Metals - II

(Non-ferrous alloys)

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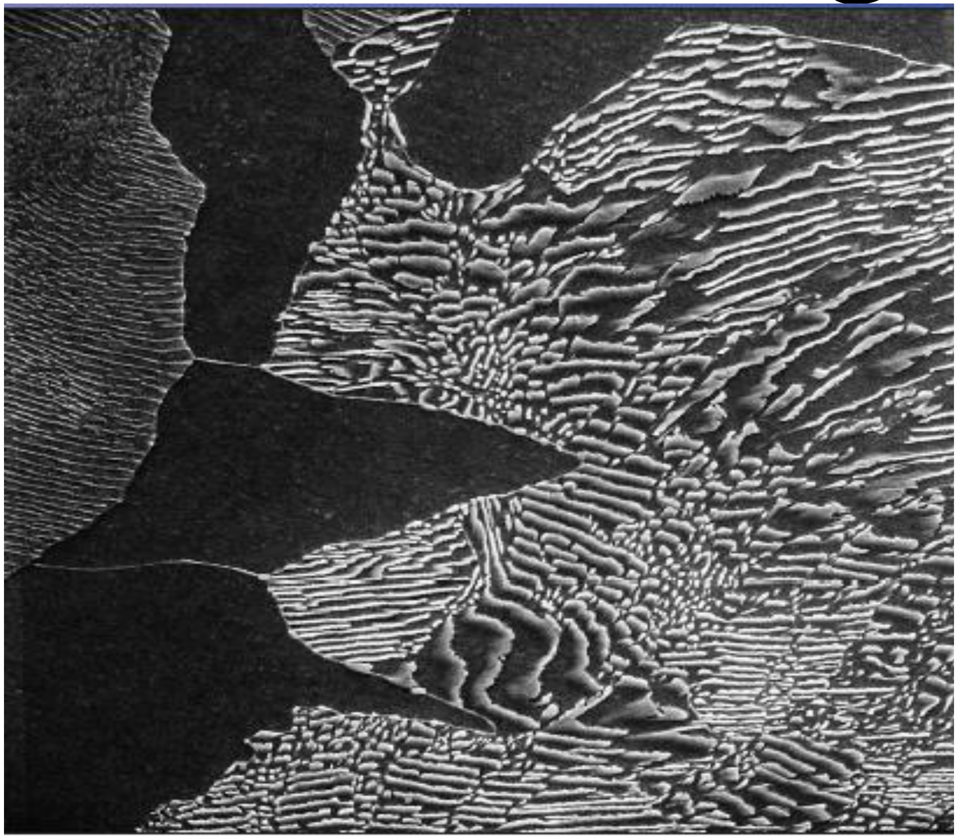
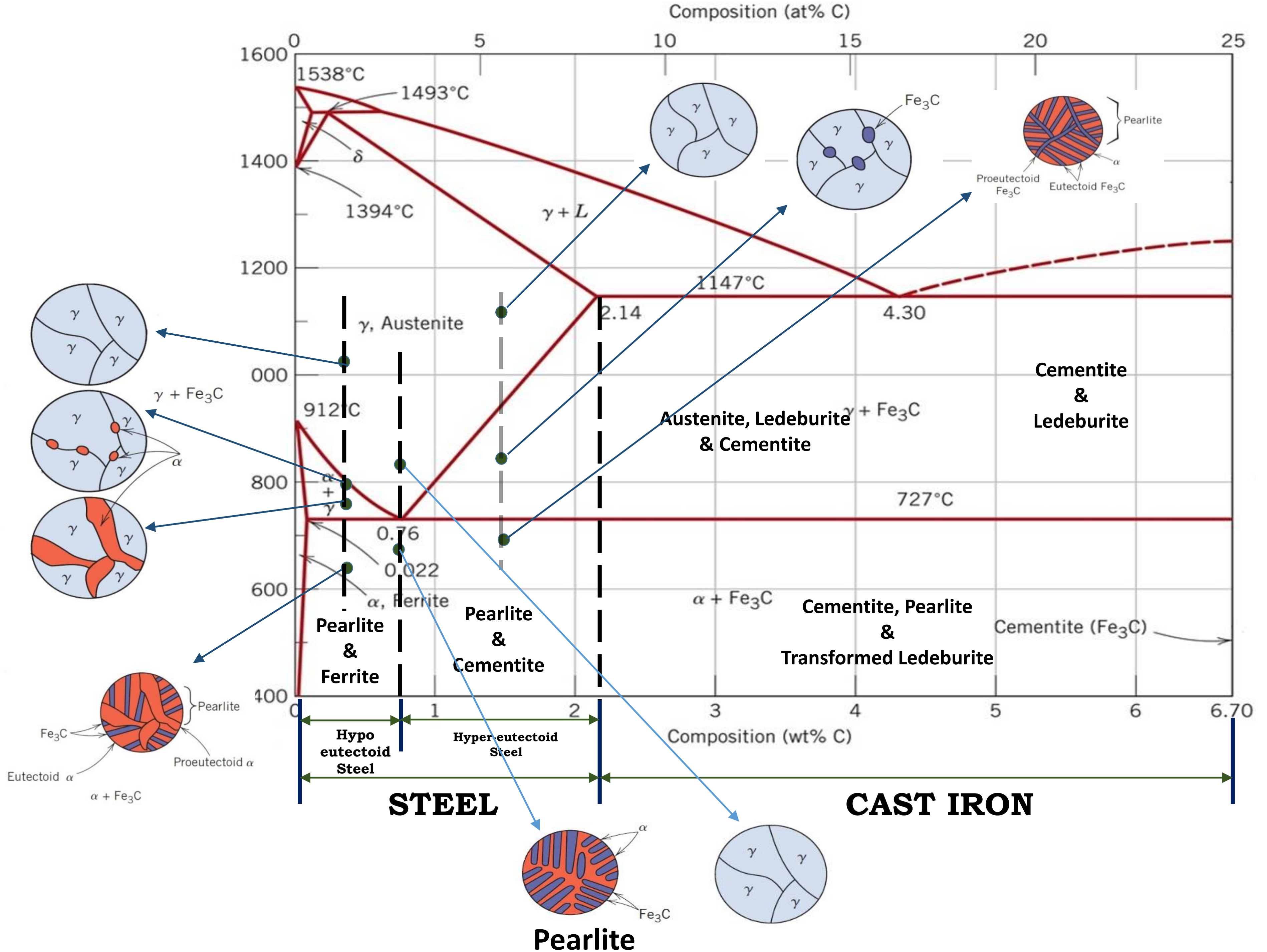
Iron Carbon Diagram

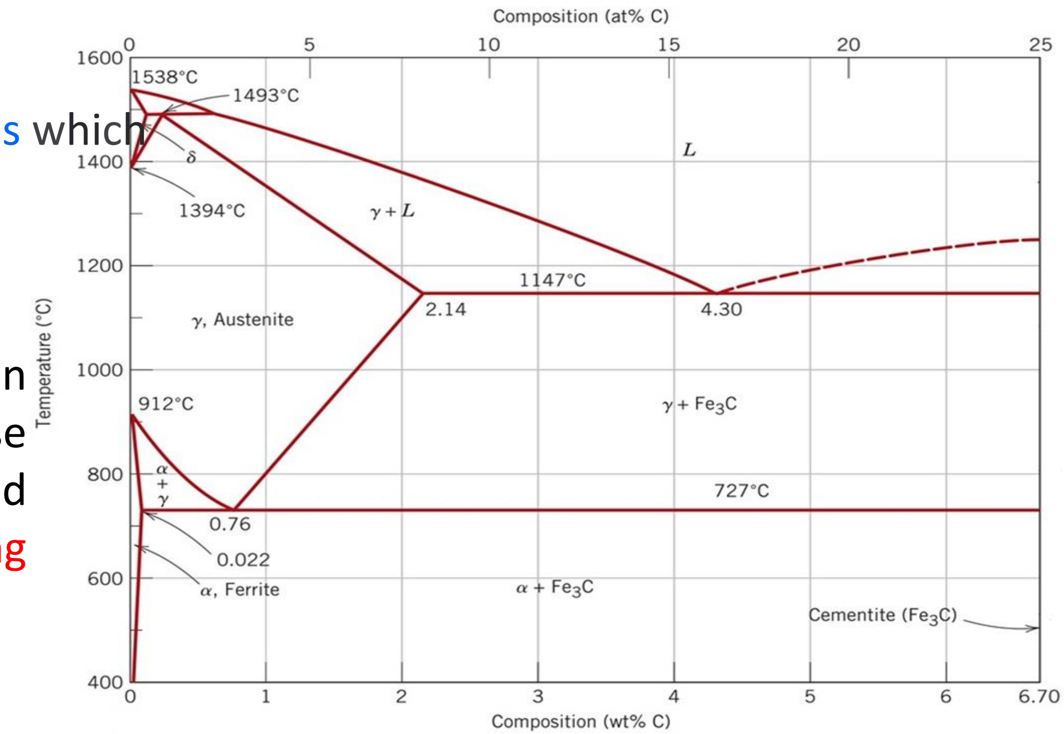


Microstructure of a plain carbon steel that contains 0.44 wt% C.



Composition (at% C)
0
5
10
15
20
25
1600
1400
1200
000
800
600
400
1538°C
1493°C
δ
1394°C
γ + L
1147°C
2.14
4.30
γ, Austenite
912°C
γ + Fe3C
α + γ
0.76
0.022
727°C
α, Ferrite
α + Fe3C
Austenite, Ledeburite & Cementite
Cementite & Ledeburite
Pearlite & Ferrite
Pearlite & Cementite
Cementite, Pearlite & Transformed Ledeburite
Cementite (Fe3C)
Fe3C
Pearlite
α
Proeutectoid Fe3C
Eutectoid Fe3C
Pearlite
Fe3C
Eutectoid α
Proeutectoid α
α + Fe3C
0
1
2
3
4
5
6
6.70
Composition (wt% C)
Hypo eutectoid Steel
Hyper-eutectoid Steel
STEEL
CAST IRON
α
Fe3C
Pearlite

The diagram shows three horizontal lines which indicate isothermal reactions:



1. Peritectic reaction (1493°C) : On Cooling, a solid phase and liquid phase will together form a new solid phase and vice-versa. – Almost no Engineering Importance.

2. Eutectic reaction (1147°C and 4.30 wt.% C) : On Cooling, a **liquid transforms** into **two solid phases** at the same time and vice-versa. They are CAST IRONS.

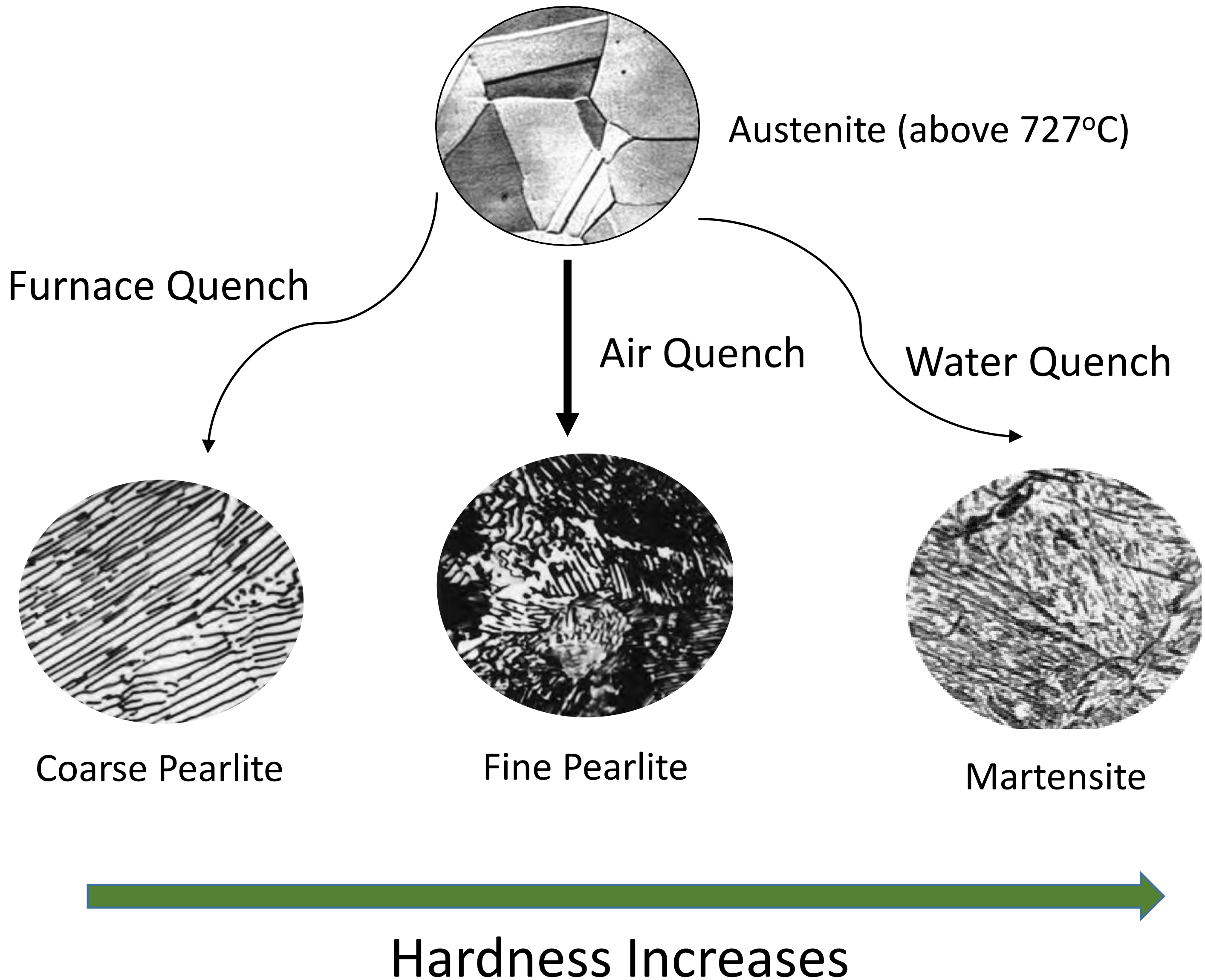
$$L \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \gamma + Fe_3C$$

Example: Ledeburite (in fig. 'L' means liquid) is the eutectic mixture of austenite and cementite. It contains 4.3% C and is formed at 1130°C.

3. Eutectoid reaction (727°C and 0.76 wt.% C) : On Cooling, a **solid transforms** into **two solid phases** at the same time and vice-versa. They are STEELS.

$$\gamma(0.76\ \text{wt\%}\ \text{C}) \underset{\text{heating}}{\overset{\text{cooling}}{\rightleftharpoons}} \alpha(0.022\ \text{wt\%}\ \text{C}) + Fe_3C\ (6.7\ \text{wt\%}\ \text{C})$$

Quenching of Steel with different medium



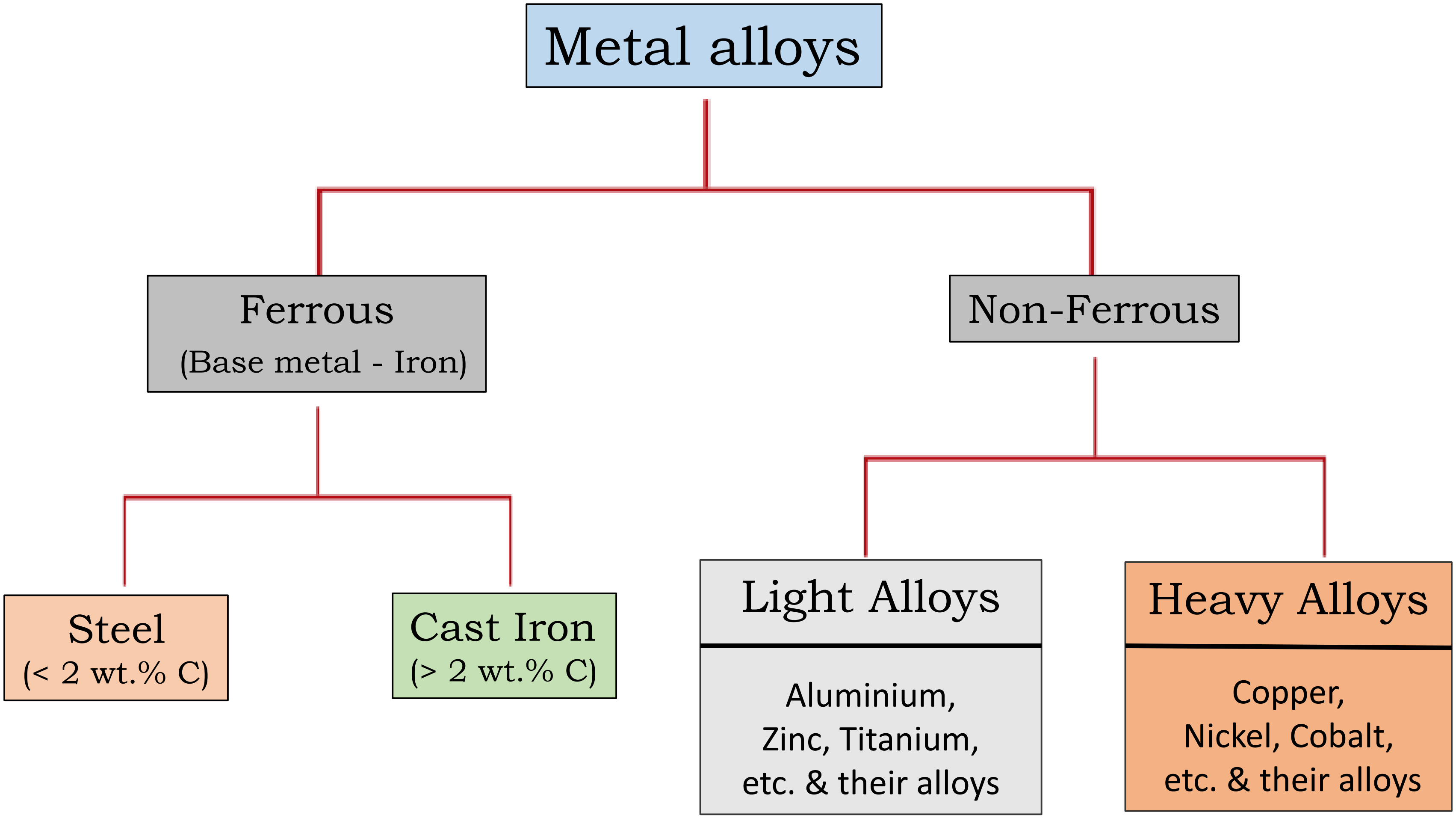
Contents

- ✓ Classification
- ✓ Aluminium & its alloys
- ✓ Titanium & its alloys
- ✓ Zinc & its alloys
- ✓ Copper & its alloys
- ✓ Nickel & its alloys
- ✓ Cobalt & its alloys
- ✓ Bulk Metallic Glass

Limitations of Ferrous alloys

- ✓ Relatively high density.
- ✓ Comparatively low electrical conductivity.
- ✓ An inherent susceptibility to corrosion in certain environments.

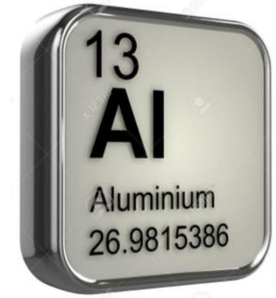
Classification of Metal Alloys



Light
Non-ferrous alloys

Aluminium

- Crystal structure: Face centered cubic (FCC)
- Melting point: 660 ^{o}C
- Density: 2700 kg/m^3 (Light)
- Elastic modulus = 70 GPa
- Silvery grey lustrous metal.
- High thermal & electrical conductivity.



Aluminium
Image: Wikipedia

Beverage can

Sheets

Fins

Wires

The Success Story of Aluminium

Reduced Fuel Consumption

- Lower energy consumption and gas emissions through reduced weight.
- Extensive use of aluminium can result in up to 300 kg weight reduction in a medium size vehicle (1400kg).

For every 100 kg reduction in the automotive sector there is

✓ 20% lower exhaust gas emissions
✓ Proportionally reduced operating costs.

Jaguar XJ Saloon (made from Al alloy)

Ref: http://kosovotimes.net/

Wing ribs of an A340 Airbus wing box are made from Aluminium alloy plate

Aerospace industry demands include:

- ✓ Improved toughness,
- ✓ Lower weight,
- ✓ Increased resistance to fatigue and corrosion.

Manufacturer: British Aluminium Plate (BAP), The Luxfer Group

Reference: http://www.azom.com/article.aspx?ArticleID=502

Aluminium Alloys

- Common alloying elements - Copper, magnesium, silicon, manganese, and zinc.

Wrought Alloy	
Series	**Alloying element**
1xxx series	Pure aluminium (min. 99%)
2xxx series	alloyed with copper (Duralium) Strength
3xxx series	alloyed with Manganese Corrosion
4xxx series	alloyed with Silicon Strength
5xxx series	alloyed with Mg Strength
6xxx series	alloyed with Mg & Si + Age Hard
7xxx series	alloyed with Zn + Age Hard
8xxx series	others elements such as Li weight
T- series	Heat treated

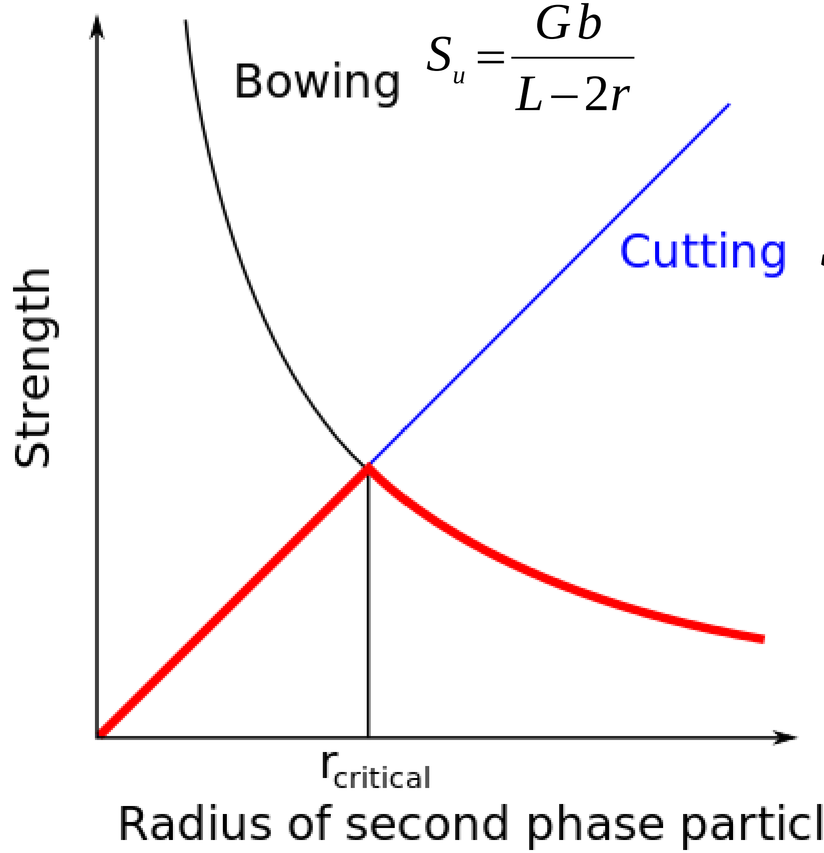
Cast Alloy	
Series	**Alloying element**
1xx.x series	Pure aluminium (min. 99%)
2xx.x series	alloyed with copper
3xx.x series	alloyed with Si, Cu &/or Mn
4xx.x series	alloyed with silicon
5xx.x series	alloyed with Magnesium
7xx.x series	alloyed with Zn
8xx.x series	alloyed with Tin (Sn)
9xx.x series	others elements

Initial xx – min. % of Al
Digit after decimal is x = 0(casting) or 1(ingot)

Age/Precipitation Hardening

- A **heat treatment** technique used to increase the yield strength of malleable materials, including most structural alloys of aluminium, magnesium, nickel, titanium, and some steels and stainless steels. In superalloys, it is known to cause yield strength anomaly providing excellent high-temperature strength.
- **Precipitation hardening** relies on changes in solid solubility with temperature to produce fine particles of an impurity phase, which impede the movement of dislocations, or defects in a crystal's lattice.

Failure in Precipitation Hardening



Bowing: $$S_u = \frac{Gb}{L-2r}$$

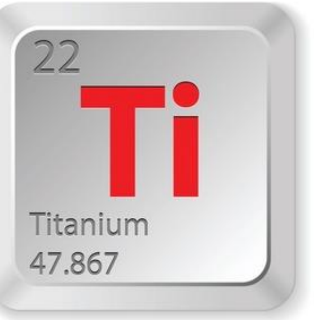
Cutting: $$S_u = \frac{\pi r \gamma}{bL}$$

b magnitude of Burgers Vector

L – Spacing between the pinning points

Titanium

Titanium
Image: Wikipedia



- Pure Titanium – low density (4500 kg/m^3)
- High Melting point (1660 ^oC)
- Elastic modulus = 107 GPa
- Tensile Strength = 150-500Mpa
- **Appearance** : Silvery grey-white metallic lustre
- Alloying required to reduce cost, increase strength & control phase.
- **Applications** – High strength & temperature components, biomedical, jewelry, etc.
- Two crystal forms – below 883^oC alpha structure (HCP) and beyond 883^oC beta (BCC)
- **Four alloys**: Alpha, Near Alpha, Alpha-Beta, Beta
- Alpha phase stabilizers: Al, Ga, Ge, C, N
- Beta phase stabilizers: Mo, V, Ta, Nb, Mn, Fe, Cr, Co, Ni, Cu, Si

Titanium Ring

Titanium alloys

a) Alpha Titanium Alloys

- Contains significantly alpha-phase stabilizers
- Low to medium strength.
- Good notch toughness.
- Reasonably good ductility.
- Excellent mechanical properties at cryogenic temperatures.
- Non-heat treatable and are generally very weldable.
- Example: **Ti-8AL-1MO-1V (Tensile strength = 950MPa) -** jet engine components.

Jet Engine

b) Near alpha Titanium alloy

- Besides alpha-phase stabilizers, near-alpha alloys are alloyed with 1–2% of beta phase stabilizers
- Offer high temperature creep strength and oxidation resistance.
- **Ti-6Al-2Sn-4Zr-2Mo (Tensile strength = 1100MPa)** used for creating high temperature jet engines components and high performance automotive valves

Titanium alloys (contd.)

c) Alpha Beta Titanium Alloys

- Metastable and generally include some combination of both alpha and beta stabilizer's.
- Weldable with the risk of some loss of ductility in the weld area.
- Strength levels are medium to high.
- Hot forming qualities are good but cold forming often presents difficulties.
- Creep strength is not usually as good as in most alpha alloys.
- **Example: Ti-6Al-4V (Tensile strength = 940MPa)** used where low density and good corrosion resistance is necessary such as aerospace industry and bio-implants and prostheses applications.

d) Beta Titanium Alloys

Landing gear

- Metastable and which contain sufficient beta stabilizers.
- Fully heat treatable.
- Generally weldable.
- Capable of high strength.
- Possess good creep resistance up to intermediate temperatures.
- Cold formability is generally excellent.
- **Ti-10V-2Fe-3Al (Tensile strength = 1200MPa)** used for critical aircraft structures, such as landing gear.

Zinc

- Crystal structure: Hexagonal close packed (hcp)
- Melting point: 420°C
- Density: 7140 kg/m^3
- Silver grey lustrous appearance.
- Easy castability

Applications of Zn alloys

- **Galvanic** coating on steel (hot-dip)
- **Corrosion protection** of structures by attaching as sacrificial anode.
- Zinc-carbon **dry battery**
- **Dietary intake** – deficiency leads to weak immunity, slow brain growth, diarrhoea and pneumonia - found in spinach, cashew, sea food, cocoa, beans

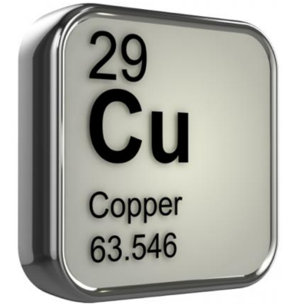
Steel dip in hot Zn bath

Battery – Zn as anode

Galvanized sheets

Heavy
Non-ferrous alloys

Copper



Copper (Cu)

- Crystal structure: Face Centered Cubic (FCC)
- Melting point: 1085°C
- Density: 8920 kg/m^3
- Distinctive reddish orange color
- Good corrosion resistance.
- Soft, malleable, ductile and very tough.
- Good machinability.
- High electrical and thermal conductivity.
  - ✓ Thermal conductivity order: Ag > Cu > Al
  - ✓ 99.99% pure copper used for wiring application.
  - ✓ Possess around 97% conductivity of Silver(Ag) at 1/8th cost.

Copper

Copper alloys

Brass – Contains **Zinc** (Zn) as a **main substitutional** impurity up to 45 wt.%

- Sn, Al, Si, Mg, Ni, and Pb are also added.
- As **Zn** content **increases**, the **strength, hardness, ductility increases** while **conductivity reduces**.
- Commercially used Brass is divided in two categories

1. α Brass (containing up to 30% Zn)

✓ **Gun metal** (~2% Zn) - bearings, bushes

✓ **Gilding Metal** (~5% Zn) – coins, medals, jewellery

✓ **Admiralty brass** (~28% Zn,1% Sn) – Condenser, Evaporator and Heat Exchanger tubes

✓ **Cartridge brass** (~30% Zn) - Ammunition cartridge cases, automotive radiators, lamp fixtures

2. α+β Brass (more than 30% Zn)

✓ **Muntz metal** (~40% Zn) – valve stem, architectural works

✓ **Naval brass** (39.25% Zn, 0.75% Sn) – marine construction, propeller shaft

Copper alloys

<u>Bronze</u> – Contains **Tin** (Sn) as a **main substitutional** impurity.

- Posses superior mechanical properties and corrosion resistance than brass.
- Comparatively hard and resist surface wear.

Commercially used bronze are:

- **Phosphor bronze** (up to 10% Sn, 1% P) – Phosphorous improves castability.
  - ✓ used in music instruments, springs
- **Aluminium bronze** (up to 11% Al, 3.5% Sn) - higher strength and corrosion resistance as compared to other bronze alloys.
  - ✓ Bearings, landing gear components in aircraft
- **Silicon bronze** (up to 3% Si) – self-lubricating, high strength and toughness.
  - ✓ Bearing cage

Wrench

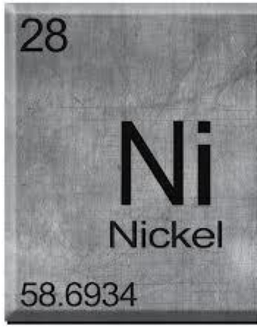
Other important Copper alloys are:

➢ **Beryllium copper** (upto 3% Be) – **highest resilience** – **spring**, screwdrivers, pliers, wrenches.

➢ **German silver** (60% Cu, 20% Ni and 20% Zn) – **Silvery appearance** but not **no silver** -
Ni increases electrical resistivity, improves strength and corrosion resistance – condenser tubes, cutlery

Nickel (Ni)

- Crystal structure: Face centered cubic (FCC)
- Melting point: 1455°C
- Density: 8900 kg/m^3
- Silvery - white lustrous metal with a slight golden colour.



Nickel
Image: Wikipedia

Applications

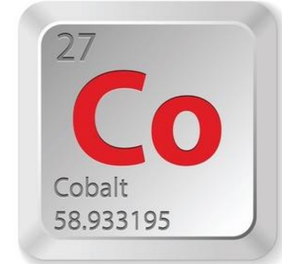
- **Nickel** metal hydride rechargeable **batteries**
- **Monel metal**
  - ✓ Primarily composed of Ni & Cu - with traces of Fe, Mn, Si, C.
  - ✓ Strong corrosion resistant.
  - ✓ Heat exchanger tubes, food processing plant, marine applications
- **Super alloys (Ni-Cr) -** high creep and oxidation resistance at elevated temperatures (approx. 1100°C) - turbine blades

Nickel metal hydride battery
Image: Wikipedia

Ni superalloy jet engine blade
Image: Wikipedia

Cobalt

- Crystal Structure : Hexagonal close packing
- Density – 8900 kg/m^3
- Melting point – 1495^{o}C
- Lustrous silver grey metal
- Elastic modulus – 209 GPa
- **Main application** – production of high performance alloys
- Cobalt-based alloys are also corrosion and wear-resistant.
- Some high speed steels also contain cobalt for increased heat and wear-resistance.
- Also used in medical orthopedic implants (Vitallium: Co-Cr-Mo alloy).
- Alloyed with 95% platinum for jewelry.
- Cobalt-based blue pigments impart a distinctive blue tint to glass.



Cobalt
Image: Wikipedia

High temperature application

Cobalt-blue glass

Amorphous Metal

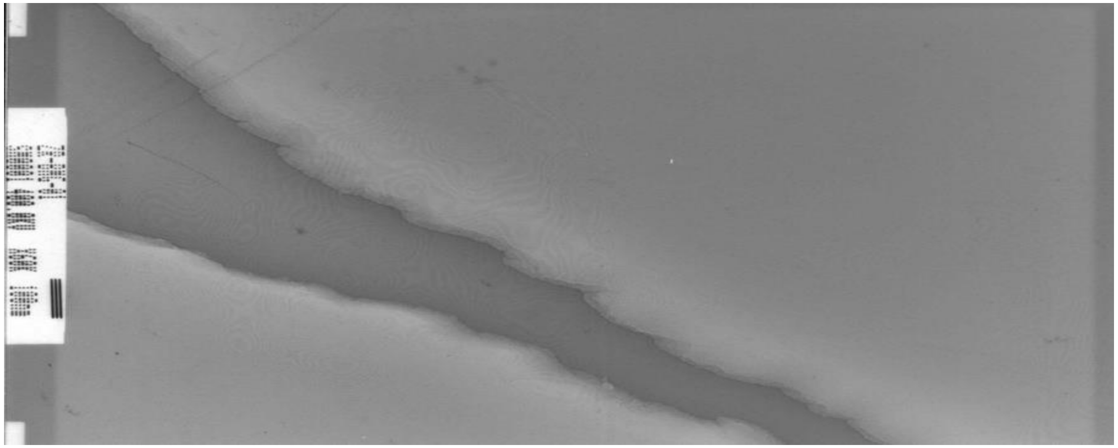
Amorphous metals can only be produced by rapid cooling from the liquid state.

Until recently, the cooling rates required were on the order of 10^5-10^6 K/s, which limits the thickness of a fully amorphous alloy to fractions of a millimeter. The resulting ribbons and wires are used extensively as transformer cores and magnetic sensors.

Bulk Metallic Glass

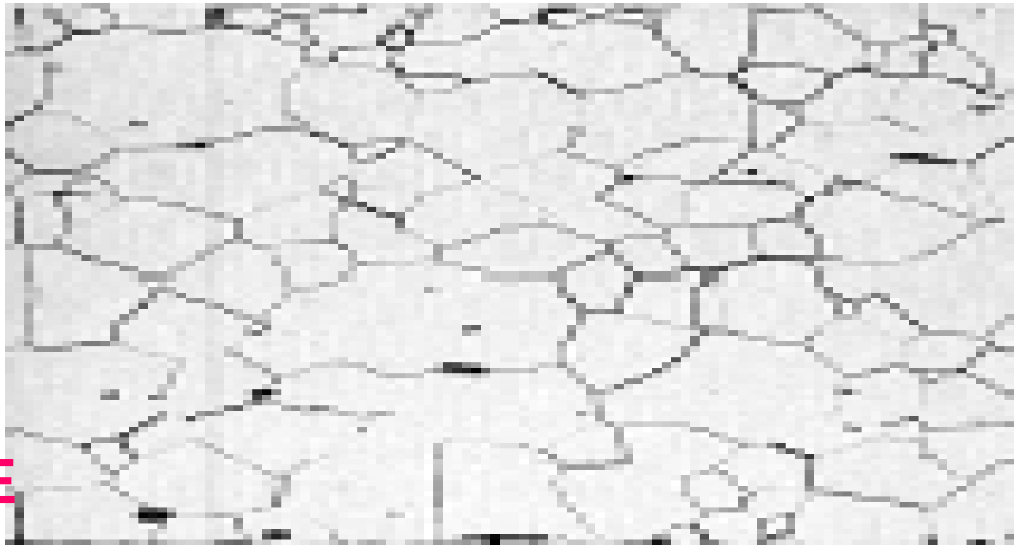
The recent development of *bulk* metallic glasses (BMG's) has opened the door for use of these fascinating materials in structural applications.

These alloys require cooling rates of only 1-100 K/s, so fully amorphous castings up to a centimeter thick can be manufactured using conventional casting methods.



BULK METALLIC GLASS

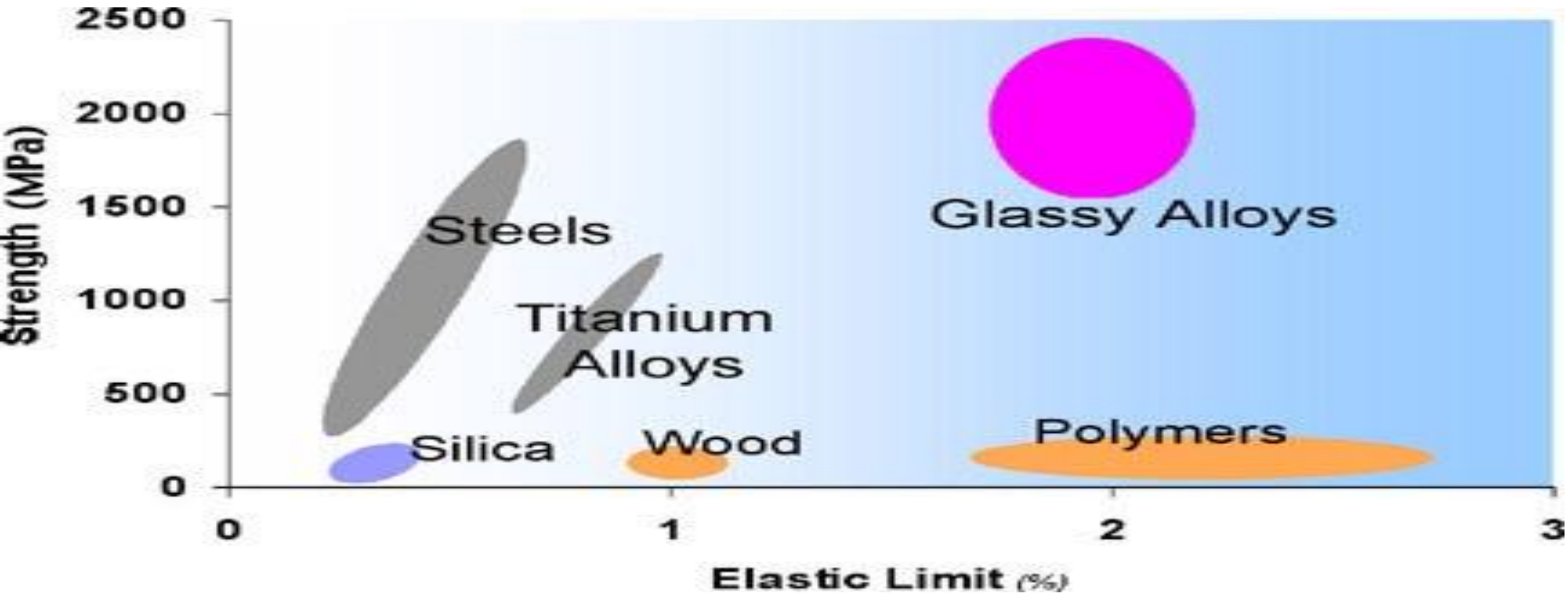
POLYCRYSTALLINE METALLIC STRUCTURE



For a Zr-Ti-Ni-Cu-Be bulk amorphous alloy, tensile strengths of 2 GPa and fracture toughness values of ~20 MPa√m have been reported.

With a density of 6.1 g/cm^3, this BMG has a higher strength to weight ratio than steels and most titanium alloys.

The alloy exhibits almost no plastic strain at failure, but typically shows up to 2.5% elastic strains. This ability to elastically store large amounts of energy per unit volume makes the alloy an excellent spring. In fact, it's first commercial application is as a golf club head.



Strength (MPa)
2500
2000
1500
1000
500
0
Glassy Alloys
Steels
Titanium
Alloys
Silica
Wood
Polymers
0
1
2
3
Elastic Limit (%)

In the **next lecture**, we will learn:

- ✓ Metal strengthening
- ✓ Metal corrosion