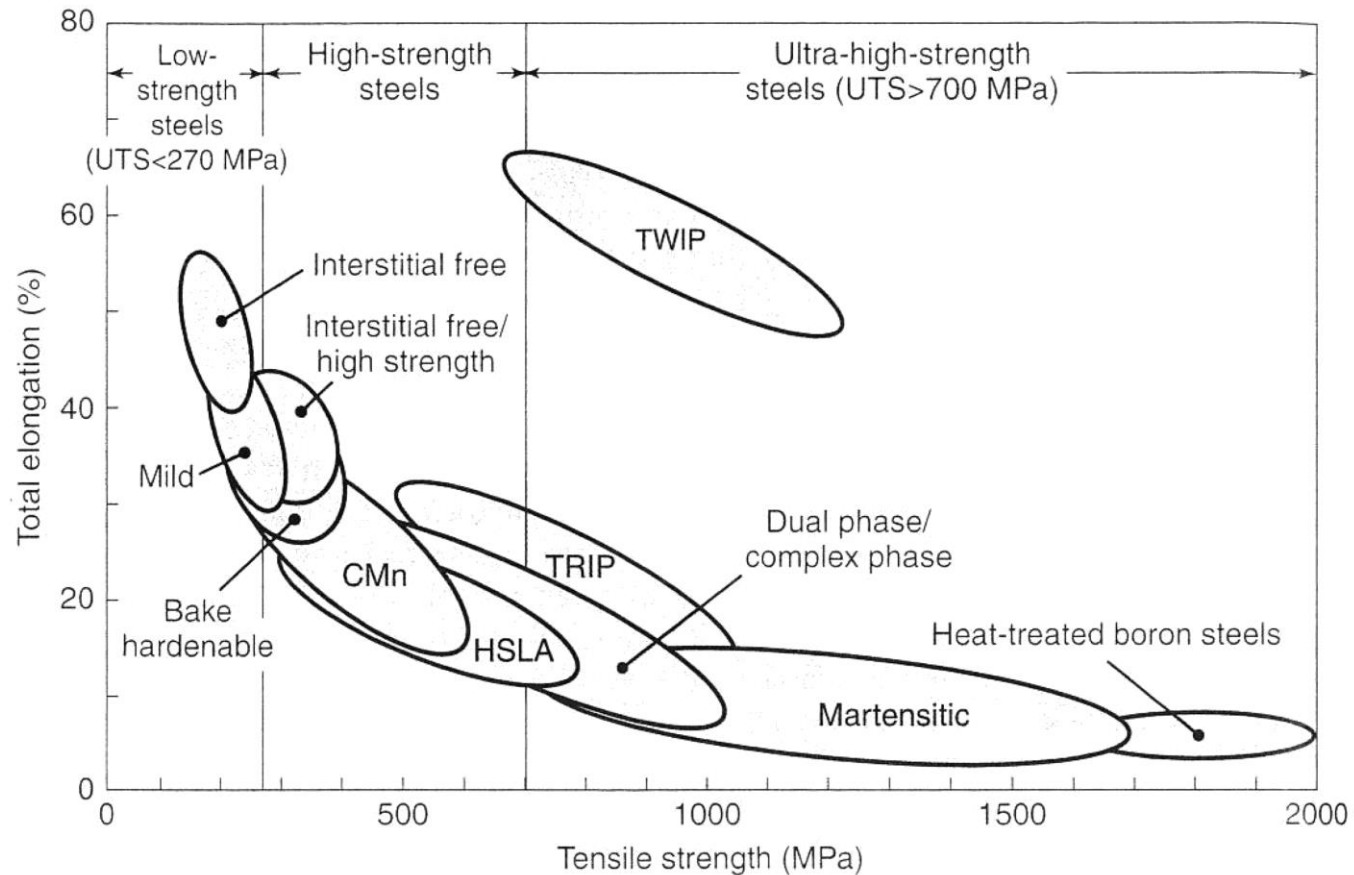
Classification of ferrous alloys



Steels - characteristics

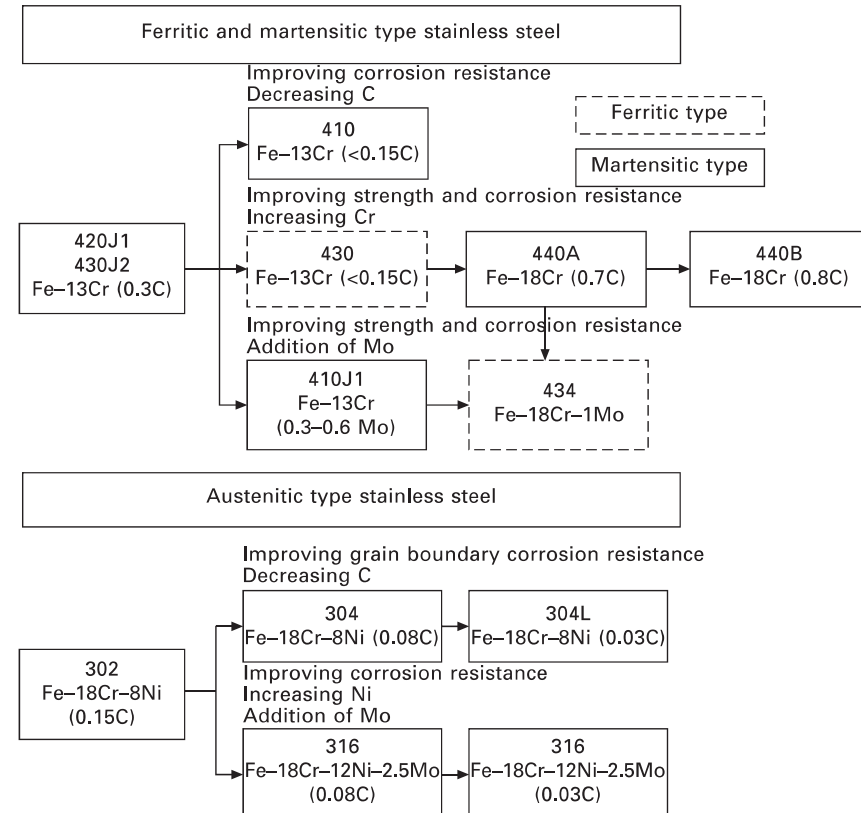
- Crystallographic structure: BCC till 950°C , FCC till 1425°C for carbon steels; FCC for most of the stainless steels
- Density: 7900 kg/m^3
- Average melting temperature: 1535°C
- Linear thermal expansion coefficient ($20\div 100^{\circ}\text{C}$): $12.2 \times 10^{-6} / ^{\circ}\text{C}$
- Redox potential: -0.04 V
- Young's modulus: $193\div 200 \times 10^9\text{ Pa}$

Steels – mechanical properties



Stainless steels

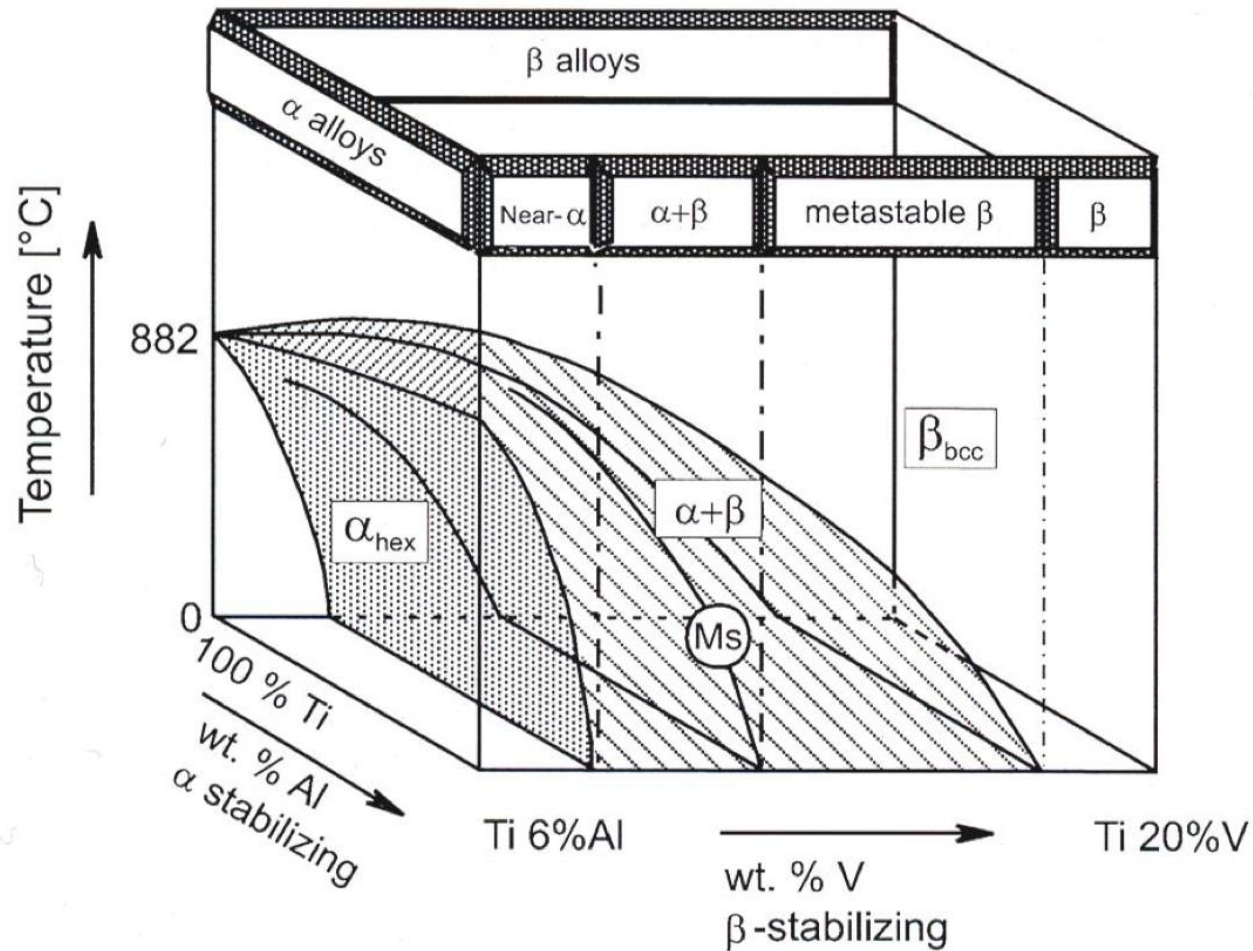
- Stainless steels are iron-based alloys containing over 12-13% mass of chromium.
- Not corroded under an oxygen atmosphere, but can be corroded by body fluids.



Titanium and titanium alloys – characteristics

- Crystallographic structure: HCP (α) till 880° C , BCC (β) above
- Density: 4500 kg/m^3
- Melting temperature: 1680° C
- Thermal conductivity: $17\text{ W/m}^{\circ}\text{ C}$
- Linear thermal expansion coefficient ($20\div 100^{\circ}\text{ C}$): $8.9 \times 10^{-6} / ^{\circ}\text{ C}$
- Electrical conductivity: 3% IACS (copper 100%)
- Redox potential: $+0.2\text{ V}$
- Young's modulus: $116 \times 10^9\text{ Pa}$
- Very high biocompatibility (especially in case of pure titanium)

Titanium and titanium alloys – classification



Titanium and titanium alloys – classification

- **Pure titanium CP**

Titanium with addition of small quantity of interstitial elements

High corrosion resistance

Low-medium mechanical characteristics

- **α alloys**

Higher mechanical characteristics than pure titanium, but lower corrosion resistance

Oxidation resistance till 300° -540° C

Thermal treatments not possible

- **$\alpha+\beta$ alloys**

High mechanical characteristics thanks to the possibility of carrying out thermal and thermo-mechanical treatments

The most utilized titanium alloys, e.g. **Ti6Al4V**

- **β alloys**

The highest mechanical properties, but the least ductile

Strength-to-weight ratio lower than in case of $\alpha+\beta$ alloys

Cobalt-chromium based alloys – characteristics

- Excellent mechanical properties
- Corrosion resistance higher than that of stainless steels
- Wear resistance higher than that of stainless steels and titanium alloys
- Plasticity and workability lower than that of stainless steels and titanium alloys

Materials		Tensile strength (MPa)	Proof strength (MPa)	Elongation (%)
Stainless steel	Type 316L	>480	>175	>40
	Solution treatment and annealing			
Co–Cr alloy	Cast	655	450	8
	ASTM F75–92			
	Wrought ASTM	860	310	30–45
	F90–92 Annealed			

Magnesium alloys – characteristics

- Crystallographic structure: HCP
- Density: 1740 kg/m^3
- Melting temperature: 650°C
- Thermal conductivity: $179 \text{ W/m}^\circ \text{C}$
- Redox potential: -2.37 V
- Young's modulus: $44 \times 10^9 \text{ Pa}$
- Biodegradable metals
- Need to control degradation and corrosion inside the human body

Mostly used biomedical metal alloys

Metals/Alloys	Benefits	Limitations
Commercially pure titanium (CP Ti)	<ul style="list-style-type: none"> - High biocompatibility - High resistance against corrosion - Direct apposition on bones - Moderately low elastic modulus 	<ul style="list-style-type: none"> - Poor fatigue and static strength for application in load-bearing implants - Low resistance against wear
Ti-6Al-4V	<ul style="list-style-type: none"> - Significant resistance against corrosion - Great biocompatibility - Direct apposition on bones - Moderately low elastic modulus - High strength in fatigue and static tests 	<ul style="list-style-type: none"> - Low wear resistance - Aluminum and vanadium ion release may cause health problems
Stainless steel 316 L	<ul style="list-style-type: none"> - Excellent ductility - High resistance against wear - Good machinability 	<ul style="list-style-type: none"> - Lower fatigue strength compared to other alloys used in implants - High elastic modulus - Poor resistance against corrosion and biocompatibility in comparison with other implants - Relatively high release of metal ions and adverse response of host organs
Co-Cr-based	<ul style="list-style-type: none"> - Excellent strength of static and fatigue - High resistance against corrosion - Good biocompatibility 	<ul style="list-style-type: none"> - Great elastic modulus - Lower corrosion resistant and biocompatibility compared with Ti alloys - Unfavorable host response to released Ni and Cr ions
NiTi (Nitinol)	<ul style="list-style-type: none"> - Good biocompatibility and corrosion resistance - Shape memory and high elastic effects - Poor stiffness 	<ul style="list-style-type: none"> - Adverse response of host organs to released Ni ions - Low wear resistance - Complicated production procedure
Magnesium-based	<ul style="list-style-type: none"> - Magnesium has good biocompatibility - Biodegradability - Lightness and low density - Good toughness 	<ul style="list-style-type: none"> - Rapid corrosion rate - Leaching of magnesium may cause health problems - Innovative fabrication and treatment processes are required for biomedical applications