Fluxes

NaCl-KCL mixtures
Cover fluxes
Rafination fluxes
Drossing off fluxes
Wall cleaning fluxes

Flux salts

spent flux salts could be a major source of problems
why do we need fluxes!

Oxidation of molten aluminium is inevitable!

\[ \rho_{\text{Al}_2\text{O}_3} \sim \rho_{\text{Si} \text{Al}} \Rightarrow \text{inclusions in suspension!} \]

\[ < \rho_{\text{Si} \text{Al}} \Rightarrow \text{inclusions float!} \]

\[ > \rho_{\text{Si} \text{Al}} \Rightarrow \text{inclusions sink!} \]

Fluxing is essential in order to

- to avoid the contact of aluminium melt with the furnace atmosphere
- to release inclusions in suspension and to improve melt quality
- to get a dry dross after skimming
- to maintain clean furnace walls

Flux selection is critical!
Critical features of fluxes

- melting point must be lower than that of Al (660 °C)! the lower the melting point of the cover flux, the more efficient its use.
- density must be lower than that of molten Al (~2.3g/cm³)!
- must be inert to furnace refractories!
- vapour pressure must be low!
- fluidity must be high!
- must be recyclable!
- must conform to the health-safety codes!
- must be cheap!
issues of flux practice

- fluxes immediately absorb atmospheric moisture: damp fluxes do more harm than good!
- Packaging is thus critical!
- fluxes must be packaged in addition dose!
- fluxes must be added in packages!
- fluxes must never be exposed to the furnace atmosphere
Flux types

- cover fluxes
- drossing off fluxes
- rafination fluxes
- wall cleaning fluxes
Cover fluxes

- must be liquid and must cover the melt in order to avoid contact with the furnace atmosphere.
- must melt at the operation temperature.
  \[ T_m \uparrow \rightarrow \text{Flux-dross layer mushy} \rightarrow \text{metal loss} \uparrow \]
  wet (high Al content) dross
  \[ T_m \downarrow \rightarrow \text{Flux-dross layer liquid} \rightarrow \text{metal loss} \downarrow \]
  flux inclusions
  handling difficult!
- the liquid flux layer protects the melt from oxidation and hydrogen pick-up.
Cover fluxes

- **NaCl + KCl : (%44 + % 56)**
  - Binary eutectic : 645°C

- **NaCl + KCl + NaF mixture**
  - Ternary eutectic : 607°C

- **Cover flux must not be intermixed with aluminium alloy melt!**

- **Cover flux must be employed after all treatments are over, for melt held for casting!**

- **Binary and ternary mixtures are also ideal carriers!**
KCl-NaCl binary phase diagram
Cover fluxes

- Most fluxes contain sodium and it is possible for the metal to pick up as much as 0.001% Na from them.
- For most aluminium alloys the sodium has no effect or is beneficial, but alloys containing more than 2% Mg may become brittle with even trace amounts of sodium, so they are treated with sodium-free fluxes.
- Approximately 0.5% of the flux is put onto the solid charge and a further 2% sprinkled evenly over the surface when the alloy is fully molten.
- When the flux becomes pasty or liquid at about 750°C, the flux is worked well into the melt with a bell plunger for about 3 minutes.
Drossing off fluxes

- A drossing-off flux is used to absorb oxides and non-metallic material, cleansing the metal and forming a good metal-free dross which can easily be removed.
- Drossing-off fluxes agglomerate the oxides allowing easy removal from the surface of the melt.
- They are used to remove the dross with the minimum metal loss (dry dross-pure in metal).
- Typical ingredients:
  \[ \text{NaCl} + \text{KCl (carrier)} + \text{KNO}_3 : \text{(nitrate, sulfate, carbonates)} + \text{fluorides} \]
Drossing off fluxes

- Exothermic compounds $\rightarrow$ thermite reactions
  $\Delta Q \rightarrow$ softening in the dross layer
  $\rightarrow$ frees trapped aluminium!

- Exothermic fluxes ensure that liquid aluminium trapped in the dross layer is returned to the melt.

- Floride compounds: contributes to oxide - metal separation owing to their high wetting capacity!

- if added too much $\uparrow \rightarrow$ metal loss $\uparrow$
  if added too little $\downarrow \rightarrow$ softening effect $\downarrow$
  $\rightarrow$ metal loss $\uparrow$
Drossing-off before pouring

- When the melt is ready for drossing-off, the flux is spread over the metal surface, allowed to stand for a few minutes until fused and then rabbled into the dross for several minutes with a skimmer.
- For best results the melt should preferably be above 700°C although fluxes will function well below 650°C.
- Doors are then closed and the burner is turned on for 10 minutes.
- This helps to activate the flux, heating the dross and giving good metal separation.
- The dross is then pulled to the door, allowed to drain and transferred to a dross bogie.
- If the dross in the bogie is raked, further metal will collect in the bottom.
In reverberatory and shaft furnaces, the quantity of flux needed will depend on the cleanliness of the charge material and on the surface area of the metal.

As a guide, it is recommended that an application of 1-2 kg/m² will suffice.

The behaviour of the flux will indicate whether the dosage needs to be reduced or increased in future applications.
Drossing-off before pouring

- In crucible furnaces, when drossing-off is carried out, the crucible sides are scraped and the required quantity of the selected flux (250 g is normally enough for the lift-out or bale-out furnace) is sprinkled onto the metal surface along with the existing flux cover and mixed into the surface of the melt until a red-glowing dross is obtained.

- This is exceptionally free of metal and can be removed with a perforated skimmer.
Rafination/cleaning fluxes

- they remove non-metallics from the melt by trapping the oxide particles as they float out!
- They help the oxides in suspension float,
- employed continuously in rafination units located in transfer systems or in melting (or holding) furnaces
- Typical ingredients:
  NaCl + KCl (carrier) + Floride compounds (upto %20 Na₃AlF₆, CaF₂, Na₂SiF₆)
Rafination fluxes

- They penetrate between the oxide particles owing to their low solubility and help to physically separate the oxide particles from the molten metal!
- They strip the oxide films on the molten metal droplets and improve the metal recovery!
- Metal-oxide interface energy is reduced and the oxides are wet by the melt → oxides in suspension are removed from the melt while the aluminium metal entrapped by the oxides return back to the melt; aluminium and oxides are thus separated
- Dry dross is skimmed off!
Rafination fluxes

- If added too much → the fluidity of the flux is impaired due to the high melting point of fluorides → metal loss ↑

- The most effective (yet the most expensive) fluoride salt is: \( \text{Na}_3\text{AlF}_6 \)

- Addition practice: stir the flux into the molten alloy!
  - Wait for 5 to 10 minutes - allow enough time for oxides to float
  - Dross is skimmed off!
Removal of Alkalines with Cl$_2$/Ar

![Graph showing the concentration of alkalines (in ppm) over the duration of fluxing (in min). The graph compares actual and modelled data for Li, Na, and Ca.]
Removal of alkalines

Removal of alkaline and alkaline earth metals via fluoride fluxing

\[ 2 \text{AlF}_3 + 3 \text{Ca} = 2 \text{Al} + 3 \text{CaF}_2 \text{ (slag)} \]

\[ \text{AlF}_3 + 3 \text{Na} = \text{Al} + 3 \text{NaF} \text{ (slag)} \]

\[ 2 \text{AlF}_3 + 3 \text{Mg} = 2 \text{Al} + 3 \text{MgF}_2 \text{ (slag)} \]

via chlorine fluxing

\[ \text{Ca} + \text{Cl}_2 = \text{CaCl}_2 \text{ (slag)} \]

\[ \text{Na} + \frac{1}{2} \text{Cl}_2 = \text{NaCl} \text{ (slag)} \]

\[ \text{Mg} + \text{Cl}_2 = \text{MgCl}_2 \text{ (slag)} \]
Removal of Mg: demagging

Specialist flux for the removal of excess magnesium from aluminium alloys. DEMAGGER B is a magnesium removing flux suitable for use with aluminium alloys where the magnesium content is over specification. We recommend using this product as manual flux.
Furnace-cleaning flux

- Aluminium melting furnace linings become coated with an oxide build-up and with time the oxide content increases to form the hard corundum phase.
- Metal quality, cleanliness is adversely affected if furnace refractories are not cleaned properly!
- In this case refractories can be cleaned only mechanically by crushing the corundum phase, causing damage to the refractories.
Furnace-cleaning flux

- The flux is mainly for application to the walls and roof of reverberatory and rotary furnaces.
- It can also be used for cleaning large transfer ladles, if these can be independently heated.
- The flux is not recommended for electric furnaces with exposed elements because of the possibility of element attack.
Furnace-cleaning flux

- Furnace cleaning flux is a strongly exothermic flux which attacks and strips oxide films.
- Typical ingredients are:
  \[ \text{NaCl} + \text{KCl (carrier)} + \text{Oxygen bearing exothermic compounds (KNO}_3, \text{Alkaline carbonates)} \]
- The heat generated and the stripping action causes entrapped aluminium to melt and run down to the furnace hearth.
- Residues on walls are thus loosened and can be removed more easily by scraping tools.
Furnace-cleaning flux

- bath level is brought to a minimum (minimum heel inside the furnace)!
- The empty furnace is heated until the lining glows red (800-850°C). the walls are sprayed evenly with flux using a Flux Gun.
- furnace doors are closed!
- burners work full capacity for 10-15 minutes!
- (walls are brought to the maximum possible temperature to help to soften the corundum layer!)
Furnace-cleaning flux

- Then the walls are scraped clean off the softened corundum layer.
- The recovered metal is finally tapped.
- A 10 tonne furnace will need about 25 kg of flux. Furnaces should be treated weekly to prevent accumulation of build-up.
- The flux can be used when making a change of alloy, to prevent contamination of the bath by residues from the preceding charge.
- Application once a week is recommended!
granulated fluxes

- The formulations of fluxes have not changed for many years, being based on powdered halides including fluorides which are of concern environmentally and which can reduce the life of furnace refractories.

- Attempts have been made to eliminate fluorides completely from the flux formulations, but unfortunately this rendered the flux ineffective.

- The morphology of the flux was found to have a major effect on its efficiency.
granulated fluxes

- Granulated fluxes have significant environmental and technical advantages over the powder fluxes and are rapidly replacing them.
- Fluxes for aluminium contain chlorides and fluorides which may give rise to potentially harmful fumes in use on molten metal. Operators must avoid inhalation of the fumes or dust.
- Used flux must be disposed with care, referring to the local authority or a specialist disposal company.
granulated fluxes

granules  powder
By using fluxes in granular form rather than as conventional powders, the effectiveness of the flux can be greatly increased, the handling improved and the undesirable, hazardous emissions can be significantly reduced.

The higher cost of granulated fluxes (arising from the additional manufacturing process involved) is compensated by the much reduced quantities needed.
Conventional powder fluxes are used at more than 0.25% by weight of the metal being melted.

The granular material is used at only 0.125% by weight so that emissions only half of normal might be expected.

In fact, tests have shown fume reduction of more than 85%.

The move from a powder to a granulated flux significantly improves working conditions, reduces the amount of waste material to be disposed of and reduces attack on furnace refractories.
Characterization of fluxes

Mineralogical analysis:
the compounds in the flux are identified by x-ray diffraction analysis.
The compounds (fluorides, chlorides, etc) identified in the XRD spectrum of flux are checked for their fitness for the particular application!
Characterization of fluxes

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Thermal Analysis:
The flux sample is melted inside a crucible and a thermocouple is inserted into the melt. The flux is allowed to cool. The variation of T with time is recorded. The melting behaviour, the change in the viscosity of the molten flux with temperature, the melting point/melting range are estimated.
Characterization of fluxes

**Moisture content**: the flux sample is weighed as received and after drying in a laboratory oven to calculate the moisture content:

\[
\text{weight as received} - \text{weight after drying} \times 100 \quad \text{weight as received}
\]
Characterization of fluxes

Analysis of the recovery capacity:
50 g foil (thickness 13μm) fines are placed inside a crucible. It is covered completely with the flux to be analyzed. Foil fines are melted under the flux. Molten flux is decanted and the aluminium melt underneath is poured on a cold plate to allow rapid solidification.
The weight of the solid aluminium is measured (w).
\( w < 50g \); several solid beads \( \rightarrow \) Modest rafination capacity
\( w \sim 50g \); single piece \( \rightarrow \) high rafination capacity
Characterization of fluxes

Katılışma Aralığı : 520-585°C
Nem Miktarı : % 0,1
Geri Kazanım Verimi : % 86
Reclamation of swarf, skimmings and turnings

- A heel of metal is melted using heavy scrap or ingot and a quantity of cover flux is added to form a fluid cover.
- The amount of cover flux depends on the degree of dirtiness and oxidation of the scrap and will vary between 1 and 5%.
- The swarf, turnings etc. are fed through the flux cover a little at a time, adding more flux as required to keep the cover in a fluid condition.
- The temperature of the melt is kept relatively low during this procedure and when charging is complete, the heat is raised to pouring temperature.
- At this stage the flux may be poured off from rotary or reverberatory furnaces but there is a significant advantage to be obtained by passing more than one melt through the same flux.
drossing
drossing

- Poor melting and drossing practices lead to the formation of dross rich in aluminium metal.
- This type of dross is referred to as **WET DROSS**.
- Dross with low metal content, **DRY DROSS**, is obtained with sound melting and drossing methods.
- Foundries must take precautions to avoid wet dross.
drossing

- Dross removed from the furnace must be cooled rapidly to avoid further thermite reactions that lead to higher metal loss.
- A simple practice to achieve this is to spread hot dross over an inclined cold concrete surface.
- Liquid aluminium trapped inside the dross can flow down over the surface and become separated.
- There are other methods which employ cooling inside inert gas chambers.
Factors that affect dross features

- Drossing temperature
- Fluxing employed before drossing
- Drossing off practice
- method and the conditions under which dross is cooled to room temperature

Dross cooling methods
- Cooling in air
- Rotary coolers
- Cooling in argon gas
- Dross presses
dross recycling

- Dross can amount up to 10% of the total yield.
- Drosses are heterogeneous in both size and chemistry.
- Metal to be recovered may be between %10-70.
dross press
bath-melt mixing

- Faster melting with less energy supply
- Rapid alloying
- Uniform chemistry throughout the bath
- Uniform temperature distribution
- Less oxidation loss
Melt mixing-homogenization

PMS
Permanent magnetic stirrers
Filtration

- A melt can contain many non-metallic particles, films, or clusters in sizes from a few μms to several mms.
- Inclusions are detrimental to the finished casting; decrease mechanical properties, increase the propensity to leak under pressure, reduce machinability. Make casting difficult by reducing the fluidity.
- Turbulence of the melt should be avoided since aluminium oxidises very readily.
- Turbulence leads to “folding in” of oxides and creation of new oxides from exposure of clean aluminium to the atmosphere.
impurities to be filtered

- $\text{Al}_2\text{O}_3$ (particularly when the fraction of scrap in charge is high!)
- Spinels ($\text{MgAl}_2\text{O}_4$ and $\text{MnAl}_2\text{O}_4$)
- $\text{Al}_4\text{C}_3$ (comes from primary ingot and scrap-returns contaminated with oil, painted scrap)
- Nitrides
- Refractory particles from eroding, worn furnace refractories
- Fe-Mn-Cr intermetallic compounds: tolerance to Fe and Mn in pressure die casting is high!)}
Advantages of filtration

**Clean aluminium melt**
High fluidity, better feeding, quality casting

**Clean casting structure**
Superior mechanical properties (UTS, yield strength, fatigue and creep resistance)!
Elongation and ductility is particularly high; often twice as much!
Better surface-shiny surface
Anodising quality is higher!
Fewer pinholes in foils; tearing in foil production reduced; foil yield is high!
Filtration practice and filter type depends on the requirement of melt cleanliness and casting quality.

Filter types
- Fiberglass textile filters
- alumina ball filters
- ceramic foam filters
- bonded particle filters
- rigid cartridge filters

Filtering mechanisms
- cake filtering: foam filters
- Deep bed filtering: cartridge filters
Textile filters

fiberglass textile filters are used in the case of not so critical products

<table>
<thead>
<tr>
<th>meş</th>
<th>Pore size (mm$^2$)</th>
<th>Open area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>17.16</td>
<td>65</td>
</tr>
<tr>
<td>36</td>
<td>11.56</td>
<td>63</td>
</tr>
<tr>
<td>50</td>
<td>7.49</td>
<td>55</td>
</tr>
<tr>
<td>100</td>
<td>2.72</td>
<td>47</td>
</tr>
<tr>
<td>200</td>
<td>1.71</td>
<td>43</td>
</tr>
<tr>
<td>400</td>
<td>0.45</td>
<td>27</td>
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</table>
Alumina ball filtration

Bed (box) filters manufactured from alumina balls. Alumina balls are placed in a ceramic box; the size variation of the balls produce a variety of pore dimensions. The pore size is not constant.
Alumina ball filtration
Ceramic foam filters

- Foam filters are produced from either sintered or cast alumina.
- Porosity is identified by the number of pores per inch length (ppi). Typical PPI values: 20, 30, 40, 50, 60, 65 and 80 ppi.
- They do not lead to blockage problems with 80-85 porosity but filtering efficiency in this case is poor.
- Hence, improvement in mechanical properties with foam filtering is limited.
Ceramic foam filters

Ceramic foam filters are used when the cleanliness of the casting is of interest.
Filtration in melt transfer
Filtration during casting
Filtration of aluminium alloy castings

● To counter this it is usual to cast aluminium using non-pressurised systems;

● for example 1:2:4 (sprue:runner:gate area) so that metal front velocities are minimised.

● The introduction of ceramic foam filters to the aluminium industry in the 1970s was a major advance.

● The foam filter has a tortuous path through its body which traps inclusions allowing clean, smooth-flowing metal to enter the mould cavity.

● By the 1980s most aerospace parts and many high integrity automotive parts were filtered.
Cleaning effect and flow smoothing of foam filters

Turbulent flow

smooth flow

metal flow
SIVEX FC filters

- Because of the filter’s high surface area, even particles smaller than the size of its pores can be captured and retained in the depth of the filter.

- The foam structure also provides smooth, non-turbulent metal flow, so that oxide formation during mould filling is reduced.

- This allows simplification of gating systems, providing significant cost savings through yield improvement.
Use of filters in conventional running systems

- Initially, there is a delay while the filter is primed; no flow occurs until sufficient pressure is created by a suitable head of metal, an initial surge of metal is then observed, followed by a steady flow until filter blockage occurs.
- The running system must be designed to fill the mould cavity before the blockage stage is reached.
- The presence of the filter ensures that the lower part of the sprue and part of the runner bar are filled before metal begins to flow, thereby avoiding turbulence and air entrapment.
Schematic pattern of flow through a ceramic foam filter

Typical filter print for horizontal filter position.

Typical filter print for vertical filter position.
Filtration during casting

Installation in pouring cup

Horizontal installation in horizontal runner

Horizontal installation in vertical runner

Vertical installation in horizontal runner
Direct pouring with filters

- Direct pouring into the top of a mould cavity offers:
  - improved yield
  - simplified sprue, gating and feeding design
  - reduced fettling costs

- However, direct pouring introduces defects due to the turbulent flow of the metal in all but the simplest of castings.

- In addition, the impingement of high velocity metal streams caused erosion of moulds or cores.

- These objections can be overcome by pouring the metal through a ceramic foam filter situated at the base of the sprue.

- Clean metal, free from turbulence and oxide, fills the mould cavity and helps to feed the casting through the filter.
Direct pouring with filters

- Directional solidification and casting soundness is promoted and gates are unnecessary.
- The impingement problem is reduced because the metal velocity is reduced as it passes through the filter.
- The unfiltered castings show a few, but very significant, low strength test pieces which microscopic examination of fracture surfaces showed to be due to oxide inclusions.
- No such low strength test pieces are seen with the filtered test pieces.
- Filtration effectively removes the oxide inclusions. Remarkably, the test bars top poured through a ceramic foam filter gives consistently better mechanical properties than filtered bottom-filled castings.
Direct pouring with filters

A schematic view of the cleaning and flow-smoothing effect of pouring directly through a filter unit.

- Turbulent flow
- Laminar flow
Bonded particle ceramic filters

- Manufactured from alumina and silicon carbide.
- They are strong and resistant to chemical attacks.
- Pore fraction is lower than foam filters: ~40%
- Filters made of SiC offer effective heating owing to a high thermal conductivity.
- Uninterrupted pore configuration provides a difficult flow pattern
Filtration-rigid media

- Rigid media filters are used when the cleanliness of the as cast structure is critical as in magnetic disks and very thin foil.
- These filters can only be used during the transfer of the melt to the casting station.
Filtration-rigid media

- Cartridge filters must be employed after the degasser. Inclusions are trapped on the surface and inside of the filter tubes.

- This is achieved by stagnation precipitation and allows the removal of solid residue much smaller than the pores of the filters.
Filtration mechanisms

cake

Deep bad
Grain refinement

Grain refining improves hot tear resistance, reduces the harmful effects of gas porosity (giving pressure-tight castings) and redistributes shrinkage porosity in aluminium alloys.

The grain size of a cast alloy is dependent on the number of nuclei present in the liquid metal as it begins to solidify and on the rate of undercooling. A faster cooling rate promotes a smaller grain size.
Grain refinement

- Additions of certain elements to aluminium alloy melts can provide nuclei for grain growth.
- Titanium, particularly in association with boron, has a powerful nucleating effect and is the most commonly used grain refiner.
- Titanium alone, added at the rate of 0.02-0.15% as a master alloy, can be used but the effect fades within 40 minutes.
- The addition of boron together with titanium produces finer grains and reduces fade.
Grain refinement - why?

Fine, equiaxed and unfirm grain structure improves the soundness and quality of the casting: dendrite coherency occurs at higher solid fractions! The feeders stay molten longer! Better feeding and mould filling!

✓ Less shrinkage

Fs~0.3

Fs~0.6
Grain refinement - why?

Fine grains // small intergranular porosity

✓ small/dispersed porosity

microsegregation = f(grain size)

✓ less segregation // shorter homogenization

✓ superior surface quality

better response to anodising and other finishing operations
Grain refinement - why?

**superior mechanical properties**
- isotropy
- high yield strength
- ductility
- high fatigue resistance

**efficient casting process**
- limited hot tearing!
- lower scrap rates!
- reliable and efficient!
Grain refinement - why?
better response to heat treatment and finishing operations
✓ (higher formability: forging/rolling/extrusion)
✓ easy to homogenize: short HT cycles
✓ easy to solutionize: shorter SHT cycles
  faster age hardening

high quality component
efficient-economic process
Grain refinement - how?

- \( \frac{dn}{dt} \downarrow \frac{dr}{dt} \)

Fine grains

\( \downarrow \frac{dn}{dt} \uparrow \frac{dr}{dt} \)

Coarse grains
Grain refinement - how?

\[ \frac{dn}{dt} \]

Effective nuclei:
Stable in the melt / not soluble!
High crystallographic epitaxy with \( \alpha \)-Al (\( >90\% \))
Similar density to \( \alpha \)-Al: \( \rho_{\text{çekirdek}} \sim \rho_{\text{Al}} \)

\( \text{TiAl}_3 \): soluble < 1500ppm Ti / 97.8%
\( \text{TiB}_2 \): insoluble / 95.7%
\( \text{AlB}_2 \): soluble < 220ppm B / 96.5% (Ti,Al)\( \text{B}_2 \)

TiC for special circumstances!
Grain refinement - how?

\[ \downarrow \text{dr/dt} \]

Balance between latent heat and heat transfer is critical!

Latent heat released during solidification = \( f(\text{partitioning of alloying elements}) \).

Partitioning of alloying elements at the solidification front (liquid-solid interface) restricts growth!: growth restriction (GRF)

<table>
<thead>
<tr>
<th>elem.</th>
<th>Mn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mg</th>
<th>Ni</th>
<th>Cr</th>
<th>Si</th>
<th>Ti</th>
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<tbody>
<tr>
<td>GRF</td>
<td>0.1</td>
<td>2.8</td>
<td>2.9</td>
<td>3.0</td>
<td>3.3</td>
<td>3.5</td>
<td>5.9</td>
<td>246</td>
</tr>
</tbody>
</table>
Desing of a commercial grain refiner

High nucleation rate
- effective nuclei
  TiB₂

↓

low growth rate
- growth restrictor
  excess Ti

Al-%1-10Ti-%0.2-3B

Al-5Ti-1B rod :
- 2.2Ti (TiB₂ insoluble )
- 2.8Ti (TiAl₃ soluble)
Commercial grain refiners
Grain refining
**AlTi5B1-wrought alloys**

<table>
<thead>
<tr>
<th>before addition</th>
<th>after addition / holding time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

**Before addition**

**2min after addition**
### continuous casting vs shape casting

<table>
<thead>
<tr>
<th>continuous casting</th>
<th>characteristic</th>
<th>shape casting</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>Undercooling before solidification</td>
<td>high</td>
</tr>
<tr>
<td>short</td>
<td>Time from inoculation to solidification</td>
<td>long</td>
</tr>
<tr>
<td>high</td>
<td>Alloy chemistry-purity</td>
<td>low</td>
</tr>
<tr>
<td>low</td>
<td>Alloy composition-Ti content</td>
<td>high</td>
</tr>
<tr>
<td>wrought ?XXX</td>
<td>Alloy content</td>
<td>casting ?XX</td>
</tr>
</tbody>
</table>
cont/semi-cont vs shape casting

**Foundry alloys**
- high levels of Si
  - ↑ fluidity / castability
  - ↓ shrinkage
  - ↓ hot tearing
  - ↓ density
  - ↑ mechanical properties

Si > %3;
Si + Ti → Ti-Si compounds: Si poisoning
- ↓Al₃Ti and TiB₂ particles / efficiency is impaired!
- ↓ Grain refining capacity / ↑fading (↑ fluidity)

∴ Grain refining of foundry alloys is **DIFFICULT!**