Defects framework – 6xxx series aluminum alloys

**Common Extrusion Alloys**

- 6360 “high performance”
- 6063 “general purpose”
- 6063 “high strength” -T54, -T65
- 6005A
- 6061 / 6351
- 6082
# Defects framework – Acceptance level

## Mill Finish
- CRASH SYSTEM
- ABS HOUSING
- TRAILOR
- PLATFORM
- SUPERSTRUCTURE
- INDUSTRIAL COMPONENT
- ENGINE PARTS
- ENGINE HOUSING

## Roughness critical
- SUNROOF RAILS
- SIDE TRIMS
- HEAT EXCHANGERS
- HEAT & FLUID TRANSFER
- HEAT SINKS

## Surface critical
- PRINTER COPIER TUBE
- COMPUTER
- MOBILE DEVICE CASE
- LUGGAGE COVER
- DECORATIVE PARTS

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## Defects classification in 6xxx aluminum extrusions

### During Extrusion / Mill Finish
- Pick-up
- Speed Cracking
- Die line
- Die streak
- Front-end TV
- Long weld
- Blister
- Tearing
- Micro die line
- Snap mark
- Back-end Creasing
- Hot spots

### After Extrusion - Metallurgical
- Coarse MgSi
- Coarse grain banding
- Corrosion pitting
- Corrosion fretting
- Spacer markings
- Inclusion cast-in
- MgSi at grain boundary
- Orange peel
- Corrosion fingerprint
- Water stain
- Excess intermetallic
- Inclusion extrusion process

### After Anodization
- Atmos. corrosion
- Alkalai corrosion
- Spatter corrosion
- Dull finish
- Coloring due to MgSi
- Acid corrosion
- Chloride corrosion
- White etch bloom
- Castle and moat
Defects occurring during extrusions / Mill Finish

During Extrusion / Mill Finish

- Pick-up
- Speed
- Cracking
- Die line
- Die streak
- Front-end TW
- Longitudinal weld
- Back-end Coring

- Blisters
- Tearing
- Micro die line
- Snap mark
- Hot spots

Pick-up

Pick-up under paint layer
Pick-up – Topography tells it all: Cauliflower appearance

Pick-up – Topography tells it all: Comet tail appearance
Pick-up – Mechanisms

Coating of aluminum oxide on the die bearing exit

- Temporary coating
  - comes off each die stop mark
- Semi-permanent coating

Pick-up – Possible causes and prevention measures

- Exit temperature too high
  - Optimize billet temperature
  - Optimize extrusion speed

“Stay in your lane!”
Pick-up – Possible causes and prevention measures

• Deterioration of die bearing condition
  − Ensure correct re-nitriding to avoid premature wear of the bearing by flacking or cracking
  − Correct die preheating to prevent excessive oxidation of the die bearing (no overheating)
  − Die bearing too long or of incorrect contour, polishing, handling…

• Extrusion environment
  Nitrogen shrouding reduces oxidation and therefore pick-up

• Inferior billet quality
  − Un-homogenized or inadequate homogenization (95% or more alpha Fe broken up)
  − High Fe content: < 0.18%
  − Inclusions: use quality billet
  − Billet skin: limit the number of billets
Not always pick-up! – foreign material

The Energy Dispersive X-Ray analysis (EDX) on the painted longitudinal section across the defect revealed the presence of foreign material composed of Al, Mg, Ca, O. This is likely a particle of clay, chalk or other pigment used to color the coating.

Not always pick-up! – various inclusions

Example of tool steel particles

Example of carbon base lubricant
Not always pick-up! – polishing compound

Longitudinal polished section.

The anodic film that wets the particle indicates it laid on the surface before the anodizing process.

Mainly silicon carbide and potassium particles compound particle caused by buffing operations.

Blister

During Extrusion / Mill Finish

- Pick-up
- Speed Cracking
- Die line
- Die streak
- Front-end
- Long
- Back-end
- Snap mark
- Tearing
- Micro die line
- Core

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Blister – Possible causes and prevention measures

- Entrapment of air during billet upsetting
  - Burp cycle not used
  - Distortion of billet front surface
  - Poor butt shearing
  - Billet too long or 2 piece-billet
  - Container liner worn out, misalignment
  - Billet quality
- Entrapment of volatile liquid via back end of billet (minimum use of lubricants)
- Extrusion of billet skin
- Billet temperature too high (front-end should be hotter than back-end)
Blister – Possible causes and prevention measures

• Use burp cycle to release entrapped air
  ➢ Trapped air from upsetting too fast - Upset-By-Distance vs. Pressure
  ➢ Billet discards show presence of air?

![Diagram of upsetting process]

• Incomplete Upset in the "die-end" of the Liner
  ➢ Check container liner condition, press alignment
  ➢ Sticky alloy, i.e. 3xxx

![Diagram of Liner condition]

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Speed cracking, tearing

During Extrusion / Mill Finish

- Pickup
- Blister
- Speed Cracking
- Tearing
- Die line
- Micro die line
- Die streak
- Snap mark
- Front-end TW
- Back end Coring
- Snap mark
- Hot spots

Sample 11194-1 as received
Figure 7: Shape of the sample

Sample 11194-1 at the tearing location
Figure 8: Appearance of the tearing

Inner surface in hollow section

Sample 11194-1, longitudinal section, as polished
Figure 9: Appearance of the tearing

Delamination
Speed cracking, tearing – Causes and prevention measures

- Excessive die exit temperature
  - Occurs near the alloy melting point
  - Ultimate limit is speed cracking

![Temperature vs % Mg2Si graph](image)

- Entrapment of billet skin in extrusions
  - Check die design to ensure die cavity at least 20 mm away from container wall
  - Check container alignment and liner condition (no excessive wear)
  - Clean container regularly to prevent build-up of aluminium oxides
  - Reduce container temperature to ensure billet to container temp differential more than 50°F
  - Increase butt length
**Not always** Speed cracking, tearing! – Coring

Presence of transverse weld (red arrows) and coring (white arrows) associate with the longitudinal weld (yellow arrows).

Tearing is associated with coring.

Caustic etched – White arrows indicate the location of the longitudinal welds.

**Not always** Speed cracking, tearing! – various inclusions

- Fragments (chips) of **tool steel** originated from die or cutting tool (scalping, shear, dummy block...).
Speed cracking, tearing – Causes and prevention measures

- **Excessive die exit temperature**
  - Should not exceed 1020°F (Use IR probe)

- **Entrapment of billet skin** in extrusions
  - Container alignment, liner condition, container 45°F-70°F colder than billet, adequate front & back-end scrap...

- **Fragments (chips) of tool steel** originating from die or cutting tool (if billet scalping is used)
  - Nitride layer, die condition, container liner, dummy block...

- **Foreign materials** such as Al oxides and other materials
  - Clean container to prevent build-up of Al oxides, increase butt length...

### Die lines

**During Extrusion / Mill Finish**

- Pick-up
- Speed Cracking
- Die line
- Die streak
- Front-end bite
- Back-end bite
- Longitudinal
- Hot spots
- Blister
- Tearing
- Micro die line
- Snap mark
- Coring
- Snap mark
Die lines / Micro die lines / Streaks – **Industry context**

Common problem for extruders
Difficult to identify the root cause:
- Billet
- Extrusion process
- Finishing process

Streaking is revealed at last step of the process

- Many contributing factors from previous steps
- Evidence removed after anodizing

Need to understand *why* before we can know *how*

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Die lines / Micro die lines / Streaks – **Definitions**

- **Die line**: deep groove
- **Micro die line**: fine lines
- **Streaks**: bands of dark or light colors
Die lines / Micro die lines – **Mechanisms**

**Die line**: deep groove

**Micro die line**: fine lines

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**Die lines – Possible causes and prevention measures**

- **Causes:**
  - Pitting in die bearing surface due to **wash-out or spalling of the nitriding layer**;
  - Presence of large **AlFeSi particles** in the aluminium coating layer on die bearing surface;
  - **Build-up of oxides** in bearing relief region;
  - **Large inclusions** in billet;

- **Countermeasures:**
  - Remove die from press for cleaning and bearing polishing
  - Improve die preparation, die preheating, die nitriding and re-nitriding practices;
  - Prevent inflow of billet skin;
  - Review and adjust extrusion conditions;
  - Use high quality billet;
Micro die lines – Mechanisms

In streak

Normal surface

Microscopic top and transverse views of a “streaky” as-extruded surface considered as die lines

Micro die lines – Possible causes and prevention measures

• Causes:
  – Deteriorated die bearing surface condition resulting from scratching by AlFeSi particles in billet skin;
  – Excessive build-up of an aluminium coating on the bearing surface due to high deformation heating in the localised area;
  – Improper design of bearing length, pocket or feeder plate opening;
  – Billet quality: surface contamination, thick segregation zone, inadequate homogenisation, high inclusion content;

• Countermeasures:
  – Prevent inflow of billet skin;
  – Improve die design, die correction and die maintenance;
  – Use high quality billet;
Streaks – Mechanisms

**TYPE I**
Caused by contaminants

**TYPE II**
Caused by die or profile design

**TYPE III**
Caused by extrusion process

Textural streak anodized
Surface topography 0.2µm
Variable grain size and attack
Streaks – Mechanisms

Non-uniform Metal Flow → Variation in Pressure and Friction Force on Die Bearing

Difference in Surface Roughness & Flatness → Difference in Light Reflection → Streaks on Mill Finish Product

Difference in Grain Orientation or Grain Size → Difference in Surface Morphology after etching → Difference in Light Reflection → Streaks on Anodised Product

Streaks – Causes and prevention measures

• Always check die bearing first
  – Bearing length:
    ▪ Correctly designed to ensure uniform metal flow
  – Bearing shape:
    ▪ No rounded edge at entrance
    ▪ Square in respect to the die face
  – Bearing surface condition:
    ▪ Flat and free of pits and damage
  – Bearing blending – smooth and no shape steps

<table>
<thead>
<tr>
<th>Bearing</th>
<th>Bearing</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✗</td>
</tr>
</tbody>
</table>

Pristine and fragile surface
### Streaks – Causes and prevention measures

**Balance metal flow**
- **Area with a screw:**
  - Reduce bearing length at the tips of the screw, better from the die front side;
  - If the flow in the screw area is still not fast enough, increase flow resistance of the flat part of the profile (but ensure no steps in bearing);
- **Area with an intersection:**
  - Check metal flow of the vertical branch during die trial and adjust bearing length/angle accordingly;
- **Area under a port**
  - Reduce web height and increase welding chamber size;
  - Delay the flow under the port by using a pre-chamber or increasing bearing length;
- **Reduce speed and increase temperature**

**Case studies:**

<table>
<thead>
<tr>
<th>Streak</th>
<th>Web intersection</th>
<th>Streaked region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>Zone 2</td>
<td>Zone 3</td>
</tr>
<tr>
<td>86</td>
<td>220</td>
<td>100</td>
</tr>
</tbody>
</table>

**Solution:** not over-restrict the flow of the vertical part near the intersection

**Solution:** remove the groove on the mandrel to prevent “overfeeding”
Streaks – Causes and prevention measures

Contaminants that build up in dead metal zone

Impact of bearing

- **Bearing squareness**, over polishing
- **Cleanliness** between runs
- **Over-heated or soaked** too long in the die oven
- Burrs, wash-out…

- **Nitride case quality**
  - Anything that causes a build-up on the bearing
  - Bearing change too abrupt, blending not smooth enough, matching to section shape…
Streaks – Causes and prevention measures

Impact of billet

- **Alloy** 6061, 6005A, 6063, 6060, 6360
- Internal structure after homogenization
- Billet surface quality and external **cleanliness**

Soft Alloys
- Extrudability decrease
- Properties increase

Medium Strength Alloys

Impact of extrusion practice

- Container too hot
- Press misalignment
- Excess skull build-up in container

BAD

NOT BAD
But not perfect
Defects occurring after extrusions / Metallurgical

- Coarse MgSi
- Coarse grain banding
- Corrosion pitting
- Corrosion scaling
- Spacer marking
- Inclusion casting
- MgSi at grain boundary
- MgSi at grain boundary
- Corrosion fingerprint
- Water stain
- Excess lubricant
- Inclusion extrusion
- MgSi image by High resolution transmission electron microscope and atom-probe
MgSi - Where does MgSi formation take place?

Temperature

- Liquid
- Solid, Mg & Si dissolved
- Deformation temperature

Time

- Casting
- Homogenization
- Preheating
- Extrusion
- Cooling
- Ageing

How much Mg & Si available?
Cooling quick enough to prevent coarsening of MgSi?
Preheating fast enough to prevent coarsening of MgSi?
Exit temperature high enough to dissolve MgSi?
Natural ageing long enough?
Cooling quick enough to prevent coarsening of MgSi?
Artificial ageing optimised?

MgSi - Aiming for the right condition!

Strength & properties of 6xxx extrusions

Large number of fine MgSi precipitates

Critical factor: temperature, temperature, temperature!
MgSi – Coarse undissolved MgSi

Good sample
Fine MgSi particles
Die exit temperature achieved

Bad sample
Coarse undissolved MgSi particles
Failure to achieve die exit temperature

i.e. Low hardness: Presence of undissolved MgSi particles oriented in the extrusion direction

Undissolved MgSi in an Extrusion

Reasons include:
- Extended billet preheat soak
- Failure to reach required die exit temperature
- Failure to reach required core temperature on heavy sections
- Low billet temperature
- Coarse homogenized structure

Recommended die exit temperatures:
6060, 6360, 6063, 6463 at 930°F minimum
6005A, 6061, 6082 at 950°F minimum

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MgSi

**After Extrusion - Metallurgical**

- Coarse MgSi
- Coarse grain banding
- Corrosion pitting
- Corrosion fretting
- Spacer marking
- Inclusion cast-in
- MgSi at grain boundary
- Change peel
- Water stain
- Excess lubricant
- Inclusion extraction process

MgSi image by High resolution transmission electronic microscope and atom-probe

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MgSi precipitation at the grain boundaries

**i.e. Low Properties:**
Precipitates concentrated at grain boundaries and more MgSi out of Solution

**i.e. Good Properties:**
No precipitates at grain boundaries and good distribution overall
MgSi precipitation at the grain boundaries

MgSi out of Solution and at the grain boundary

Reasons include:
- Inadequate press quenching
- Premature ageing on run out table (soft spots)

MgSi

After Extrusion - Metallurgical

Coarse MgSi
Coarse grain banding
Corrosion pitting
Corrosion fretting
Spacer marking
Inclusion cast-in

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Coarse grain banding (PCG) - Crack

Appearance of the cracked area

Bad part
Appearance of the PCG area

Good part
uniform grain

Cracked sample, longitudinal section, as polished
Arrow shows undissolved MgZn2 platelets

Cracked sample, SEM image
Appearance of the fractured surface, presence of dimples
Coarse grain banding (PCG) – Causes and prevention measures

**Objective:** Produce a fully Rx structure or a completely un-Rx structure

- **Die conditions**
  - Bearing length and choke angle influence the PCG thickness in quenched profiles
  - Extrusion speeds with acceptable PCG thickness can be several times higher with long choked bearings and in addition the onset of speed cracking can be delayed.

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**MgSi**

After Extrusion - Metallurgical

- Coarse MgSi
- Coarse grain banding
- Corrosion pitting
- Corrosion etching
- Spacer marking
- Inclusion extrusion

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MgSi precipitates at the grain boundaries: Orange Peel

Orange peel – Causes and prevention measures

Possible causes:

- **Alloys metallurgy**
  - Alloys suitable to bending condition: *not subject to coarse grain outer-band*

- **Extrusion conditions**
  - Slow billet preheating
  - Exit temperature not high enough to dissolve MgSi
  - Exit temperature too high favours re-crystallized outer-band
  - Insufficient press quenching and avoid delay into the quench box
  - Over stretching
  - Ensure billet to container temperature differential more than 50°F
Defects occurring after anodization

After Anodization
- Atmos. corrosion
- Alkal. corrosion
- Spacer marking
- Dull finish
- White etch bloom
- Inadequate rinse
- Acid corrosion
- Rinse water corrosion
- Chloride contamination
- Coloring due to MgSi
- Spangle
- Castle and moat

Spacer mark

After Anodization
- Atmos. corrosion
- Alkal. corrosion
- Spacer marking
- Dull finish
- White etch bloom
- Inadequate rinse
- Acid corrosion
- Rinse water corrosion
- Chloride contamination
- Coloring due to MgSi
- Spangle
- Castle and moat
Spacer mark

Also known as hot spots, dull spots, or black spotting.

- Typically visible after anodization
- Cool and reheat section creates the environment for a rapid precipitation of MgSi

Dull finish

After Anodization

- Atmos. corrosion
- Alkal. corrosion
- Spacer marking
- Dull finish
- White with bloom
- Intergranular attack

- Acid corrosion
- Passe water corrosion
- Chloride contami.
- Coloring due to MgSi
- Spangle
- Castle and moat
Dullness Appearance

“Good” Surface

Dull Surface

Desirable Sample – less precipitates at grain boundaries and overall

Dull Sample – note precipitates at grain boundaries
Dullness Appearance

Desirable Sample – less precipitates at grain boundaries and overall

Dull Sample – note precipitates at grain boundaries

Color finish

After Anodization

- Atmos. corrosion
- Alkali corrosion
- Spacer marking
- Dull finish
- White rust bloom
- Inadequate rinse

- Acid corrosion
- Rinse water corrosion
- Chloride contains
- Coloring due to MgSi
- Spangle
- Castle and moat

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Color finish

The anodic layer:
- light sample: 16-18 µm thick
- dark sample: 20-22 µm thick

<table>
<thead>
<tr>
<th>AA6063</th>
<th>Dark</th>
<th>Light</th>
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<tbody>
<tr>
<td>Si</td>
<td>0.42</td>
<td>0.43</td>
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<tr>
<td>Fe</td>
<td>0.22</td>
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<tr>
<td>Cu</td>
<td>0.027</td>
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<td>Mn</td>
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<td>Mg</td>
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<tr>
<td>Zn</td>
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<td>0.002</td>
</tr>
<tr>
<td>Ti</td>
<td>0.015</td>
<td>0.005</td>
</tr>
</tbody>
</table>

High MgSi precipitates concentration in the “bad” dark sample
Low MgSi precipitates concentration in the “good” light sample

Color finish – Mechanisms pits & grooves during etching

Increased Fe content promotes matt finish
Color finish – Mechanisms pits & grooves during etching

Caustic etching is microstructure sensitive

Acid etching minimizes sensitivity of alloy composition
Dull and Color Appearance – Mechanisms

Dull / Color appearance

Diffusion of reflected light

Pits & grooves formed during alkaline etching

Pits in grain interior

Fe intermetallic

MgSi

Alloy

Homo

whole process

Grooves in grain boundaries

MgSi

Grain size

Grain orientation

Profile

Die

Whole process

Possible causes:

- **Over-ageing**
  - Ageing conditions not optimised: can occur on purposely over-aged products
  - Poor control of ageing oven: conduct yearly oven survey

- **Extrusion conditions that lead to MgSi coarsening**
  - Slow billet preheating
  - Exit temperature not high enough to dissolve MgSi
  - Insufficient press quenching

- **Poor billet quality**
  - High Fe content in alloy (i.e. secondary billet): < 0.18%
  - Billet not or not adequately homogenized
  - Slow post-homo cooling rate
Spangle

After Anodization

- Atmos. corrosion
- Alkaline corrosion
- Spacer marking
- Dull finish
- White etch bloom
- Inadequate rinse

Acid corrosion
Nurse water corrosion
Chloride contamination
Coloring due to MgO
Castle and moat

Spangle – “grainy” or “galvanized” surface

Normal surface
Spangle surface
Coarse grain size

SEM - varying level of attack after caustic etch
preferential grain attack

Irregular surface
Anodic layer thickness 6μm
Irregular surface
Anodic layer thickness 14μm

SEM - Step
Spangle – Causes and prevention measures

- **Metal composition**
  - Presence of zinc as a contaminant in the alloy: Zn below 0.025%

- **Extrusion - Metallurgy**
  - Hollow more prone than solids because of their generally coarser grain size.
  - Coarse grain structure in the extrusion: composition, extrusion process

- **Etching and anodizing conditions**
  - Presence of free zinc as a contaminant in the caustic etch solution: Zn below 6ppm
  - Long life vs. recovery process: Crystallizers do not remove Zn along with the aluminum in recovery process and no additive as the filters can clog by the precipitate. Long-life etch the additive (usually sodium sulfide) precipitates the zinc (as zinc sulfide) and is skimmed off the top.
  - Appropriate level of caustic soda: 50-60 g/l achieve the same etching as 100 g/l.
  - High-speed or high etching temperature: 125-135 °F and extend time if needed