aluminium technologies

3.11.2015
Term paper topics

Cenk Eken
ultrasonic processing of aluminium melts

Murat Teke
assessment of melt quality via K-mold method

Emre Açıçıl
applications of aluminium foams

Gazican Özkan
injection casting of aluminium alloys

Engin Kılınç
high integrity casting processes

Mehmet Ağilkaya
additive manufacturing of aluminium alloys

Haluk Erdemir
rheo-casting of aluminium alloys and their applications

Serhan Köktaş
friction stir processing of aluminium alloys

Alper Güneren
production of aluminium foams

Emre Baran
FSW automotive aluminium

Berkay Oral
casting of hypereutectic Al-Si alloys and their applications

Erkut Özer
Casting of Al-Mg based foundry alloys and their applications

İzzet Nahid Demir
surface treatment of aluminium alloys

Mehmet Yasak
severe plastic deformation of aluminium alloys

Kürşat Kambur
steel vs aluminium for automotive applications

Papers in word format due on 22.12.2015
Midterm exam (%25)
10.11.2015, Tuesday 09:30

you will be responsible for every topic we will have covered up until the end of this lecture!
Hot tearing

- Hot tear cracks may be encountered in the casting after solidification.
- The section that have solidified may induce stresses on the other sections which are yet to solidify.
- Cracks may initiate if these semi-solid regions are too thick and the feeding is insufficient.
- Alloy composition has a significant impact on hot tearing.
- Alloy composition directly affects the supply of liquid eutectic phase for the feeding of the solidifying regions.
Hot Tears

initial stage: Hexagonal grains surrounded by liquid film

Application of tensile strain leads to grain impingement and the creation of intergranular pools

Continuous extension leads to the opening of tears
Hot Tears

Characteristics of Hot Tears

- Ragged, branching crack
- Generally intergranular
- Dendritic morphology on failure surface
- Heavily oxidised failure surface
- Often located at hot spot
- Random occurrence and extent
- Alloy specific
Hot tearing

parameters that need to be controlled to avoid hot tears:

- Casting design
- Effectiveness of the grain refinement practice
- Stiffness of the mold

Tensile stresses that develop during solidification
Hot tearing

Hot tearing in a DC cast 7XXX billet produced by ETỊ Aluminium!
Hot tearing

Hot tearing in a DC cast 7XXX billet produced by ETİ Aluminium!
prevention of hot tears

- Alter casting design
- Chill hot spots
- Reduce constraint from mould
- Add brackets and webs
- Employ effective grain refinement
- Reduce casting temperature
- Adjust/optimise alloying
- Reduce contracting length
prevention of hot tears

- It may be possible to alter the geometry of the casting to reduce stress concentrations and hot spots, for example, by providing generous radii at vulnerable sections.
- Local hot spots can be reduced by local chilling which will strengthen the metal by taking it out of the susceptible temperature range.
- There are various ways of reducing the mould strength so that it provides less constraint to the contracting casting.
- Brackets and webs can be placed across a vulnerable corner or hot spot to provide mechanical support and to enhance local cooling.
prevention of hot tears

- A reduction in the casting temperature can sometimes help, probably because it reduces the grain size.
- Grain refinement should help to reduce tear initiation since the strain will be spread over a greater number of grain boundaries.
- Increasing the volume fraction of eutectic liquid may help by increasing the pre-tear extension and by decreasing the cracking susceptibility.
- Finally, it is sometimes possible to site feeders carefully so that the casting is effectively split up into a series of short lengths to reduce the strain concentration.
Cold cracks

- Form below the solidus temperature
- Straighter and smoother than hot tears
- Transgranular or intergranular
- Can be oxide-free (if formed at low T’s)

Sources of stress
- Differential cooling
- Mould/core restraint
- Phase transformation
- Heat treatment

Prevention
- Reduce stress raisers
- Avoid abrupt changes of section
- Eliminate oxide defects
- Reduce mould/core restraint
- Eliminate or use alternative heat treatments
Reduction in quenching stresses

Rates of cooling of a 20mm diameter aluminium bar when quenched by various means from 500 °C.

Effect of quenching medium on ductility

<table>
<thead>
<tr>
<th>Quenching Medium</th>
<th>Elongation, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water (70°C)</td>
<td>4.73 +/- 2.72</td>
</tr>
<tr>
<td>Cold water</td>
<td>6.47 +/- 1.67</td>
</tr>
<tr>
<td>Water-glycol mixture</td>
<td>5.81 +/- 0.96</td>
</tr>
</tbody>
</table>

Elongation, %

Mean +/- 2.5 σ | Minimum
Permanent mould cast Al-12 Si alloy with 1% Fe; $\beta$-Al$_5$FeSi needles $\alpha$-AlFeSi intermetallic “chinese script” morphology
Fe-based intermetallic particles

Cracks that form due to the stress concentration at the tip of AlFeSi intermetallic needles.

$\beta$-AlFeSi needles physically block interdendritic melt flow and lead to micro shrinkage.
Fe-based intermetallic particles

$\beta$-${\text{Al}}_5{\text{FeSi}}$ particles exhibit an acicular morphology and have a very negative impact on ductility.
Silicon modification

1. seviye
2. seviye
3. seviye
4. seviye
5. seviye
6. seviye
lack of modification

A fatigue crack that follows unmodified Silicon particles in an aluminium cylinder head casting.
segregation

*Diagram showing segregation with symbols $c_k$, $c_s$, and $c_o$ for temperature and composition.*
segregation

Compositional fluctuations that scale with the dendritic structure: dendritic segregation-coring

6XXX alloys

7XXX alloys
segregation

As-cast 206 alloy (4.4% Cu-0.3 %Mg-0.3 %Mn)
Segregation in the as-cast component can be largely eliminated by a high temperature soak called homogenization. Homogenization is a must for parts that will be subjected to forming Operations.
Homogenization anneal

High temperature annealing treatment to remove dendritic segregation!

We use Fick’s Law to estimate the T and t of the heat treatment to be employed to eliminate compositional fluctuations

\[ x = \sqrt{D \cdot t} \]

X is the distance over which diffusion will take place; dendrite arm spacing, t is time and D is diffusion coefficient.
Homogenization anneal

An aluminium casting with a dendrite arm spacing of DAS 100 micron is annealed at 480°C. The homogenization anneal time to eliminate Mg segregation:

\[ t = \frac{x^2}{D} \]

For Mg diffusion in aluminium at 480°C

\[ D = 1 \times 10^{-14} \text{ m}^2/\text{s}. \]

\[ t = \frac{(0.0001 \text{ m})^2}{1 \times 10^{-14} \text{ m}^2/\text{s}} = 10^6 \text{ s} = 278 \text{ h} \]

If DAS were = 10 microns

\[ t = \frac{(0.00001 \text{ m})^2}{1 \times 10^{-14} \text{ m}^2/\text{s}} = 1 \times 10^4 \text{ s} < 3 \text{ h} \]
Segregation in strip casting
Nonmetallic inclusions melt quality

- impair surface quality
- impair machinability
- reduce mechanical properties
- decrease corrosion resistance!
- increase porosity!
- produce pinholes in foils!
- reduce fluidity and castability!
- cause filter blockage!

Casting quality

Process efficiency
Oxides
Oxide inclusions
Extraneous oxide inclusions
<table>
<thead>
<tr>
<th>Defect</th>
<th>Non-fills and cold shuts</th>
<th>Gas porosity and blisters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible main cause for</td>
<td>Solid fraction too high; mould filling speed too low; mould</td>
<td>Turbulent mould filling; runner's geometry not adequate; not</td>
</tr>
<tr>
<td>defects</td>
<td>too cold.</td>
<td>enough venting; water in mould; die parting agent produces</td>
</tr>
<tr>
<td></td>
<td>Increase liquid fraction; increase speed; heat mould more.</td>
<td>gases.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use smooth runners with cylindrical cross sections. If</td>
</tr>
<tr>
<td></td>
<td></td>
<td>necessary, use vacuum.</td>
</tr>
</tbody>
</table>

**Examples**

Non-fills

Gas porosity and blisters
Possible defects

<table>
<thead>
<tr>
<th>defect</th>
<th>inclusions (mainly oxides)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible main cause</td>
<td>Retention system for oxide skin of metal not efficient enough; the two metal fronts hit together</td>
</tr>
<tr>
<td>Ways to avoid defects</td>
<td>Use and optimize oxide retention systems; fronts with oxides should be brought into overflows</td>
</tr>
</tbody>
</table>

![Diagram of a runner bar system with labels]

- **Overflow**: The point where the molten metal exits the casting process.
- **Runner bar extension**: The extension of the runner bar system.
## Possible defects

<table>
<thead>
<tr>
<th>Defect</th>
<th>Possible main cause</th>
<th>Way to avoid defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shrinkage porosity</td>
<td>Feeding of large cross sections is not good enough.</td>
<td>Dimension runner and gating systems for good feeding; use numerical simulation to control and optimise them.</td>
</tr>
</tbody>
</table>
## Possible defects

<table>
<thead>
<tr>
<th>Defect</th>
<th>Segregations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Possible main cause for defects</td>
<td>Geometry of channels, high flow velocities can lead to separations between solid and liquid phases.</td>
</tr>
<tr>
<td>Way to avoid defects</td>
<td>Increase mould filling speed gives often good results; improve channel's geometry (smoother flow path).</td>
</tr>
</tbody>
</table>

### Examples

![Image of possible defect](Segregations)
why aluminium castings?
Properties of castings

- Roughly two thirds of all aluminium castings are automotive where the use of aluminum castings continues to grow at the expense of iron castings.
- Although aluminium castings are significantly more expensive than ferrous castings, there is a continuing market requirement to reduce vehicle weight and to increase fuel efficiency.
- Aluminium castings are widely used in cars for engine blocks, cylinder heads, pistons, rocker covers, inlet manifolds, differential casings, steering boxes, brackets, wheels etc.
- Al castings in EU cars is expected to reach 200 kg by year 2020.
Aluminium casting alloys

Easy to cast!
- Al-Si alloys with sufficient Si exhibit outstanding flowing properties during casting and facilitates the casting of huge complex components.
- Design features can be produced easily with minimum tolerances.
- The mold filling capacity of 3xx.x alloys is exceptionally high!
- Hence, 3xx.x alloys are preferred in the casting of big complex parts.
Aluminium casting alloys

High strength!

- High strength levels are possible through heat treatment!
- High strength and toughness can be achieved by a precise mold design that allows for rapid cooling during solidification.
- Highest strength values are possible with 2xx.x alloys; however, casting of these alloys is relatively more difficult and requires special attention.
- These alloys are selected for aerospace applications where strength is a critical issue.
Aluminium casting alloys

Surface quality

- A very high surface quality is possible by a careful selection of the casting alloy.
- 5xx.x and 7xx.x alloys offer outstanding surface quality.
- However, casting of these alloys is difficult and they are employed only in those applications where surface quality is a must!
- For example, rulman uygulamaları için 7xx.x alloys are preferred for bearing applications owing to their high surface quality.
aluminium casting processes
Aluminium production routes

Primary production → 99.7 wt%Al
Melting + melt treatment
Alloying

Foundry alloys
- Shape casting
  - Sand casting
  - Permanent casting
  - Pressure casting
- Castings

Wrought alloys
- Semi-cont casting
  - Direct Chill (DC) casting
    - Slab/ingot
    - Hot-cold rolling/extrusion
    - Profile/sheet/foil
- Cont. casting
  - Twin roll casting/TRC
  - Twin-belt casting/TBC
  - Coiled sheet
  - Cold rolling
  - Sheet/foil
Shape casting processes
Aluminium alloys can be cast with several processes:

- Sand casting
- Permanent mould (gravity die) casting
- Low pressure diecasting, (metal die+sand cores)
- Pressure diecasting
- Lost Foam casting
- Squeeze casting
- Investment casting
- Plaster moulding precision casting techniques (for aerospace castings)

Some alloys are suitable for more than one casting method.
Selection of casting process

- Sand casting for high quality casting of intricate components!
- Sand casting for a limited number of parts (as in casting of prototypes)!
- Permanent mould casting for high strength parts with high elongation values!

Sand cores can be used in permanent mould casting (but not in pressure die casting!).
Selection of casting process

- Low pressure die casting → bottom feeding with a linear melt flow → high quality castings!
- LPDC offers solidification under pressure (although low) → reduced shrinkage!
- LPDC offers advantage particularly in the casting of round symmetrical parts!
- High Pressure Die Casting is the most popular and most widely used casting process!
- HPDC is limited to uncored castings!
- HPDC if high quality surface and minimum finishing are essential.
Sand Casting

- Gravity and low pressure diecasting are inherently slow because the die is effectively out of use during the time that the casting is solidifying.
- When the casting is removed, the die must be reloaded with cores and closed before the next casting is poured.
- This may take 10 minutes or more for a large, complex casting such as a cylinder block.
- In order to achieve the high production rates required by automotive manufacturers, expensive multiple die sets are required.
Sand Casting

re-usable, permanent patterns are used to make the sand moulds.
The preparation and the bonding of this sand mould is the critical, the rate-controlling step of this process.

Mould designing is a particularly complex art.

Half mould with cores and an example of a cast air intake for a turbocharger
Sand Casting

With the exception of pressure diecasting, green sand casting is the most productive casting process.
Sand Casting

Sand casting includes green sand core assembly processes lost foam process

- It accounts for 12-15% of all aluminium castings.
- It is generally used for high-volume production.
- Two main routes are used for bonding the sand moulds:
  - The "green sand" consists of mixtures of sand, clay and moisture.
  - The "dry sand" consists of sand and synthetic binders cured thermally or chemically.
- The sand cores for forming the inside of hollow parts of the casting are made using dry sand components.
With sand casting, productivity is not affected by the solidification time but only by the rate at which the sand mould/core package can be produced. (In GDC and LPDC, the die is effectively out of use during the time that the casting is solidifying.)

With automatic green sand moulding and cold-box coremaking, mould/core packages can be made and assembled in times which enable high production rates to be achieved without the need for the costly multiple tooling sets needed by diecasting.

Moulding machines can produce moulds at the very high rate of one every 12 seconds.
Green sand casting

- The slower rate of cooling of sand castings compared with die castings leads to smaller temperature gradients and a wider solidification time range, making feeding more difficult.

- The grain structure of slower-cooled sand cast aluminium is usually regarded as inferior to that of chill cast alloys.

- To counter this potential problem, moulding sand based on magnetite ore can be used to increase the chilling effect.
Green sand casting

- There has also been some concern that aluminium alloys may pick up hydrogen from moisture in the green sand, but it is not a problem if the sand system is correctly controlled to avoid excessive water.
- Unlike green sand used for iron casting, it is not necessary to have coal dust in the sand to improve casting surface finish.
- To make high integrity sand castings, the melt must be carefully treated to remove hydrogen and oxides from the melt and must be grain refined and modified.
Green sand casting

- The simplest method of filling moulds rapidly and without introducing oxide defects into the casting is by using ceramic foam filters in the running system.
- Ceramic filters remove already entrained oxide and reduce turbulence downstream of the filter.
- **Top pouring** through a filter is an efficient way of filling sand moulds, giving high yield and excellent mechanical properties.
- To produce *shrinkage porosity-free* castings, **directional solidification** must be encouraged, with the use of feeders to supply liquid metal to the last sections of the casting to solidify.
- Simulation techniques are increasingly being used to design running and feeding systems.
Green sand casting

The traditional green sand casting process, combined with high-speed moulding lines, is a very flexible process with high productivity for the manufacture of aluminium castings.

For automotive applications, the process is used to cast:
Intake manifolds
Oil pan housings
Structural parts
Chassis parts

Green sand castings
Automated green sand casting

- **AGSC** offers a reasonable alternative to conventional die casting processes (high pressure/low pressure/vacuum-assisted or not).
- This holds for middle and high volume series, especially for automotive applications.
- Manufacturing in high pressure die casting is limited by wall-thickness and design. I.e. producing a complicated inner structure by using lost cores is still not economically feasible in this process.
- Low pressure die casting's productivity is limited by solidification time, leading to cycle times of typically several minutes.
- Automated green sand casting has no such limits.
Automated green sand casting

Examples of AGSC castings
From left:
Heat Exchanger
Hat Profile
Brake Calipers
Knuckles
wheel
Automated green sand casting

- The AGSC casting process is a container-less sand casting process.
- The mold is divided upright.
- Front and rear mold half are formed by the shaped faces of every sand block.
- Stacked on a conveyor belt, the pouring cavity is between two blocks each.
- Insertion of individual cores or whole core packets is possible and can be carried out in an automated manner.
- The finished molds are pushed forward when a new sand block is added.
Automated green sand casting can produce and fill up to 400 sand molds per hour. By using multiple cavities for smaller parts an hourly output surpassing all other casting processes is achievable.
Overview of the AGSC Process

Complete Control of Mold Filling Combined With High Productivity
Core package casting

- The entire sand mould consists of single sand cores,
- Industrially applied first in 1970 using low pressure filling by means of an electromagnetic pump.
- Due to low productivity, the process is restricted to low volume series.
- However, the increasing interest in the outstanding dimensional quality and possible complexity of the castings led to further developments and thus, (e.g.) the Core Package System (CPS®) has become an established casting process for the volume production of engine blocks.
Core package casting

Partly assembled core package for a 4-cylinder engine block

Core package for V6 engine block
4-cylinder engine block produced with the CPS® process
the mould is not destroyed at each cast but is permanent, being made of a metal such as cast iron or steel. There are a number of die casting processes.

- **High pressure die casting** is the most widely used, representing about 50% of all light alloy casting production.
- **Low pressure die casting** currently accounts for about 20% of production and its use is increasing.
- **Gravity die casting** accounts for the rest, with the exception of a small but growing contribution from the recently introduced vacuum die casting and squeeze casting process.
Die Casting Processes

Classifications of die casting processes.

- High pressure die casting (~50%)
- Low pressure die casting (~20%)
- Gravity die casting
- Vacuum die casting
- Squeeze die casting
High Pressure die casting

half of all light alloy castings are made by the pressure die casting process, in which the liquid metal is injected at high speed and high pressure into a metal mould.

It is the most widely used casting process for aluminium alloys.
High Pressure Die Casting

- In high pressure diecasting, molten alloy is injected under pressure into a highly accurate split metal mould.
- The die halves are closed and locked together hydraulically to withstand the high injection pressure.
- Molten metal is introduced through a pouring slot into the shot tube, then a steel plunger forces the liquid metal into the die cavity under pressure.
- Once the die is filled, pressures are maintained on the casting until solidification is complete.
- The metal solidifies rapidly because of the good thermal contact with the water-cooled die.
- The die set is opened to eject the finished casting together with its sprue, the process is then repeated.
High pressure die casting

- Fixed platen
- Die
- Bolster
- Casting
- Shot sleeve
- Piston
- Moving platen
- Ejectors
- Gate
High pressure die casting

High filling speeds and high pressures are distinct features of HPDC.

Aluminium alloys are cast in cold-chamber diecasting machines.
High pressure die casting

HPDC machines are size rated by the closing force. A fairly common 600 ton HPDC machine

Source: IdraPres
High pressure die casting

- Die filling times are very short, castings with wall thickness of 3-4 mm are filled in less than 0.1 seconds.
- Cycle times depend on size and section thickness of the component, being typically 40 shots/h for a 5 kg component.
- Production rates are fast, the process can be highly automated, and dimensional accuracy and surface finish are excellent.
- Thin-walled components are possible and little or no machining is needed on the cast component since holes, grooves and recesses can be finish cast.
High Pressure Die Casting

- Dies are expensive but can survive more than $10^5$ shots. The process is therefore most suitable for long runs of castings.
- With a highly automated operation, the HPDC process is capable of extremely high levels of productivity.

<table>
<thead>
<tr>
<th>Casting pressure (bars)</th>
<th>Al and Mg</th>
<th>Zn</th>
<th>Brass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard parts</td>
<td>up to 400</td>
<td>100–200</td>
<td>300–400</td>
</tr>
<tr>
<td>Technical parts</td>
<td>400–600</td>
<td>200–300</td>
<td>400–500</td>
</tr>
<tr>
<td>Pressure-tight parts</td>
<td>800–1000</td>
<td>250–400</td>
<td>800–1000</td>
</tr>
</tbody>
</table>
High pressure die casting

● One drawback of the process is that almost inevitably some air is trapped in the die with the liquid metal.

● Lack of internal soundness is a cause for concern when strength and leak tightness are required.

● Turbulence and air bubble entrapment often cause poor metallurgical properties and leaks.

● Special precautions must be taken to limit gas inclusions which cause blistering during subsequent heat-treatment or welding of the casting product.
High Pressure Die Casting

- For this reason, the process has mainly been used for castings which do not require the highest strength.
- Another disadvantage is that sand cores cannot be used, since the high pressure liquid metal would penetrate the core.
Die issues

- Dies are made of hot work tool steels.
- Dies must be **correctly heat treated** to achieve the maximum life.
- Die design is clearly crucial to the success of the process.
- the die must be designed to withstand the large forces involved. Mechanical strength of the die is critical!!
High pressure die casting - summary

- Rapid filling of the die
- Rapid solidification under pressure
- Density and the surface quality is high
- Fine grain structure
- Good (!!!) mechanical properties and fatigue resistance
- Air entrapped in the die $\rightarrow$ gas porosity
- Turbulence during die filling $\rightarrow$ gas porosity
- Thick sections are not as strong as thin sections
- In other casting processes, however, thickness is increased when strength is required.
High pressure die casting - summary

- HPDC parts are used as cast!
- Heat treatment, welding and machining are not employed for HPDC castings!
- HPDC dies must be stronger than permanent moulds used in gravity die casting; Hence, are more costly!
- A minimum of 10,000 parts must be cast for economy!
- Suitable for small parts and thin sections.
High pressure die casting
High pressure die casting

Productivity is usually enhanced via multi-cavity die designs, e.g. 4 to 8 cavities per die. Production rates are up to 100 parts per hour per cavity.

Transmission cases are one of the largest automotive parts commonly diecast.
High pressure die casting

Metallurgical design considerations:

- Part ductility is limited by process considerations to <3% on average.
- Die castings should not be used for load bearing safety critical parts.
- Die castings are not heat treatable.
- Die castings are generally produced using secondary (recycled) alloys; this reduces cost.
- Fatigue properties of die castings are good so long as the very smooth as-cast surface is not machined away.
High pressure die casting

**Macrostructure:** Die castings exhibit three regions internally:

- **The surface skin** - dense and fine. The skin gives die castings good fatigue life. It should not be machined away unless absolutely necessary.

- **The interior body** of the casting - sound metal.

- **The core** - at the centre of the part, the core is usually porous. It may not be present in high quality parts. It is harmless in many applications. Core porosity may be a combination of entrained air and shrinkage.
High pressure die casting

Macro section showing entrained air frozen into a high pressure die cast part

Low magnification view of a section through a typical die cast part

Entrained Air makes HPDC parts non-heat treatable. Air bubbles entrapped under high pressure during solidification will cause HPDC parts to blister during solutionising.
High pressure die casting

Common Al Die casting Alloys:
AlSi8Cu3 (AA 380) $R_{p0.2\%}=160$ MPa, $R_m =325$ MPa, $A_5=0.5-3\%$
AlSi10Cu (AA 383) $R_{p0.2\%}=150$ MPa, $R_m =310$ MPa, $A_5=1-3\%$

These are the most common alloys in use for general-purpose die castings.
General utility castings, transmission cases, blocks etc.
Popular alloys in Al-Si system
High pressure die casting

Special Purpose Al Die casting Alloys

AlSi5 (AA C443) $R_{p0.2} \%= 110$ MPa, $R_m = 230$ MPa, $A_5 = 9\%$
Where exceptional ductility at moderate strength is required. Increased corrosion resistance (low Cu). (eg. steering wheels)

AlSi12 (AA 413) $R_{p0.2} \%= 140$ MPa, $R_m = 300$ MPa, $A_5 = 0.5-2\%$
For intricate thin castings.

AlSi17Cu4Mg (AA 390) $R_{p0.2} \%= 240$ MPa, $R_m = 280$ MPa, $A_5 = 1\%$
A hypereutectic wear-resistant alloy. Used for parent bore engine blocks, compressor parts, pulleys, brake shoes.

Caution: HPDC Properties are very process/part dependent
Al\textsubscript{18}Si (AA 391) Alloy Microstructure - Primary Si Imparts Wear Resistance

Typical Al\textsubscript{18}Si\textsubscript{8}Cu (AA 380 microstructure), Hypoeutectic Al-Si plus Fe phases
Low pressure diecasting

- A metal die is mounted above a sealed furnace containing molten metal.
- A refractory-lined tube, called a riser tube or stalk, extends from the bottom of the die into the molten metal.
- When air is introduced into the furnace under low pressure (15-100 kPa), the molten metal rises up the tube to enter the die cavity with low turbulence, the air in the die escaping through vents and the parting lines of the die.
- When the metal has solidified, the air pressure is released allowing the still-molten metal in the riser tube to fall back into the furnace.
Low Pressure Die Casting

The die is filled from a pressurised crucible below, and pressures of up to 0.7 bar are usual.

Low-pressure die casting is especially suited to the production of components that are symmetric about an axis of rotation. Light automotive wheels are normally manufactured by this technique.
Low pressure die casting

- Mould filling is controlled by regulating the pressure in the casting furnace.
- The melt flows through the riser tube which is positioned under the melt surface of the furnace and fills the mould very smoothly with clean melt from the bottom up.
- After mould filling, solidification starts from the opposite end of the mould in the direction of the tube.
- By increasing the pressure in the casting furnace, good feeding is guaranteed.
- Cycle times are long since the casting is connected to the big melt volume by the riser tube during solidification.
Low pressure die casting

LPDC is used in the production of aluminium wheels and big V-engine blocks in hypereutectic aluminium alloys and in the casting of air-cooled cylinder heads for motor cycles.
Low pressure die casting

LPDC cast V-8 cylinder block
Low pressure diecasting

- The process is capable of making high quality castings.
- Directional solidification may be achieved with correct die design.
- This may eliminate the need for risers, the casting being filled and fed from the bottom.
- Because there is usually only one ingate and no feeders, casting yield is exceptionally high, generally over 90%.
- Good dimensional accuracy and surface finish are possible and complex castings can be made using sand cores.
LPDC-Die design

- Dies must be coated with a suitable dressing to avoid welding of the molten aluminium to the die and to control the rate of heat extraction.
- The dressings are the same as those used for gravity diecasting.
- They are sprayed with the die at a temperature of 120-200°C to facilitate a quick dry.
- The die must then be reheated above working temperature before casting metal.
- It is very important that particular care is taken in cleaning dies regularly, say once per week, by “shot”-blasting using glass beads, otherwise tolerance and surface finish of the castings will soon deteriorate.
- Die life is normally around 30 000-50 000 “shots”.
LPDC-Cores

- Sand cores made by any of the usual processes - shell, cold box, hot box etc. - can be used.

- As with any casting process, cores must be permeable and provision made for venting core gases to avoid gas defects in the castings.

- Where complex coring is needed, such as for cylinder heads, it is usual to preassemble a core package which can quickly be inserted into the die to avoid slowing down the casting cycle.
The process is rather slow since the die must be filled slowly to avoid turbulence and air entrapment.

The casting must solidify progressively from the extremities back to the gate and the gate must solidify before the pressure can be released.

Cycle times are similar to gravity diecasting, about 9 shots per hour are typical for a component such as a cylinder head.
The commonly used aluminium alloys include:

- Al-Si5Cu3 (LM4, US 319)
- Al-Si12 (LM6, US 413)
- Al-Si7Mg (LM25, US A356)

It is usual to fully treat the metal by degassing, grain refining and modifying.
LPDC-typical applications

- Aluminium automotive parts:
  - wheels,
  - cylinder heads,
  - blocks,
  - manifolds
  - housings
- Critical aerospace castings
- Electric motor housings
- Domestic kitchenware such as pressure cookers
- Large castings up to 150 kg (Al) can be made but can only be justified in special cases because of high die costs.
LPDC-Casting quality

- The process produces castings of high quality, both metallurgically and dimensionally:
  - The metal is drawn from the bottom of a bath of molten alloy, avoiding the contaminated surface layer,
  - The mould is filled gently without turbulence so avoiding oxide entrapment,
  - Solidification is directional, enabling constant feeding of the casting by maintenance of pressure from below,
  - casting extraction is relatively damage-less to the die: dimensional accuracy should be maintained throughout the life of the die.
Although metal is drawn from below the surface of the melt, oxide inclusions may still be present due to the turbulence arising when the furnace is topped up from the transfer ladle.

The density of aluminium oxide is close to that of the metal itself so oxide inclusions may not all float to the surface.

Further turbulence is introduced in the furnace by the fall of the metal in the riser tube each time a casting is made and the pressure released.

Casting quality can be improved by fitting a ceramic foam filter in the sprue to prevent inclusions from entering the casting.
LPDC-Casting quality

- Casting tolerances in low pressure diecasting are similar to those of gravity diecasting.
- Variation in the dosing of die coating is one of the main reasons for dimensional inaccuracies.
- Die distortion over time will also affect dimensions of the castings.
Gravity Die Casting (GDC)

- Gravity die casting is the simplest die-casting process.
- It enables castings to be produced with only a very modest capital investment, although plenty of hard physical work is required!
- However, it can also be automated with either horizontally or vertically-parted dies.
- Good quality castings can be produced if sufficient care is taken to design running and gating systems which minimise surface turbulence in the metal as it flows into the die.
gravity die casting

- one of the standard processes for the manufacture of high-integrity automotive castings.
- precision technology for the production of large batch quantities.
- used in carousel casting units or in shuttle technique particularly for the manufacture of engine castings.
- Optimum heat dissipation from the solidifying casting through the die leads to short solidification times.
- This results in castings which have good mechanical properties, especially after an additional heat treatment.
gravity die casting

In gravity die casting processes, the melt is metallurgically treated in the holding furnace, which is positioned near the dies.
Gravity die casting is suitable for mass production and for fully mechanised casting.
gravity die casting

- The molten metal is poured under gravity into a refractory-coated permanent mould or die.
- The technique is sometimes known as “permanent mould” or “chill” casting.
- The dies are made of a fine-grained, pearlitic cast iron or a low alloy steel.
- Simple retractable cores may be made of high grade alloy steel, but resin bonded sand cores are used to produce complex internal shapes.
gravity die casting

- With the exception of pressure diecasting, the process is the most widely used of the aluminium casting methods due to its inherent simplicity and the metallurgical quality and complexity of castings that can be made.
- The process is used for castings made in numbers from 1000 to more than 100,000 per year, for example manifolds, cylinder heads, water pump housings etc.
- Casting size ranges from less than 1 kg to over 50 kg.
The dies are coated with a refractory-based coating. The coating reduces the heat transfer to the die so that cooling rates are faster than in sand moulds but slow enough for complex castings to be filled satisfactorily. Different coatings are available which allow faster or slower cooling as the shape and section of the casting requires. The time before the casting can be extracted from the die may vary from 4-10 minutes depending on the type of casting. The process is therefore relatively slow.

### Solidification times of Al castings made by different processes

<table>
<thead>
<tr>
<th>Casting process</th>
<th>Mould material</th>
<th>Solidification time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent mould</td>
<td>Steel</td>
<td>47</td>
</tr>
<tr>
<td>Core</td>
<td>Silica sand</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>Zircon sand</td>
<td>80</td>
</tr>
<tr>
<td>Disamatic</td>
<td>Silica/clay</td>
<td>85</td>
</tr>
</tbody>
</table>
The gravity die casting process produces castings of high metallurgical quality. Metallurgical structures and properties benefit from the chilling achieved by gravity die casting.

The objective of running the metal into the cavity is to make entry as smooth as possible, avoiding turbulence which would introduce oxide film defects.

The speed of filling is a compromise between getting the metal to the furthest point of the die quickly enough to avoid misruns, and pouring slowly enough to avoid turbulence.

Bottom gating is the traditional way of achieving turbulence-free filling but bottom gated castings have poor yields and incorrect thermal gradients.
Feeders need to be at the top of the casting and must be the last masses to freeze, but optimum directional solidification is not easy to achieve when the metal is bottom gated and has to traverse the die cavity and any cored passages before reaching the feeders.

One way of improving feeding is to tilt the die when pouring in such a way that the last metal is poured into the feeder.

Special tilting machines are available to allow this to be done.
The widespread use of ceramic foam filters and insulating feeders has greatly improved the quality of gravity castings in recent years.

A recent development has been the use of direct pouring methods, either through a filter fitted directly in the die or through a combined filter/feeder.

This greatly improves yield, achieves turbulence-free filling and also feeds the casting with the hottest metal.
The usual alloys cast by gravity die casting are:

- AlSi5Cu3, A319
- AlSi12, A413
- AlSi7Mg, A356

- AlSi12, A413, being the eutectic alloy, has the best fluidity and is good for thin section castings but its machining characteristics are poor.
- AlSi7Mg has good fluidity and good machining properties, it can be heat treated and is corrosion resistant.
- Al-Si5Cu3, A319 has somewhat lower fluidity due to its low Si content and has good machinability.
Melting and metal treatment

- It is advantageous for a foundry to use the minimum number of different alloys, allowing bulk melting to be used for the majority of the castings.

- Since gravity diecasting is capable of making high quality castings and is used for critical castings such as cylinder heads, hydraulic castings etc., it is usual to fully treat the metal by degassing, grain refining and modifying.
gravity die casting

- Permanent moulds are manufactured from high alloy steels (hot work tool steels (H13) are used in the manufacture of pressure die casting moulds).
- Casting quality is superior with respect to that obtained in sand casting.
- Preferred for parts with high surface quality and with limited dimensional tolerances.
- Mechanical properties in gravity die cast parts are at least 20% better than sand cast counterparts.
- Up to 100,000 shots can be produced with permanent moulds.
gravity die casting

- Minimum wall thickness must be 3mm (2 mm is possible in small parts.
- Weight of castings range between several hundred grams and several hundred kilograms.
- In addition to producing ever more complicated cylinder heads for petrol and diesel engines, gravity die casting is also used for the manufacture of diesel engine blocks with cast-in grey iron liners.
- Some foundries use gravity die casting to produce cylinder blocks weighting 300 kgs.
Gravity diecasting
Special requirements for gravity diecasting

Thin section (<5 mm) gravity die castings cool so quickly that it is sometimes considered unnecessary to grain refine or modify the alloy. For castings having sections above 5 mm, grain refinement is beneficial and modification of eutectic alloys (10-13% Si) may be used.

Melting practice for high quality gravity die castings and low pressure die castings is generally the same as for sand casting. In some less-critical gravity die castings, a small amount of gas in the metal may be beneficial since dispersed gas porosity may be considered less harmful than shrinkage. The metal is melted as usual using the appropriate cover flux. Degassing is not usually necessary. Skim off the dross and cast.
The die casting processes are limited by their poor productivity since it is necessary to wait for the metal to solidify before the die can be opened.

As an example, the cycle time for producing a typical die-cast cylinder head is about 5 - 7 minutes, although this can be as long as 15 minutes for larger variants, such as a Jaguar cylinder head.

Therefore, die casting should be restricted to thin-walled components.

The other limitations with all forms of die casting are the high cost of the dies themselves and their limited lives as a result of thermal fatigue which causes craze-cracking of the working faces.
gravity vs pressure die casting

- Porosity that is almost inevitable in pressure die casting degrades mechanical properties and leads to blisters after heat treatment.
- Gravity die castings have less porosity; are more sound and leak tight.
- Gravity die castings can be machined with no evidence of porosity on the surface. Pressure die cast components, on the other hand, cannot be machined due to the presence of porosity!
- Surface quality is higher in pressure die casting
- A machined pressure die casting may be stronger than a permanent mold casting. However, the latter is more reliable because of less porosity.
gravity vs pressure die casting

- Pressure die casting is superior with thin sections and due to closer dimensional tolerances.
- Die-tooling costs are lower.
- Parts that cannot be cast with pressure die casting due to sand cores can be cast with the gravity die casting route.
- Pressure die casting is faster and yields more parts in unit time.
- Dies in pressure die casting must be stronger than in gravity casting and are thus more expensive.
- Cost per part is lower (for high volume production).
- Alloys for die casting are few as high castability is a must!
### Casting Processes Comparison

<table>
<thead>
<tr>
<th>Property</th>
<th>Sand</th>
<th>Gravity</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Good</td>
<td>Best</td>
<td>Good</td>
</tr>
<tr>
<td>Density</td>
<td>Good</td>
<td>Best</td>
<td>Medium</td>
</tr>
<tr>
<td>Repetability</td>
<td>Medium</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Tightness</td>
<td>Good</td>
<td>Best</td>
<td>Medium</td>
</tr>
<tr>
<td>Cost per part</td>
<td>Medium</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Production rate</td>
<td>Medium</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Alloy variability</td>
<td>Best</td>
<td>Good</td>
<td>Medium</td>
</tr>
<tr>
<td>Tolerances</td>
<td>Medium</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Design flexibility</td>
<td>Best</td>
<td>Good</td>
<td>Medium</td>
</tr>
<tr>
<td>Dimensions</td>
<td>Best</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Surface quality</td>
<td>Medium</td>
<td>Good</td>
<td>Best</td>
</tr>
<tr>
<td>Tool preparation</td>
<td>Best</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Cost of die</td>
<td>Best</td>
<td>Good</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Applications of die castings

- The use of modern die casting techniques improves the metallurgical quality of die castings.
- Heat treatment is possible with some processes so extending the application of the die casting to components such as hydraulic manifolds, brake callipers, engine brackets, suspension arms, engine blocks etc.
- One limitation of pressure die casting is that complex cored castings cannot be made.
- It is not possible to use sand cores since the high injection pressure causes metal penetration.
- Special salt cores have been used, but are difficult to remove from the casting.
- Coring is limited to using tool steel “pulls”.
Metal handling in the die casting foundry

- The commonly used pressure diecasting alloys contain 8-10% Si and 2-3% Cu with around 1% Fe.
- The presence of iron reduces the tendency for the casting to “solder” to the steel die but it tends to deposit inclusions in melts that are held for any length of time.
- The most frequently used alloys are:
  - Al-Si8Cu3Fe (LM24, US A380)
  - Al-Si10Cu2Fe (LM2)
  - Al-Si9Cu3Fe (LM26)
Metal handling in the die casting foundry

- Metal is normally melted in a bulk melter, either electric induction or gas-fired shaft or crucible furnaces.
- For many years, it was not considered worthwhile to degas the alloy before casting (because some gas porosity is accepted as inevitable).
- Furthermore, the cooling rate in the die is so fast that grain refinement and modification are also not required.
- However, it is found that treatment of the liquid alloy by a Rotary Degassing Unit is effective in removing non-metallic inclusions, reducing sedimentation of hard iron-manganese inclusions as well as lowering gas content.
- Increasingly diecasters are using Rotary Degassing in the transfer ladle for this reason.
- Some diecasters find that modification with strontium is also valuable.
Metal treatment

- It is important to keep melting and holding furnaces clean to prevent hard inclusions of corundum from entering the castings.
- Regular use of a cleaning flux, is recommended.
- Bulk melting is carried out under a covering/drossing flux to ensure minimum metal loss, forming a complete cover, adding half early and the rest at final melt down.
- The metal is poured into the transfer ladle and degassed. Modification may also be done at the same time.
- Note that sodium modification is not suitable since the metal may be held for a long time in the holding furnace before use.
- In the holding furnace, a low temperature flux can be used as a cover to reduce metal loss.
Die coating

- Refractory die coatings are **not used** for pressure diecasting, since high heat transfer is needed to cool the casting quickly and achieve fast casting cycle times.
- However, the die must be sprayed between each shot with a lubricant.
- The die cycles at a high temperature (250-300°C) and at regular intervals molten metal is injected at high pressure.
- All the alloys cast commercially will attack and weld to steel dies.
- The lubricant must protect the expensive die from direct metallurgical attack and erosion as well as lubricate slides, cores, ejector pins etc. to prevent them seizing at the high operating temperature.
- The coating also has a cooling function.
## Share of Al castings market held by various processes

<table>
<thead>
<tr>
<th>Casting method</th>
<th>% by weight (1991)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USA</td>
</tr>
<tr>
<td>High pressure diecasting</td>
<td>60–65</td>
</tr>
<tr>
<td>Low pressure and gravity diecasting</td>
<td>20</td>
</tr>
<tr>
<td>Sand</td>
<td>10</td>
</tr>
<tr>
<td>Lost Foam</td>
<td>2–5</td>
</tr>
<tr>
<td>Others</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>
Modification of the diecasting process

The pressure diecasting process is such a powerful casting process, producing castings of such excellent surface finish and dimensional accuracy, that many developments have been made to overcome the basic problem of low internal integrity of the castings due to air entrapment.

Vacuum diecasting
The shot tube and die cavity are evacuated before metal injection to reduce the amount of air that is trapped.

Pore-free diecasting
The cavity is flushed with oxygen rather than air. The oxygen should then combine with the liquid aluminium, forming oxide which is less harmful than gas entrapment.
Vacuum die casting of precision engineered die cast products

Used when no surface flaws such as blisters etc are forgiven. When high temperature powder coating is an essential step in manufacturing cycle.
Modification of the diecasting process

Indirect squeeze casting

- Metal is injected into a closed die cavity by a small diameter piston which also exerts sustained pressure during solidification.
- A special thermally insulating die release agent is used to provide a significant thermal barrier between the casting and the die during filling allowing the metal to be fed further into the die cavity without freezing.
- When pressure is applied to the full cavity, the die coating is compressed reducing its insulating effect.
- The metal velocity during filling is controlled to ensure non-turbulent flow so that air entrapment is minimised.
- When the cavity has been completely filled, the pressure is applied (from 60 to 100 MPa).
Modification of the diecasting process

- It is most important that the temperature gradients within the die are controlled so that the casting freezes directionally towards the gate area.
- This gate area is made deliberately very thick so that it will be the last area to solidify.
- In this way, all the metal freezes under pressure reducing the possibility of shrinkage porosity.
- The low metal velocities used do not wash release agent from the die faces so that contact between the alloy and the die steel is reduced.
- There is no need to use high-iron alloys to prevent Soldering.
Modification of the diecasting process

- The resulting physical properties of the castings are much enhanced over conventional pressure diecastings.
- The gas content is low so that heat treatment is possible and hydraulic integrity good. Indirect squeeze castings can be used for critical components such as brake callipers and hydraulic components.
Modification of the diecasting process

disadvantages:

- large, thin, wall castings are not possible,
- yield is reduced because of the large gate section that must be used,
- shot rates are slower than in conventional pressure diecasting and
- the machines are expensive.
Investment Casting

- Wax patterns are coated with a refractory (i.e. the patterns are invested in alternate layers of slurry and stucco), and are subsequently melted out to leave a hollow shell into which the metal is cast.
- It is an extremely slow process and the production rate is governed by the time to make the mould.
- The production of a wax pattern might take only 1 or 2 minutes but most ceramic shell moulds require between 7 and 14 coats and take at least 24 hours and sometimes as long as several days to complete.
- However, it is now normal practice to make several hundred moulds automatically in one batch and, of course, each mould may comprise several dozen or over a hundred small components.
Investment Casting Processes

Stages in investment (lost wax) casting

- Make wax pattern in die
- Assemble patterns onto 'tree'
- Build up ceramic shell mould
- Dewax and fire shell
- Pour metal and allow to solidify
- Remove shell
- Separate castings from runner system and fettle
The Lost Foam Casting process

- The actual LFC-process uses patterns of expandable polystyrene (EPS) for industrial applications.
- These patterns, directly foamed to shape, are immersed in a moulding box with binderless sand.
- The liquid metal, which is poured into the cups of the downsprues, vaporises the EPS pattern, which is precisely replaced by the metal.
- With the possibility of assembled patterns very complex shapes can be created and the castings can be reproduced with remarkable dimensional accuracy.
The Lost Foam Casting process

- The filling rate of the mould is determined by the rate at which the EPS pattern is destroyed by the liquid alloy.
- This in turn is greatly affected by the properties, particularly permeability, of the coating.
- The result is an essentially turbulence-free mode of filling, whether from the bottom, side or top.
- Due to the freedom from turbulence and its associated trapping of oxide films, lost foam aluminium castings can be of high metallurgical integrity.
- The process is therefore increasingly used for critical automotive castings such as cylinder heads and blocks, water, brackets, inlet manifolds up to about 20 kg weight.
The Lost Foam Casting process

- LFC offers the possibility of a direct production of nearly any complex geometry including complicated undercuts and cavities without tapers and the need for considerable finishing work.
- Compared to the conventional sand casting methods it has economical and ecological advantages.
- It is still used for rapid prototyping of intricate components or large castings.
The 'lost foam' process

Stages in the 'lost foam' process

- Produce expanded polystyrene pattern
- Assemble patterns onto runner system
- Coat with ceramic slurry and dry
- Embed in sand and vibrate to consolidate
- Pour metal
- Remove from sand
- Clean and fettle castings
The ‘lost foam’ process

Pattern making. First step in the LFC-process is the pre-expansion of EPS beads. After maturing the beads are blown into a mould forming the pattern sections. The mould is then steamed to expand the beads further and tightly fill the cavity of the mould. Hot steam and expansion of the beads causes them to weld together.

Cluster assembly. Complicated parts including undercuts and hidden cavities cannot be moulded in one working step, but are assembled from pattern segments into a final pattern. Joining techniques used are gluing, heated platen welding and plugging. In order to increase the efficiency of the total process several patterns are combined into a cluster and supplied with a common gate system, also made of EPS.
The ‘lost foam’ process

Pattern assembly
Source: BMW AG
Landshut

Cluster with two cylinder heads
The ‘lost foam’ process

Coating:

- The clusters are coated with a refractory coating layer by immersion in a water soluble ceramic slurry.
- The coating layer has the function of guiding the gasification process of the pattern and to form a barrier between the moulding material and the gas-filled bubble which exists between the still solid EPS-pattern and the intruding aluminium melt.
- After the coating has dried, a thin, hard and permeable coating remains.
- The coatings are typically applied to a foam cluster by dipping, spraying or pouring.
The ‘lost foam’ process

Embedding in sand:
- After the coating has dried, the cluster is placed in a flask and backed up with unbonded quartz sand without chemical additives.
- The sand is compacted through vibration with various frequencies, which causes the sand to fill all hidden cavities of the patterns.
The ‘lost foam’ process

Coating of a cluster with two cylinderheads
The ‘lost foam’ process

Pouring: During the filling process the molten metal flows via the gate system into the EPS-patterns, which is gasified, filling up the cavity and replacing exactly the pattern geometry. During this stage it is important to avoid turbulences, support the casting cavity wall and to realise a progressive elimination of the foam pattern. The gas originating from EPS decomposition permeates the coating layer and escapes into the sand, possibly supported by an external vacuum.
The ‘lost foam’ process

Form filling velocity and type of metal flow, i.e. laminar or turbulent, determine the part's quality by influencing the amount of oxide inclusions and porosity.

Specifically, the following sets of parameters have to be tuned to each other:

- permeability of coating,
- optional external vacuum,
- metal temperature,
- EPS-pattern density and type of adhesive,
- geometry of the gating / riser system and of the patterns
The ‘lost foam’ process

Dumping, quenching and trimming:
After solidification of the casting, the sand can be removed from the flask and be prepared for the following moulding. Clusters are quenched and knocked-off from the gate system. The castings are purged and controlled w.r.t. defects. In many applications the castings don't require any further mechanical finishing.
Advantages

- **Low tooling cost**: Though tools are expensive, their life is long, up to 500,000 cycles are possible. So for long-running, high volume parts overall tool costs are much lower than for conventional casting process. For shorter running parts the advantage is less and may even be a disadvantage.

- **Reduced finishing**: There is a major advantage on most castings since finishing is restricted to removing ingates.

- **Reduced machining**: For many applications, machining is greatly reduced and in some cases eliminated completely.
Advantages

- **Ability to make complex castings:** For suitable applications, the ability to glue patterns together to make complex parts is a major advantage.

- **Reduced environmental problems:** Lost Foam is fume-free in the foundry and the sand, which contains the EPS residues, is easily reclaimed using a simple thermal process. (binder-less recirculated sand/no sand reclaiming system)

- **high productivity**

- **high flexibility**

- **potential for Rapid Prototyping**

- **good surface quality.**
Disadvantages

- The process is difficult to automate completely; cluster assembly and coating involve manual labour unless a complete casting plant is dedicated to one casting type so that specialised mechanical handling can be developed.
- Methoding the casting is not easy and a good deal of experimentation is needed before a good casting is achieved.
- Cast-to-size can be achieved but only after several tool modifications because the contractions of foam and casting cannot yet be accurately predicted.
Disadvantages

- long lead times are inevitable for new castings.
- it is difficult to achieve the highest metallurgical quality in Al castings because of the need to cast at rather higher than normal temperatures. (However, new thermally insulating coatings are available for the patterns and allow lower casting temperatures.)
- possible deformation of pattern during sand fill and compaction,
- possible entrapment of plastic residues caused by non-optimised gating systems,
- large number of process parameters need to be controlled for optimum form filling.
Lost foam casting

Cylinder heads
BMW AG Landshut
The Lost Foam casting process

1. Foam Sections
2. Foam Assembly
3. Assembled Cluster
4. Coated Cluster
5. Fluidise
6. Pouring
7. Compaction
8. Sand Fill
9. Extraction
10. Quench
11. Trim
Applications

- The usual alloys used for sand and gravity casting can be cast successfully by Lost Foam and the methods of melting and treatment are the same.
- The automotive industry is a major user.
- The inlet manifold was the first successful high volume application.
- Cylinder heads are being made in growing numbers. Use of Lost Foam gives the designer rather more freedom to cool the working face effectively, the combustion chambers can be formed “as-cast”, avoiding an expensive machining operation, and bolt holes can be cast.
Applications

- Lost Foam offers significant design advantages over other casting processes for cylinder blocks; features can be cast in, such as the water pump cavity, alternator bracket, oil filter mounting pad.
- Oil feed, drain and coolant lines can also be cast more effectively.
- A variety of other automotive parts are being made including water pump housings, brackets, heat exchangers, fuel pumps, brake cylinders.
Semi-solid processing
Semi-solid-route?

Solid feedstock forging

Solid (%60)-liquid (%40): Semi-solid forging

Solid (<%10)-liquid (>%90): Semi-solid casting

1: pressure die casting
2: thixo-route
3: forging
Thixocasting

- This process makes use of the thixotropic behaviour of semi-solid metallic alloys.
- Slugs of aluminium alloy are inductively heated into a semi-solid state; the slug is introduced into the shot sleeve by a robot arm.
- The globular feedstock behaves like a solid (high viscosity) if not sheared.
- As soon as shearing occurs, viscosity decreases by orders of magnitude.
- Under certain conditions this effect is reversible.
Thixocasting

Metallic alloys have strong thixotropic behaviour if:

- it is possible to bring the metal homogeneously to the required semi-solid state, i.e. enough solidification range is present,
- a microstructure with very fine and round grains exists.

All semi-solid forming processes are characterised by:

- 10 to 70% solid phase during forming,
- Thixotropic properties: initially the metal's viscosity is high. After being sheared its viscosity decreases strongly.
- the metal solidifies during forming.
Thixocasting

Specific properties of the products:

- Since only part of the metal is liquid, shrinkage porosity is reduced.
- Solidification takes place very rapidly and little heat extraction is necessary.
- Since the viscosity of the metal is high, mould filling occurs in a very laminar way.
- Net-shape parts can be produced.
Process steps of Thixocasting

Liquid metal is first DC-cast to fine grained billets which are then reheated to the semi-solid state and formed to the final product.

This process has been mainly used during the last 20 years.
Metallurgical aspects of SS process

Thixocasting
- The metal used has to show very fine and spherical grains to increase the shear thinning effect during forming.
- DC-casting is normally combined with strong electromagnetic stirring. This leads to fine rosette like grains.
- During re-heating the metal, grains become spherical, as required for semi-solid forming,
- During forming, the weak bridges between the grains break, leading to a strong reduction of viscosity (shear thinning).
Metallurgical aspects of SS process

Microstructure of AlSi7Mg0.3 before re-heating

Microstructure of AlSi7Mg0.3 after re-heating
Rheocasting

Liquid metal is directly cooled down to the semi-solid state and processed to the final product. Since 1999, this process family is gaining new attention

Process steps of Rheocasting

1. Pouring
2. Cooling
3. Temperature holding
4. Forming
Rheocasting

- During cooling the liquid to the semi-solid state, some specific conditions have to be fulfilled to get the fine grains required.
- A very high amount of grain seeds have to be built. This can be produced by using chemical grain refiners, suitable thermal conditions or mechanical vibrations in the melt,
- During the process of partial solidification, the many grain seeds grow and, after touching their neighbours, get spherical.
Rheocasting

Microstructure of AlSiMg0.3 alloy ready for forming