AOT Session 8:

Better Metal Handling at the Die Casting Machine to Minimize Inclusions and Cold Flakes

NADCA Webinar

Wednesday May 23, 2018

Presented by Paul Brancaleon,
Director of Research, Education and Technology
NADCA
Outline

• **Introduction**: How does metal handling impact part quality?
• Types of Inclusions
• Control of Inclusions
• Externally Solidified Product
• Control of Cold Flakes
• Summary
No castings are perfect. At a high enough load, every casting will break. Inevitably that break initiates at a defect. Porosity. Inclusion. Cold flake.

Minimizing defects in castings can increase the service life of the part by raising the failure load and the fatigue life.

Inclusions and cold flakes are frequently found on fracture surfaces of castings.

Secondary machining operations are susceptible to premature tool failure when they hit these defects.

Control of these defects can largely be managed by shop floor practices.
Types of Inclusions
What Are Inclusions

• Inclusions/Nonmetallic Inclusions –
  a) Particles of foreign material in a metal matrix; b) any nonmetal material in the die casting alloy.

• Usually oxides, refractory particles, and sludge, but can be any material foreign to, and essentially insoluble in, the metal matrix.
Types of Inclusions

- Inclusions are mostly a problem in aluminum die casting, but there are issues in zinc and magnesium also.
- Can cause quality issues
  - Strength
  - Hard spots
  - Flow issues
- The most prevalent type of inclusions are oxides.
Oxide Inclusions

- The cast alloy is shiny, as evidenced by a casting that has been machined or a furnace that has been just skimmed.
- The gray surface on castings or on the surface of the liquid metal is oxide.
- This oxide layer on a casting can be very thin - from a few microns thick to a few thousands.
Types of Inclusions

Oxide Inclusions

• Oxides in the furnace can not be totally eliminated.
• Aluminum we use is recycled, has had a lot of exposure to air and has generated oxide.
• Oxygen is picked-up during metal melting and handling.
• Once formed in the furnace, the oxide particles or skins remain.
Types of Inclusions

Oxide Inclusions

- Aluminum, zinc, and magnesium oxidize to form dross.

- When aluminum oxide is first formed
  - Fairly soft
  - Less dense than the molten metal
  - Gamma $\text{Al}_2\text{O}_3$, dross
Types of Inclusions

Oxide Inclusions

• Exposed to 1800°F or higher in the presence of more oxygen gamma aluminum oxide transforms to very hard more dense phase.
  – Alpha Al$_2$O$_3$, corundum
  – Next to diamond on the Mohs scale
  – Grinding wheel material
Types of Inclusions

- Corundum can form in the melting or holding furnaces in most plants.
- The oxides stick to the wall and are scraped off in the cleaning procedures.

Oxides form at hot corners.
Types of Inclusions

- Corundum can form in the melting or holding furnaces in most plants
- The oxides stick to the wall and are scraped off in the cleaning procedures.
  - Oxides form at hot corners
Types of Inclusions

- Corundum can form in the melting or holding furnaces in most plants
- The oxides stick to the wall and are scraped off in the cleaning procedures.

- Oxides form at hot corners
Types of Inclusions

Oxide Inclusions

Casting which contained dross from dip-out well
Types of Inclusions

Cross-section of a casting containing dross
Residual corundum particle from improper furnace cleaning
Dispersion of corundum particles that can look like porosity
Types of Inclusions

Refractory Particles

• Furnace refractory particles come off the wall during furnace cleaning.
Refractory Particles

• Typical forms: brick, mortar, castable, crucible

• Some common refractory materials:
  › Alumina
  › alumino-silicates
  › zircon
  › graphite
  › clay-graphite
  › silica
  › silicon carbide
Types of Inclusions

Refractory Particles

Refractory particles, corundum, and flux
Types of Inclusions

Sludge

• Intermetallic compounds whose formation is composition and temperature dependent.

• Factors contributing to sludging:
  – Metallic impurities
  – Some alloying elements
  – Low holding temperatures
  – Swings in temperature

• Once formed almost impossible to dissolve.
• Fe, Mn and Cr can form sludge in aluminum alloys.
• Al, Mn primary actors in forming sludge in magnesium alloys. Also Zn, Cu, Si, Fe and Ni.
• Fe and Al in zinc alloys form an intermetallic.
Types of Inclusions

Sludge

- Aluminum sludge factor
  \[ \text{Fe} + 2\text{Mn} + 3\text{Cr} \]

- Hold to \(<= 1.8\)

Note: Drop in Fe can cause tendency to solder
Types of Inclusions

Sludge

(b) sludge (AlSiFeMn(Cr)) in a die casting alloy[3].

Sludge particles in aluminum alloy
Types of Inclusions

Sludge

X-ray of a hard spot (more dense inclusion)
Types of Inclusions

Excess Flux

• Fluxes are used for various functions
  – Cover fluxes protect the melt from oxidation
  – Wall-cleaning fluxes react with wall build-up
  – Degassing fluxes remove hydrogen
  – Drossing or cleaning fluxes assist in partial removal of oxides and reduction/recovery of metal from dross
  – Refining fluxes may modify, grain refine, or remove specific metallic impurities
• Too much flux gets entrained in the metal
Types of Inclusions

Excess Flux

Flux inclusion
Types of Inclusions

Mixture of flux and oxide
Control of Inclusions
Control of Inclusions

• What we don’t want!
Control of Inclusions

• Dross
  – Minimize exposure to air and metal temp.
  – Use proper drossing procedures
  – Allow enough time after disturbing molten metal bath.
Control of Inclusions

• Corundum
  – Minimize formation of Al dross.
  – Don’t use higher than necessary metal temperature.
  – Allow at least 30 minutes after furnace cleaning for settling of particles.
Control of Inclusions

- Refractory particles and sludge
  - Use proper furnace cleaning procedures
  - Allow at least 30 minutes after furnace cleaning for settling of particles
Control of Inclusions

• Oxides can be removed by filtering, fluxing, or by de-gassing the liquid metal.

• Refractory particles, sludge, intermetallics can be removed by filtering.
Externally Solidified Product
Externally Solidified Product

ESP Definition

• Externally solidified product: 1) A portion of the melt that solidifies outside the die cavity in a cold chamber operation. 2) Some of the liquid alloy that solidified on the shot sleeve wall during the period when liquid enters and dwells in the shot sleeve.

• We call the resulting shards that get into the casting cold flakes, ESP, or pre-solidified product (PSP)
Externally Solidified Product

How ESP Forms

• Molten metal solidifies a thin film at the metal/shot sleeve interface.
• Advancement of the plunger tip scrapes off film into shards/flakes.
• Shards mix with molten metal and are injected into the casting.
• The shards are called cold flakes, ESP or PSP.
How The Flakes Travel

- Most of the flakes remain just ahead of the plunger tip.
- The flakes enter the runner during the later stages of injection.
- The flakes then can enter the cavity and collect at the gate.

May be difficult to see without microstructural examination.
Effects of ESP

• ESP may cause:
  – Reduced fluidity
  – Restricted flow
  – Surface defects: flow lines and cold shuts
  – Porosity
  – Oxide films
  – Pressure tightness in thin sections
  – Uneven/irregular gate breakout
  – Property degradation
Externally Solidified Product

Flow Lines and Cold Shuts

- Reduced fluidity and/or restricted flow at the gate impacts fill time and flow pattern, hence quality
Porosity

- ESP flakes collecting at the gate can cause a pressure drop in the cavity resulting in more/larger gas and shrinkage pores
Porosity

• Percent porosity measured in castings produced with an unheated and heated shot sleeve (from T99-085)
Externally Solidified Product

Porosity

- Voids are often seen at the interface between the ESP and matrix interface.
压力密封性

- 大而相互连接的冷片可以导致薄壁中的漏气

Externally Solidified Product

压力密封性

- 大而相互连接的冷片可以导致薄壁中的漏气

![图像](image_url)
Irregular Gate Breakout

• Cold flakes in the gate area can cause uneven breakout resulting in dimensional issues.
**Externally Solidified Product**

- Tensile strength can be reduced by the presence of cold flakes

<table>
<thead>
<tr>
<th>Condition Delay (sec)/Lube (g)</th>
<th>Number of Tests</th>
<th>Average Fracture Stress Average (Stdev)</th>
<th>Average Fracture Strain Average (Stdev)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 / 1.3</td>
<td>13</td>
<td>35.1 (6.4)</td>
<td>1.22 (0.42)</td>
</tr>
<tr>
<td>0.5 / 2.6</td>
<td>12</td>
<td>35.6 (3.3)</td>
<td>1.21 (0.34)</td>
</tr>
<tr>
<td>6.5 / 1.3</td>
<td>12</td>
<td>33.4 (4.6)</td>
<td>0.93 (0.36)</td>
</tr>
<tr>
<td>6.5 / 2.6</td>
<td>12</td>
<td>33.4 (4.3)</td>
<td>1.08 (0.30)</td>
</tr>
<tr>
<td>13 / 1.3</td>
<td>11</td>
<td>23.7 (6.4)</td>
<td>0.54 (0.25)</td>
</tr>
<tr>
<td>13 / 2.6</td>
<td>8</td>
<td>25.7 (8.6)</td>
<td>0.66 (0.37)</td>
</tr>
</tbody>
</table>

Casting produced by Briggs & Stratton on a 900T machine
Property Degradation

- Fatigue strength can be reduced by the defects caused by cold flakes

<table>
<thead>
<tr>
<th>Casting Feature</th>
<th>Number of Samples/Total</th>
<th>Cycles to Failure (@ 12 ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Shape</td>
</tr>
<tr>
<td>Cold Shut</td>
<td>15 / 62</td>
<td>0.44</td>
</tr>
<tr>
<td>Surface Flow Marks</td>
<td>12 / 62</td>
<td>0.68</td>
</tr>
<tr>
<td>ESP/oxide film</td>
<td>15 / 62</td>
<td>0.68</td>
</tr>
<tr>
<td>Macroporosity</td>
<td>8 / 62</td>
<td>1.43</td>
</tr>
<tr>
<td>NOD</td>
<td>7 / 62</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Axial fatigue, reversal ratio of 0.1
Control of Cold Flakes
Control of Cold Flakes

Corrections for ESP

• Minimize shot delay time.
• Keep fill % in sleeve as high as possible.
• Keep sleeve temperature as high as possible (a safe ID operating temperature ranges from 600°F-1100°F).
• Keep metal temperature high.
• Keep the biscuit size comfortably above the minimum.
Control of Cold Flakes

Shot Delay Time

- Modeling studies show that solid fraction increases linearly with time
Control of Cold Flakes

Shot Delay Time

• Modeling shows that alloys with higher latent heat solidify less in the sleeve.

![Graph](image.png)
Control of Cold Flakes

Higher Fill Reduces Heat Loss

Shot sleeve material: H-11 (chromium type hot-work tool steel)
Molten metal: Alloy GD-AlSi₈Cu₆(380)
Inner diameter of the shot sleeve: 116 mm
Outer diameter of the shot sleeve: 200 mm
Total length of the shot sleeve: 700 mm
Deflected length of the shot sleeve: 340 mm
Pouring time: 4.0 sec
Filling percentage: 55%
Initial temperature of shot sleeve: 125°C(282.6°F)
Initial temperature of molten metal: 680°C(1281.6°F)

Fig. 3. Temperature history of molten metal associated with different filling percentages.
Control of Cold Flakes

Sleeve Temperature

- A safe ID operating temperature ranges from 600°F-1100°F.
- Keep variation in sleeve less than 90°F.
- Heat or cool as appropriate.
- Consider cycle time.
Biscuit Thickness Matters

The distribution of cold flakes decreases from the tip side to the die side of the biscuit.
Summary

• Inclusions can cause quality issues.
• Types of inclusions
  – Oxides
  – Sludge
  – Refractory particles
  – Excess flux
• Can control inclusion formation to an extent.
• Can filter out inclusions.
Summary

• ESP forms in the shot sleeve.
• The resulting cold flakes can impact casting quality and degrade properties
• The impact of cold flakes can be mitigated by:
  – Minimizing shot delay time
  – Minimizing the temperature difference between the molten metal and shot sleeve
  – Using adequate biscuit thickness
Additional Resources

- EC-302 Metal Melting and Handling Course
- EC-201 Magnesium Die Casting Course
- EC-202 Zinc Die Casting Course
- E-515 Die Casting Defects Book
- High Integrity Aluminum Die Casting (#307)
- Magnesium Die Casting Handbook (#201)
- Zinc Die Casting Process (#202)
- Congress Transactions
- DCE Articles
Thank You
Questions?

Name: Paul Brancaleon
Phone: 847-808-3160
Email: brancaleon@diecasting.org