Aluminum in Aerospace and Automobile Parts

9th/ Aug./ 2017
TADASHI MINODA
Research & Development Division
UACJ Corporation
1. Introduction of UACJ Group

2. Variety of Wrought Aluminum Alloys

3. Variety and Features of Aluminum Alloys for Aircrafts
   • Development of Aluminum Alloys for Aircrafts
   • Applications of Aluminum Alloys
   • Future development of aircraft materials
   • AA2013 alloy developed by UACJ

4. Applications for Automotive Parts
   • Heat Exchangers (Laying pipe, Hose joints, MFC)
   • Automotive panel materials
   • Bumper
   • Truck tilt
   • Forgings
   • Compressor Wheel for Turbo Charger

5. Summary
Introduction of UACJ Group

- **Furukawa-Sky Aluminum Corp.**
- **Sumitomo Light Metal**

Merged on 1st / Oct. 2013

**UACJ Corporation**
Flat Rolled Products Business
Utilizing World-leading Manufacturing Capabilities to Deliver High-quality Flat Rolled Products

UACJ boasts some of the most advanced aluminum sheet manufacturing capabilities in the industry, including precise thickness control technologies and some of the world’s largest rolling mills, measuring over 2,000 mm wide. This technological prowess enables us to supply the best products to a wide range of industries:

- Automotive sheet and aerospace materials
- Automotive parts and components
- Building and construction materials
- Industrial and machinery materials
- IT consumer goods
- Advanced aerospace components for aerospace
- Major appliances and construction major appliance thick pieces
- EMI shielding materials
- Container-making alloys

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Extrusion and Foil Businesses

Extrusion Business

Utilizing Comprehensive, Industry-leading Technological Processes to Meet Needs in a Wide Variety of Fields

Supported by engineers highly experienced in manufacturing, welding, die-casting, and extrusion processing fields, UACJ utilizes its technological prowess to produce extruded products of the highest quality. Capitalizing on these comprehensive capabilities, we are able to meet the needs of customers from a wide variety of industries or automotive, industrial machinery, aviation and office equipment. We continually work to further improve technologies and quality at our production sites in Japan and overseas in order to better meet demands for higher quality.

- Automotive heat exchanger and tubing materials
- Motorcycle frame materials
- Photocopier photoconductive drum materials
- Machine parts materials

Foil Business

Utilizing Unparalleled Foil Technologies to Supply Products Designed to Meet the Latest Needs

UACJ produces aluminum and metallic foil of the highest quality for use in a variety of fields. Applications include everything from foil for lithium ion battery current collectors and packaging for foodstuffs and products to medical products, electronic products, and industrial applications such as electrolytic capacitors.

- Capacitor foil
- Medical industry and medical products packaging foil
- Chemicals and packaging foil
- Lithium ion battery current collector foil
- Construction foil
- Outfitting foil
The other Businesses

Casting and Forging Business
Delivering Highly Competitive Products Utilizing Advanced Technologies and Production Network

In the molding field, UACJ incorporates pressing casting technologies in the production of compressors that is part of a truck larger than builds the two-stage of the automotive turbocharger market. When it comes to forging, we operate on Japan's largest forging press, uniquely positioning us to meet large-scale forging needs.

- Turbocharger compressor shells
- Forged products for aviation and aerospace materials
- Forged products for railways
- Forged products for liquid crystal production facilities

Precision-machined Components Business
Utilizing a Wide Array of Equipment and Technologies in Response to Various Processing Needs

From rolling processes to stamping processes, surface treatment and plating, UACJ has the facilities and technologies to respond to demands in any industry worldwide. Regardless of size, shape or function required, we're ready to meet the needs of a wide range of industries.

- Structural products
- Electrical products
- Functional material products

Copper Tubing Business
Meeting a Wide Range of Needs with the Superior Materials Characteristics of Copper

Utilizing the exceptional materials characteristics of copper such as heat conduction, corrosion resistance, workability and antimicrobial properties, we deliver products that satisfy wide-ranging needs. From products for heating, cooling, electrical, and plumbing to medical devices, electrical and mechanical devices to heat pipes for cooling electronic devices, UACJ's ready service.

- Copper/brass internally grooved copper tubing
- HVAC system tubing
- Copper coil tubing
- Lead exchange tubing
- Copper tube/pipe tubing
- Threaded condenser tubing
Research & Development

Applying Advanced Aluminum Expertise
to Create New Innovations

UACJ continuously develops next-generation products and technologies as we explore the potential of aluminum and create new value in society. These R&D initiatives are spearheaded by Research and Development Office.

Research & Development
Headquarters

Pursuing new possibilities for aluminum

UACJ’s Research and Development Department accelerates the development of R&D projects and meets the needs of the global market. The Head of R&D presents an overview of the R&D projects undertaken and their potential contributions to the Group as a whole.
Our Strengths

- UACJ meets the needs of a variety of industries thanks to its comprehensive abilities.
- UACJ is a World Class Manufacturer of Flat Rolled Products.

Flat-rolled aluminum (sheets and coils) production capacity rankings (kilo-tons/yr): Over 1 million tons for UACJ.
Global Network of UACJ (Sheet)

Japan – 3 locations
- Nagoya
- Fukuyama
- Fukui (Aerospace material)

Thailand
- Rayong
Global Network of UACJ Extrusion Group

Producing aerospace material

Japan

World

Gunma Corporation

Oyama Corporation

Head Office

Nagoya Corporation

Nagoya Works

Anjo Works

Shiga Corporation

Kansai Branch

Chubu Branch

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UACJ Extrusion Group in Asia

① UACJ Extrusion (Tianjin) Corporation
   3 Extrusion, 1 Drawing
   MPE, Pipe, Bar, & Shape
   ① China

② UACJ indal Aluminum PT
   4 Extrusion, 2 Drawing
   MPE, Pipe, Bar, & Shape
   ② Indonesia

③ UACJ Extrusion (Thailand) Co., Ltd.
   a) Ayutthaya Plant
      1 Extrusion, 1 Drawing
      MPE, Pipe, Bar, & Shape
   b) Prachinburi Plant
      1 Extrusion

Location of UACJ Extrusion (Thailand)

Rojana Industrial Park
Ayutthaya Plant
70 km from Bangkok

304 Industrial Park
Prachinburi Plant
140 km from Bangkok

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5. Summary
Variety of Aluminum Alloys

Aluminum alloys are classified into 7 series.

- 1xxx : Pure aluminum (include Fe, Si impurities)
- 2xxx : Al + Cu (+ Mg) ••• Duralumin (A2017)
- 3xxx : Al + Mn
- 4xxx : Al + Si
- 5xxx : Al + Mg
- 6xxx : Al + Mg + Si
- 7xxx : Al + Zn + Mg (+ Cu) ••• Extra Super Duralumin (A7075)
- 8xxx : Other elements (Ex. Fe)
Variety of Aluminum Alloys

Fig. Tensile strength ranges of aluminum alloys.

- **1xxx** (Strain hardening alloys)
- **2xxx** (Age hardening alloys)
- **3xxx** (High strength, lower corrosion resistance)
- **4xxx** (Middle strength, higher corrosion resistance)
- **5xxx** (Middle strength, higher corrosion resistance)
- **6xxx** (Lower corrosion resistance)
- **7xxx** (Aircraft structure, lower corrosion resistance)

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<table>
<thead>
<tr>
<th>Alloy</th>
<th>Corrosion</th>
<th>Formability</th>
<th>SCC</th>
<th>Brazing</th>
<th>Welding (Argon)</th>
<th>Forging</th>
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<td>A</td>
<td>C</td>
<td>A-B</td>
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<td>D</td>
<td>D</td>
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<td>A-B</td>
<td>A-B</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>4000</td>
<td>C</td>
<td>-</td>
<td>-</td>
<td>D</td>
<td>B</td>
<td>B</td>
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<tr>
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<td>A</td>
<td>A-B</td>
<td>A-B</td>
<td>C-D</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>6000</td>
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<td>C</td>
<td>C</td>
<td>A</td>
<td>D</td>
<td>D</td>
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<tr>
<td>7000 (Cu≤0.3%)</td>
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<td>B</td>
<td>B</td>
<td>D</td>
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<td>D</td>
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<tr>
<td>7000 (Cu≥0.5%)</td>
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<td>C</td>
<td>C</td>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

A: Good  D: Worse
Contents

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5. Summary
1906: Development of “Duralumin” by Wilm (Germany)
   • Quench test of Al-3.5Cu-0.5Mg. (2xxx alloy)
     An assistant measured the hardness on Saturday.
     The hardness was measured again on Monday.
     => Development of age hardening.
   • The patent was transferred to Durener Metallweke A.G.
     “Duralumin” was a contraction of Durener and Aluminium.

-1930: “Super-Duralumin, SD”
   • ALCOA Al-Cu-High Mg (2xxx alloy)

1936: “Extra-Super-Duralumin, ESD”
   • Requirement of new alloy with 600MPa strength.
   => Development of Al-Zn-Mg-Cu alloy by Dr. Igarashi
     and Mr. Kitahara in Japan. (7xxx alloy)
     (Improvement of SCC by Cr and Mn addition)
   • 1938 Application for Zero-fighter
   • 1943 Registration of similar alloy as 7075 (USA)
Development of Aluminum Alloys for Aircrafts

Application of “ESD” for Zero-fighter

“ESD” was developed in Japan, and it was applied to spars in Main wing in the Zero-fighter.
Development of Aluminum Alloys for Aircrafts

Map of development and improvement of high strength aluminum alloys

- **Al-4Cu**
  - **2014** Al-4.4Cu-0.5Mg-0.8Si
    - **2219** Cu+, Mg x Weldability
  - **2017 Duralumin** Al-4Cu-0.5Mg
  - **2024 Super Duralumin** Al-4Cu-1.5Mg
    - **2124** Fe, Si - High toughness
    - **2224** Fe, Si - High toughness
  - **2419** Fe, Si - High toughness
  - **2519** Mg+ High strength
  - **2618** Ni+ Heat resistance

- **7075 Extra Super Duralumin** Al-5.6Zn-2.5Mg-1.6Cu-0.2Cr
  - **7175** Fe, Si - High toughness
  - **7475** Fe, Si - Toughness
  - **7049** Zn+ Strength
  - **7149** Fe, Si - Toughness

- **7175** Fe, Si - High toughness
  - **7049** Zn+ Strength

- **7050 Zn, Cu+, Zr+** Strength, toughness
  - **7150** Fe, Si - High toughness
  - **7055 Zn+ Highest strength

- **7085** Zn+, Mg- High strength

2xxx alloys have higher **fatigue strength**
7xxx alloys have higher **static strength**
### Development of Aluminum Alloys for Aircrafts

#### Comparison of properties of typical aluminum alloys for aircrafts

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Temper</th>
<th>Static strength</th>
<th>Fracture toughness</th>
<th>Crack propagation</th>
<th>SCC</th>
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<td></td>
<td>Thin</td>
<td>Thick</td>
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<td>A</td>
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<td>C</td>
<td>D</td>
<td>C</td>
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<tr>
<td>2124</td>
<td>T851</td>
<td>—</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>7075</td>
<td>T6, T651</td>
<td>A</td>
<td>B</td>
<td>D</td>
<td>C</td>
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<td>T73, T7351</td>
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<td>B</td>
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<td>—</td>
<td>A</td>
<td>A</td>
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<td>T7351</td>
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<td>A</td>
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<td>T76, T7651</td>
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<td>A</td>
<td>B</td>
<td>B</td>
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<td></td>
<td>T7451</td>
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<td>B</td>
<td>B</td>
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<td>7150</td>
<td>T6151</td>
<td>A</td>
<td>AA</td>
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<td>C</td>
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<td></td>
<td>T7751</td>
<td>—</td>
<td>AA</td>
<td>C</td>
<td>C</td>
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<tr>
<td>7055</td>
<td>T7751</td>
<td>—</td>
<td>AA</td>
<td>C</td>
<td>C</td>
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</tbody>
</table>

Better: AA > A > B > C > D : Worse
Development of Aluminum Alloys for Aircrafts

Registration flow of new alloys for aerospace

① Registration in AA (Aluminum Association)
   - Alloy Number
   - Heat Treatment (Temper)

② Publication of AMS (Aerospace Material Standards)
   - Alloy specifications (Tensile properties, Corrosion resistance, etc.)

③ Registration of material properties into MMPDS (Metallic Materials Properties Development & Standardization)
   - Physical properties
   - Static strength
   - High temperature strength
   - Fatigue crack propagation
   - Fracture toughness

The materials which are used for aerospace structure need above registrations.
Applications of Aluminum Alloys

Body structure

- Stringer
- Skin
- Frame
Applications of Aluminum Alloys

Boeing 747 (Relatively old plane)

Main wing
- Upper plate (7075-T651)
- Lower plate (2024-T351)

Vertical stabilizer (7075-T651)

Frame (7075-T73)

Main frame (7075-T73)

Outer panel (2024-T351)

Stringer (7075-T651)

Main wing spar (7075-T651)

Cowling (2024-T42)
Boeing 777 (Relatively new plane)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Temper</th>
<th>Product Form</th>
<th>Thickness (in)</th>
<th>T fy (MPa)</th>
<th>Ftu (MPa)</th>
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<td>T6</td>
<td>Sheet</td>
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<td>538</td>
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<tr>
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<td>T6</td>
<td>Sheet</td>
<td>0.063~0.249</td>
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<td>503</td>
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<tr>
<td></td>
<td>T7351</td>
<td>Plate</td>
<td>0.250~1.000</td>
<td>393</td>
<td>476</td>
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<tr>
<td>7475</td>
<td>T651</td>
<td>Plate</td>
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<td>490</td>
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<td>T7751</td>
<td>Plate</td>
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<td>572</td>
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# Applications of Aluminum Alloys

## Aluminum alloys for aircrafts

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<tr>
<th>Airplane</th>
<th>Shape</th>
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<th>B727</th>
<th>B747</th>
<th>B777</th>
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<td>Main wing</td>
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<td>7075-T6</td>
<td>7178-T651</td>
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<td></td>
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<td>Extru.</td>
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<td>2024-T351</td>
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<td>Plate</td>
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<td>7079-T6</td>
<td>7075-T73</td>
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</table>

**Main wing: Upper** - Compression stress [Static strength] => 7xxx alloys

(Alcladding of Al-1%Mg alloy; Resistant to corrosion)

**Lower** - Tension stress [Fatigue strength] => Mainly 2xxx alloys

(Alcladding of pure aluminum; Resistant to corrosion)

**Body: Outer plate** - Tension stress [Fatigue strength] => Mainly 2xxx alloys (Same as above)

**Frame, Stringer** - [Static strength] => 7xxx alloys
Applications of Aluminum Alloys

**Body panel, Wing panel**

**Milling of body skin**

- **Body panel**
  - Skin
  - Stringer
  - Frame
  - Shear tie
  - Stringer clip

- **Wing panel**
  - Skin
  - Stringer
  - Frame

- **Max. 7.2m**
- **Max. 2.3m**
- **Tier strap**
- **Maximum 7 steps**
- **Thickness before milling: 5.1mm**

Fig. Example of body skin milling
Applications of Aluminum Alloys

Secondary structures and others

Cargo container

Galley and container

Seat frame
The max. takeoff weight: 400 tons

The composite ratio is increasing in middle and large size aircrafts.
Future development of aircraft materials

Airbus A350XWB

The max. takeoff weight; 250 tons

In recent aircrafts, Al-Li alloys are also used.
Future development of aircraft materials

<Advantages and weaknesses of Al-Li alloys>

1. Lower density; The density decrease 3% with 1%Li addition.
2. Higher young’s modulus; The modulus increase 6% with 1%Li addition
3. Risk; Li is extremely active
   • Melting; Eating of refractory
   • Casting; Risk of “explosion” by contact of molten metal with water
   • Heat treatment; Surface oxidation by Li
   • Recycle; Reaction of machined chip with moisture, acid and alkali.
   Difficult to re-melt by existing facilities.
UACJ developed AAZ013-T651 1 alloy to replace 2024-T3

Background to the Development

- Lower maintenance costs
- Lower material costs
- Even slightly lighter
- Lower density
- Excellent extrudability
- Resistance
- Improved corrosion
- Strength: Equal or superior
### AA2013 alloy developed by UACJ

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
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<td>Rem.</td>
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<td>0.10</td>
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<td>0.15</td>
<td>Rem.</td>
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<td>0.25</td>
<td>0.15</td>
<td>Rem.</td>
</tr>
</tbody>
</table>

Compared with 6013 alloy,
Copper was increased to improve strength.
Transition element changed from Mn to Cr for grain control.

**2013 alloy was designed for the extrusion process.**
### Static Properties

<table>
<thead>
<tr>
<th>Strength</th>
<th>Tension *1</th>
<th>Compression</th>
<th>Shear</th>
<th>Bearing (e/D=2.0)</th>
<th>Bearing (e/D=1.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fty</td>
<td>Ftu</td>
<td>Fcy</td>
<td>Fsu</td>
<td>Fbry</td>
</tr>
<tr>
<td>Average (MPa)</td>
<td>390</td>
<td>411</td>
<td>389</td>
<td>293</td>
<td>711</td>
</tr>
<tr>
<td>A value (MPa)</td>
<td><strong>365</strong></td>
<td><strong>400</strong></td>
<td><strong>365</strong></td>
<td><strong>283</strong></td>
<td><strong>662</strong></td>
</tr>
<tr>
<td>2024-T3511</td>
<td>290</td>
<td>393</td>
<td>234</td>
<td>200</td>
<td>490</td>
</tr>
<tr>
<td>A value (MPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison</td>
<td>1.3</td>
<td>1.0</td>
<td>1.6</td>
<td>1.4</td>
<td>1.2</td>
</tr>
<tr>
<td>with 2024-T3511</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A value: At least 99% of population equals or exceeds value with 95% confidence or the specification minimum when it is lower.

*1 A basis of tensile elongation is 8 pct.

2013 alloy is superior to 2024 in static strength.
AA2013 alloy developed by UACJ

Examples of Integrated Structures

Thin wall hollow shapes can be extruded with 2013 alloy.
AA2013 alloy developed by UACJ

Application examples of AA2013 alloy

① Electronic device rack of aircraft
② Emergency ladder for train
Contents

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3. Variety and Features of Aluminum Alloys for Aircrafts
   • Development of Aluminum Alloys for Aircrafts
   • Applications of Aluminum Alloys
   • Future development of aircraft materials
   • AA2013 alloy developed by UACJ

4. Applications for Automotive Parts
   • Heat Exchangers (Laying pipe, Hose joints, MFC)
   • Automotive panel materials
   • Bumper
   • Truck tilt
   • Forgings
   • Compressor Wheel for Turbo Charger

5. Summary
Laying Pipe for Automobile Air Conditioner

Cross section of 3-layer clad pipe (φ17 x t1)

Example of expanding (φ8 x t1)

UACJ alloy and feature

<table>
<thead>
<tr>
<th>Alloy</th>
<th>AA</th>
<th>Temper</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>403S</td>
<td>3003</td>
<td>O</td>
<td>Excellent corrosion resistance.</td>
</tr>
<tr>
<td>CT201</td>
<td>-</td>
<td>O</td>
<td>2-layer clad alloy (outer;7072, core;3003).</td>
</tr>
<tr>
<td>CT209</td>
<td>-</td>
<td>O</td>
<td>3-layer clad alloy (outer and inner;7072, core;3003).</td>
</tr>
</tbody>
</table>

Fig. Layout of automotive air conditioner.
Hose joint for automobile air conditioner

![Image of a car and hose joint]

Aluminum pipes for connecting compressor and rubber hose.

**Bend samples**

**Finished product**

**Fig. Layout of automotive air conditioner.**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>AA</th>
<th>Temper</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>63S</td>
<td>6063</td>
<td>T83, T4</td>
<td>Excellent corrosion resistance, surface treatment and extrudability.</td>
</tr>
<tr>
<td>204SA</td>
<td>3004</td>
<td>O</td>
<td>Excellent corrosion resistance.</td>
</tr>
</tbody>
</table>
MFC (Multi Flow Condenser Tube)

Excellent workability, corrosion resistance, brazing and heat conduction.

UACJ alloy and feature

<table>
<thead>
<tr>
<th>Alloy</th>
<th>AA</th>
<th>Temper</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA105</td>
<td>3021</td>
<td>H112</td>
<td>Excellent workability, corrosion resistance, brazing and heat conduction.</td>
</tr>
</tbody>
</table>
Automotive Panel Materials

Features of UACJ materials

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Type 5000 or 6000 rolled sheet alloy</td>
</tr>
<tr>
<td>Surface finishes</td>
<td>Dull or milled finished</td>
</tr>
<tr>
<td>Surface treatments</td>
<td>Acid washing possible</td>
</tr>
<tr>
<td>Lubricants</td>
<td>Can be coated with various types of lubricant</td>
</tr>
<tr>
<td>Shapes</td>
<td>Coils and sheets (longitudinal circular sheets also possible)</td>
</tr>
</tbody>
</table>
For “Corporate Average Fuel Economy (CAFE) Standards” in North America, Ford adopted aluminum alloys to the upper body of F150, which is the most mass production model.
# Bumper

UACJ alloy and feature

<table>
<thead>
<tr>
<th>Alloy</th>
<th>AA</th>
<th>Temper</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZK170</td>
<td>7046</td>
<td>T7</td>
<td>High strength and corrosion resistance</td>
</tr>
</tbody>
</table>
Truck Tilt

Inlaid structure of tilt

Alloy: 6063
Compressor Wheel for Turbo Charged

<Form>
Casting / Extrusion (Milling)
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5. Summary
Summary

Aluminum alloys have been used for aerospace structures.
- 2xxx alloys; higher fatigue strength => Main wing lower and Body outer plate
- 7xxx alloys; higher static strength => Main wing upper, Body frame and stringer

Integrated structure by milling have been applied. The newest aircrafts use composites over 50% in weight.

The aluminum alloys which are used for aerospace structures need AA and AMS registrations and MMPDS data.
The manufacturer need AS9100 (ISO 9100/ JIS Q 9100) quality control system to produce aerospace materials or parts.

For automotive uses, aluminum alloys are widely used for their laying pipes and for heat exchangers.
Also, Aluminum automotive body materials, bumpers, compressor wheel for turbo charger is increasing.
Thank you for your attention!!