Aluminum Extrusion Quality for Anodizing Characteristic

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Jerome Fourmann – September 19-21, 2018 – Seattle, WA
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"As pioneers in mining and metals, we produce materials essential to human progress."
Rio Tinto - An integrated aluminium supplier

- 44 Mt Bauxite mines
- 8 Mt Alumina refineries
- Secured power
- 3.6 Mt Power stations
- 550 Customers

In 60 countries
Outline

1. Aluminum alloys
2. Alloys selection
3. Extrusion process
4. Defects
Designation System For Wrought Alloys

- **1000 series**: Al – dilute alloys Al > 99%
- **2000 series**: Al + Cu
- **3000 series**: Al + Mn
- **4000 series**: Al + Si
- **5000 series**: Al + Mg
- **6000 series**: Al + Mg + Si
- **7000 series**: Al + Zn + Mg/Cu
- **8000 series**: Al + Other elements

* Most extrusions are made from these alloy series

Heat treatable alloys, other are non-heat treatable
2xxx – Al + Copper

- Where **strength** is a primary consideration with good fracture toughness

**Applications**

Structural members aerospace & military (2014 / 2024)

Machining stock (2011)

**Disadvantages**

Low extrudability

High demands on cooling speed

Bad corrosion properties
4xxx – Al + Silicon

Not widely used in extruded form, except:

- **4032**

  **Forging stock** for pistons where wear resistance and thermal stability are required

- **4021**

  ABS brake components, machineable, strength close to AA6061 / AA6082
**5xxx – Al + Magnesium**

- Where good **corrosion resistance** is needed
- Where good **weldability** and good post-welded strength are required
- Alloys with useful strength (~5% Mg) are difficult to extrude

**Applications**

Ship superstructures

Cryogenic applications

Offshore construction

Automotive
### 6xxx – Al + Magnesium + Silicon (Soft)

- **6060 / 6063 / 6360 / 6560**
  - Most popular extrusion alloys
  - Fast extruding, lower strength, anodize well
  - General applications i.e. door and window, heat sinks, architectural, transportation

- **6463 / 6463A**
  - Specialized “6063” type to give bright finish after chemical brightening.
  - i.e. tub and shower, picture frame
6xxx – Al + Magnesium + Silicon (Medium Strength)

- **6061 / 6082 / 6005 / 6005A**
  - Medium strength, transportation, ladders, scaffolding, general engineering, gas cylinders, forging stock, welded construction…
7xxx – Al + Zinc-Magnesium

• Where strength >6xxx is required, along with extrudability, ease of quenching and weldability. Stress corrosion has to be managed

• Can be processed on standard presses

Applications

Bumpers systems

Automotive

Transportation

Military bridging
7xxx – Al + Zinc-Magnesium-Copper

• Where **high strength and toughness** are required

• Available **Complex process route, low extrudability - not compatible with standard extrusion operations**

**Applications**

Major structural members - Aerospace

Military application

Medical cylinders
8xxx – Other aluminum alloys

- Other alloying elements: Li, Fe, Zr…

Applications

Al-Li: high stiffness, low density → Aerospace structural components
Outline

1. Aluminum alloys
2. Alloys selection
3. Extrusion process
4. Defects
Extrudability falls with increasing flow stress and lower melting point.
Alloy Selection – Mechanical Properties

Approximate Steel Equivalent (MPa) (by density ratio)

- Low Strength
- Medium Strength
- High Strength
- Ultra High Strength...

Elongation %

Tensile-Yield strength MPa
Alloy Selection – Heat treatment process

**Natural ageing:** ambient temperature slow hardness increase over time

**Artificial ageing:** heat treat. forming precipitates enhancing the properties

### Table: Alloy Selection

<table>
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<th>HB</th>
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</table>

* SHT: Solution heat treatment

**Formal SHT*: Some extruders specialize in these products

**Specialized Process**

- Difficult to cast

**Age Hardenable**

- 1xxx
- 3xxx
- 5xxx

**Non Age Hardenable**

- 2xxx
- 7xxx (Al-Zn-Mg-Cu)
- 6xxx
- 7xxx (Al-Zn-Mg)

**Possible on most commercial presses**

**Difficult to cast**

- Some extruders specialize in these products

* SHT: Solution heat treatment
Outline

1. Aluminum alloys

2. Alloys selection

3. Extrusion process

4. Defects

Photo courtesy of FEM, Schwäbisch Gmünd, Germany
Thermal profile of the extrusion process

<table>
<thead>
<tr>
<th>Temperature °C / °F</th>
<th>Billet supplier Dependent</th>
<th>Extruder Dependent</th>
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<tr>
<td>185</td>
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DC casting mold
Temperature through the extrusion process

- Melting starts (solidus)
- Mg and Si in solution (solvus)
- Critical preheat range
- Critical quench range
- Gas fired furnace 35°F/min (20°C/min)
- Induction furnace 900°F/min 250°C/min

Process has to put Mg and Si in the correct form for ageing

Nano-sized MgSi precipitates
How is this metallurgical process monitored?

- Billet temperature
- Extrusion temperature
- Quench rate
- Ageing temperature

= Thermal Profile of the Extrusion Process
Outline

1. Aluminum alloys
2. Alloys selection
3. Extrusion process
4. Defects
Defects framework – the alloy influence

Common Extrusion Alloys

- 6360 “high performance”
- 6063 “general purpose”
- 6063 “high strength” -T54, -T65
- 6005A
- 6061 / 6351
- 6082

Soft Alloys

Extrudability decrease

Properties increase

Medium Strength Alloys
Defects framework – the extrusion process influence

EXTRUSION SPEED

- Insufficient pressure
  - Soft alloy
  - More available pressure

- High extrusion ratio
  - Complex shape

- Operating window
  - Coarse Mg Si
  - Thick sections
  - Max properties

- Low mechanical properties

- Billet temperature

- Poor surface finish

- Tearing
  - Pick-up
  - Surface melting

- Complex shape

- Soft alloy

- Operating window
During Extrusion / Mill Finish
- Pick-up
- Speed
- Cracking
- Die line
- Micro die line
- Die streak
- Snap mark
- Front-end TW
- Back-end Coring
- Longit. weld
- Hot spots

After Extrusion - Metallurgical
- Coarse MgSi
- MgSi at grain boundary
- Corrosion pitting
- Orange peel
- Corrosion fretting
- Corrosion fingerprint
- Corrosion pitting
- Water stain
- Inclusion cast-in
- Inclusion extrusion process

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

During Extrusion / Mill Finish

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

Hot spots
Welds definition

Transverse Weld

Longitudinal Weld

Back-end condition / Coring

Coring

Transverse weld (non-balance port)

Longitudinal welds
1- Longitudinal weld
1- Longitudinal weld

[Images of weld diagrams and samples showing good and bad welds]
1- Longitudinal welds - can be unsatisfactory for several reasons

- Pores
- Contamination
- Recrystallisation
- Poor weld
2- Metal flow in direct extrusion
2- Front-end flow: Transverse Weld

- Continuous extrusion means “joints”
  - billet to die pocket
  - billet to billet

![Diagram of front-end flow: Transverse Weld]

- Old billet
- Transverse weld
- Die stop mark
- New Billet
3- Back-end flow: Coring
Streaks

During Extrusion / Mill Finish

- Pick-up
- Blister
- Speed Cracking
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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
Die lines / Micro die lines / Streaks

**Die line:** deep groove

**Micro die line:** fine lines

**Streaks:** bands of dark or light colors
Textural streaks

TYPE I
Caused by contaminants

TYPE II
Caused by die or profile design

TYPE III
Caused by extrusion process
Textural streaks

Textural streak anodized
Surface topography 0.2µm
Variable grain size and attack
Streaks - Dead metal zone

Contaminants that build up in dead metal zone

- Core / mandrel
- Rim of body
- New metal
- Old metal
- Feeder
- Die
- Die Face
- Feeder Wall
- Dead Zone
- Billet # 60
- Billet # 59
- Billet # 58
- Billet # 57
Pick-up

During Extrusion / Mill Finish

- Pick-up
- Speed
- Cracking
- Die line
- Die streak
- Front-end
  - TW
- Longitudinal
  - weld
- Blister
- Tearing
- Micro die
  - line
- Snap mark
- Back-end
  - Coring
- Hot spots

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Coating of aluminum oxide on the die bearing exit

Often starts with a deposit and ends with a narrowing tail

- Extrusion conditions: high profile temperatures promotes pick up formation
- Billet quality: chemical tolerances, homogenization
- Die condition: presence of sticking-sliding transition on the bearing generates pick ups: choked bearings reduces pick up
Not always pick-up

Example of carbon base lubricant
Grain size

After Extrusion - Metallurgical

- Coarse MgSi
- MgSi at grain boundary
- Orange peel
- Corrosion pitting
- Corrosion fingerprint
- Water stain
- Spacer marking
- Excess lubricant
- Inclusion cast-in
- Inclusion extrusion process

- Corrosion fretting
- Corrosion pitting
- Corrosion fretting
- Water stain
- Spacer marking
- Excess lubricant
- Inclusion cast-in
- Inclusion extrusion process
Orange peel

**Bad part**
Appearance of the PCG area

**Good part**
Uniform grain
Coarse grain banding

Machining Grade AA6061

Standard AA6061
Coarse grain banding – Causes and prevention measures

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

  ![Coarse grain banding diagram]

- **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.
Corrosion

After Anodization

- Atmospheric corrosion
- Alkali 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

- AA6063 non-protected cladding on RTA research center installed in 1949
- 65 years exposure in industrial environment
- Only ~ 400 microns of localized pitting corrosion
Atmospheric pitting corrosion

Rate of pitting slows down with time due to passivation by build up of corrosion product.

**Solution** – make metal **thick enough or protect!**
Acid / Alkali pitting

Alkali pitting – general attack

Typical form of pitting where the etching has removed evidence

Acid pitting – intergranular

typical source acid fume from chemical processes

typical source alkali contamination, i.e. cement dust
Alkali pitting prior to anodization

The small **round pits** are **covered** with a **continuous anodic layer** 8-10µm. The defect was **formed prior to anodizing process**.

The corrosion pits are **shallow** and **rounded** with a **smooth surface**, no sign of inter-granular attack (alkali corrosion vs. acidic corrosion)

- Macrographic surface appearance
- Longitudinal section as polished
Thank you for your attention
Contact information

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