Universidad
Carlos III de Madrid
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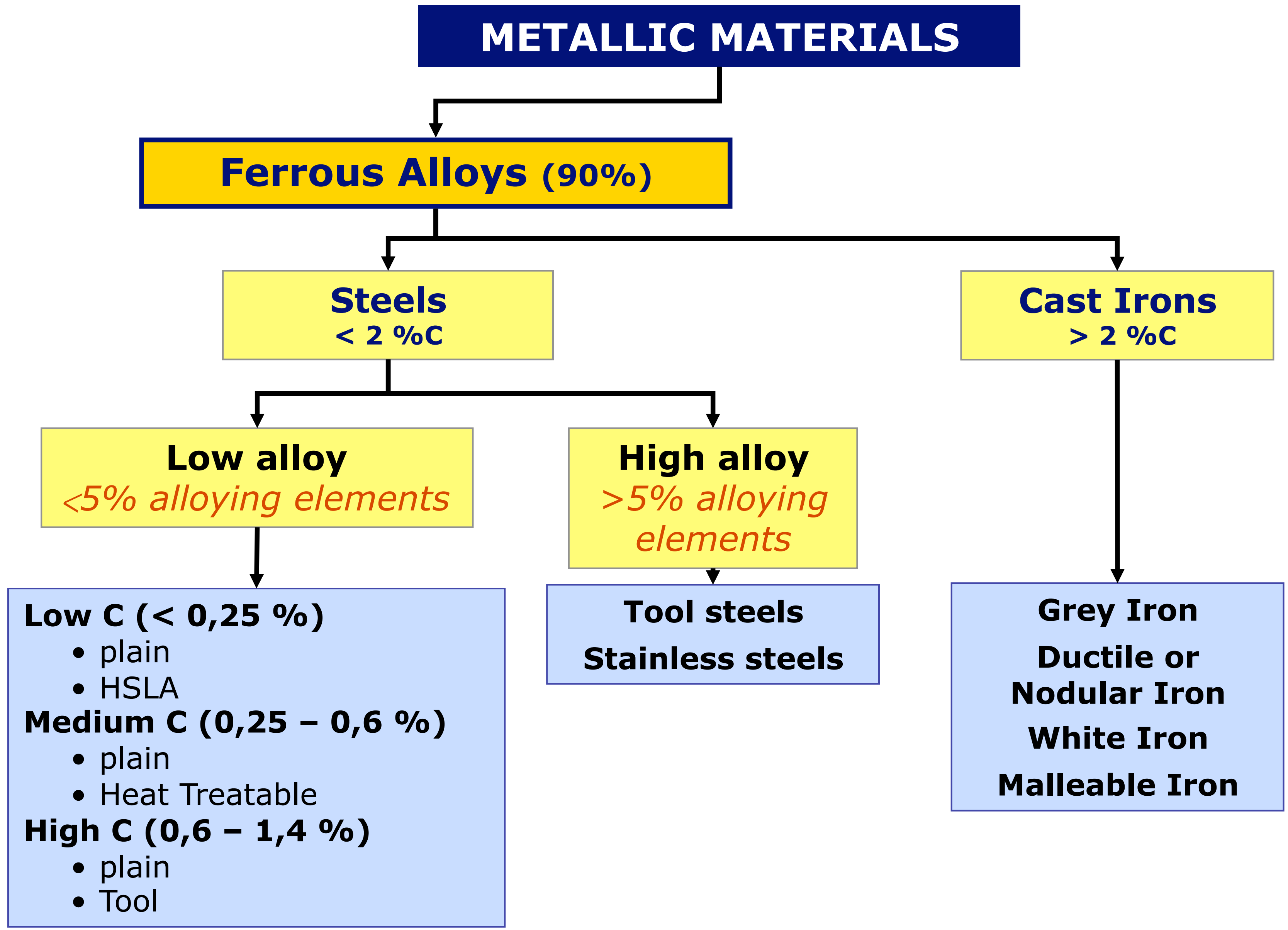
MATERIALS SCIENCE AND ENGINEERING

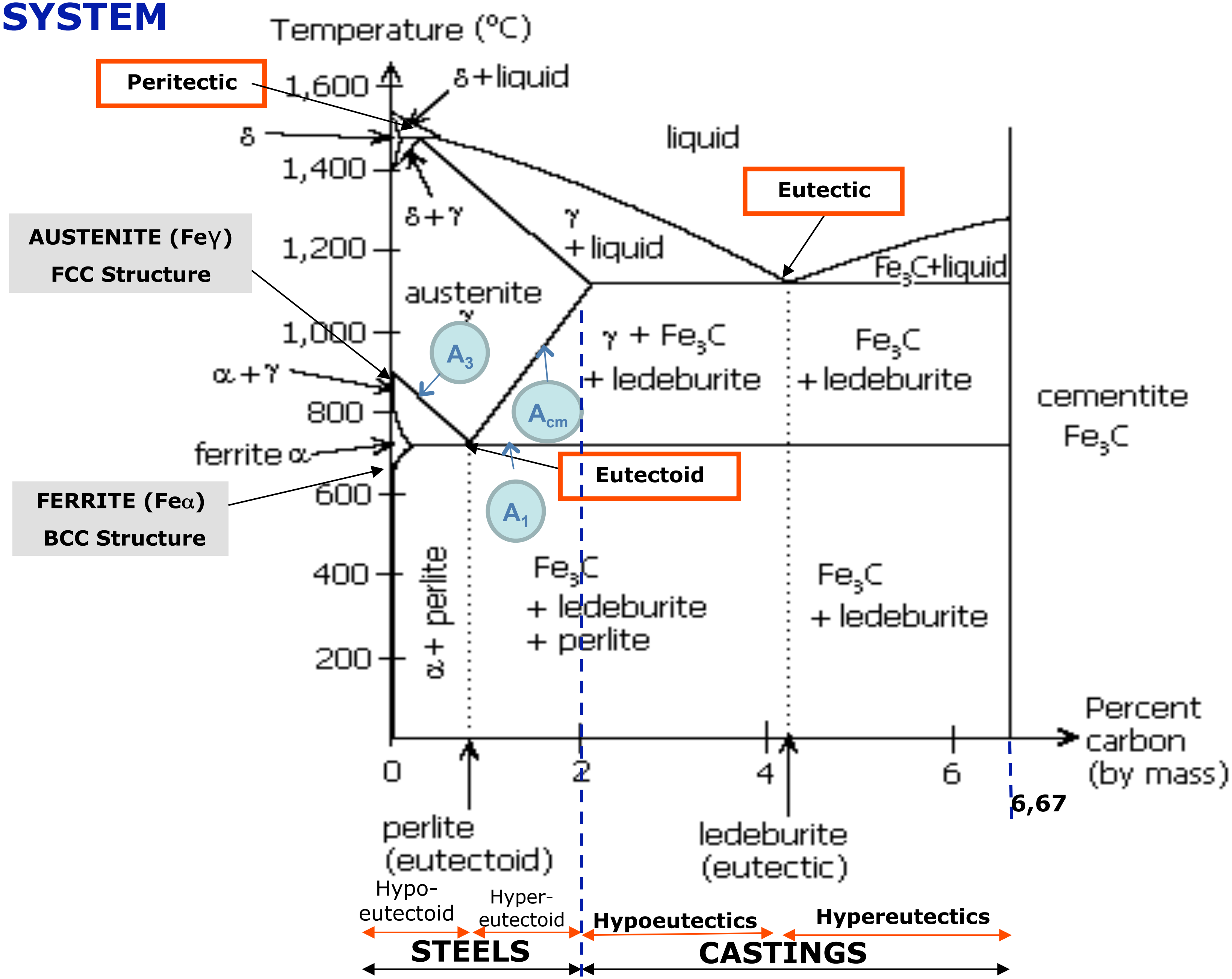
# TOPIC 5. METALLIC MATERIALS

## Topic 5.3:

- Most important ferrous alloys:
  - Low alloy
  - Stainless
  - Tool steels
  - Cast Irons
- Light Alloys:
  - Aluminium alloys
  - Titanium alloys
  - Copper-based alloys: brasses and bronzes


METALLIC MATERIALS
Ferrous Alloys (90%)
Steels
< 2 %C
Cast Irons
> 2 %C
Low alloy
<5% alloying elements
High alloy
>5% alloying elements
Low C (< 0,25 %)
• plain
• HSLA
Medium C (0,25 – 0,6 %)
• plain
• Heat Treatable
High C (0,6 – 1,4 %)
• plain
• Tool
Tool steels
Stainless steels
Grey Iron
Ductile or Nodular Iron
White Iron
Malleable Iron

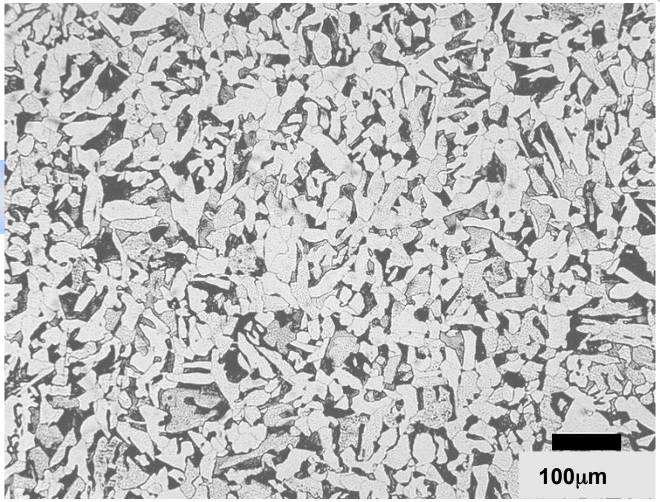
# Fe-C SYSTEM


Temperature (°C)
Peritectic
δ+liquid
δ
liquid
Eutectic
δ+γ
γ + liquid
AUSTENITE (Feγ)
FCC Structure
austenite γ
Fe3C+liquid
A3
γ + Fe3C + ledeburite
Fe3C + ledeburite
α+γ
Acm
cementite Fe3C
ferrite α
Eutectoid
FERRITE (Feα)
BCC Structure
A1
α + perlite
Fe3C + ledeburite + perlite
Fe3C + ledeburite
1,600
1,400
1,200
1,000
800
600
400
200
0
2
4
6
6,67
Percent carbon (by mass)
perlite (eutectoid)
ledeburite (eutectic)
Hypo-eutectoid
Hyper-eutectoid
Hypoeutectics
Hypereutectics
STEELS
CASTINGS

# Ferrous Alloys: **Low alloy steels**

## LOW-CARBON STEEL (Mild Steel)

**0.1 - 0.25 % C →** Ferrite proeutectoid
+ Pearlite (small quantities)



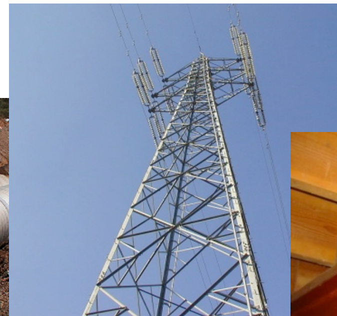

Ferrite (light gray) and perlite (dark gray)

**(0.18% carbon)**

- High formability, high ductility: **deformation: ~30%**
- Relatively low strength; **yield strength 200~400MPa**
- **Good weldability**
- **Can NOT** be hardened by **heat treatment**
- Normally **hardened** by **cold working**
- **Typical applications: pipelines, sheets, car body components, cans, structural shapes, I beans, etc.**

http://commons.wikimedia.org/wiki/File:Hyundai_car_assembly_line.jpg

http://commons.wikimedia.org/wiki/File:114_inch_pipe_installation.jpg



http://en.wikipedia.org/wiki/File:Steel_tower.jpg

http://en.wikipedia.org/wiki/File:I-Beam_002.JPG

# Ferrous Alloys: **Low alloy steels**

## MEDIUM-CARBON STEEL (STRUCTURAL STEELS)

**0.25-0.55%C** → Ferrite proeutectoide + pearlite

- Good combination of strength and ductility
- **Yield strength: 300~ 600MPa**
- **Tensile strength: 400~ 800MPa**
- **Deformation: ~25%**
- **Strengthened by heat treatment**
- Weldable (weldability ↓ as % C ↑)
- **Used for structural applications, railway wheels and tracks, crankshafts, gears, heavy machinery, mining, cranes**

http://commons.wikimedia.org/wiki/File:Reduction_Gear.jpg

http://commons.wikimedia.org/wiki/File:Cranes.jpg

http://commons.wikimedia.org/wiki/File:DrillingMachine_Drill_bits.jpg

# Ferrous Alloys: **Low alloy steels**

## HIGH-CARBON STEELS

springs

http://commons.wikimedia.org/wiki/File:Spring05.jpg

**Steels for springs**: 0.6~0.8%C → Pearlite (predominantly)

Normally strengthened by heat treatment
High strength / moderate toughness

**Tool steels** :

0.8~1.2%C → Cementite proeutectoide + pearlite

High hardness, low toughness, difficult to machine

**Used for chisel, hammer, knifes, saw blades, drill bits, dies, punch, cutlery and wear applications**

low weldability and machinability

Punches and dies

http://www.winstonandallan.co.uk/punches_dies.html

# Ferrous Alloys: **Low alloy steels**

## MICROALLOYED STEELS: High Strength Low Alloy, HSLA

Steels with high yield strength

Composition: **C**: 0.05-0.1% **Nb, V, Ti:** ≈ 0.1%

Properties:

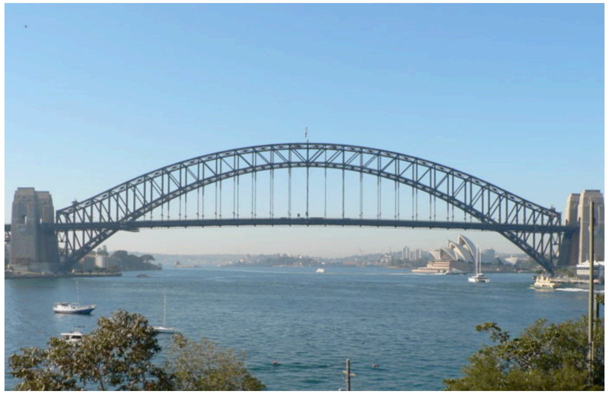
↑ strength, ↑ $\sigma_y$, good toughness ($T_{trans.}$=-70 ºC),

↓ Cost

Microestructure:

Fine Ferrite grain with MC and MN precipitates.

**Applications: big welded structures (Sydney bridge), marine laminated sheets, marine platforms, tubes for pipelines, pressure vessels and storage tanks.**



Ferrous Alloys: **Low alloy steels**

# General considerations

| ADVANTAGES | DISADVANTAGES |
|---|---|
| ↓ Cost<br>↑ Weldability<br>Most used | Relatively low strength<br>Low hardenability<br>Low corrosion resistance |

# Ferrous Alloys: **High alloy steels**

Fe-C with more alloying elements: **> 5% in weight of alloying elements**

- **They are stainless if weight % of Cr> 12%**
  **(STAINLESS STEELS)**

**(>20%Cr:** excellent high temperature oxidation resistance: REFRACTORY STEELS)

Corrosion resistance:
Cr presents ↑↑ affinity for $O_2$ ⇒ protective impermeable $Cr_2O_3$ layer

TYPES: **AUSTENITIC Stainless Steels**
**FERRITIC Stainless Steels**
**MARTENSITIC Stainless Steels**

**Corrosion resistance:**
Austenitic>Ferritic>Martensitic

**Mechanical strenght**
Martensitic>Austenitic>Ferrític

- **High mechanical properties: ↑↑hardness**
  **(TOOL STEELS)**

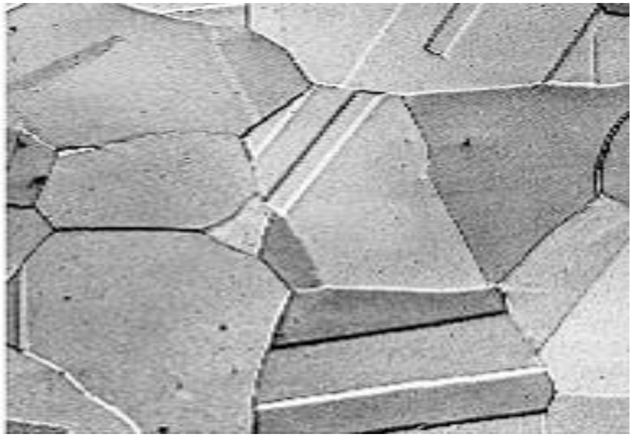
# Ferrous Alloys: **Austenitic Stainless Steels**

Alloying elements: Cr 16-25 %; Ni 7-20 % and C<0.25%

Microstructure: austenite (Ni is $\gamma$-stabilizing)

No heat treatment (always austenite)

Problem: Sensitization or formation of Cr carbides → pitting corrosion



Austenite

Materials Science and Engineering An Introduction", William D. Callister, Jr. John Wiley & Sons, Inc.

## Properties

- Low strength and high deformation
- They are not ferromagnetic
- ↑ toughness, ↓ σ thermal resistance
- ↑ corrosion resistance (the highest resistance)
- High cost

**USES:**

**Petrochemical industry, Marine platforms, etc**

| AISI type no. | Nominal composition, % C | Mn | Cr | Ni | Others |
|---|---|---|---|---|---|
| 301 | 0.15 max | 2.0 | 16–18 | 6.0–8.0 | |
| 302 | 0.15 max | 2.0 | 17–19 | 8.0–10 | |
| 304 | 0.08 max | 2.0 | 18–20 | 8.0–12 | |
| 304L | 0.03 max | 2.0 | 18–20 | 8.0–12 | |
| 309 | 0.20 max | 2.0 | 22–24 | 12–15 | |
| 310 | 0.25 max | 2.0 | 24–26 | 19–22 | |
| 316 | 0.08 max | 2.0 | 16–18 | 10–14 | 2–3Mo |
| 316L | 0.03 max | 2.0 | 16–18 | 10–14 | 2–3Mo |
| 321 | 0.08 max | 2.0 | 17–19 | 9–12 | (5 × %C) Ti min |
| 347 | 0.08 max | 2.0 | 17–19 | 9–13 | (10 × %C) Nb-Ta min |

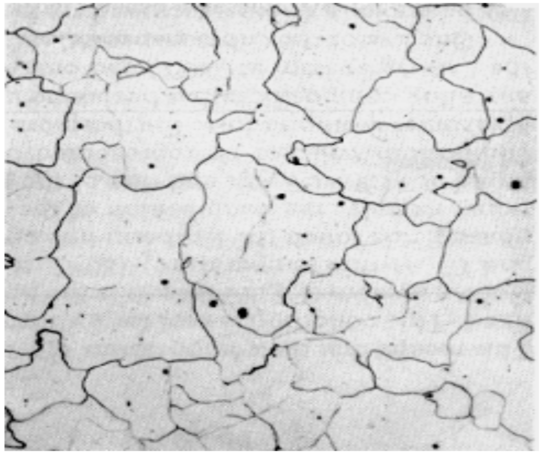
# Ferrous Alloys: **Ferritic Stainless Steels**

Alloying elements Cr 12-30 %; C↓↓ **NO NICKEL!!**

Microstructure: ferrite

No heat treatment (always ferrite)

Problem: Embrittlement



Ferrite

Materials Science and Engineering An Introduction", William D. Callister, Jr. John Wiley & Sons, Inc.

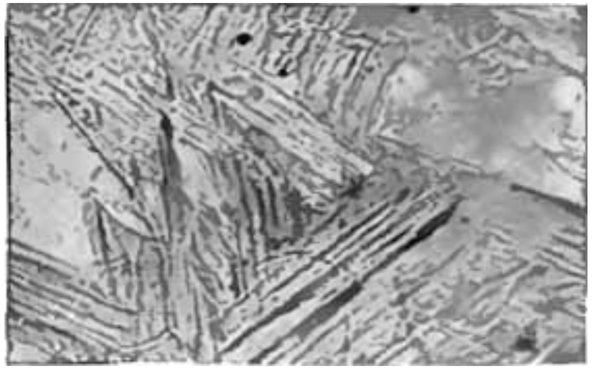
## Properties

- Cheap, magnetic, lower ductility
- Strengthen by cold deformation
- Corrosion resistance > than martensitic and< than austenitic

| AISI type no. | Nominal composition, % C | Mn | Cr | Others |
|---|---|---|---|---|
| 430 ............. | 0.08 max | 1.0 | 16.0–18.0 | |
| 430F .......... | 0.12 max | 1.25 | 16.0–18.0 | 0.6Mo max |
| 430F Se........ | 0.12 max | 1.25 | 16.0–18.0 | 0.15Se min |
| 446............. | 0.20 max | 1.5 | 23.0–27.0 | 0.25N max |

**Applications:** **Vehicles, appliances exposed to $HNO_3$, food industry, refineries, etc.**

# Ferrous Alloys: **Martensitic Stainless Steels**



- Alloying elements **Fe-Cr-C** (C: 0.15-0.7%) (Cr: 12-17%)
- Microstructure: **martensitic** ⇒ after heat treatment similar to carbon steels

**Properties**

- ↑ mechanical strength, ↑ hardness, ↑ wear resistance
- Moderate corrosion resistance (up to 750ºC)
- Less amount of alloying elements ↔ Lower cost

**USES:**
**Cutlery, surgical tools, valves, etc**

http://commons.wikimedia.org/wiki/File:Dissection_tools.jpg

# Ferrous Alloys: **Tool Steels**

- Can be plain carbon steels, or alloyed steel, that can be heat treated by **quenching and tempering**.
- They are fabricated by **melting** and **forming** in order to **achieve the desired properties**.
- They can be used as hand tools, or as machine components for cutting and forming both for **cold** or **hot working.**
- In all its applications **wear resistance, mechanical strength and toughness** are necessary requirements.

Their properties are a consequence of the **martensitic matrix** and the presence of **carbides** (high hardness particles) in the microstructure.

# Ferrous Alloys: **Tool Steels**

**Properties**

harness (up to 65 HRC)

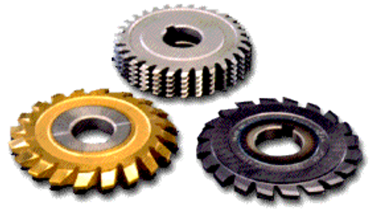
Hardness at high temperatures

Toughness

Hadenability

Wear resistance

http://commons.wikimedia.org/wiki/File:TiNCoatedPunches_NanoShieldPVD_Thailand.JPG



punching dies and cutting tools

Drill bits

## AISI Classification

## (American Iron and Steel Institute)

Quenched in water

Low alloyed for special applications

For dies

Resistant to thermal shock

For cold working

For hot working

High speed steel

( - ) alloying elements

Main alloying elements

Cr, V, W, Mo, Co, Mn

( + ) alloying elements

**Cr, V, W, Mo:** ***carbide forming***
**Mn:** ***hardenability***
**Co:** ***high temperature resistance***

## Ferrous Alloys: **Tool Steels**

In general, for tool steels, the heat treatments performed after forming are very important.

**In HIGH SPEED STEELS (HSS) the phenomenon of secondary hardness its observed.**

**During the tempering process after quenching, the material hardens, as opposed to conventional steels where they become softer.**

| Alloying compositions of common high speed steel grades (by % wt) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Grade | C | Cr | Mo | W | V | Co | Mn | Si |
| M2 | 0.95 | 4.2 | 5.0 | 6.0 | 2.0 | - | - | - |
| M7 | 1.00 | 3.8 | 8.7 | 1.6 | 2.0 | - | - | - |
| M35 | 0.94 | 4.1 | 5.0 | 6.0 | 2.0 | 5.0 | - | - |
| M42 | 1.10 | 3.8 | 9.5 | 1.5 | 1.2 | 8.0 | - | - |
| Note that impurity limits are not included | | | | | | | | |

# Ferrous Alloys: **Cast Irons**

CAST IRONS (low melting T →casting)

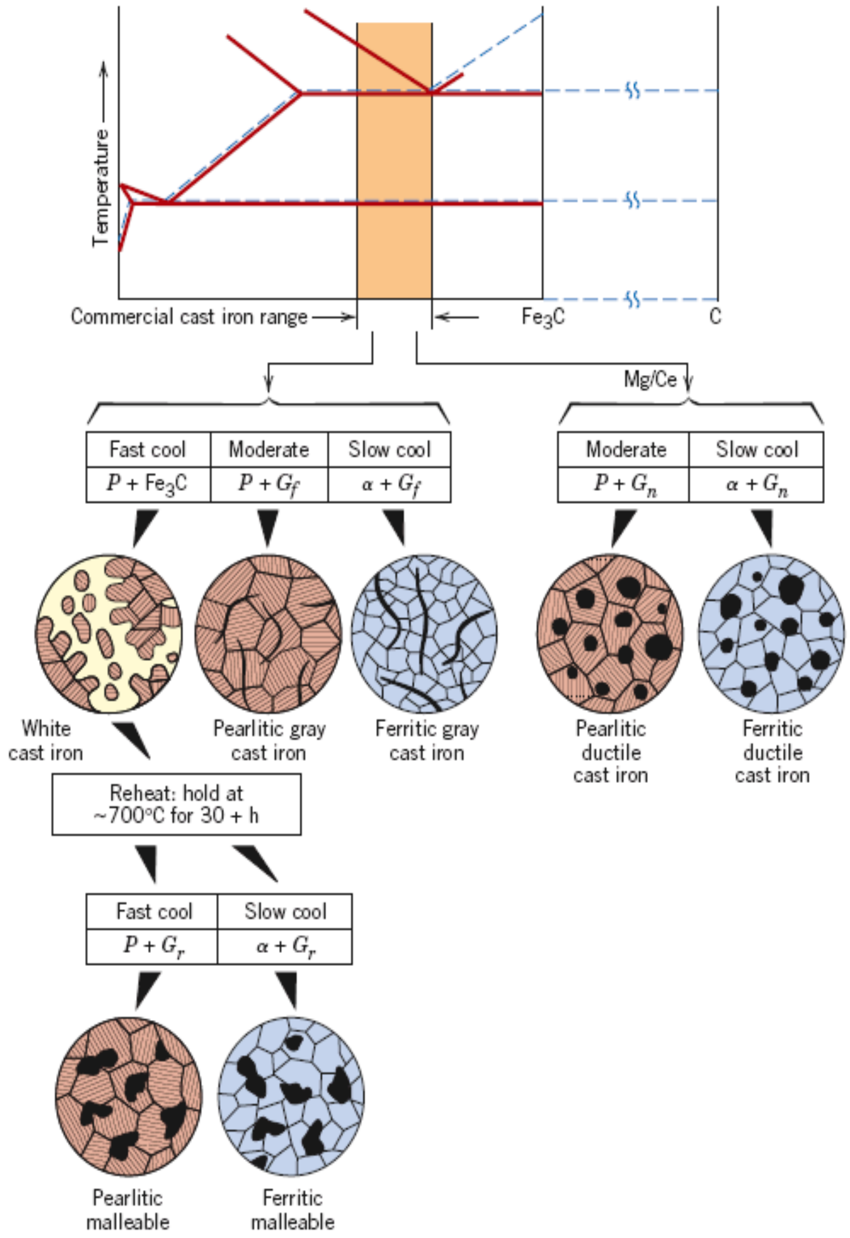
Fe-C alloys with %C > 2 %

## White Cast Iron

Solidification according to the metastable Fe-$Fe_3C$ diagram
Presence of cementite. No graphite.
High hardness and wear resistance; brittle. Limited applications - compression

## Gray Cast Iron

Solidification according to stable Fe-C diagram
No eutectic cementite. Graphite present in different morphologies.
Most used industrially.



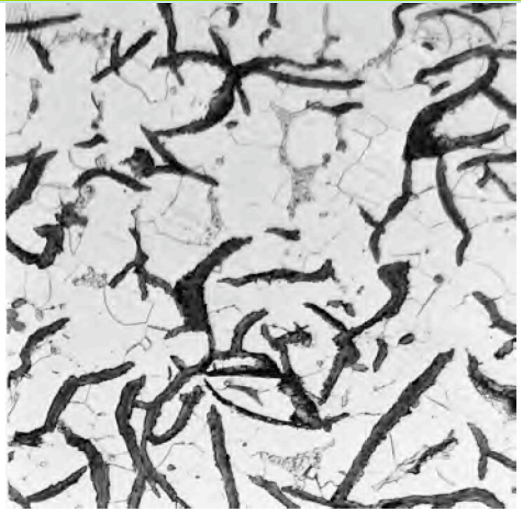

*"Materials Science and Engineering An Introduction", William D. Callister, Jr. John Wiley & Sons, Inc.*

# Ferrous Alloys: **Cast Irons**

## White iron

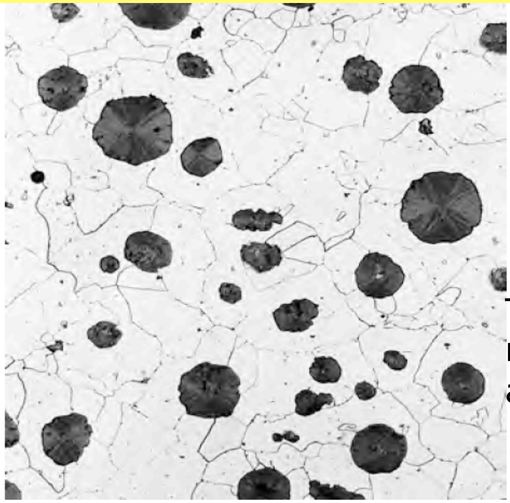
Light **cementite** regions are surrounded by **pearlite** (which has the ferrite-cementite layered structure) (x400)

## Gray iron



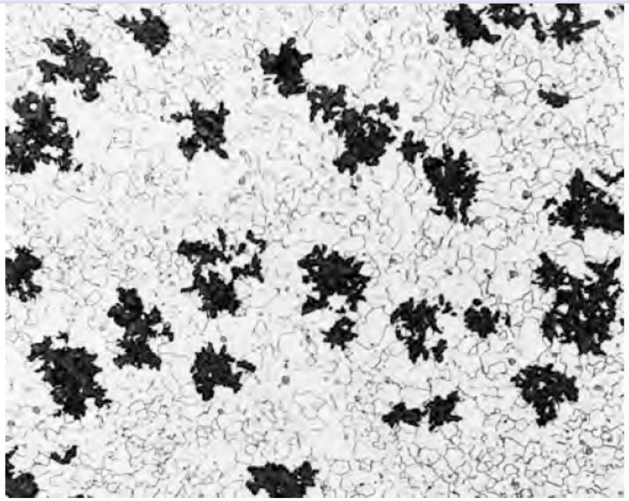
The dark **graphite** flakes are embedded in a α–**ferrite** matrix (x200)

## Ductile (nodular) iron



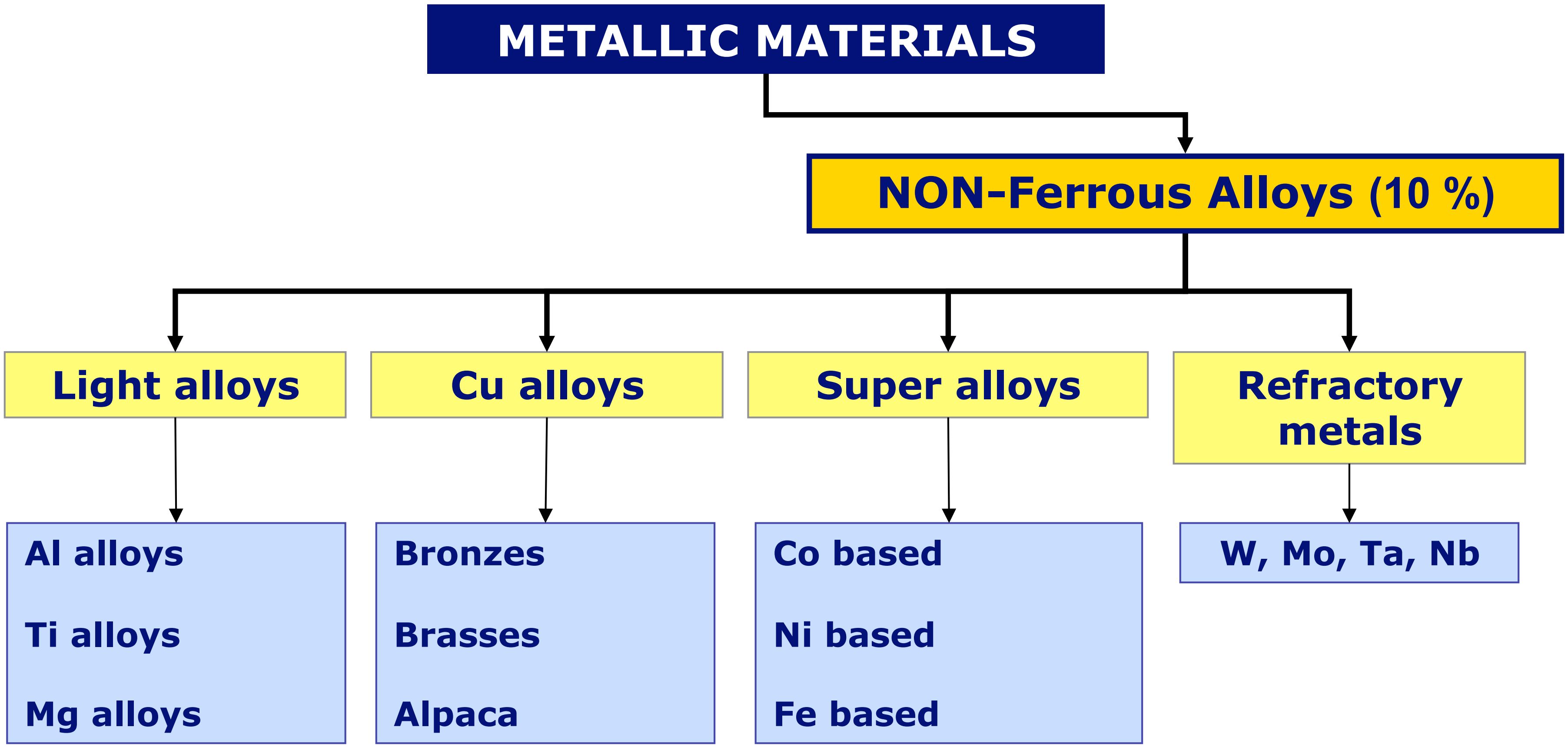
The dark **graphite nodules** regions are surrounded by an **a-ferrite** matrix (x200)

## Malleable iron



Dark **graphite rosettes** (temper carbon) in an **a-ferrite** matrix (x150)

*"Materials Science and Engineering An Introduction", William D. Callister, Jr. John Wiley & Sons, Inc.*


METALLIC MATERIALS
NON-Ferrous Alloys (10 %)
Light alloys
Cu alloys
Super alloys
Refractory metals
Al alloys
Ti alloys
Mg alloys
Bronzes
Brasses
Alpaca
Co based
Ni based
Fe based
W, Mo, Ta, Nb

# Light Alloys vs. Iron

| | Units | Aluminium | Titanium | Copper | Iron |
|---|---|---|---|---|---|
| **Crystalline structure** | | FCC | Hexagonal **882ºC** ↓ BCC | FCC | BCC 910ºC ↓ FCC 1410ºC ↓ BCC |
| **Density** | $g/cm^3$ | 2,7 | 4,5 | 8,9 | 7,8 |
| **Mleting Temp.** | ºC | 660 | 1660 | 1356 | 1535 |
| **Specific Heat** | cal/g.ºC | 0,215 | 0,124 | 0,092 | 0,114 |
| **Expansion coefficient** | $x\ 10^6$ | 23,5 | 8,9 | 17 | 12 |
| **Thermal conductivity** | W/m.K | 238 | 17 | 397 | 71 |
| **Electrical conductivity** | % | 64 | 4 | 100 | 17 |
| **Electrochemical potential** | V | -1,7 | -1,6 | +0.34 | -0,4 |
| **Voxide/Vmetal** | | 1,3 | 1,7 | 1,6 | 2,2 |
| **Corrosion Resistance** | M-R-B-E | Good | Excellent | Good | Regular |
| **Young's Modules** | GPa | 70 | 120 | 130 | 200 |
| **Tensile Strength** | MPa | 700 | 1400 | 220 | 1600 |
| **Content in earth's crust** | % | 8 | 0,9 | 0.12 | 5,8 |
| **Relative price** | | 1 | 5 | 1 | 0,1 |

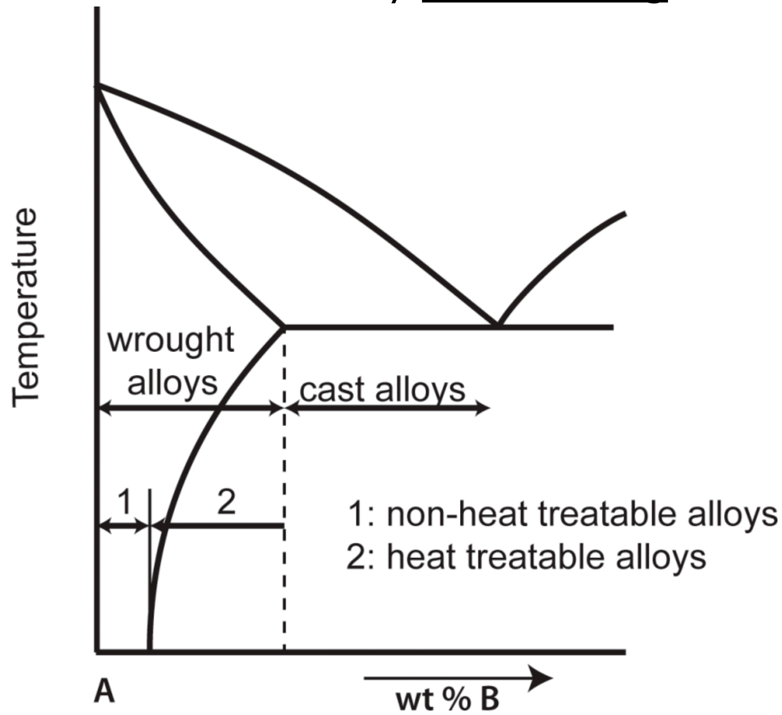
# Light Alloys: **aluminium alloys**

## Classification of aluminium alloys

- **Wrought** aluminium alloys: <u>**Heat-treatable:**</u> Hardened by heat treatment: Precipitation Hardening (natural or artificial).

  <u>**Nonheat-treatable**</u>: Cannot be hardened by heat treatment : Hardened by <u>cold working</u>.

- **Cast** aluminium alloys.




Classification of aluminum alloys

# Light Alloys: **aluminium alloys**

## Classification of aluminium alloys

## Non heat-treatable Wrought aluminium alloys

**1xxx** – Al high purity > 99,0
**3xxx** – Al-Mn, Al-Mn-Mg
**5xxx** – Al-Mg
**8xxx** – Al-Ni-Fe, Al-Sn-Ni-Cu, Al-Li

**DESIGNATION SYSTEM FOR AL-ALLOYS**

| Numerals | Major alloying elements (s) |
|---|---|
| 1XXX | None (> 99.00% Al) |
| 2XXX | Cu |
| 3XXX | Mn |
| 4XXX | Si |
| 5XXX | Mg |
| 6XXX | Mg and Si |
| 7XXX | Zn |
| 8XXX | Other elements |

**General properties :**

-Low mechanical strength

-↑ductility

-↑ Corrosion resistance

-↑ weldability

**Applications:**

**1xxx: Electrical and chemical**: heat exchangers, electrical conductors and capacitors, sheet packaging, coatings for other alloys with lower corrosion resistance

**3xxx: General use where moderate and good formability is required**. Beverage cans, kitchen utensils, storage tanks, canopies, furniture, roofing (architecture applications), traffic signs.

**5xxx: Sheet fabrication.** Boats, ships, architectonical applications, ornamentals; light posts; storage tank, automobile structures

# Light Alloys: **aluminium alloys**

## Classification of aluminium alloys

## Heat-treatable Wrought aluminium alloys

Alloys **2xxx** (Al-Cu)

Alloys **6xxx** (Al-Mg-Si)

Alloys **7xxx** (Al-Zn-Mg-Cu)

**General properties:**

-Medium-high mechanical strength

(higher than non-heat treatble alloys)

-↑ductility

-↑corrosion resistance

**DESIGNATION SYSTEM FOR AL-ALLOYS**

| Numerals | Major alloying elements (s) |
|---|---|
| 1XXX | None (> 99.00% Al) |
| 2XXX | Cu |
| 3XXX | Mn |
| 4XXX | Si |
| 5XXX | Mg |
| 6XXX | Mg and Si |
| 7XXX | Zn |
| 8XXX | Other elements |

**Applications:**

**2xxx: Pieces and structures that require high specific strength at T<150ºC**: Track and aircraft wheels; suspension pieces in tracks; Fuselage in aircrafts; Wing lining, structural pieces

**6xxx: Structural:** bicycle frames; transport equipment; bridge rails; welded structures

**7xxx:** Structures subjected to high stresses; Structures for aircraft frames; mobile equipment

# Light Alloys: **aluminium alloys**

## Classification of aluminium alloys

## Heat-treatable Wrought aluminium alloys

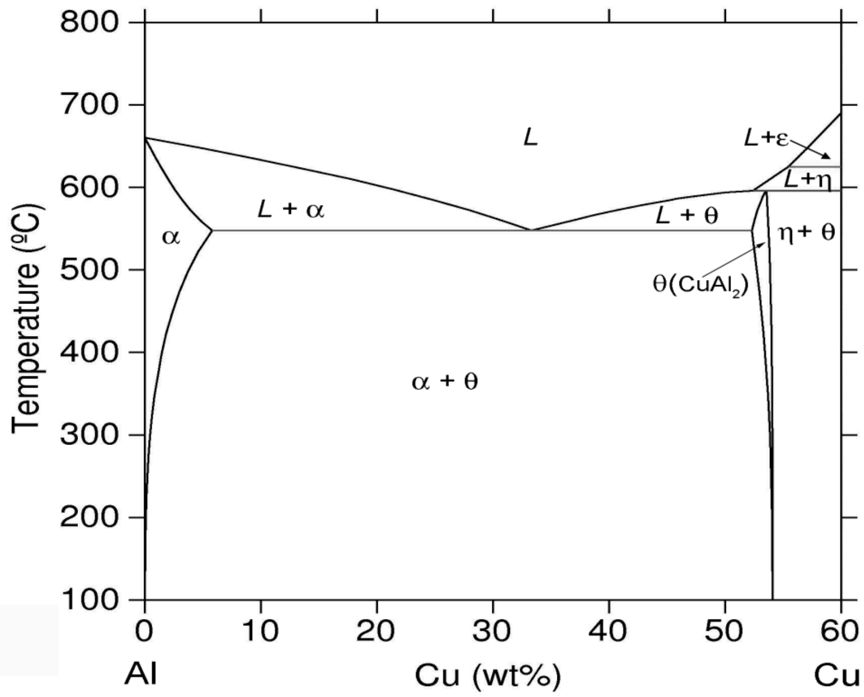
Alloys **2xxx** (Al-Cu)

Alloys **6xxx** (Al-Mg-Si)

Alloys **7xxx** (Al-Zn-Mg-(Cu)

**DESIGNATION SYSTEM FOR AL-ALLOYS**

| Numerals | Major alloying elements (s) |
|---|---|
| 1XXX | None (> 99.00% Al) |
| 2XXX | Cu |
| 3XXX | Mn |
| 4XXX | Si |
| 5XXX | Mg |
| 6XXX | Mg and Si |
| 7XXX | Zn |
| 8XXX | Other elements |




**Heat treatment: solution heat treatment + quench + aging or precipitation heat treatment → precipitation hardening**

Typical phase diagram in order to be able to apply precipitation hardening heat treatment (necessary, but not sufficient condition for precipitation hardening)

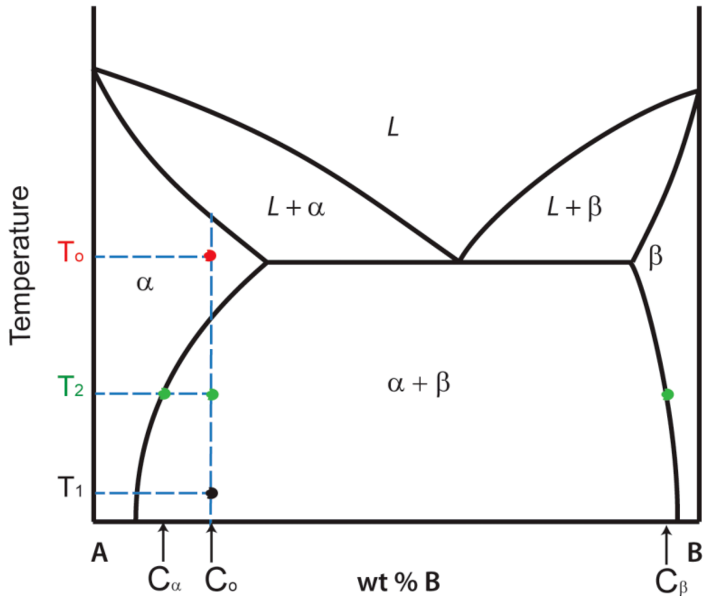
## Light Alloys: **aluminium alloys**

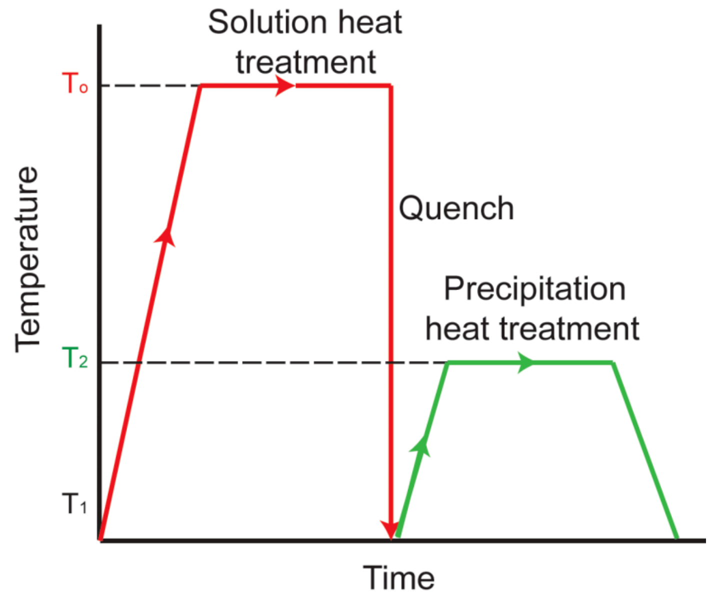
### Precipitation hardening or age hardening

**Dislocations are anchored due to the formation of precipitates that hinder their movement.**

Three stages:

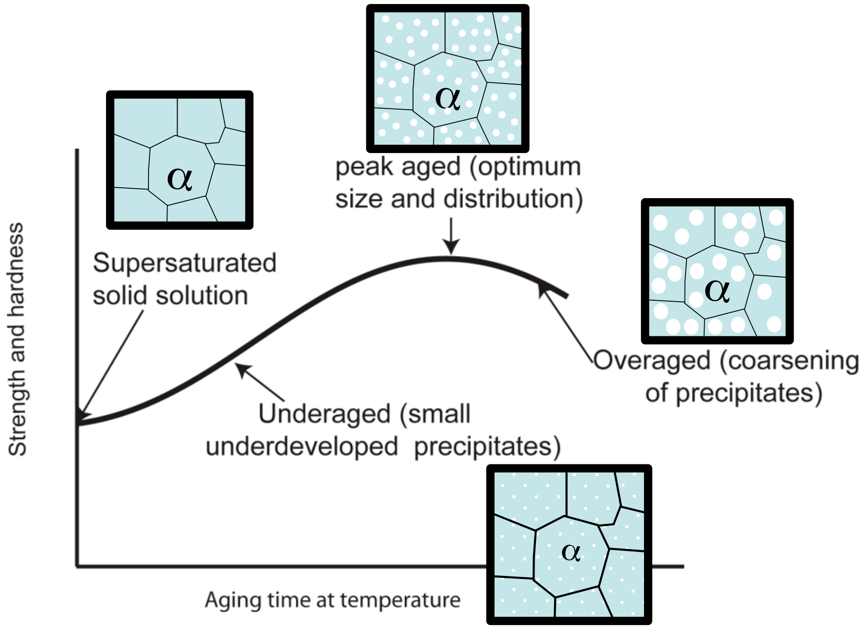
1. **Solution heat treatment:** dissolve β phase (intermetallic)
2. **Quench** (rapid cooling; NOT martensitic quench) in order to create a super-saturated solid solution
3. **Aging or precipitation heat treatment**: precipitation of fine particles of β phase. Can be NATURAL (at room Temp.) or ARTIFICIAL (heating below $T_{solvus}$)

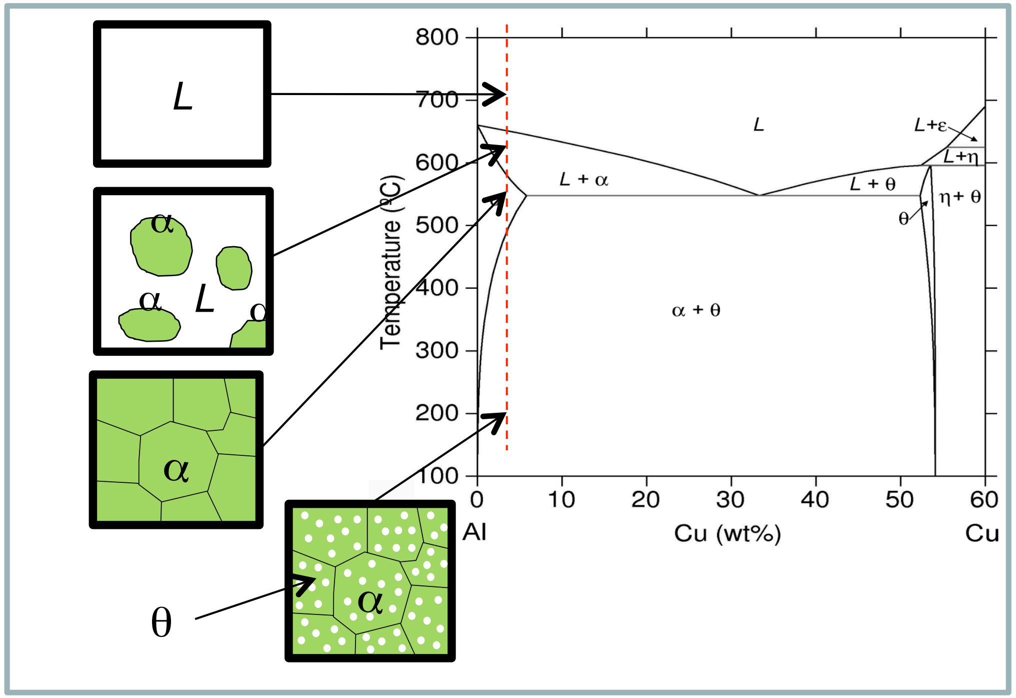


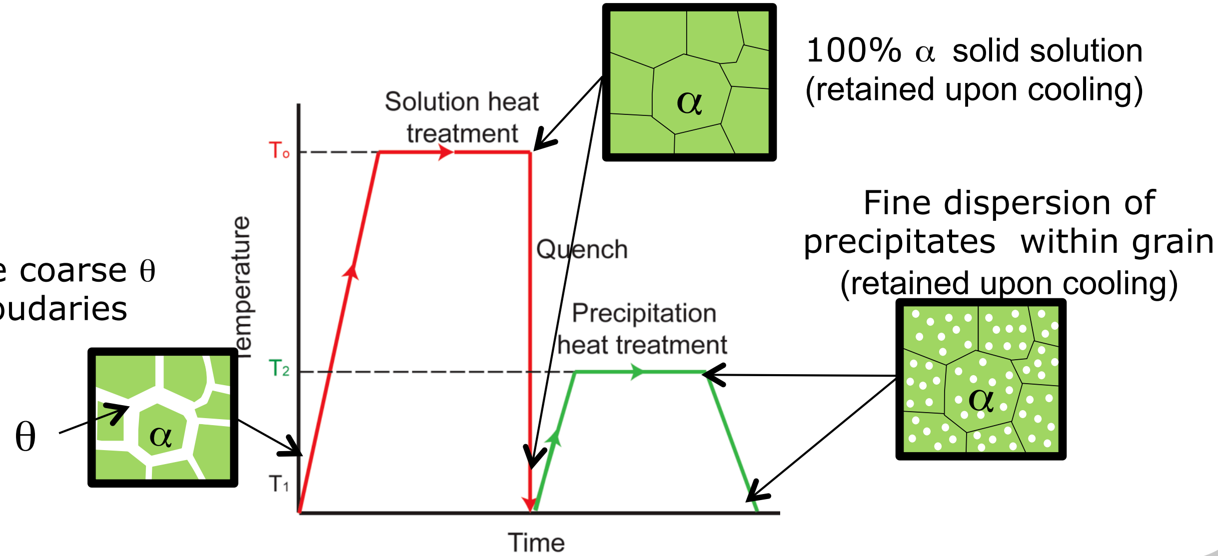
# Light Alloys: **aluminium alloys**

## Precipitation hardening




Equilibrium microstructure coarse θ precipitates at α grain boudaries

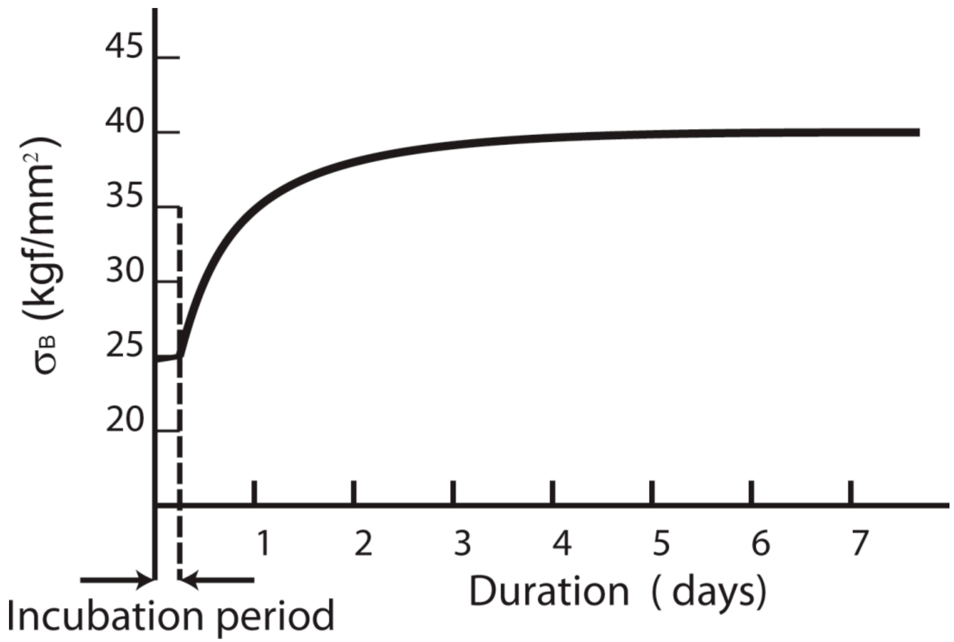


Light Alloys: **aluminium alloys**

## Precipitation hardening or age hardening

**Aging or precipitation heat treatment:**

- natural ($T_{room}$)
- artificial ($T_{solvus}$>T>$T_{room}$)




Before precipitation can begin, an INCUBATION TIME is necessary

TECHNOLOGICAL IMPORTANCE : During the incubation time the alloy has a high plastic deformation capability

## Precipitation hardening or age hardening

**During precipitation the precipitates form sequentially, through the following 5 stages :**

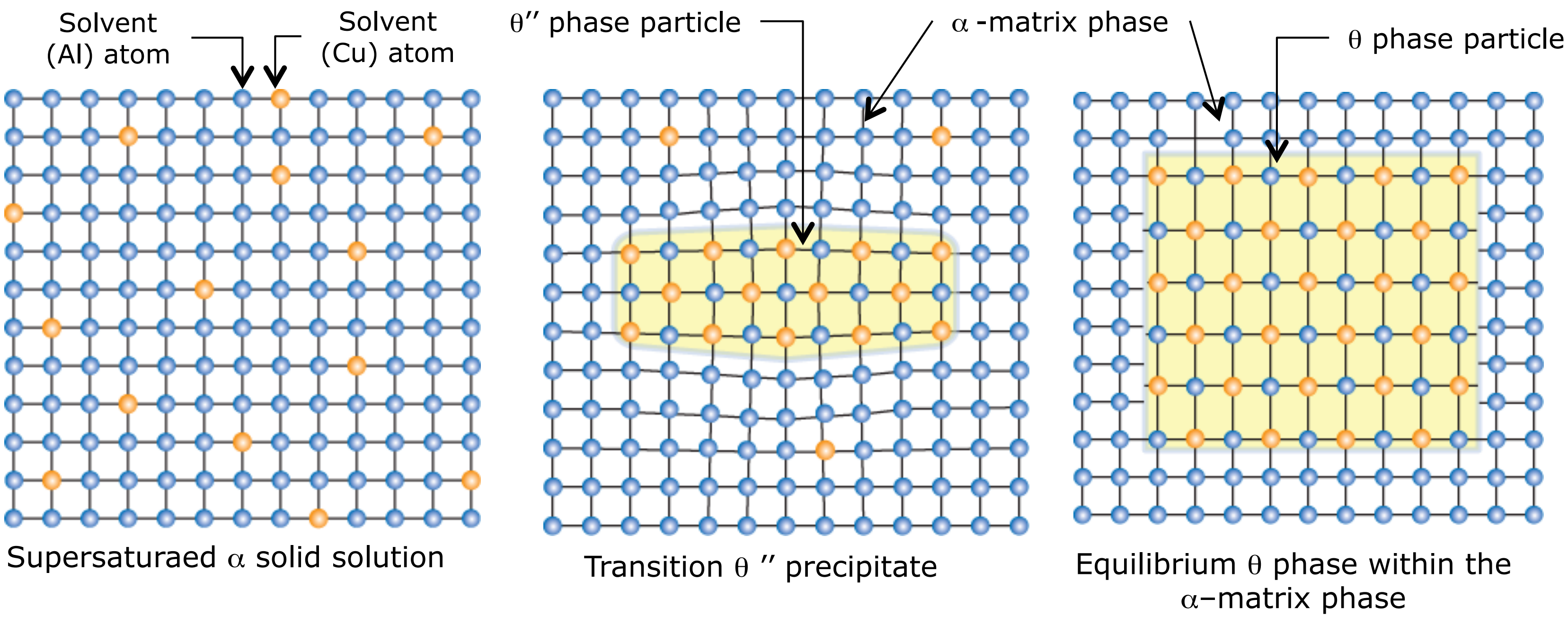
**.- supersaturated α solution solid**

**.- GP1 (Guinier-Preston) zones ⇒ zones ↑[Cu]** } coherent precipitates

**.- GP2 (or phase θ´´) zones ⇒ ↑ size than GP1** } coherent precipitates

**.- phase θ´ ⇒ incoherent precipitate (tetragonal structure)**

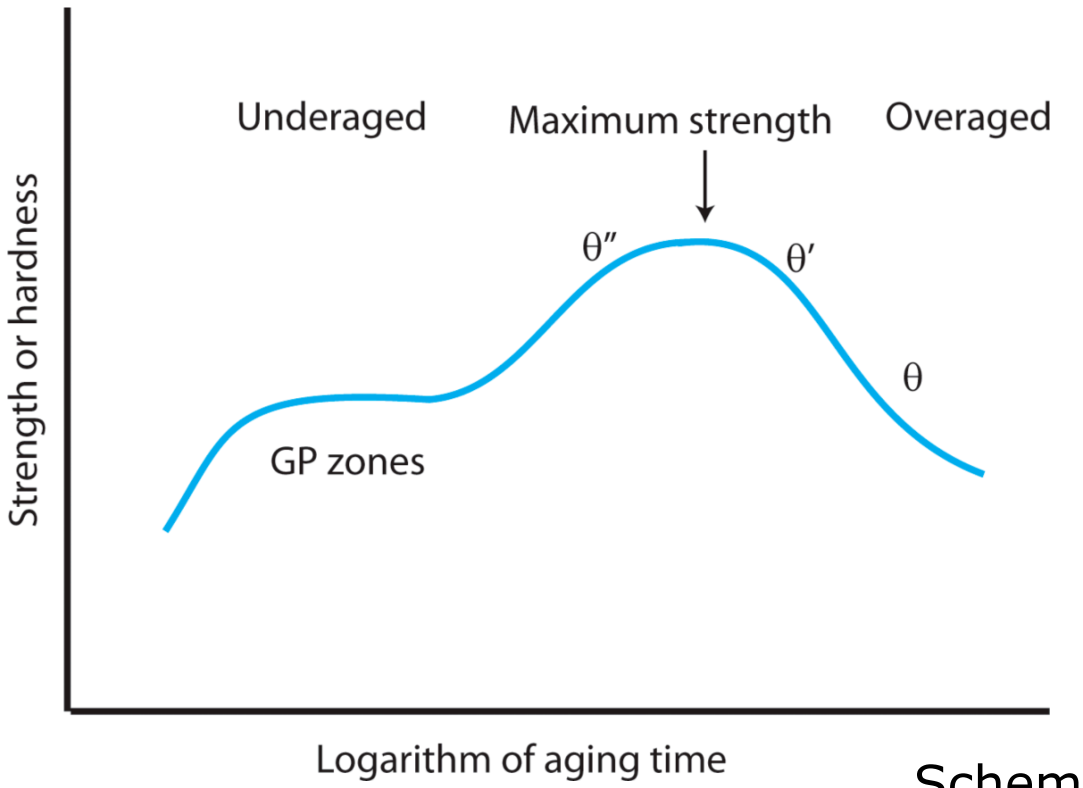
**.- phase θ ($CuAl_2$) ⇒ equilibrium. Incoherent precipitate. Bct structure**




Stages in the fortmation of the equilirium precipitate (θ) phase.

Light Alloys: **aluminium alloys**

## Precipitation hardening



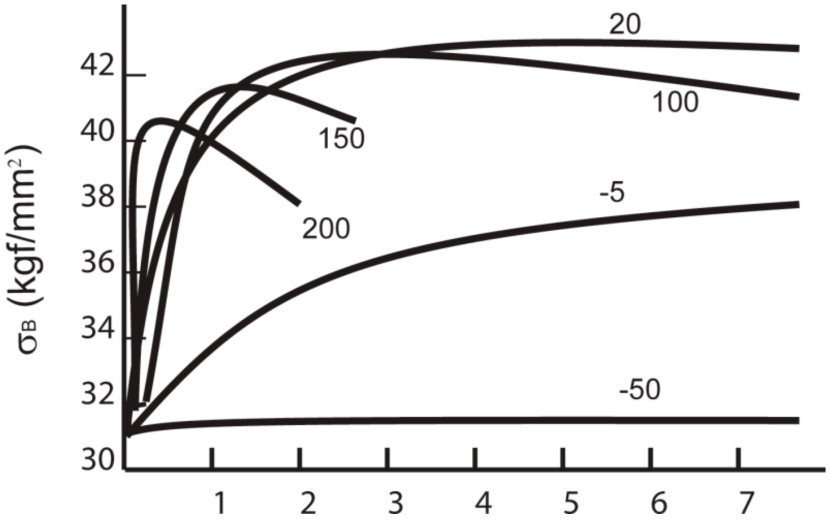

**The alloy has maximum strength when the precipitates are coherent**

Schematic diagram showing strength and hardness as a function of the logarithm of aging time at constant temperature during the precipitation heat treatment.

Light Alloys: **aluminium alloys**

## Precipitation hardening

Incubation rate = f (T)




Age hardening curves at different temperatures

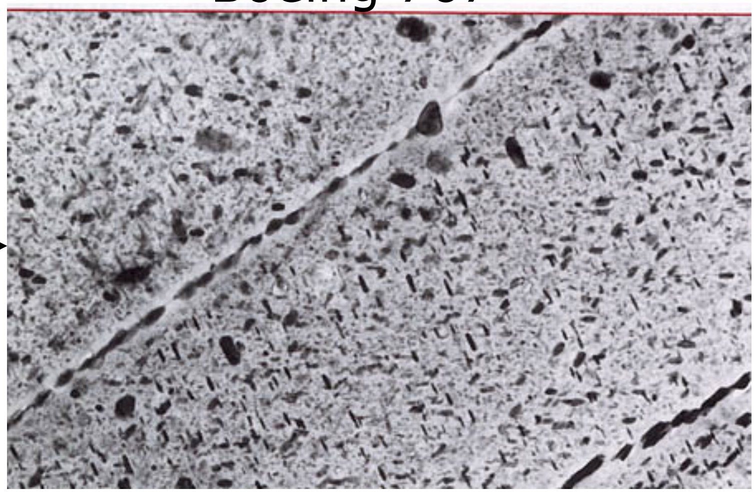
Micrograph of the wing of an aircraft
*(precipitation hardened Al-alloy)*

## Hardening process is accelerated with temperature

**T↓↓ ⇒ lack or precipitation hardening**

**T ≥ 150ºC: Overaging**


Boeing 767



*"Materials Science and Engineering An Introduction", William D. Callister, Jr. John Wiley & Sons, Inc.*

## Classification of aluminium alloys

## Cast aluminium alloys

**Aluminium-Silicon (series 4xx.x)**

- % Si : 10-13
- High fluidity
- Short freezing range (eutectic concentration)
- Low hardenabillity by quenching + tempering
- Applications: kitchen utensils, carburettor bodies, tubing accessories.

**modified Aluminium-Silicon** :

Addition of Na or Sr salts in liquid state.

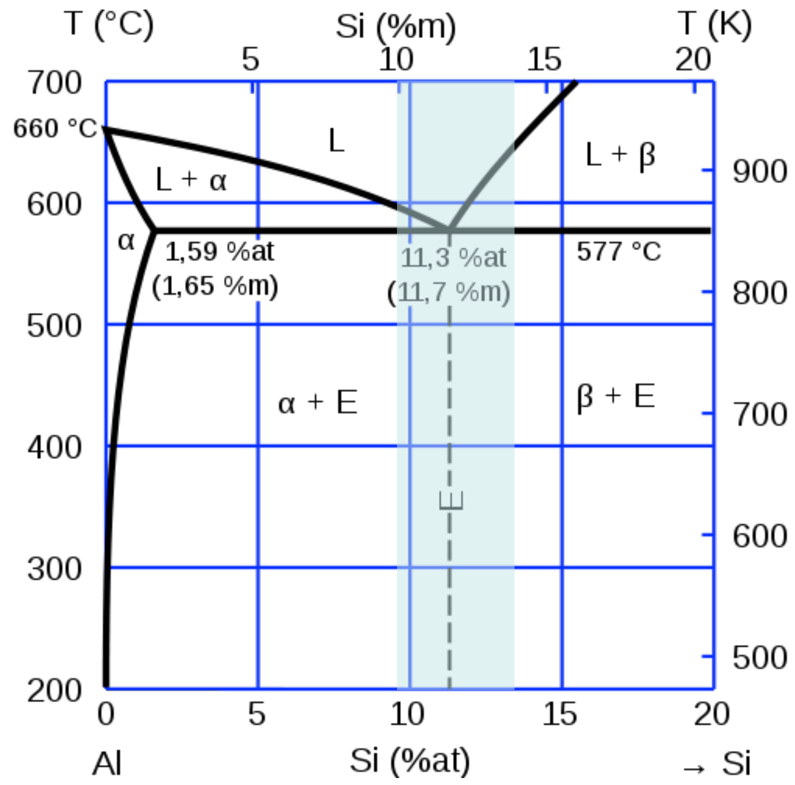
Effects:

$\downarrow T_{crist.}$ Si

Displaces the eutectic to higher %Si and lower T

**microestructural changes**

eutectic Structure or hypereutectic to hypoeutectic




http://commons.wikimedia.org/wiki/File:Diagramme_binaire_al_si_fonderie.svg

Light Alloys: **aluminium alloys**

## Classification of aluminium alloys

## Cast aluminium alloys

Special Aluminium–Silicon alloys (series **3xx.x**)

Hypoeutectic Aluminium-Silicon alloys (4-10% Si) + Cu, Mg and/or Mn

Mechanical properties: UTS= 20-25 Kg/mm$^2$ and A= 1-6%

Effect of alloying elements :

Mg (0.3-1%) : ↑ strength (precipitation hardening $Mg_2Si$)

Cu (1-4%) : ↑ strength at high T

**Applications**: pistons, cylinders blocks and lids (combustion motors)

automatic transmissions

# Light Alloys: **titanium alloys**

| | Units | Aluminium | Titanium | Copper | Iron |
|---|---|---|---|---|---|
| **Crystalline structure** | | FCC | Hexagonal<br>**882ºC** ↓<br>BCC | FCC | BCC<br>910ºC ↓<br>FCC<br>1410ºC ↓<br>BCC |
| **Density** | $g/cm^3$ | 2,7 | 4,5 | 8,9 | 7,8 |
| **Mleting Temp.** | ºC | 660 | 1660 | 1356 | 1535 |
| **Specific Heat** | cal/g.ºC | 0,215 | 0,124 | 0,092 | 0,114 |
| **Expansion coefficient** | $x\ 10^6$ | 23,5 | 8,9 | 17 | 12 |
| **Thermal conductivity** | W/m.K | 238 | 17 | 397 | 71 |
| **Electrical conductivity** | % | 64 | 4 | 100 | 17 |
| **Electrochemical potential** | V | -1,7 | -1,6 | +0.34 | -0,4 |
| **Voxide/Vmetal** | | 1,3 | 1,7 | 1,6 | 2,2 |
| **Corrosion Resistance** | M-R-B-E | Good | Excellent | Good | Regular |
| **Young's Modules** | GPa | 70 | 120 | 130 | 200 |
| **Tensile Strength** | MPa | 700 | 1400 | 220 | 1600 |
| **Content in earth's crust** | % | 8 | 0,9 | 0.12 | 5,8 |
| **Relative price** | | 1 | 5 | 1 | 0,1 |

# Light Alloys: **titanium alloys**

## Generals characteristics

- 4º most common metal, after Al, Fe and Mg
- High cost (difficultly in extraction and processing, very reactive)
- Light Metal: density ~4,5 g/cm$^3$
- High strength
  - $\sigma_y \approx$ 410 MPa (titanium comercially pure) - 1300 MPa (alloys)
- High strength/weight ratio (aeronautical and aerospacial industry )
- Excellent corrosion resistance in salt water or acids
  - Microscopic protective oxide film over the surface
- At temperatures above 480°C the oxide is dissolved in titanium causing embrittlement → resistance to high temperature (up to 480 ºC).
- High $T_m$
- Allotropic Metal ($\alpha$ hcp →$\beta$ bcc, to 882ºC)

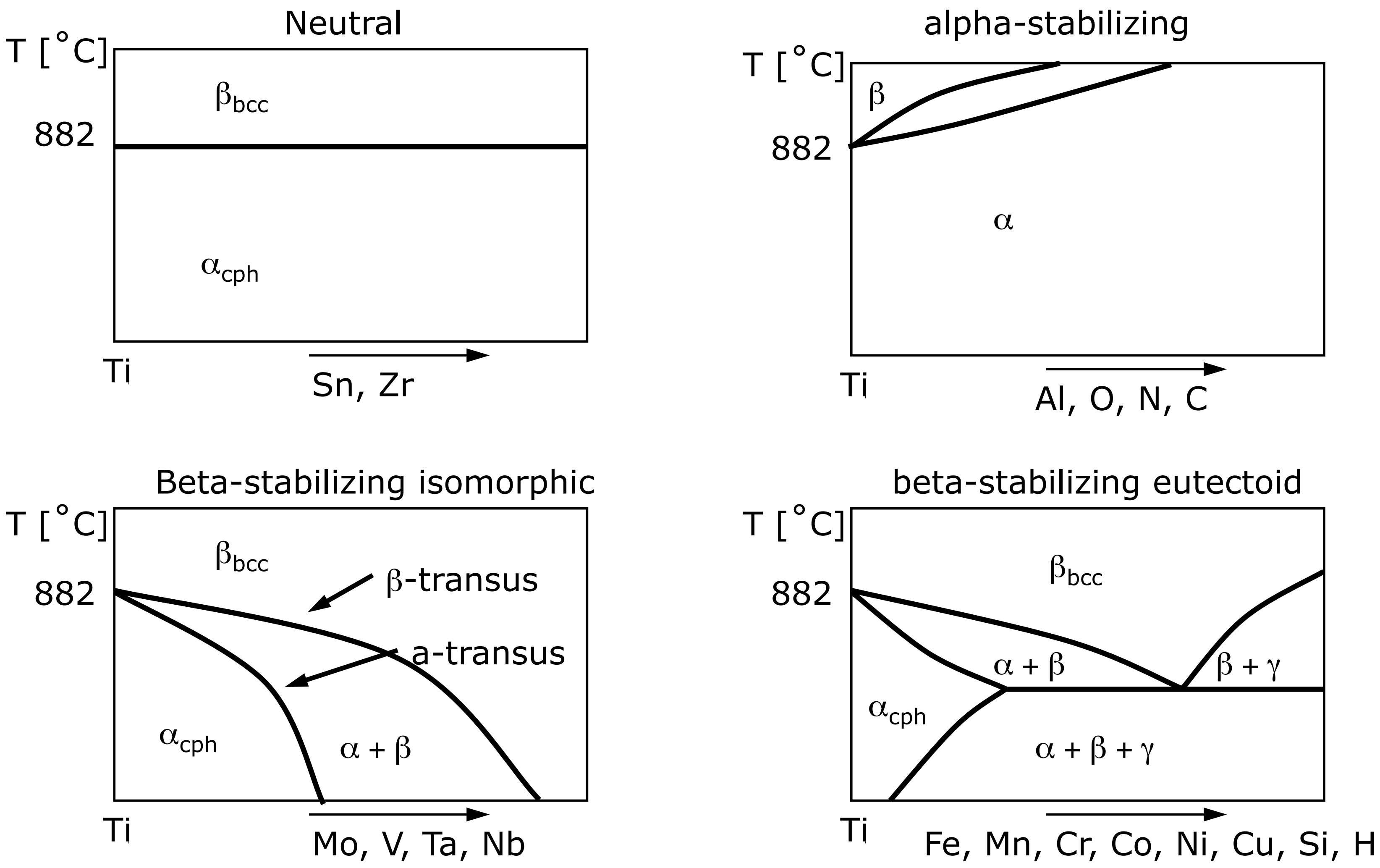
## Types of alloying elements

α-stabilizing : Al, O, N, C
β-stabilizing isomorphic: Mo, V, Nb, Ta
β-stabilizing eutectoid: Cu, Si (active), Cr and Fe (slow)
Neutral: Zr, Sn
They can be:
Interstitial → hardening
Substitutional

http://www.titanium.org

# Light Alloys: **titanium alloys**

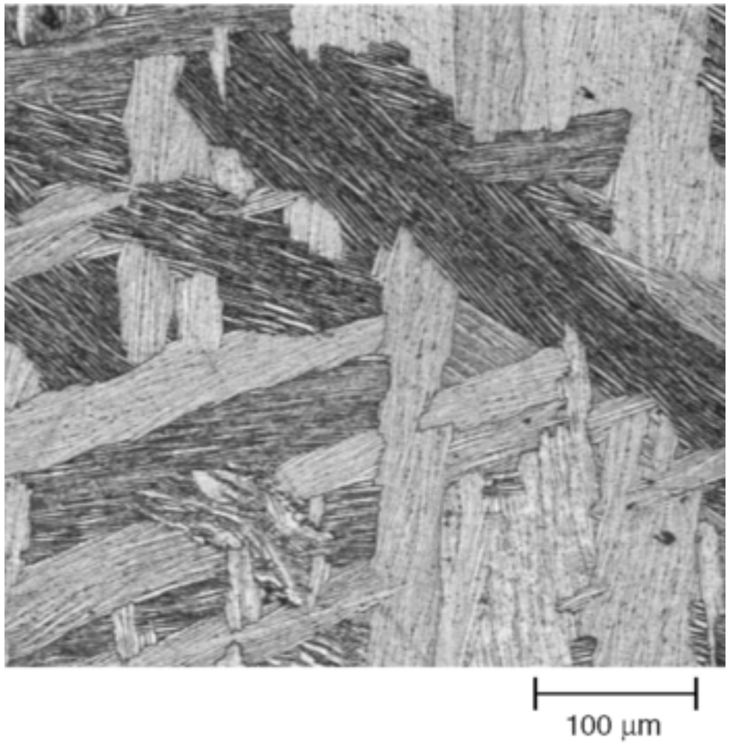
## Influence of alloying elements



# Light Alloys: **titanium alloys**

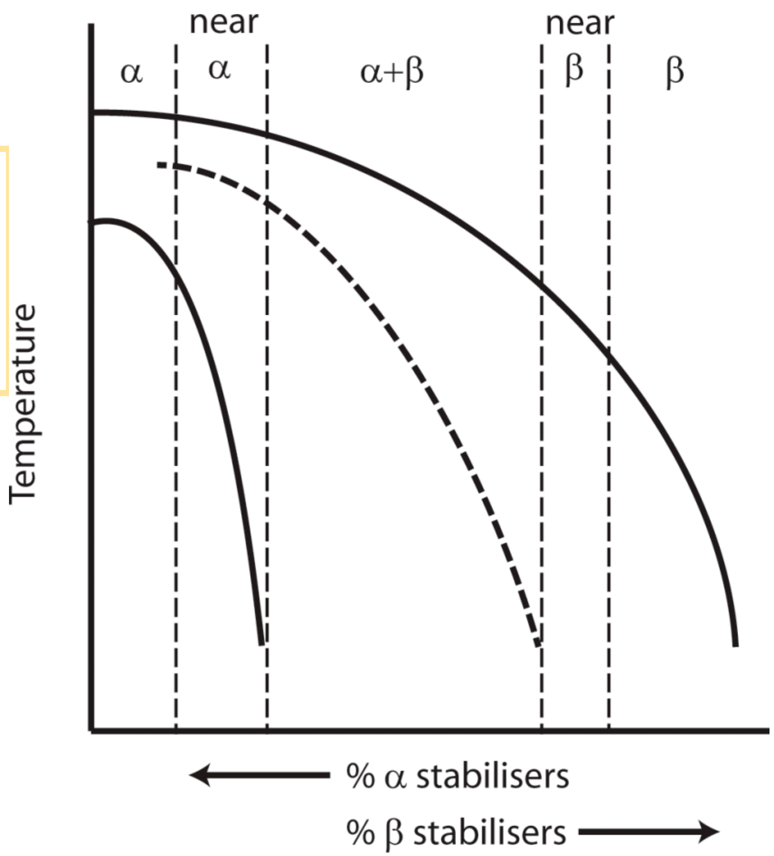
## Four commercial groups

Ti commercially **pure**
**alpha** (**α**) alloys and "near alpha alloys"
**α +** β alloys
**β metastable** alloys




Microstructure of **Ti6Al4V** alloy. Basketweave (acicular) microstructure from a cast and annealed Ti-6Al-4V alloy.

*Metallography and Microstructures,* Vol 9, *ASM Handbook, ASM* International,



Light Alloys: **titanium alloys**

## Phase Transformations in titanium

- $\beta \rightarrow \alpha$ transformations :
  - **Martensitic transformation**
    - **Rapid cooling**
    - $\beta$ (bcc) $\rightarrow$ hexagonal $\alpha'$ martensite
      - $\alpha'$ massive (CP Ti and dilute alloys)
      - $\alpha'$ acicular (alloys with high solute content)
    - $\rightarrow$ orthorhombic $\alpha''$ martensite (distorted structure, high solute)
    - $\rightarrow$ athermal $\omega$ phase : alloys with Ms < room T
  - **Nucleation and growth (diffusion)**
    - **Slow cooling** :
      - precipitation of $\alpha$ at the grain boundary of $\beta$: laminar structure
      - Higher rate: basket weave type structure (Ti-6-4)

# Light Alloys: **titanium alloys**

## APLICACIONS

✓Aeronautic Industry

✓ Gas Turbine, compressors

✓ Biomaterials (implants)

✓Chemical Engineering and other

✓Sports


http://commons.wikimedia.org/wiki/File:EJ200-Eurofighter-Turbine-apel.JPG

http://commons.wikimedia.org/wiki/File:Guggenheim_titanium_panels.jpg

# Copper Alloys

| | Units | Aluminium | Titanium | Copper | Iron |
|---|---|---|---|---|---|
| **Crystalline structure** | | FCC | Hexagonal **882ºC** ↓ BCC | FCC | BCC 910ºC ↓ FCC 1410ºC ↓ BCC |
| **Density** | $g/cm^3$ | 2,7 | 4,5 | 8,9 | 7,8 |
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| **Specific Heat** | cal/g.ºC | 0,215 | 0,124 | 0,092 | 0,114 |
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| **Relative price** | | 1 | 5 | 1 | 0,1 |

# Copper Alloys

http://commons.wikimedia.org/wiki/File:Memos_Makris_00.jpg

## General Characteristics

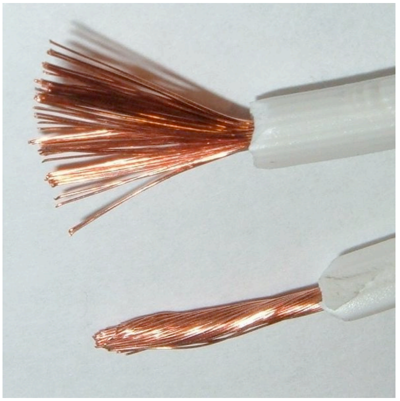
- ↑ Corrosion resistance (Eº = +0.34 V; noble metal )
- ↑ stability against $H_2O$
- Oxidation at T >450 ºC

  $Cu + O_2 \rightarrow CuO$ (granular eutectic) ⇒ ↓ Corrosion resistance (welding problems)
- Embrittlement in $H_2$ presence (Cu not deoxidized)

  $Cu_2O + H_2 \rightarrow 2\ Cu + H_2O\ (g)$ $\Delta V > 0 \Rightarrow$ microcracks

  Solution:
  - P addition
  - $O_2$ Elimination (heat treatment in reducing atmosphere). Oxygen free high conductivity (OFHC) copper
  - Soluble in weak acids and $NH_3$ in air

## Applications



Marine Industry

Conduction energy electrical, electronic

Fabrication of manufacturing goods and industrial machinery

transport and automobile Industry

Construction

Food industry

http://www.copper.org

# Copper Alloys

## DESIGNATION OF COPPER ALLOYS

### Wrought alloys

| | |
|---|---|
| C1xxxx | Coppers and alloys with high content of Cu |
| C2xxxx | Cu-Zn alloys (brass) |
| C3xxxx | Cu-Zn-Pb alloys (leaded brasses) |
| C4xxxx | Cu-Zn-Sn alloys (zinc-tin brasses) |
| C5xxxx | Cu-Sn alloys (Tin bronzes) |
| C6xxxx | Cu-Al alloys (aluminum bronzes), Cu-Si alloys (silicon bronzes), and other Cu-Zn alloys |
| C7xxxx | Cu-Ni alloys and Cu-Ni-Zn alloys (nickel silver or alpaca) |

### Cast alloys

| | |
|---|---|
| C8xxxx | Cast coppers, cast brasses, Cu-Zn-Si alloys (bronzes and silicon brass) |
| C9xxxx | Tin bronzes and leaded tin bronzes, nickel tin bronzes, aluminum bronzes, Copper nickel, aplaca, etc. |

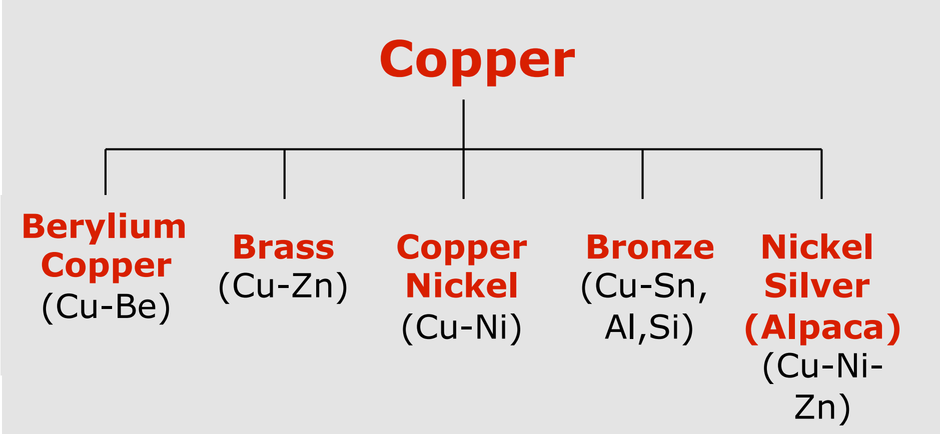
*According to Copper Development Association (CDA)*

# Copper alloys

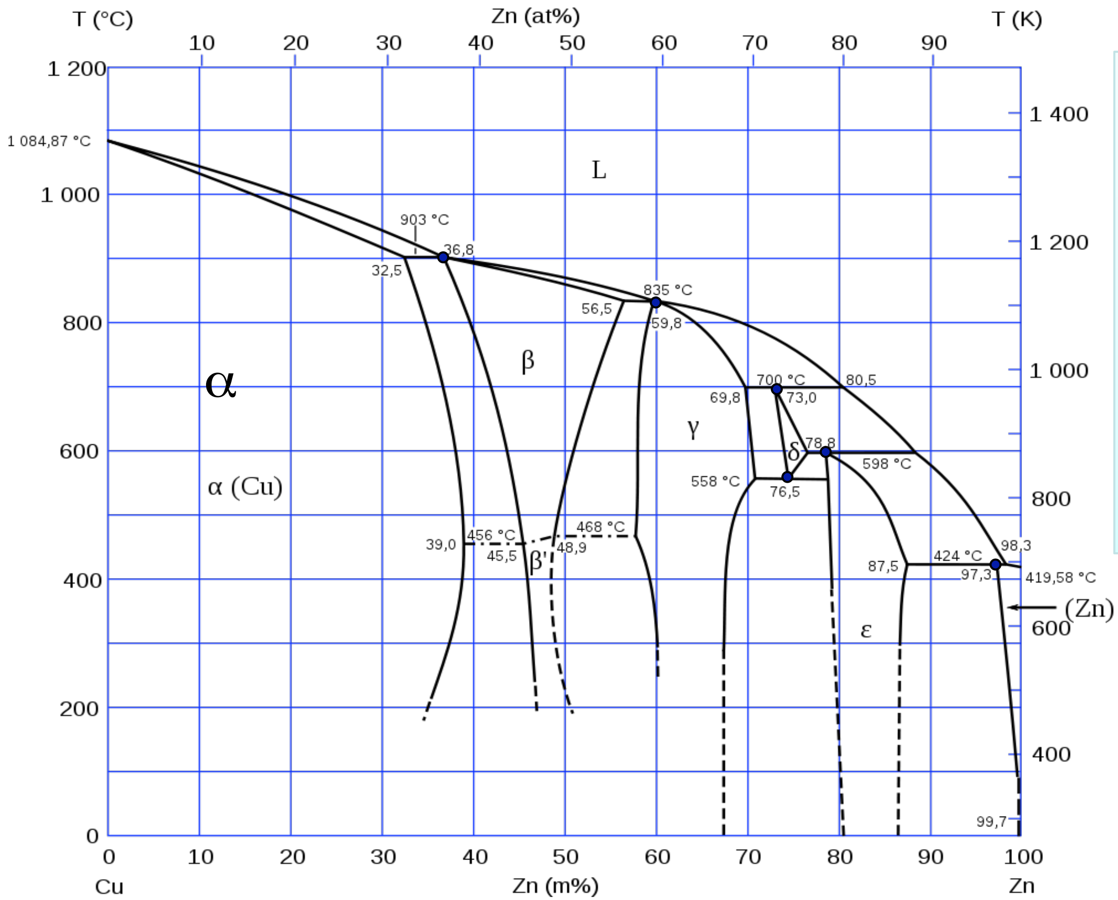
## Classification of copper alloys

**Low alloyed coppers**

| | |
|---|---|
| **Brass** | - Common brass<br>- Alloyed brass |
| **Bronze** | - Common bronze<br>- Alloyed bronze<br>- Special bronze |



# Copper Alloys : Brass




**Industrial brass**:
α Brass (single phase): Zn<39%
α +β brass (two phase):Zn=39-45%

Properties depend on the phase and Zn content.

**phase** α: fcc (easily deformable) σ ↑ when ↑ %Zn
**phase** β: bcc (not cold worked)
T< 456-468: β' (ordered phase)
T >456-468: β (disordered phase)
**phase** γ: cubic complex ($Cu_5Zn_8$) (very hard an brittle)

# Copper Alloys: Bronze

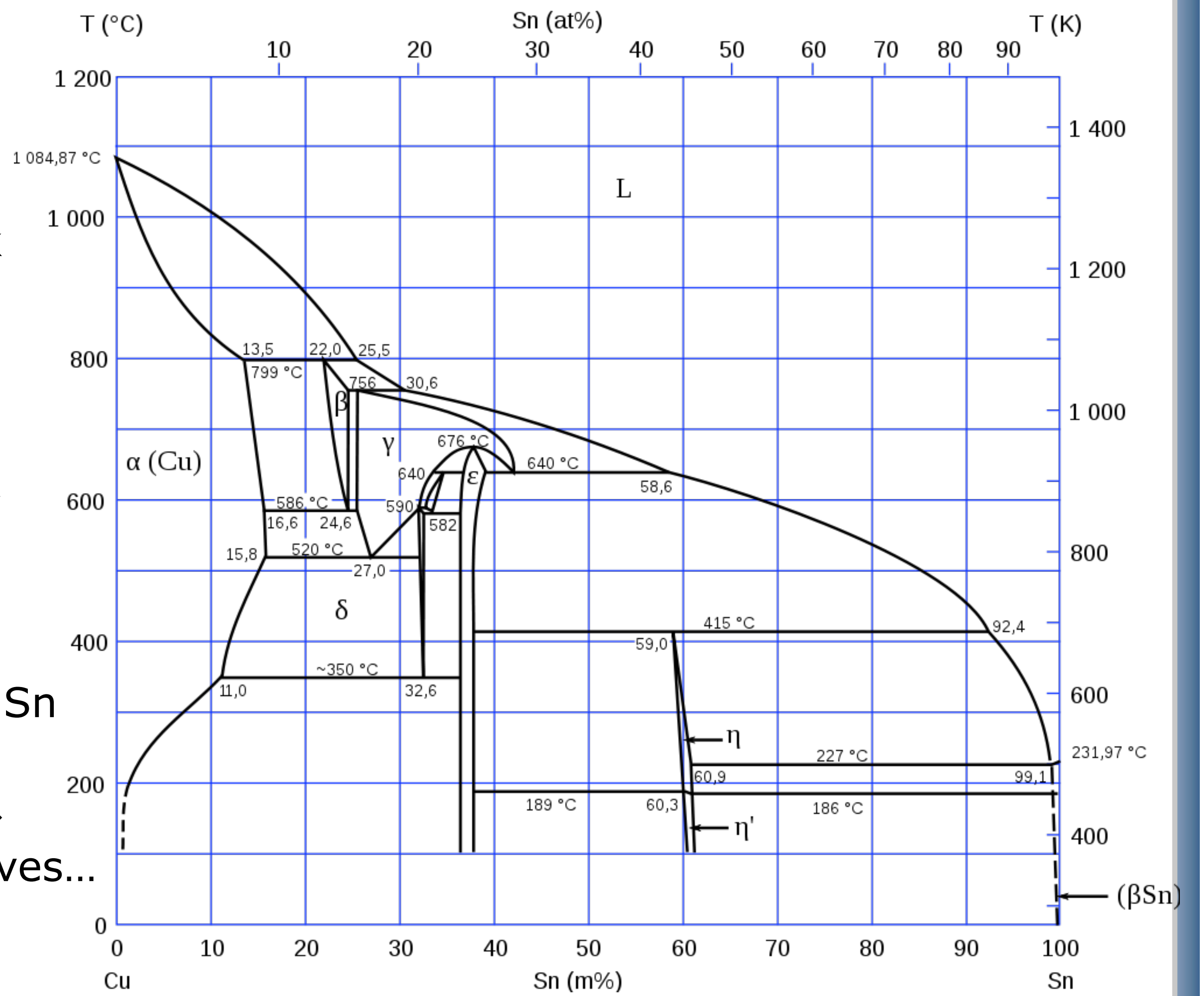
## Cu-Sn Alloys

### Single phase bronze

Phase a, below ~ 16% Sn
Deformable (FCC) and work hardenable.
Good thermal and electrical conductivity. Corrosion resistance.
Applications: springs, coins, plates, wires

### Two phase bronze

Phases α+δ, below ~ 22 % Sn
Properties depend on δ
Low melting Temperature → good for casting: gears, valves…
NO PLASTIC DEFORMATION
Low friction coefficient → bearings




***Phase diagram complexity between 20-50% Sn***