Topics to discuss today …

1. Aluminium alloys castings
2. Aluminium alloys casting processes
3. Aluminium alloys casting properties
4. Melting and moulding practices
5. Scrap diagnosis
Aluminium Alloys Castings

- Use of aluminium casting alloys is second only to the ferrous castings.
- Worldwide, approximately 20% of total aluminium production is, on average, converted into cast parts.

Why use aluminium alloys?

- Wide range of mechanical properties
  - low specific gravity, high stiffness ratio, property enhancement after heat treatment
- Architectural and decorative value
- Good corrosion resistance
- Nontoxicity
- Good electrical and thermal conductivity
- Ease of machining
- Good casting properties
  - good fluidity, low melting point, low density, negligible gas solubility (except hydrogen), fast heat exchange, good chemical reproducibility, good as-cast surface finish
- Low shipping cost per piece

Why don’t use of aluminium alloys?

- Mechanical properties inferior to those of wrought products
  - low strength, toughness and hardness
- Lack of resistance to abrasion and wear
- Low resistance to severe corrosion
- Casting difficulties
  - low density, high shrinkage during solidification (3.5 – 8.0%), low gas solubility in solid state

Selection of a particular alloy based upon

- castability (fluidity, hot tearing, shrinkage characteristics)
- mechanical properties
- usage properties
Aluminium castings in automotive industry

- 60-70% of all aluminium castings produced are used in transportation industry.
  - engine blocks, cylinder heads, intake manifolds, pistons, wheels, compressor parts,
    brake callipers, transmission and steering systems

- cost effective replacement for ferrous parts

- generally produced by permanent mould and sand casting processes
  (because of the large numbers involved)
  although the permanent mould process (gravity and low pressure) are the most used
  (when good mechanical properties are required)

- Possible Competitors: (to manufacture engine block and cylinder heads)
  - magnesium alloys
  - thin-walled cast irons

Commercial aluminium casting alloys

Aluminium Association (AA)   Society of Automotive Engineers (SAE)
The British Standards (BS)       American Society for Testing and Materials (ASTM)

Cast alloy nomenclatures
as developed by the Aluminium Association (AA)

<table>
<thead>
<tr>
<th>3-digit system followed by a decimal value for cast alloys</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium, ≥99.00%</td>
<td>1xx.x</td>
</tr>
<tr>
<td>Aluminium alloys, grouped by major alloying element(s):</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>2xx.x</td>
</tr>
<tr>
<td>Silicon, with Cu and/or Mg</td>
<td>3xx.x</td>
</tr>
<tr>
<td>Silicon</td>
<td>4xx.x</td>
</tr>
<tr>
<td>Magnesium</td>
<td>5xx.x</td>
</tr>
<tr>
<td>Zinc</td>
<td>7xx.x</td>
</tr>
<tr>
<td>Other elements (e.g., tin)</td>
<td>8xx.x</td>
</tr>
<tr>
<td>Unused series</td>
<td>6xx.x and 9xx.x</td>
</tr>
</tbody>
</table>

- In 1xx.x, the second two digits indicate aluminium purity. In 2xx.x – 8xx.x groups, the second two digits indicate alloy content.
- Last digit separated by decimal indicates product form (0 – castings, 1 & 2 – ingots).
  - An "1" (one) after decimal indicates the chemistry limits for ingot used to make the alloy casting.
  - A “2” (two) after decimal also indicates ingot but with somewhat different chemical limits (with tighter control)
- An alphabetic number in front of the numerical designation indicates alloy modification or impurity limits in unalloyed aluminium.
### Common aluminium alloy systems for foundry applications

#### Binary Al-Si alloys
- Sand die cast alloys (413.0, 443.0) are the materials of choice for many automotive, domestic food and pump castings. Other applications include food processing equipment, castings exposed to marine atmosphere.

#### Al-Si-Cu alloys
- Alloys 319.0 is obtained from recycled materials. Parts made with these alloys include cylinder heads and intake manifolds.
- Hypereutectic 390.0 alloys are used to pressure die cast engine blocks without iron liners. Low pressure die cast engine block are also produced.
- 380.0 alloys are used to pressure die cast engine blocks with cast-in iron liners. Engine castings, transmission parts and various other automotive parts are also produced.

#### Al-Si-Mg alloys
- Properties of A356.0 and A357.0 alloys are very attractive for many automotive and aircraft part applications.
- Heat treated C355.0 alloys are cast to produce tank engines, pump parts, high speed rotating parts and impellers.

#### Al-Si-Cu-Mg alloys
- Automobile gas and diesel pistons and cylinders are made of die cast 332.0 alloys. Addition of Ni improves elevated temperature properties.

#### Nowadays, Al-Cu alloys (2xx.x series) become obsolete because of their greater tendency to hot tearing and micro-shrinkage formation, and low fluidity, requiring good feeding and gating to ensure casting soundness.
Aluminium Alloys Casting Processes

- Can be produced by more than one process.
- Quality requirements, technical limitations and economic considerations dictate the choice of a casting process.
- Three main casting processes (represents about 90% of all aluminium cast parts):
  - sand casting – large casting (up to several tons), one to several thousands in quantity
  - permanent mould casting (gravity and low pressure) – medium sized (up to 100 kg), 1000 to 100,000 units
  - high pressure die casting – small castings (up to 50 kg), large quantities (10,000 to 100,000)
- High pressure die casting accounted for the largest share (58 %). permanent mould casting and sand castings accounts for 30 % and 8% (1996)

### Die casting alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>308.0</td>
<td>Lawnmower housings, gear cases, and cylinder heads for air-cooled engines</td>
</tr>
<tr>
<td>A380.0</td>
<td>Streetlamp housings, typewriter frames, and dental equipment</td>
</tr>
<tr>
<td>360.0</td>
<td>Frying skillets, cover plates, instrument cases, and parts requiring corrosion resistance</td>
</tr>
<tr>
<td>413.0</td>
<td>Outboard motor parts such as pistons, connecting rods, and housings</td>
</tr>
<tr>
<td>518.0</td>
<td>Escalator parts, conveyor components, aircraft and marine hardware, and fittings</td>
</tr>
</tbody>
</table>

### Permanent mould (gravity die) casting alloys

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</thead>
<tbody>
<tr>
<td>336.0</td>
<td>Automotive pistons</td>
</tr>
<tr>
<td>355.0, C355.0, A357.0</td>
<td>Timing gears, impellers, compressors, and aircraft and missile components requiring high strength</td>
</tr>
<tr>
<td>356.0, A356.0</td>
<td>Machine tool parts, aircraft wheels, pump parts, marine hardware, valve bodies</td>
</tr>
<tr>
<td>B443.0</td>
<td>Carburettor bodies, waffle irons</td>
</tr>
<tr>
<td>513.0</td>
<td>Ornamental hardware and architectural fittings</td>
</tr>
</tbody>
</table>

### Sand casting alloys

<table>
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<tr>
<th>Alloy</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>C355.0</td>
<td>Air-compressor fittings, crankcases, and gear housings</td>
</tr>
<tr>
<td>A356.0</td>
<td>Automobile transmission cases, oil pans, and rear-axle housings</td>
</tr>
<tr>
<td>357.0</td>
<td>Pump bodies and cylinder blocks for water-cooled engines</td>
</tr>
<tr>
<td>443.0</td>
<td>Pipe fittings, cooking utensils, and ornamental marine fittings</td>
</tr>
<tr>
<td>520.0</td>
<td>Aircraft fittings, truck and bus frame components, levers, and brackets</td>
</tr>
<tr>
<td>713.0</td>
<td>General-purpose casting alloy for applications requiring strength without heat treatment or involving brazing</td>
</tr>
</tbody>
</table>
Aluminium Alloys Casting Properties

- The production of good castings requires that the casting alloys possess favourable foundry properties
- Those considered of importance are:
  - minimum solidification shrinkage (and maximum yield)
  - adequate fluidity
  - freedom from hot tearing or cracking
  - minimum difficulty on producing pressure-tight castings
  - minimum problem with gas absorption and drossing

Solidification
- Isothermal solidification (eutectic alloys) – No hot tear/cracking
- Long-range solidification – Cause hot shortness, difficult to cast

Solidification shrinkage
- 6.5 – 8.5 % contraction in volume
- Low density results low hydrostatic pressure (unable to suppress defect formation)
  
Fluidity
- Si-rich alloys with low copper content favour fluidity and resistance to tearing with a maximum for alloys having 16 – 18 % Si
Dross and gas absorption

- Readily oxidised and form dross; extensive dross formed in Mg-containing alloys
- Readily absorb gases and form porosity
- Careful gating design and melting and pouring practice required

Pressure tightness

- Absence of leakage of fluid, especially under pressure, is required in some applications (pump housing, valve bodies, pipe manifolds, etc.)
- Two main defects responsible for this are:
  1. highly localised cavity extended throughout the section due to gross unfed solidification shrinkage. Improved gating and feeding design necessary.
  2. dispersed interconnected cavities, often related to alloy type and design of casting (e.g., severe in Al-4Mg and Al-10Mg alloys, less severe in Al-Si alloys). Pouring at low temperature, improved gating and feeding design to obtain directional solidification necessary.

Melting and Moulding Practices

Key points to consider

1. Start with clean and dry charge of known analysis
2. Use clean melting practice
3. Keep temperature low until pouring
4. Avoid water vapour and other hydrogen-bearing/wet gases whenever possible
5. Do not agitate/stir more than is absolutely necessary
6. Use adequate flushing and/or fluxing practices
7. Skim the surface only when ready to pour
8. Avoid turbulence when pouring
9. Use proper pouring temperature and pouring practice
Modification

- The discovery modification process was one of the most significant related to aluminium foundry alloys.
- Primarily performed in Al-Si alloys
- Due to slow cooling in sand cast and gravity die cast alloys, primary chunky silicon (for hypereutectic alloys) and coarse lamellar eutectic plate structures (for hypo and eutectic alloys) are formed.
- Changes in eutectic silicon and primary silicon are necessary to remove the adverse effects of needles/platelets shapes of these silicon particles.
- The transformation of silicon phase from acicular (large plates with sharp sides and ends) to fibrous (with a fine, apparently globular morphology) structure is termed as modification.

A somewhat modified eutectic structure can be obtained, in the absence of chemical modifiers, by rapid solidification.
  - quench modified structures have silicon similar to that produced in an unmodified structures.
  - this structure is simply an exceedingly fine form of unmodified eutectic occasioned by very rapid solidification.

Chemical modification can be resulted due to the addition of several chemical elements at very low concentration levels (typically 0.01 – 0.02%).
- Some of the commercially important chemical modifiers are Sr, Na, and P.
  - give finely dispersed eutectic fibre and fine primary silicon particle
  - found to be more effective at higher freezing rates
  (thus, it is much easier to modify a chill casting than a heavy section sand casting)
- Additions of Sr or Na (about 0.01 – 0.02%) change eutectic microstructure from needle-like to fibrous.
- Additions of P (0.003 – 0.015%) is added to control the primary chunky silicon particles in hypereutectic alloys.
as-cast microstructure hypo-eutectic AlSi7Mg alloy (Alloy 356.0)
modified microstructure hypo-eutectic AlSi7Mg alloy (Alloy 356.0)
as-cast microstructures of hyper-eutectic AlSi17 alloy (Alloy 390.0)
modified microstructures of hyper-eutectic AlSi21CuNi alloy (Alloy 393.0)

Rating system for modified microstructures

Class 1: Fully unmodified structure
Class 2: Lamellar structure
Class 3: Lamellar structure
Class 4: Absence of lamellar structure
Class 5: Fibrous silicon eutectic
Class 6: Very fine structure

Class 1: Unmodified
Class 2: Undermodified
Class 3: Undermodified
Class 4: Absence of lamellar structure
Class 5: Modified
Class 6: Supermodified
Class 1: Acicular
Class 2: Lamellar
Class 5: Fibrous
Grain Refinement

- added to produce a fine equiaxed grain structure
- also improves resistance to hot tearing, decreases porosity and increases mass feeding

**Grain refining by rapid solidification**

- If a melt is rapidly cooled (chilled),
  - the liquid undercools as its temperature falls below the liquidus temperature.
  - if this undercooling is sufficient, multiple nucleation is resulted, which produces fine as-cast grain size.
  - effective only for thin-sectioned castings

![Graph showing variation of DAS with cooling rate](image)

**Chemical grain refinement**

- most widely practiced, and the most foolproof method of grain refinement
  - additions of effective nuclei are made to the melt through either master alloys or fluxes
  - fine grain size is promoted by the presence of an enhanced number of nuclei, and solidification proceeds at very small undercoolings

- Common grain refiners
  - Ti (0.02 – 0.15 %) or (Ti+B) mixture (0.01-0.03% Ti and 0.01 % B).
  - May be made as master alloy or as flux.
  - Provide nucleating sites in liquid to produce finely dispersed primary silicon in eutectic matrix.

- Most of the grain refiners are hygroscopic.
  - Can cause to increase porosity.
  - Advisable to degas after nucleation.
Typical melting practices of aluminium alloys

- Melt under a covering / drossing flux. Continue charging until melt is complete, add more flux as necessary. Do not exceed temperature 750 C.
- Degas. Allow to stand for about 5 min, add more flux. Skim off the slag.
- If separate grain refinement is required, add grain refiner before degassing.
- With temperature between 720 and 740 C, modify the alloy, if necessary. After reaction, stir the melt without breaking the surface. Add more flux.
- Allow to stand for about 5 min, add more flux. Skim off the slag.
- Check temperature and pour immediately.
- Suggested pouring temperature:
  - Light casting (under 15 mm) – 730 C
  - Medium casting (15–40 mm) – 710 C
  - Heavy casting (over 40 mm) – 690 C

Moulding practices

- Point to Consider
  - Low melting temperature, low density, turbulence, gas absorption
- Common moulding processes
  - Greensand and dry sand casting, plaster moulding, permanent mould, die casting
- Moulding sand properties
  - High reusability of sand
  - Finely graded (light casting) or medium graded (medium casting), uniformly distributed sand (AFS 50 – 60), low permeability (40 – 50)
  - High green strength, low dry strength
  - Low moisture content
- Core sand
  - For light to medium casting – same as moulding sand
  - For heavy casting – dry sand
  - Core collapsibility is essential (to reduce hot tear)
Gating and feeding

Point To Consider

1. Drossing tendency
2. Gas entrainment
3. Gas absorption
4. Solidification shrinkage
5. Difficulty in eliminating microshrinkage
6. High thermal conductivity

“Place feeders high to feed downhill, place ingates low to fill uphill”

Scrap Diagnosis

- Pinhole porosity
- Shrinkage cavity
- Oxide and dross inclusion
- Sand inclusion
- Misrun and coldshut
- Unsatisfactory fracture
- Gas hole (blow holes)
Next Class
MME 345, Lecture 43

Casting Defects