Alcoa Aluminum: Rolled Products

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Alcoa covers every stage of aluminum production and is a leader in major end markets.

**Operations**

**Upstream (41%)**
- Bauxite mining
- Alumina refining
- Aluminum smelting
- Aluminum recycling

$7.5bn

**Midstream (33%)**
- Aluminum Sheet & Plate
- Aluminum Can Stock

$6.1bn

**Downstream (26%)**
- Fastening Systems
- Super-alloy castings
- Wheel & Transportation
- Building & Construction
- Forgings & Extrusions

$4.8bn

**Primary Aluminum**

**Automotive Transportation**

**Packaging**

**Building/Construction**

**Aerospace**

**Industrial**

**Oil & Gas**

**Consumer Electronics**
Global Rolled Products – a global business spread across 5 continents

Alcoa Global Packaging (AGP)

Product Lines:
• Can (Beverage & Food)
• Specialty Foil
• Industrial

Aero, Transportation & Industrial (ATI)

Product Lines:
• Commercial Aerospace
• Auto Body & Brazing
• Industrial
• Commercial Transportation

China & Consumer Electronics (CRP)

Product Lines:
• Can (Beverage)
• Brazing
• Commercial Transportation
• Consumer Electronics

GRP business unit structure and operating locations

Market-facing Global Business Units...

...with a Global footprint

North America
Europe
Russia
China
Latin America
Middle East
Australia
Global Rolled Products – a global business spread across 5 continents

Global Rolled Products (GRP) Location Map and Summary Data

North America
Davenport
Lancaster
Tennessee
Texarkana (idled)
Warrick

Europe
Kitts Green (UK)
Kofem (HU)
Fusina (IT)
Castelsarrasin (FR)
Amorebieta (SP)
Alicante (SP)

Russia
Samara
Belaya Kalitva

Middle East
Saudi Arabia
Ma’aden project location.
First production in 2013

China
Bohai
Kunshan

Latin America
Itapissuma (BR)

Australia
Yennora
Point Henry
Research Directions at Alcoa Technical Center in Sheet and Plate Products:

1. Improve Process Efficiency:
   - improve conversion (secondary processing) efficiency
   - reduce scrap (improve recovery – planned and unplanned)
   - improve output (ROC)
   - reduce labor content per kg

2. Improve Sustainability
   - reduce effluent (solids, volatiles, etc.)
   - reduction in greenhouse gas generation
   - improve recycling

3. Introduce Improved Products
   - superior process performance (for our processes)
   - superior process performance (for our customers’ processes)
   - superior service performance (for their customers)
Example: Davenport Works - 65 Years Serving Our Customers

- Began production in 1948
- $716M in Total Assets
- 132 acres under roof
- 2,300 employees
- 110 alloys, 8,000 specs
- 1,100 global customer locations

Operations:
- Metal Purification
- Casting
- Rolling, Stretching
- Sawing/Machining
- Heat Treatable & Non-Heat Treatable
- Sheet & Plate

Diversified Product Base:
- Aerospace and Defense
  - Sheet & Plate
- Automotive Sheet
- Industrial Sheet & Plate
- Commercial Transportation
Other elements are added to improve strength and/or corrosion resistance or both.

Major aluminum alloy families:

- 1XXX series – Generally 99% pure, (non-heat treat)
- 2XXX series – typically 1%-4% copper, (heat treat)
- 3XXX series – typically 0.5%-1.5% manganese, (non-heat treat)
- 5XXX series – typically 2%-5% magnesium, (non-heat treat)
- 6XXX series – typically 0.5%-1.5% silicon/magnesium + Cu (heat treat)
- 7XXX series – typically 2%-7% zinc +Mg + Cu (heat treat)

Tempers:

- F – As fabricated, no mechanical property limits
- O – Annealed, improved ductility
- T – Thermally treated (for HT like 2xxx, 6xxx and 7xxx)
- H – Strain hardened, relates to non-heat treatable grades (1xxx, 3xxx, 5xxx)
Sheet and Plate Manufacturing at Davenport Works

- Ships 500 million lbs/yr. or 1.3 M lbs. a day of finished product
- Produces plate products up to 220” wide and 110 feet long
- Three reversing hot mills, 220” wide, 160” wide, 144” wide
- 100” 5 stand hot mill
- Two 100” cold mills
- 86” wide continuous heat treat line
- New 88” wider continuous heat treat line (exclusively for automotive)
- Two vertical heat treat lines
Theme:
Understanding the metallurgical thinking and microstructural changes as we follow aluminum through the processing flowpath....
Multiple ingots are cast at a single composition using direct chill (DC) casting.

To remove “liquated” layer and provide a flat surface for rolling, ingots are scalped prior to homogenization.
Solidifies as dendritic grains (also known as: cells/crystals)

Non-uniform tinting within grains is due to the non-uniform distribution of elements such as Mg, Mn, etc.

Constituent Particles

250 microns
Tracking the Metallurgical Evolution: As-Cast Microstructure

**Constituent Particles**

Si - much of it combines with Mg to form Mg$_2$Si particles. (these appear dark as-polished)

Fe - very low solubility in solid Al. It tends to form Al$_3$Fe and Al$_{12}$Fe$_3$Si$_2$ type particles in the last stages of solidification – these are constituents.

Aluminum Matrix - has Mg, Mn*, Cu, etc. dissolved within it - usually not uniformly distributed.

* Mn, like Fe, is also has low solubility in solid Al - but is unable to partition into liquid during solidification and gets trapped in solid. Will come out during ingot homogenization as dispersoids.

5182 Can End Stock

50μm
Mn, although highly insoluble in Al was trapped in solid during solidification.

During the long thermal exposure during ingot homogenization, Mn is able to diffuse and form discrete dispersoids of $\text{Al}_6(\text{Mn,Fe})$.

...and perhaps also some $\text{Al}_{12}(\text{Mn,Fe})_3\text{Si}_2$. 

Tracking the Metallurgical Evolution: After Homogenization
Ingots are rolled down to progressively thinner gauges in reversing mills. Deforming becomes more *plane strain* (the sheet maintains its width and gets progressively longer) as rolling proceeds. Rolled plate seen on the run-out table to the right...
Coil After Exit from Hot Continuous Mill

Hot rolled coils, with gauges in the 2mm to 8 mm range, are now either given an anneal treatment or are passed directly to cold rolling to reduce the gauge and modify the crystallographic texture.
Hot rolled products can be come off the mill fully recrystallized, partially recrystallized or unrecrystallized, depending on the alloy, the reduction schedules and the rolling temperature.

When recrystallization occurs the elongated, strained hot rolled grains are replaced by a new set of low aspect ratio, strain-free grains.

Hot rolled product, therefore, can be either \textit{self-annealed} or \textit{unannealed}.

A \textit{batch anneal} (also called an hot line anneal or intermediate anneal) can be imposed to complete recrystallization, if so desired...
## Tracking the Metallurgical Evolution: Cold Rolling and Annealing

As-Hot Rolled 5xxx...

<table>
<thead>
<tr>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Roll 50%</td>
<td>Cold Roll 33%</td>
<td>Anneal</td>
<td>Cold Roll 60%+</td>
</tr>
<tr>
<td>Anneal</td>
<td>Anneal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cold Roll 20%</td>
<td>Cold Roll 40%</td>
<td>Cold Roll 60%</td>
<td></td>
</tr>
</tbody>
</table>

**Anneal**

- Yield Strength 88 MPa
- Yield Strength 91 MPa
- Yield Strength 101 MPa
- Yield Strength 105 MPa
After exiting the hot continuous mill, the strip *recrystallizes*....

Some/many of the recrystallized grains are of the cube orientation....

When the cube faces of face centered cubic crystal structure of Al is lays in the sheet plane & FCC edges are parallel to rolling direction, we have *cube texture*.
The cube texture from hot rolling imparts ‘0-90°’ earing tendencies to the recrystallized strip….

Crystallographic Texture and Earing
The cold rolling texture causes ears to be formed at all locations \( \sim 45^\circ \) from RD (actually closer to \( 48^\circ \))....
So, the secret to low earing is to product the right amount of cube texture in the hot rolling process to balance with the texture subsequently introduced in cold rolling to final gauge.…

So while zero earing is only possible with random textures, earing can be reduced by balancing crystallographic textures introduced in different steps in the rolling process…
Crystallographic Texture and Earing

Real World Example: Aluminum Can Stock
AA3104

Real World Example: Aluminum End Stock
AA5182
Crystallographic Texture Control is Important for Manufacturability:
  - Forming
  - Hemming
  - Isotropy in Properties

But it is also Important for Service Performance:
  - Surface Appearance
Surface appearance in aluminum autobody sheet can be compromised by bands of cube oriented grains that are remnants from the hot rolling process. These “ridging” or “roping” lines are a cause for rejection....
The product of aging of Al-Cu-Li Alloys: strengthening precipitates...

Figure 1 Aluminum Plate Product Typical Properties vs. Year First Used on Specific Aircraft
Precipitation Strengthening: High Strength Aerospace Alloys
1. **Manufacture of Rolled Aluminum Products is a Multi-Step Operation**
   - Ingot Casting
   - Homogenization
   - Scalping
   - Hot Rolling
   - Intermediate Annealing
   - Cold Rolling
   - Heat Treatment (coil annealing, continuous heat treatment, aging)

2. **Thermo-Mechanical Processing is used to Control Product Gauge, Properties and Anisotropy**
   - Strength
   - Toughness
   - Corrosion Resistance
   - Surface Appearance
   - Crystallographic Texture

3. **The Microstructural Evolution through the Process Guides Metallurgical Decisions**