Aluminium and its alloys

Alumina raw materials

Alumina can be processed from bauxite, kaolinite and nepheline

- Bauxite

  > *30-50% Alumina (Al_2O_3)*
  > *3-13% Silica (SiO_2)*
  > *10-18% Titanium oxide (TiO_2)*
  > *Balanced water (H_2O)*

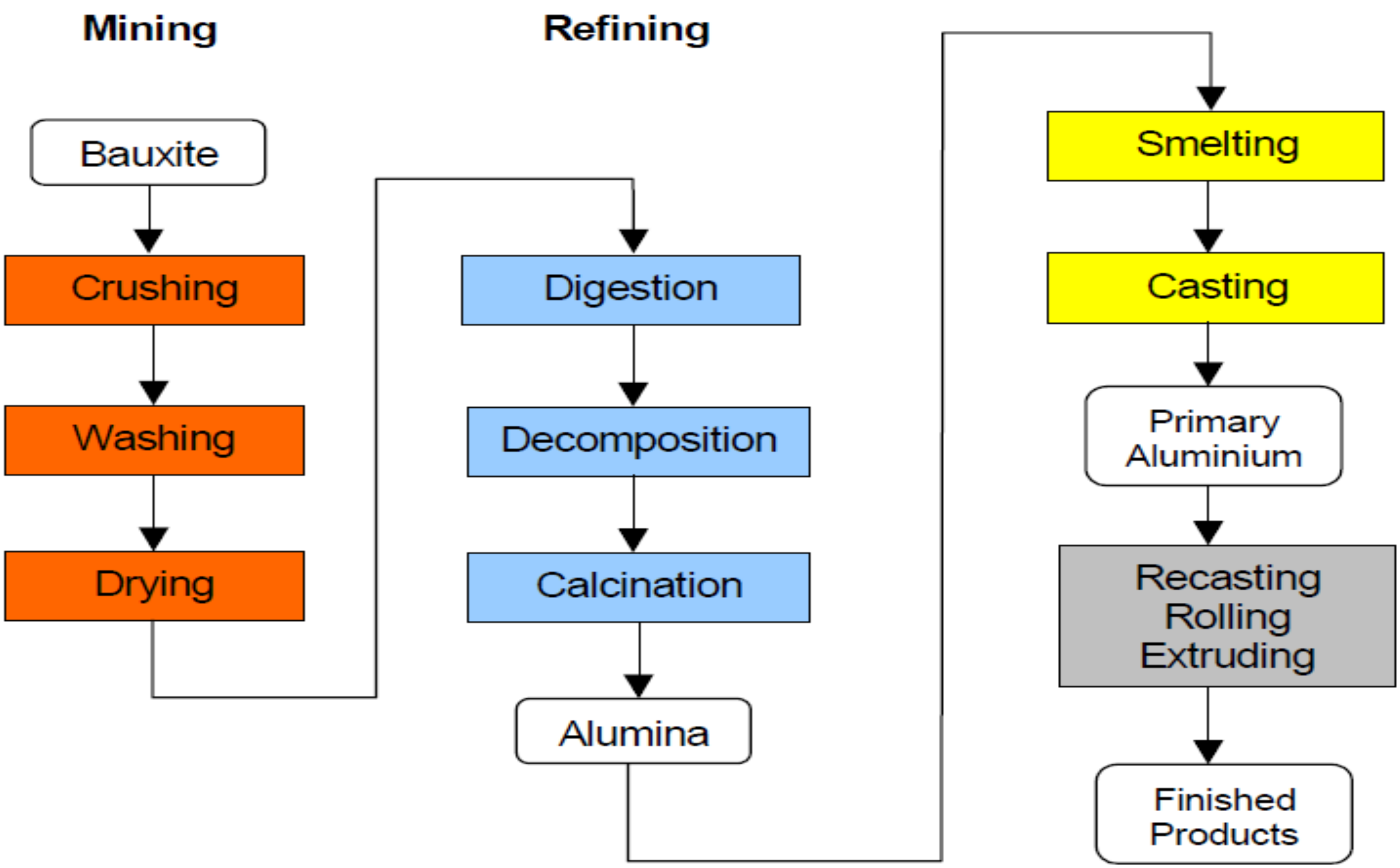
- Kaolinite

  > *30-32% Alumina (Al_2O_3)*
  > *Balanced Silica (SiO_2) and water (H_2O)*

- Nepheline

  > *30% Alumina (Al_2O_3)*
  > *40% Silica (SiO_2)*
  > *20% $Na_2O + K_2O$*

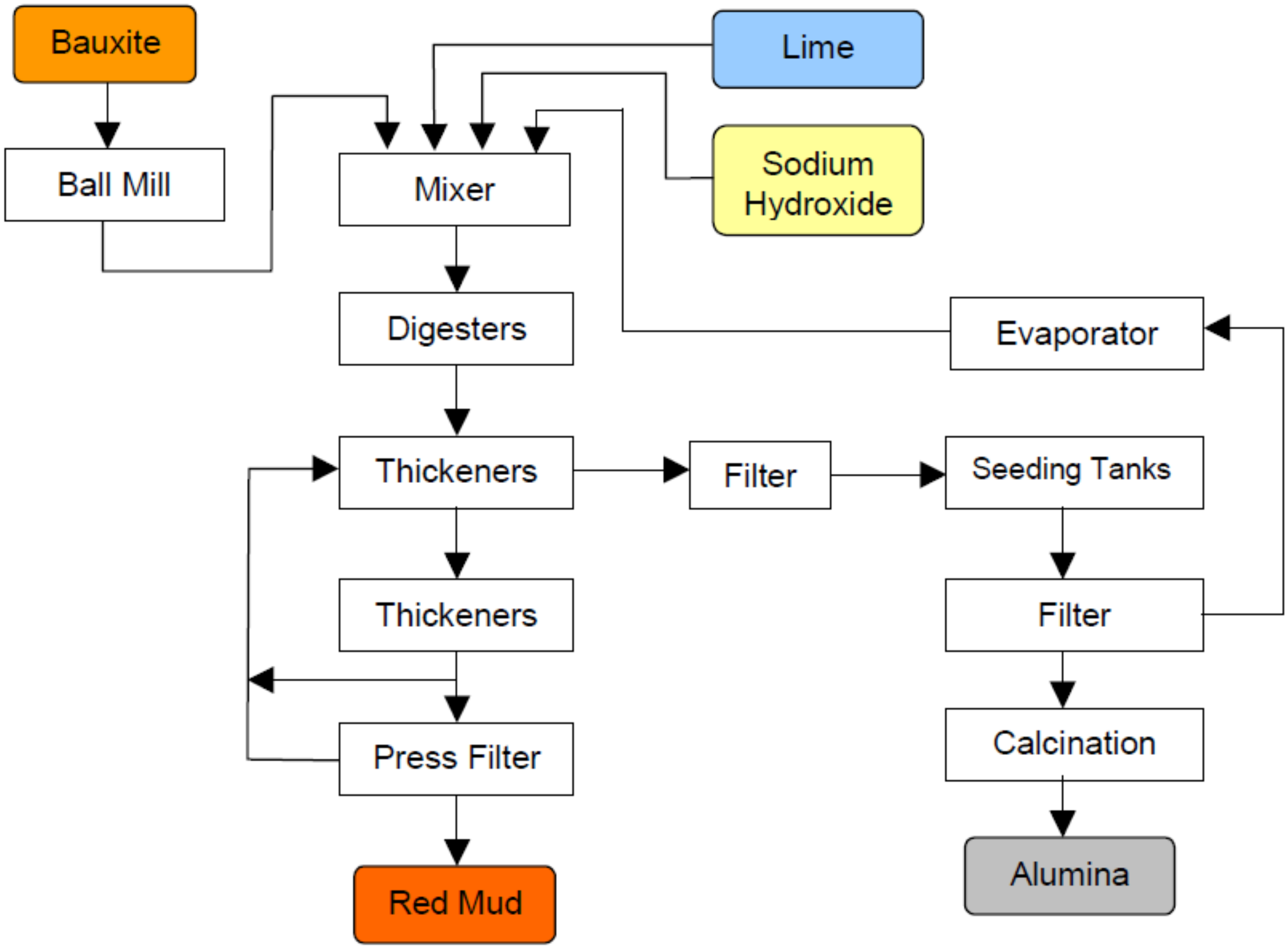
Bayer Process



Bayer Process

- Bauxite is washed ground and dissolved in caustic soda (NaOH) at high pressure and temperature
- Sodium aluminate solution containing nonsoluble bauxite residues sink to the bottom red mud.
- Seeding agent is added to the clear sodium aluminate solution to give alumina precipitates
- Precipitates are passed through a rotary kiln for calcination at ~1100 oC to give white powder of pure alumina.

Bayer Process



(Aluminium smelting/electrolysis)

Feed Material: Alumina (Al_2O_3)

Electrolyte: Cryolite (Na_3AlF_6)

Anode material: Carbon

Cathode material: Carbon/graphite

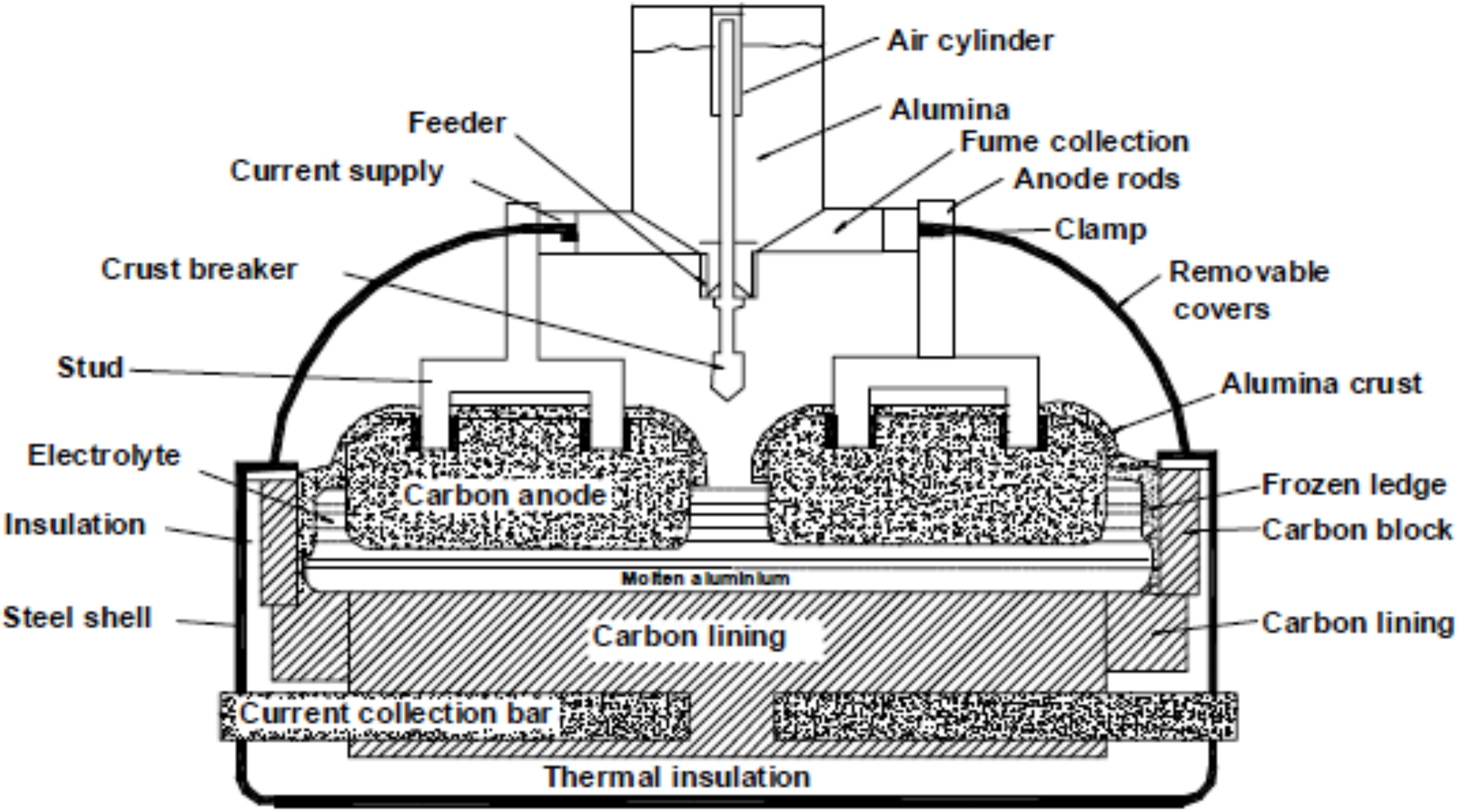
Anode: $2O^{2-} \longrightarrow O_2 + 4e-$

$2O^{-2} + C \longrightarrow CO_2 + 4e-$

Cathode: $Al_3 + 3e- \longrightarrow Al$

Overall Rxn: $2Al_2O_3 + 3C \longrightarrow 4Al + 3CO_2$

Hall-Héroult process



Properties of Aluminium

- High corrosion resistance
- Excellent machining properties
- Light weight
- High thermal/electrical conductivity
- High ductility/easily deformable

Wrought Aluminium alloys

Composition of aluminium alloys are regulated by internationally agreed classifications system

- 1XXX Al of 99% minimum purity
- 2XXX Al - Cu alloys
- 3XXX Al - Mn alloys
- 4XXX Al - Si alloys
- 5XXX Al - Mg alloys
- 6XXX Al - Mg - Si alloys
- 7XXX Al - Zn - Mg alloys
- 8XXX Miscellaneous alloys, e.g. aluminium-lithium alloys

Main groups of wrought aluminium

1xxx series (Super-purity and commercial-purity aluminium)

- 3xxx series (Al-Mn and Al-Mn-Mg alloys)
- 5xxx series (Al-Mg alloys)
- 8xxx series (Miscellaneous alloys

- 2xxx series (Al-Cu and Al-Cu-Mg alloys)
- 6xxx series (Al-Mg-Si alloys)
- 7xxx series (Al-Zn-Mg and Al-Zn-Mg-Cu alloys

Main groups of wrought aluminium

Non-heat-treatable alloys

- 1xxx series (Super-purity and commercial-purity aluminium)
- 3xxx series (Al-Mn and Al-Mn-Mg alloys)
- 5xxx series (Al-Mg alloys)
- 8xxx series (Miscellaneous alloys

Heat-treatable alloys

- 2xxx series (Al-Cu and Al-Cu-Mg alloys)
- 6xxx series (Al-Mg-Si alloys)
- 7xxx series (Al-Zn-Mg and Al-Zn-Mg-Cu alloys

Aluminium alloys and temper designations

Alloy identification systems

4-digit series	Aluminium content or main alloying elements
1 xxx	99.00% minimum
2 xxx	Copper
3 xxx	Manganese
4 xxx	Silicon
5 xxx	Magnesium
6 xxx	Magnesium and silicon
7 xxx	Zinc
8 xxx	Others

- The first digit indicates the alloy group.
- The second indicates modifications to alloy or impurity limit.
- The last two identify the aluminium alloy or indicates the aluminium purity.

Temper designations
(Added as suffix letters of digits to the alloy number)

Suffix letter F, O, H, T or W indicates basic treatment or condition.	First suffix digit indicates secondary treatment used to influence properties*	Second suffix digit for condition H only. Indicates residual hardening*

- F – As - fabricated
- O – Annealed-wrought products only
- H – Cold-worked (strain hardening)
  - 1 – Cold worked only
  - 2 – Cold worked and partially annlealed
  - 3 – Cold worked and stabilized
    - 2 – 1/4 Hard
    - 4 – 1/2 Hard
    - 6 – 3/4 Hard
    - 8 – Hard
    - 9 – Extra hard
- T – Heat treated (stable)
  - 1 – Partial solution plus natural ageing
  - 2 – Annealed cast products only
  - 3 – Solution plus cold work
  - 4 – Solution plus natural ageing
  - 5 – Artificially aged only
  - 6 – Solution plus artificial ageing
  - 7 – Solution plus stabilizing
  - 8 – Solution plus cold work pus artificial ageing
  - 9 – Solution plus artificial ageing plus cold work

* Where a second digit is used for T tempers, or a third is used for condition H, this indicates a specific treatment, e.g. amount of cold work to secure specific properties.

Examples of alloy and temper descriptions
1) 5152 H36 =
Aluminium-magnesium alloy, cold worked and stabilised to develop a ¾ hard condition
2) 6061 T6 =
Aluminium – magnesium – silicon alloy, solution heat treated followed by artificial ageing.

Aluminium alloy and temper designation systems (IADS system)

Properties and applications wrought Al alloys

1xxx series

Properties:

- Low tensile strength (90 MPa)
- Yield stress of 7-11 MPa.

Applications:

- Electrical conductors
- Chemical process equipment
- Foils
- Decorative finishes
- Capacitor (by panasonic)

Properties and applications wrought Al alloys

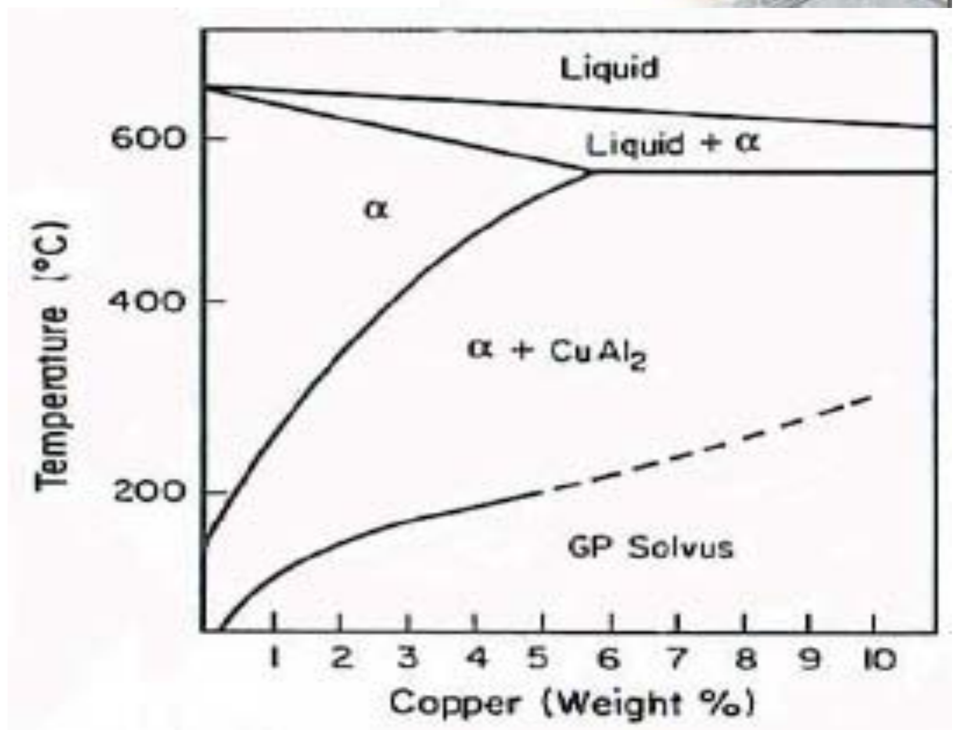
2xxx series

Properties:

- High strength (2119: σTS 505 MPa).
- Good creep strength at high temp.
- High toughness at cryogenic temp.
- Good machinability.

Applications:

- Welding wires
- Fuel Tanks
- Aircraft body



Properties and applications wrought Al alloys

3xxx series

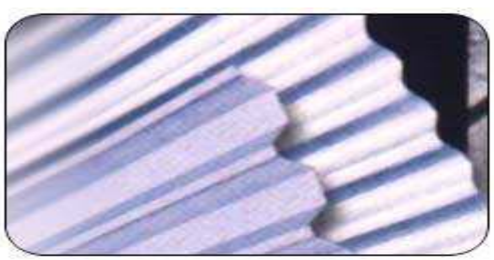
Al-Mn alloys (upto 1.25% Mn)
Greater amount leads to large primary Al6Mn particles) deleterious local ductility)

Properties:

- Moderate strength, i.e., σTS ~ 110 MPa in annealed 3003
- High ductility
- Excellent corrosion resistance

Applications:

- Foil
- Roofing sheet



Al-Mn-Mg alloys
(provide solid solution strengthening)
and widely used in a variety of strain hardened tempers

Properties:

- Moderate strength, i.e., σTS ~ 180 MPa in annealed 3004.
- Readily fabricated
- Excellent corrosion resistance

Applications:

- Manufacturing beverage cans

Properties and applications wrought Al alloys

4xxx series

Aluminum / Silicon alloys (Silicon ranging from 0.6% to 21.5%)

Properties:

- Excellent weldability and fair weld strength of 120 MPa
- Moderate strength
- Has heat and non-heat-treatable properties
- Excellent corrosion resistance

Applications:

- Used as filler material
- Welding and brazing wire
- Forged engine pistons

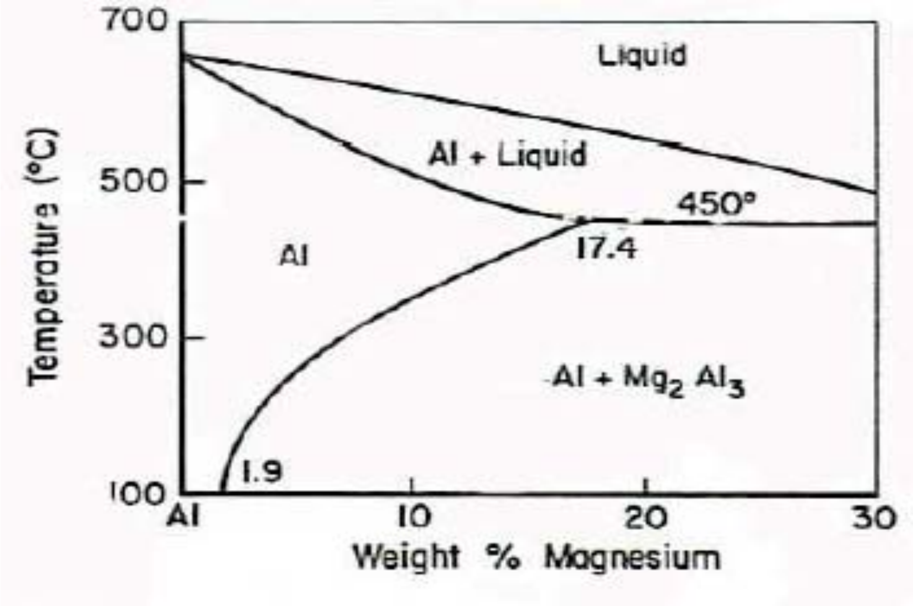
Main application: Architectural applications

Properties and applications wrought Al alloys

5xxx series

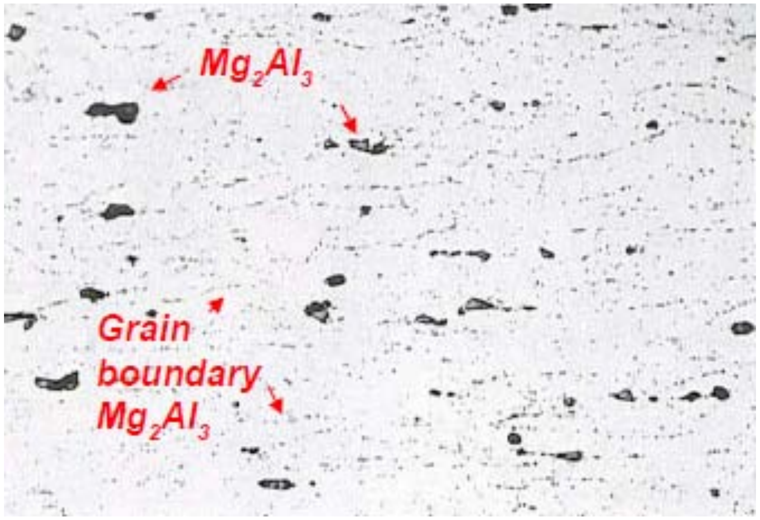
Properties:

- Al-0.8Mg (5005):σy 40 MPa, σTS 125 MPa
- Al-(4.7-5.5)Mg (5456): σy 160, σTS 310 MPa
- High rate of work hardening
- High corrosion resistance
- Bright surface finish



Applications:

- Transportation structural plates
- Large tanks for petrol, milk, grain
- Pressure vessel
- Architectural components



Properties and applications wrought Al alloys

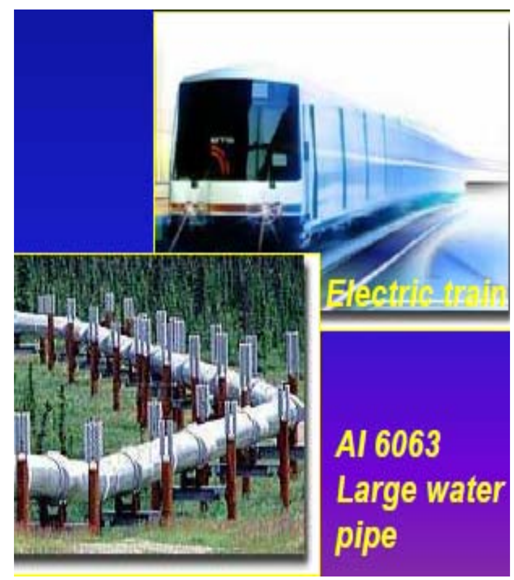
6xxx series

Properties:

- Medium-strength structural alloys (most widely used 6063-T6, σy 215 MPa, σTS 245)
- Higher strength on ageing, 6013 - Al-Mg-Si-Cu, σy 330 MPa(T6) and 415 (MPa) T8.

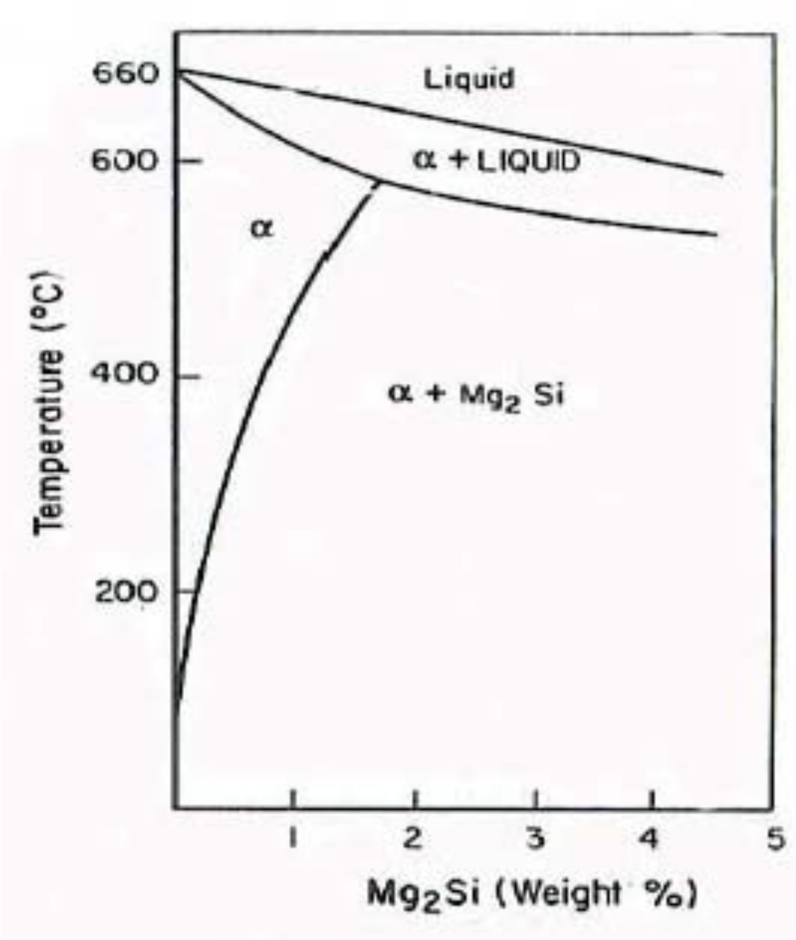
Applications:

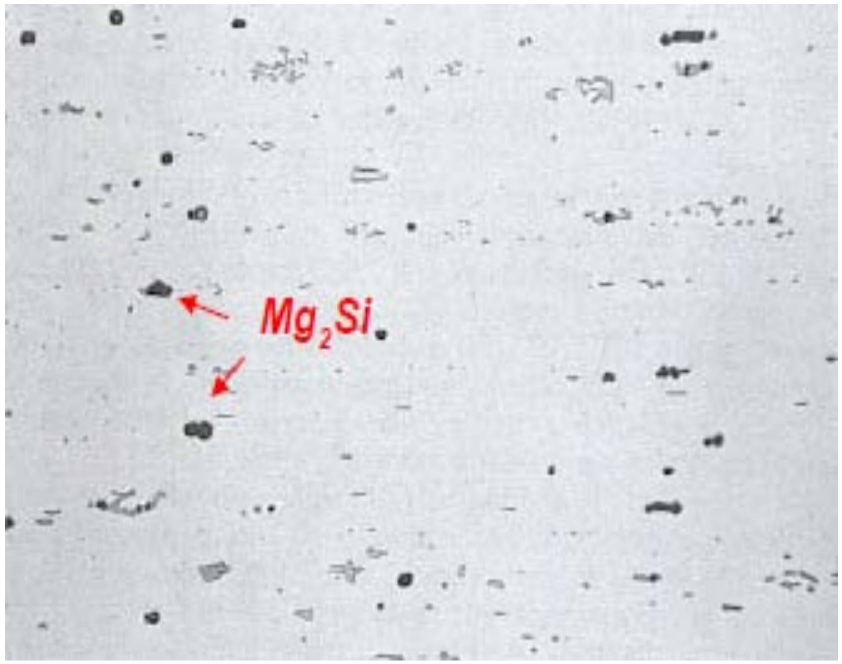
- Transportation structural plates
- Large tanks for petrol, milk, grain
- Pressure vessel
- Architectural components



Properties and applications wrought Al alloys

6xxx series





Properties and applications wrought Al alloys

7xxx series

Properties:

- Strength is insensitive to cooling rate hence suitable for welding
- Yield strength might be double to Al-Mg and Al-Mg-Si alloys (~ upto 600 MPa)
- Stress corrosion cracking resistance in Al-Zn-Mg-Cu alloys

Al 7039 aircraft construction

Applications:

- Light weight military bridge
- Aircraft construction

Al 7075 Component in motorcycle

Al 7005 post box

Properties and applications wrought Al alloys

8xxx series

Properties:

- High corrosion resistance at
- high temp & pressure
- Deep drawing

Applications:

- Al-1.1Ni-0.6Fr (8001) - nuclear
 energy installations
- Al-0.75Fe-0.7Si (8011) - bottle caps.
- Al-Sn (up to 7%) soft bearings

- Al-Li for aerospace applications

Designations of cast aluminium alloys

United States Aluminium Association system (Using four-digit system)

- 1xx.x Al, 99.00% or greater Al alloys grouped by major alloying elements
- 2xx.x Cu
- 3xx.x Si with added Cu and/or Mg
- 4xx.x Si
- 5xx.x Mg
- 7xx.x Zn
- 8xx.x Sn
- 9xx.x Other elements
- 6xx.x Unused series

1xx.x series

- Second two digits indicate the minimum percentage of Al, Eg: 150.x = 99.50% Al.
- Last digit (after decimal point) indicates product forms. 1 = casting, 2 = ingot

2xx.x to 9xx.x series

- Second two digits identify the different aluminium alloys
- Last digit (after decimal point) indicates product forms

Cast aluminium alloys

Properties required for good casting

- Low melting temperature
- Low solubility of gases except H2
- Good fluidity
- Good surface finishes

Main disadvantage

- High solidification shrinkage (3.5-8.5%)

Factors controlling properties

- Melting and pouring practices
- Impurity levels
- Grain size
- Solidification rate

Cast aluminium alloys are widely used for transport applications, Eg: Cast engine block

Strengthening Mechanism of Metals
(Solid Solution Strengthening)

Adding other elements in solid solution

Mechanism:

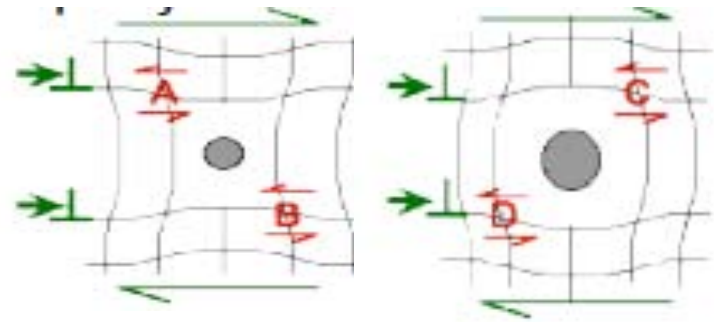
- Dissolved impurities ***distort lattice*** *by*

Substitutional / Interstitial

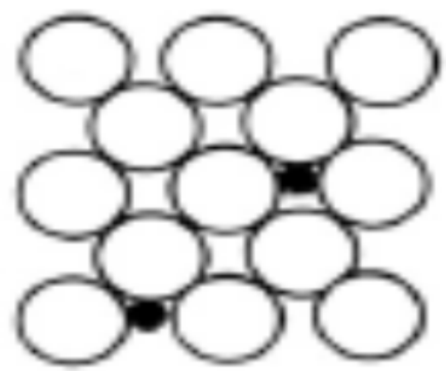
- strengthening effect increases as

|Δr|↑ (Δr = rhost – rimpurity)

- The stress generated can produce a barrier to dislocation motion

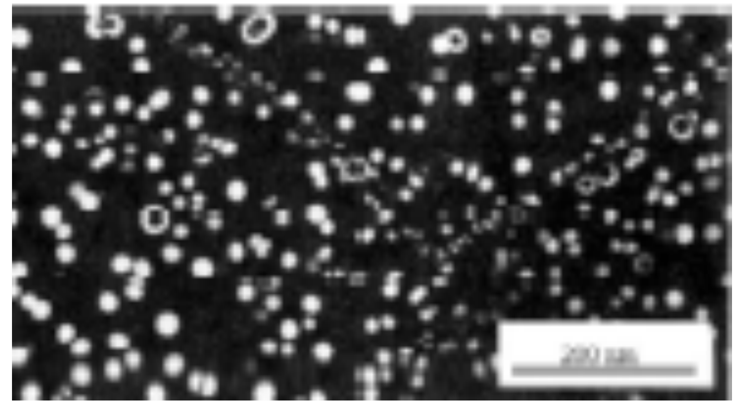


Smaller and bigger substitional impurity (atom)


Impurities (atoms) occupying interstitial positions

Strengthening Mechanism of Metals
(Precipitation(Age Hardening)/dispersion hardening)

Adding second phase particles or precipitation of supersaturated solid solution

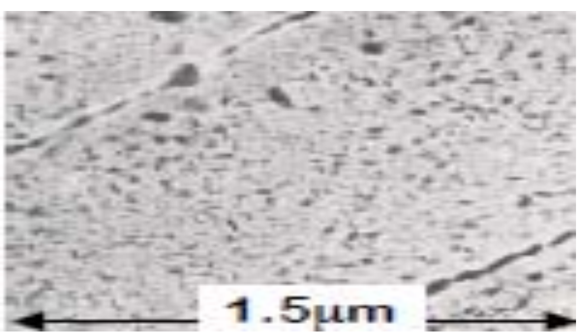


Al_3Li precipitates

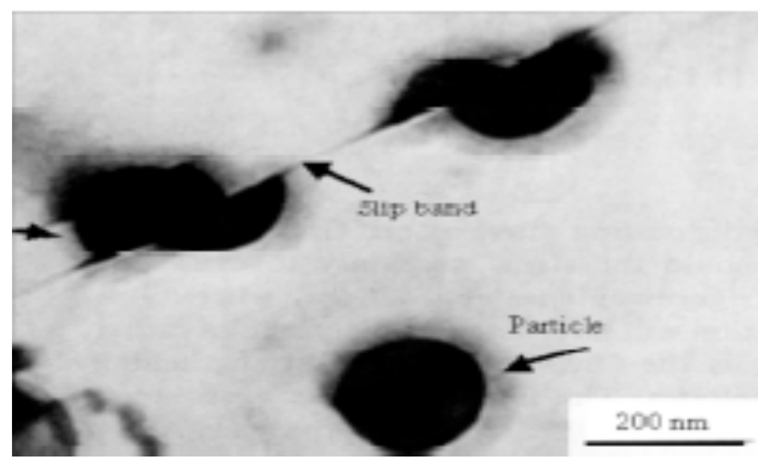
Mechanism:

- dislocation movement is impeded across grain boundaries between different phases

- *Example is* Al-4%Cu alloy



Al_2Cu_3 precipitates at grain boundaries



Strengthening Mechanism of Metals
(Strengthening by Grain Size Reduction)

Strengthening by reduction in grain size

Mechanism:

In general, slip across grain boundary involves

- Discontinuity of slip planes
- Change in slip direction
- For many materials, the yield strength increases with a decrease in grain size

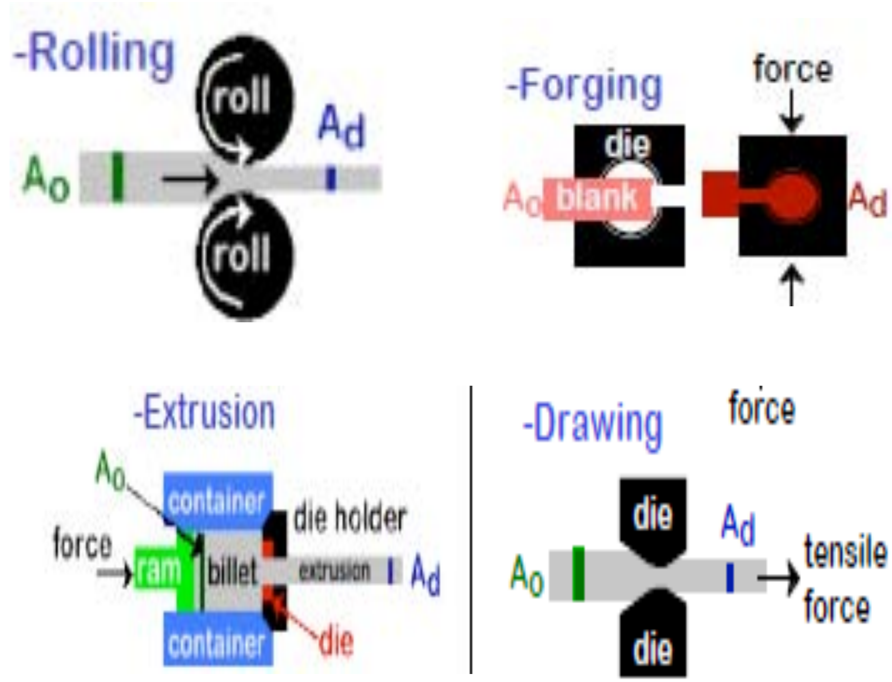
- The yield strength and the grain size are related by the

Hall-Petch Equation

$$\sigma_{yield} = \sigma_o + k_y d^{-1/2}$$

Strengthening Mechanism of Metals
(Strain Hardening)

Cold work (strengthening by low-temperature plastic deformation)



Mechanism:

- Plastic deformation creates dislocations
- Upon repeated or extensive deformation, dislocations multiply, move, and (on average) repel each other thereby decreasing dislocation mobility
- This increases the yield strength and the ultimate tensile strenght

References