Chapter 8

Applications and Processing of Metal Alloys

The University of Jordan

Chemical Engineering Department

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ISSUES TO ADDRESS...

- How are metal alloys classified and what are their common applications?
- What are some of the common fabrication techniques for metals?
- What heat treatment procedures are used to improve the mechanical properties of both ferrous and nonferrous alloys? (will not be covered this semester)

Classification of Metal Alloys

Metal Alloys

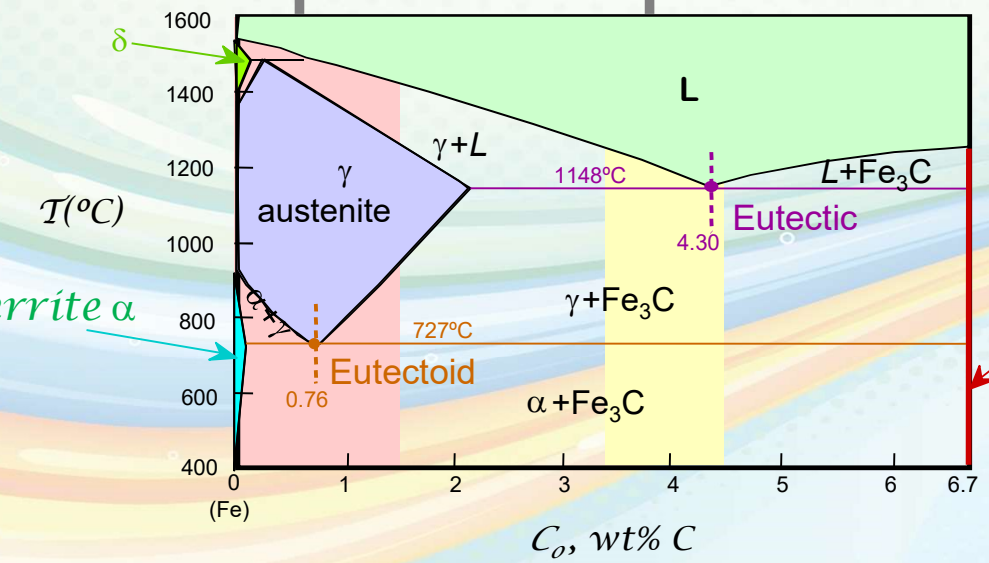
Ferrous

Nonferrous

Steels
<1.4wt% C

Cast Irons
3-4.5 wt% C

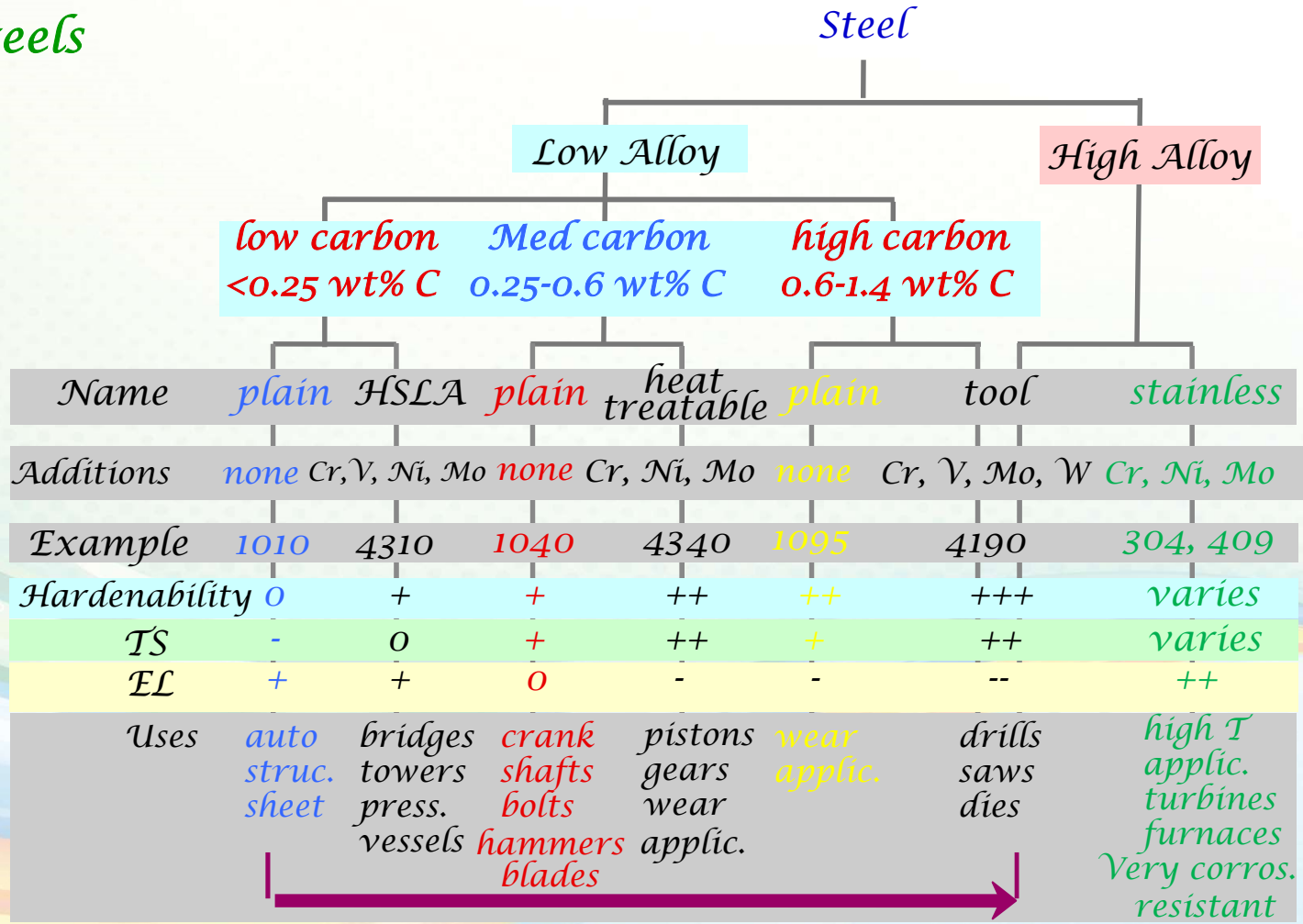
microstructure: ferrite, graphite/cementite



Ferrite α

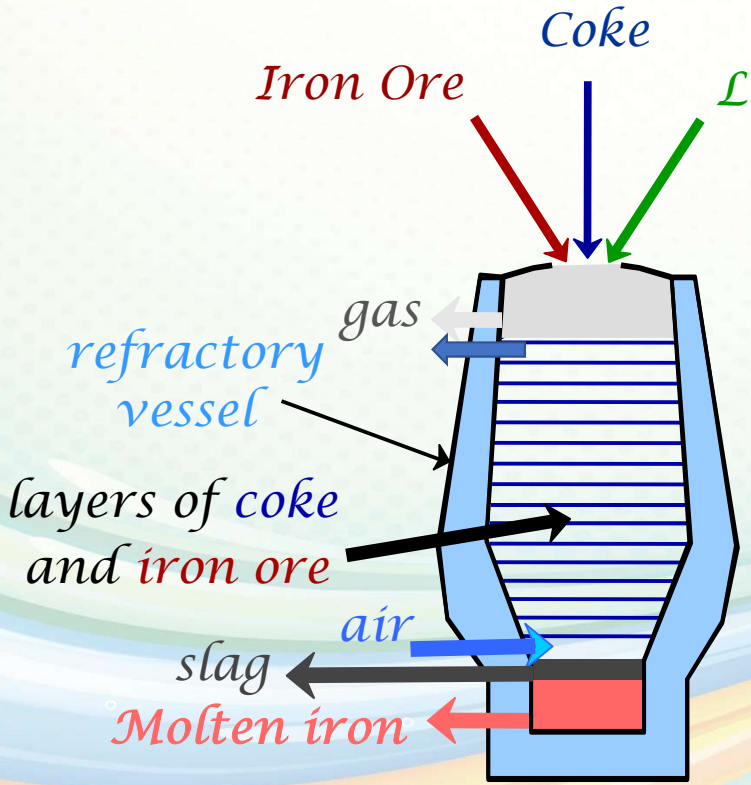
Cementite Fe3C

Steels



increasing strength, cost, decreasing ductility

Refinement of Steel from Ore



BLAST FURNACE

heat generation

$$C + O_2 \rightarrow CO_2$$

reduction of iron ore to metal

$$CO_2 + C \rightarrow 2CO$$
$$3CO + Fe_2O_3 \rightarrow 2Fe + 3CO_2$$

purification

$$CaCO_3 \rightarrow CaO + CO_2$$
$$CaO + SiO_2 + Al_2O_3 \rightarrow slag$$

Ferrous Alloys

- Iron-based alloys:
  - Steel
  - Cast Irons
- Nomenclature for steels (AISI/SAE)

10xx	Plain Carbon Steels
11xx	Plain Carbon Steels (resulfurized for machinability)
15xx	Mn (1.00 - 1.65%)
40xx	Mo (0.20 ~ 0.30%)
43xx	Ni (1.65 - 2.00%), Cr (0.40 - 0.90%), Mo (0.20 - 0.30%)
44xx	Mo (0.5%)

where xx is wt% C x 100

Example: 1060 steel – plain carbon steel with 0.60 wt% C

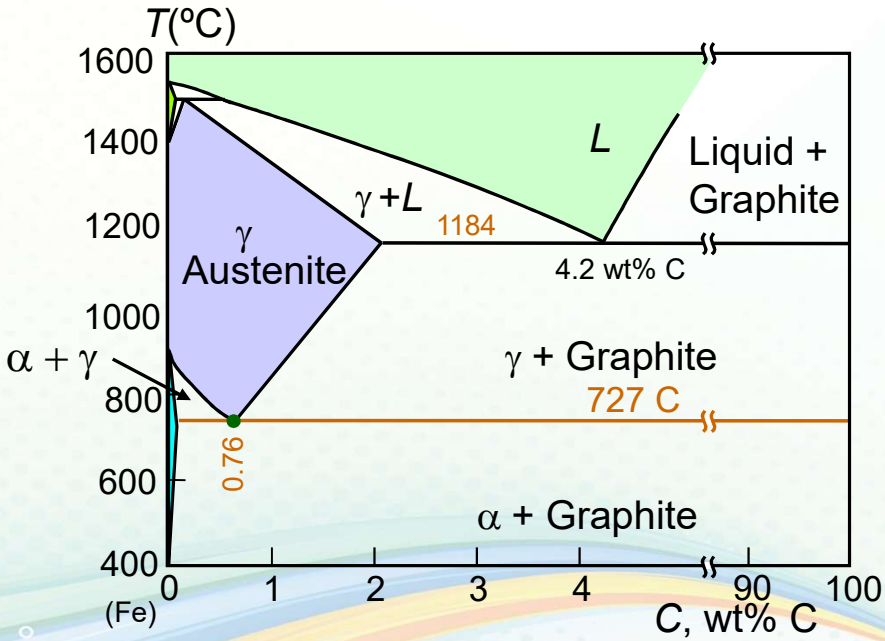
Stainless Steel >11% Cr

Cast Irons

- Ferrous alloys with > 2.1 wt% C
  - More commonly 3 - 4.5 wt% C
- Low melting – relatively easy to cast
- Generally brittle
- Cementite decomposes to ferrite + graphite

$$Fe_3C \rightarrow 3\,Fe\,(\alpha) + C\,(graphite)$$

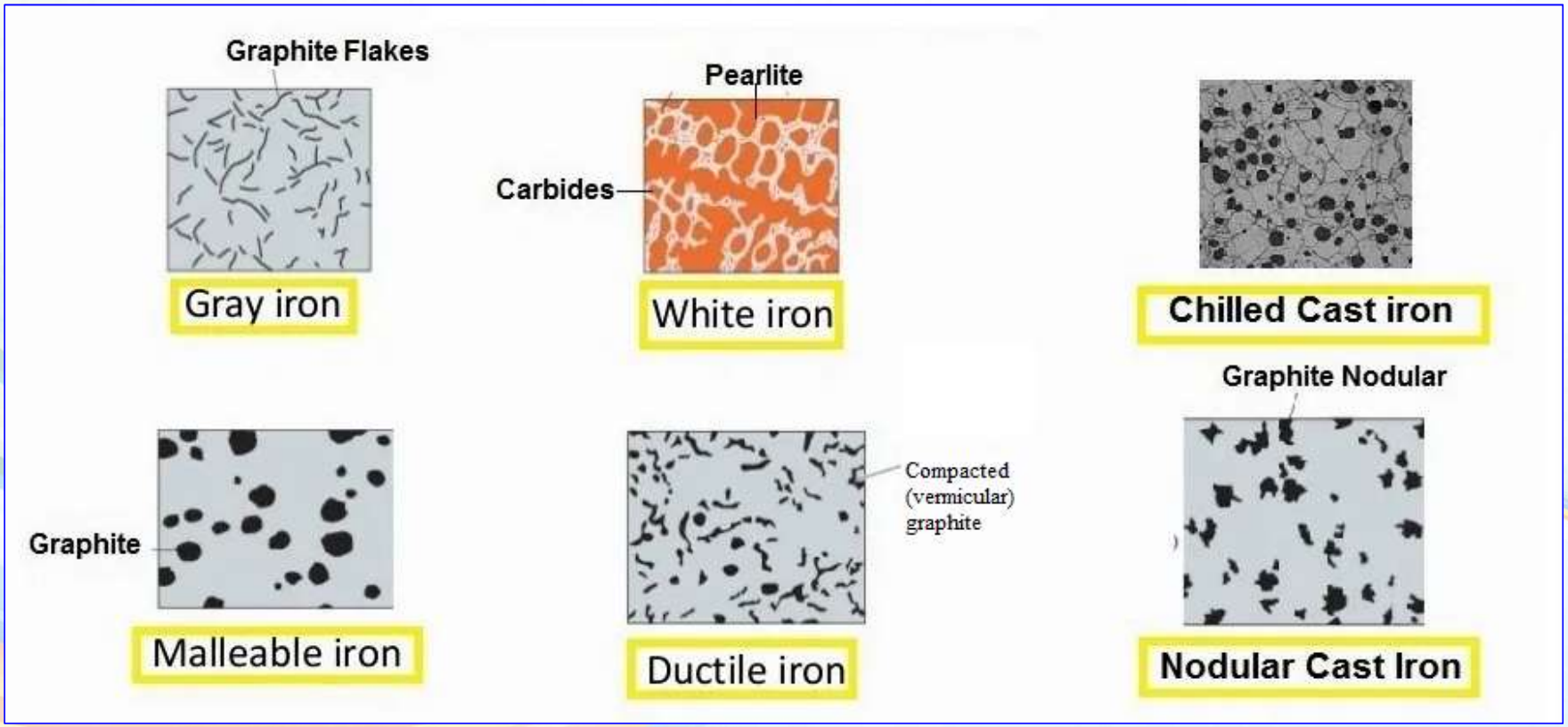
- This decomposition process is generally a slow process



Graphite formation promoted by:

- ✓ Si > 1 wt%
- ✓ slow cooling

Types of Cast Iron

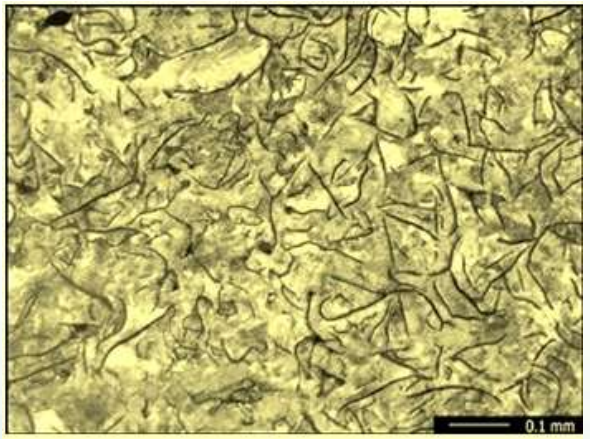


Types of Cast Iron

Types of Cast Iron

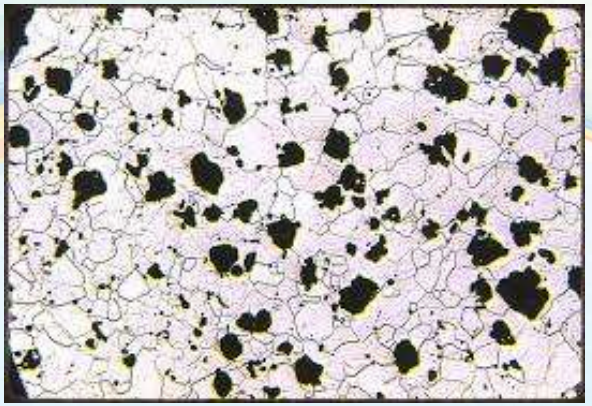
Gray Iron

- Graphite flakes
- Weak & brittle in tension
- Stronger in compression
- Excellent vibrational dampening
- Wear resistant



Ductile Iron

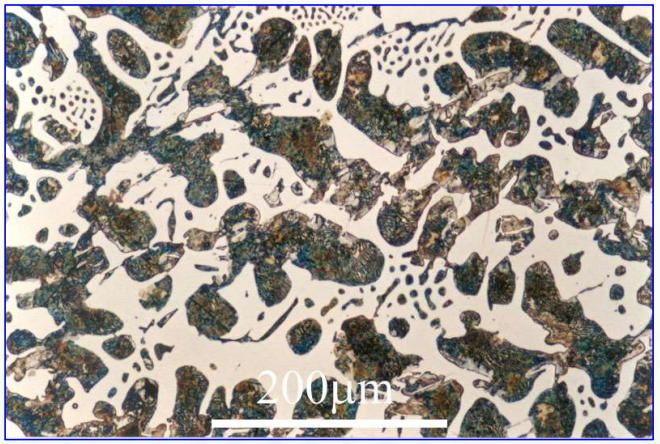
- Add Mg and/or Ce
- Graphite as nodules not flakes
- Matrix often pearlite – stronger but less ductile



Types of Cast Iron

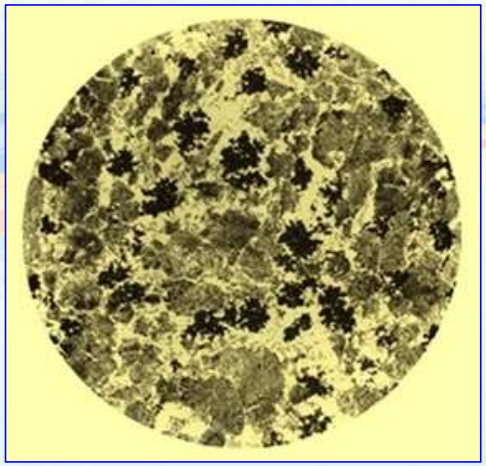
White iron

- < 1 wt% Si
- Pearlite + cementite
- Very hard and brittle



Malleable iron

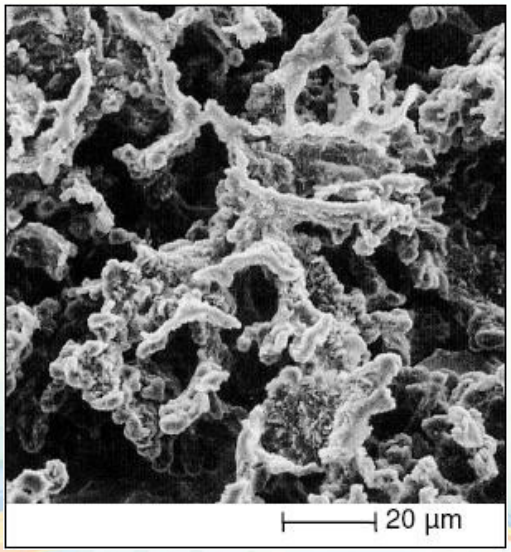
- Heat treat white iron at 800-900°C
- Graphite in rosettes
- Reasonably strong and ductile



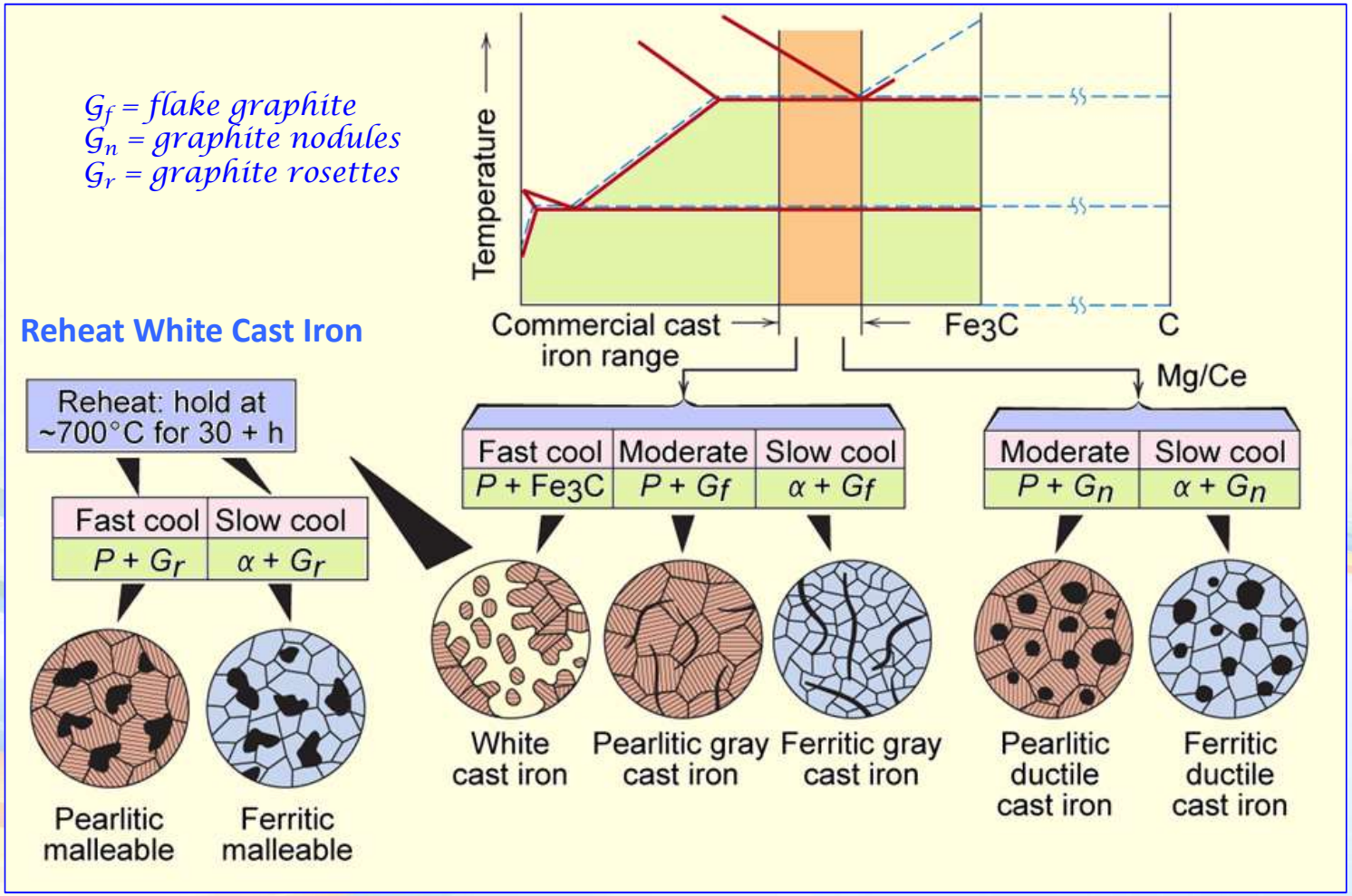
Types of Cast Iron

Compacted graphite iron

- Can be prepared by addition of small amount of Ce or Mg to gray cast iron
- Relatively high thermal conductivity
- Good resistance to thermal shock
- Lower oxidation at elevated temperatures



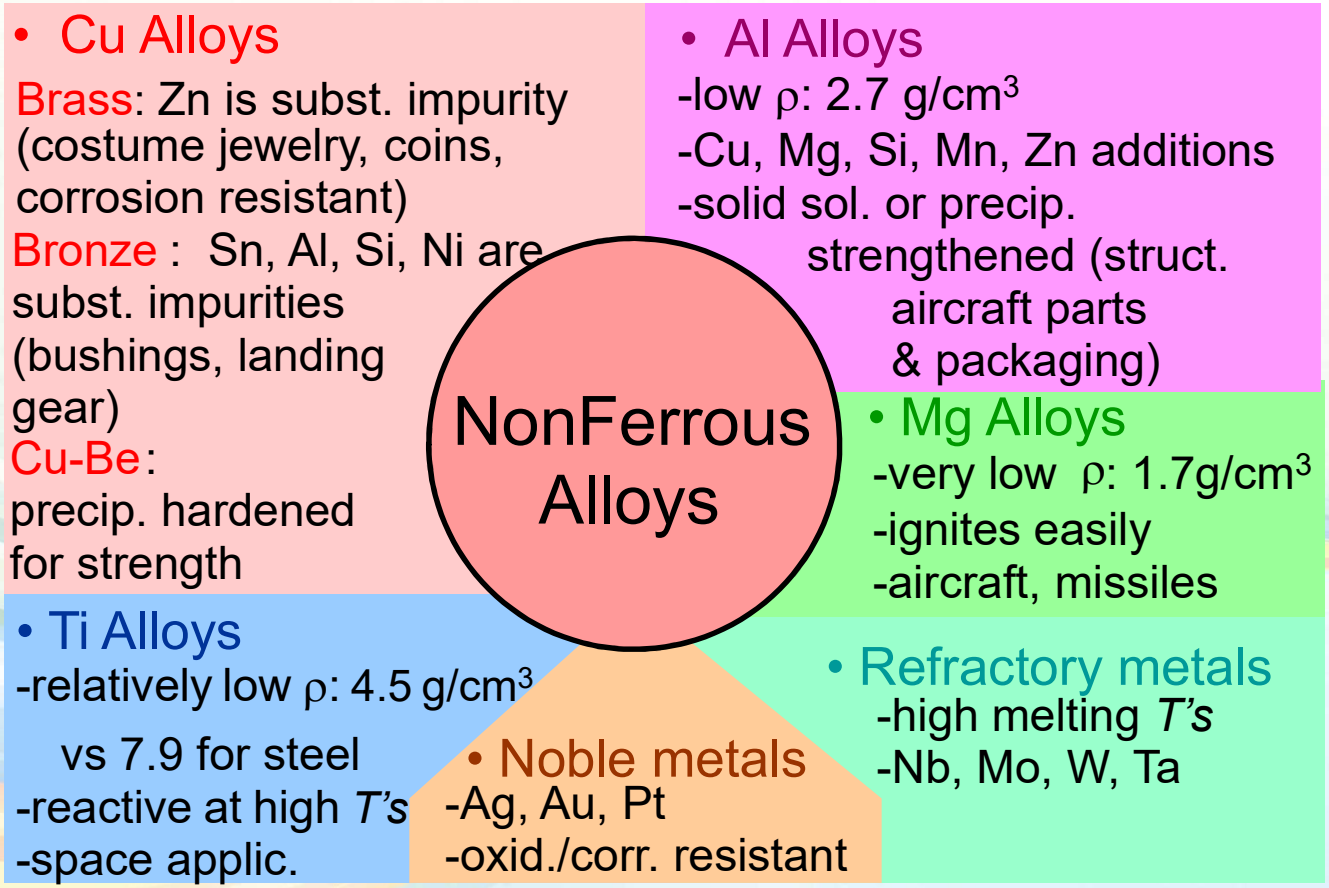
Production of Cast Irons



Limitations of Ferrous Alloys

- One main drawback of ferrous alloys is their environmental degradation i.e. poor corrosion resistance.
- Other disadvantages include:
  1) Relatively high densities.
  2) Relatively low electrical conductivities
  3) High cost to finish product
- In ferrous materials the main alloying element is carbon

Nonferrous Alloys



Metal Fabrication

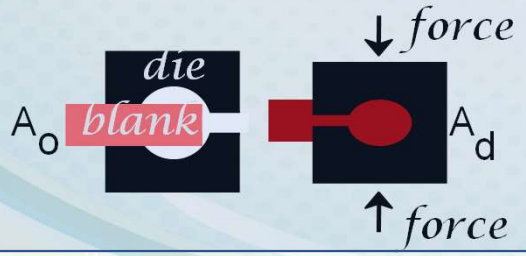
- How do we fabricate metals?
  - Blacksmith - hammer (forged)
  - Cast molten metal into mold
- Forming Operations
  - Rough stock formed to final shape

Hot working	vs.	Cold working
✓ Deformation temperature high enough for recrystallization		✓ Deformation below recrystallization temperature
✓ Large deformations		✓ Strain hardening occurs
		✓ Small deformations

Metal Fabrication Methods (i)

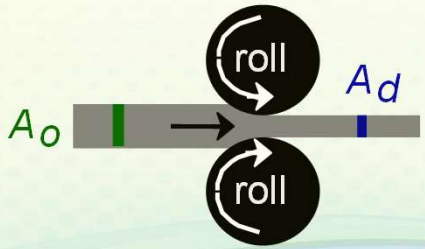
FORMING | CASTING | JOINING

- **Forging (Hammering; Stamping)**
  (wrenches, crankshafts)



often at elev. T

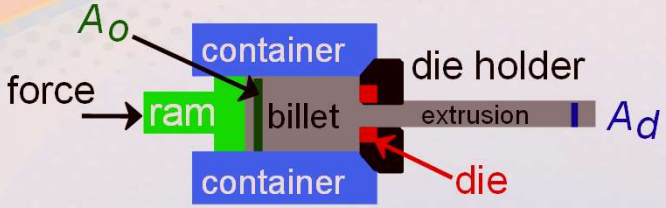
- **Rolling (Hot or Cold Rolling)**
  (I-beams, rails, sheet & plate)



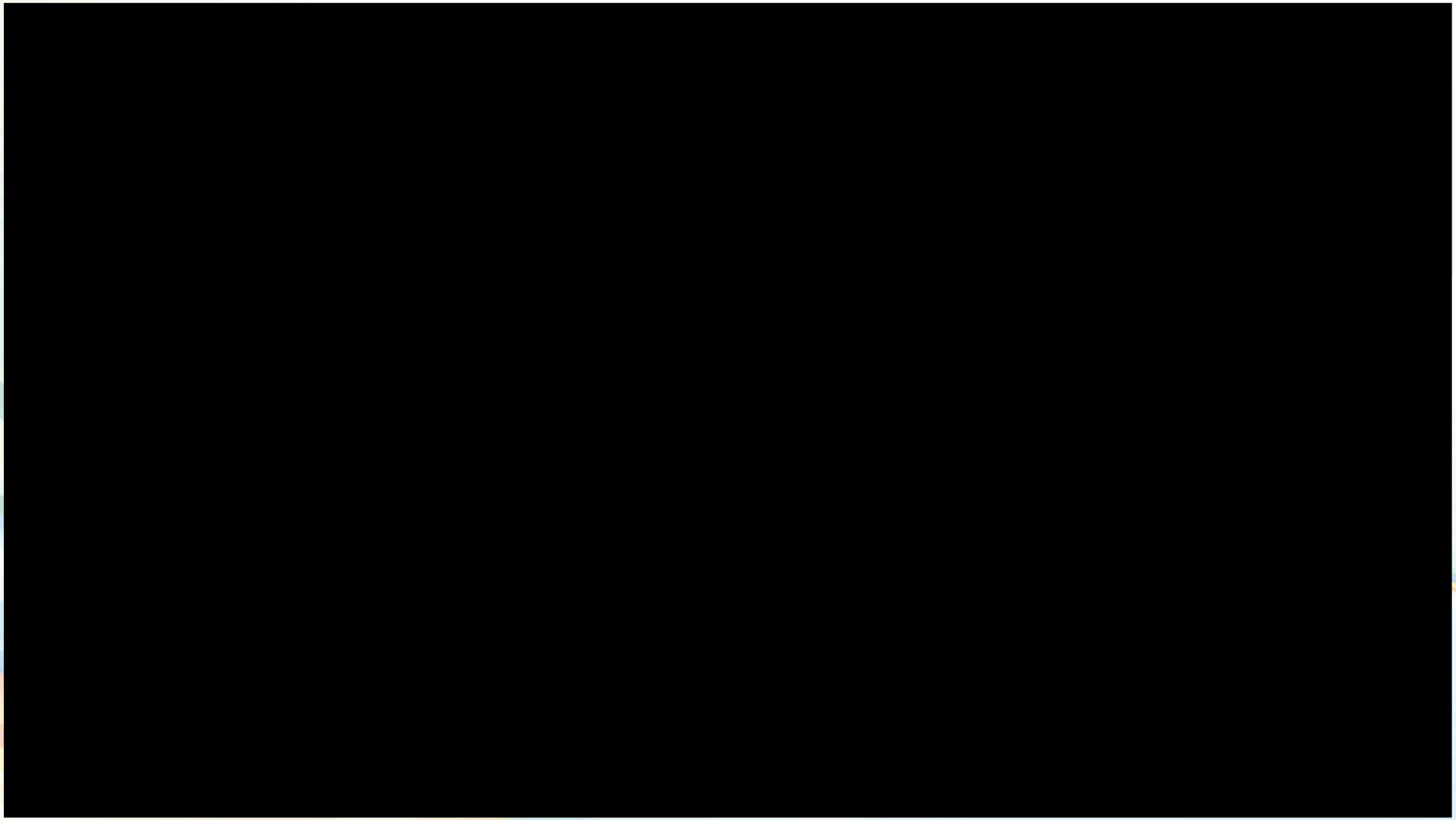
- **Drawing**
  (rods, wire, tubing)

die must be well lubricated & clean

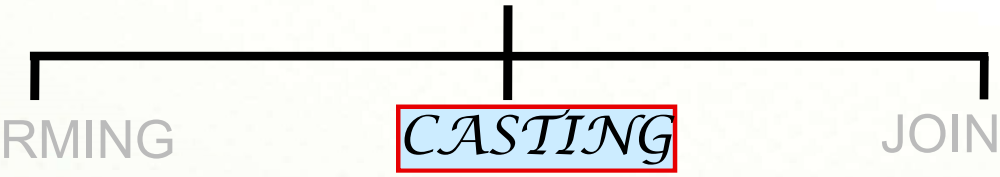
- **Extrusion**
  (rods, tubing)



ductile metals, e.g. Cu, Al (hot)



Metal Fabrication Methods (ii)

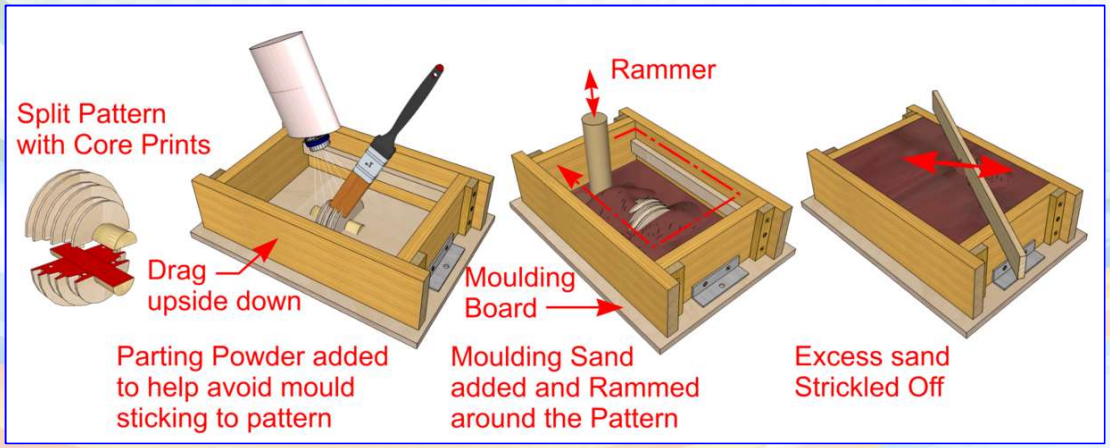


- Casting- mold is filled with molten metal
  - Metal melted in furnace, perhaps alloying elements added, then cast in a mold
  - Common and inexpensive
  - Gives good production of shapes
  - Weaker products, internal defects
  - Good option for brittle materials

Metal Fabrication Methods (ii)

FORMING | **CASTING** | JOINING

- **Sand Casting**
  (large parts, e.g., auto engine blocks)



- What material will withstand $T > 1600°C$ and is inexpensive and easy to mold?

  Answer: sand!!!

- To create mold, pack sand around form (pattern) of desired shape

Metal Fabrication Methods (ii)

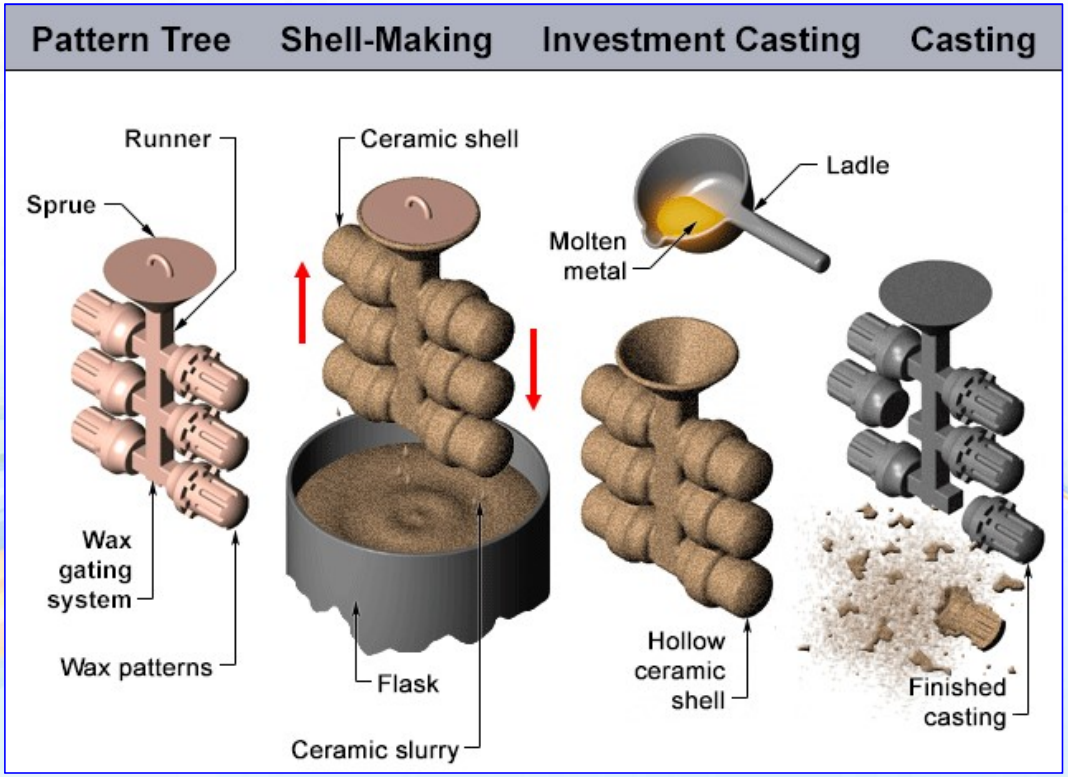
FORMING | **CASTING** | JOINING

- ***Investment Casting*** *(low volume, complex shapes e.g., jewelry, turbine blades)*

  Stage I: Mold formed by pouring plaster of paris around wax pattern. Plaster allowed to harden.

  Stage II: Wax is melted and then poured from mold—hollow mold cavity remains.

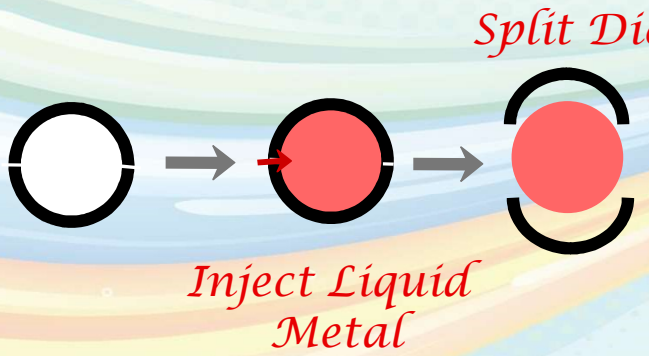
  Stage III: Molten metal is poured into mold and allowed to solidify.



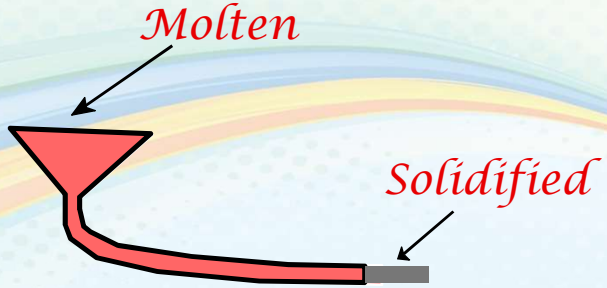
Metal Fabrication Methods (ii)

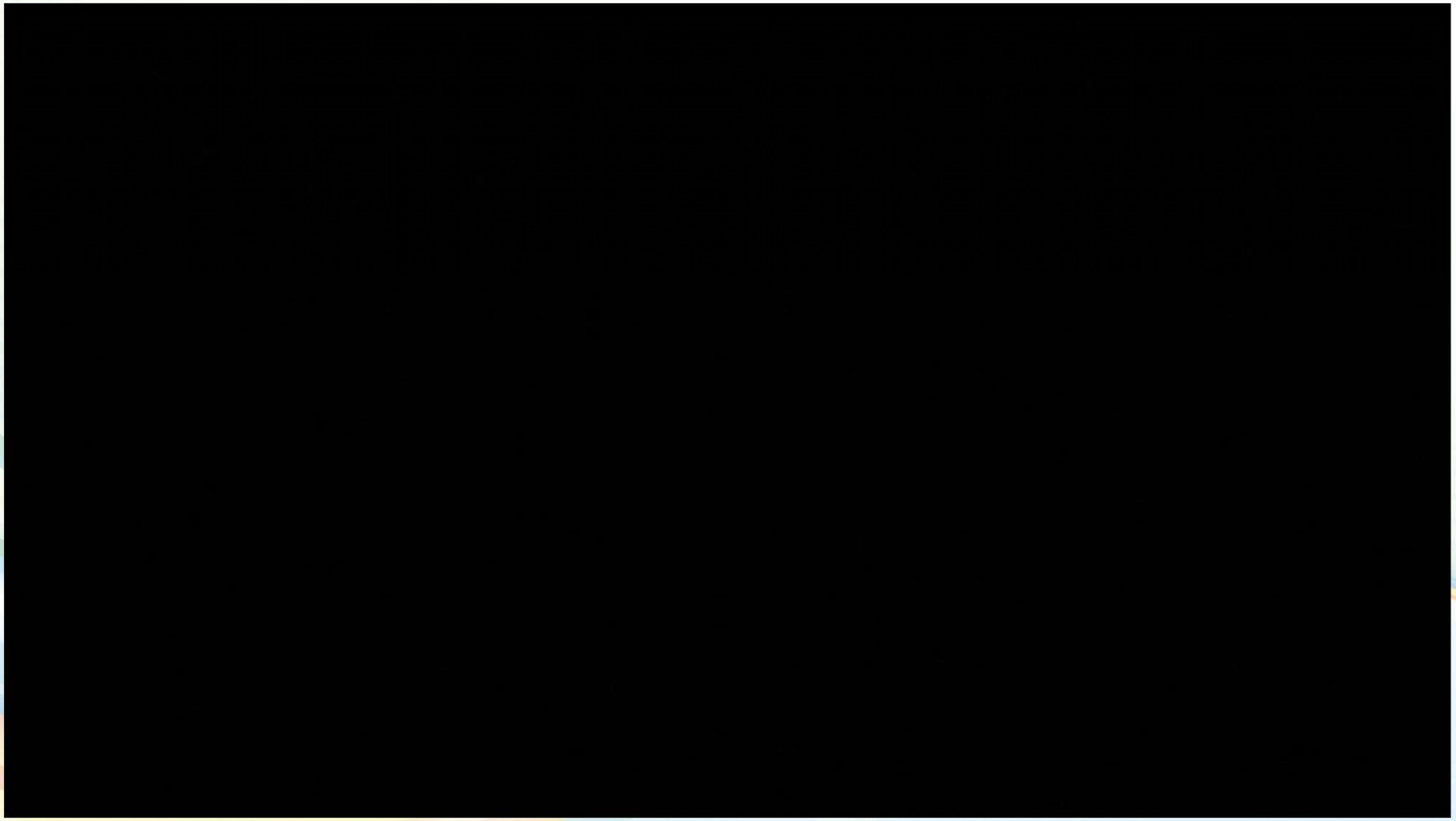
FORMING | **CASTING** | JOINING

- **Die Casting**
  - High volume
  - For alloys having low melting temperatures

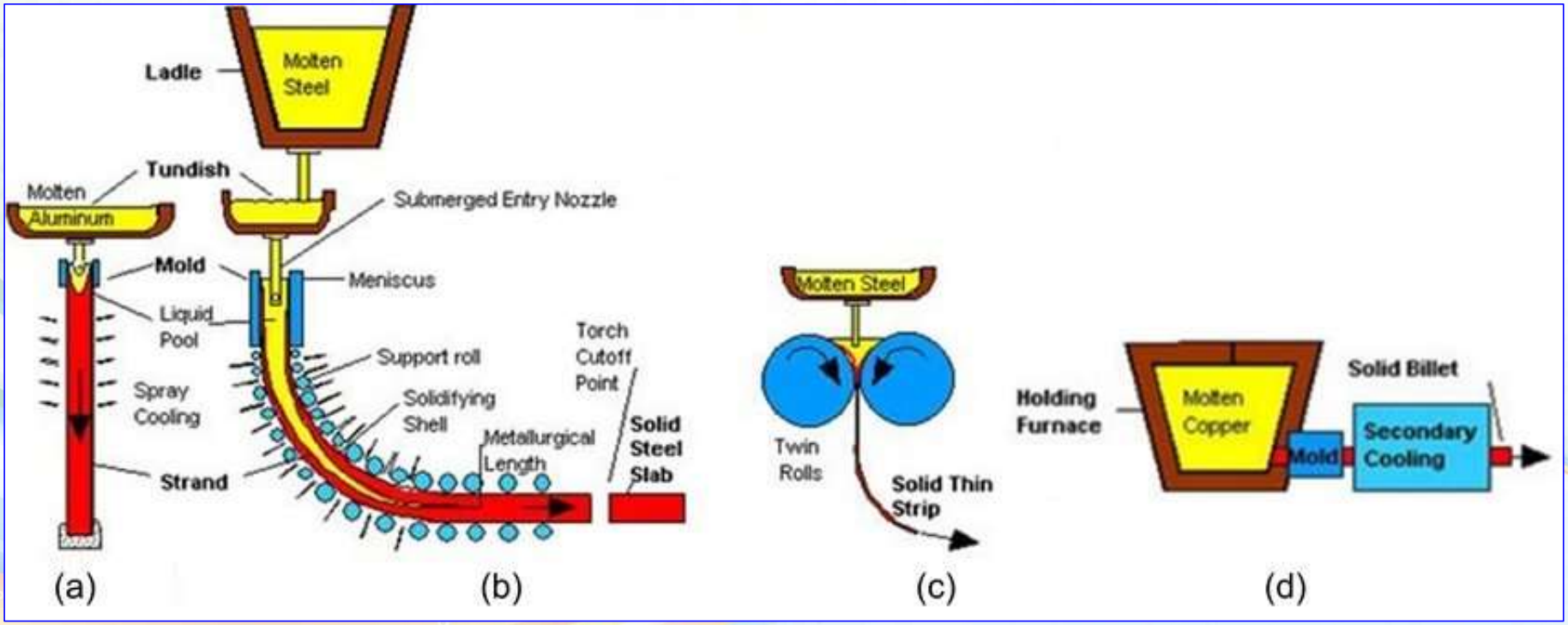


- **Continuous Casting**
  - Simple shapes: rectangular slabs, cylinders





Continuous Casting

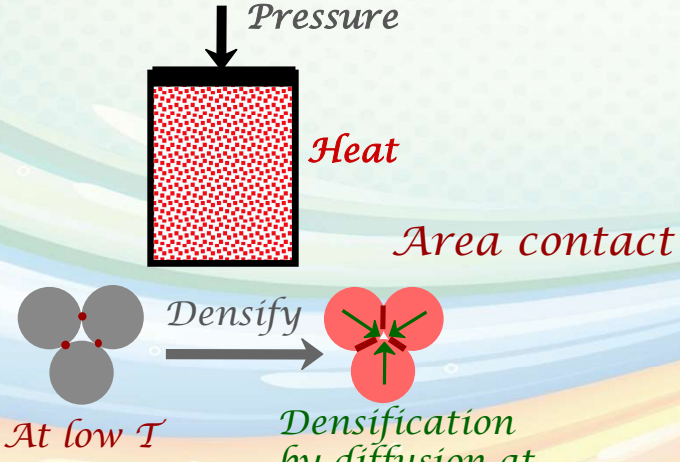


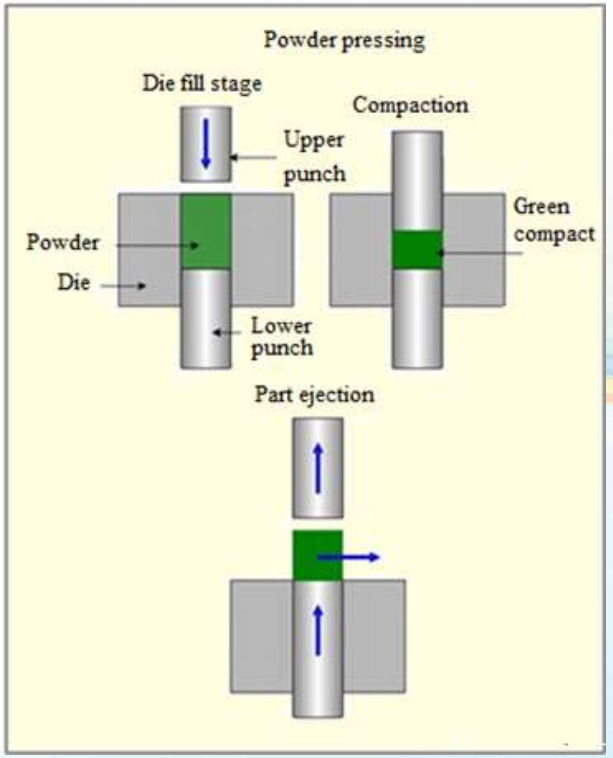
Metal Fabrication Methods (ii)

FORMING | CASTING | **JOINING**

- **Powder Metallurgy**

  (metals with low ductility)





Metal Fabrication Methods (ii)

FORMING | CASTING | **JOINING**

- **Welding**

  (when fabrication of one large part is impractical)

  - **Heat-affected zone:** (region in which the microstructure has been changed).