NEW DEVELOPMENTS IN ALUMINUM FOR AIRCRAFT AND AUTOMOBILES

Jocelyn I. Petit

Alcoa Technical Center
Alloy Technology Division
100 Technical Drive
Alcoa Center, Pennsylvania 15069

Telephone 412-337-5922
Common bond for aircraft and automobiles is need for cost-efficient, lightweight structure.

Aluminum base materials

New Developments in Aluminum for Aircraft and Automobiles

• Automotive
  – Needs
  – Developments
  – Directions

• Aircraft
  – Needs
  – Developments
  – Directions
Forces Shaping Future Automotive Materials Needs

- Need for fuel efficiency
- Changing consumer preferences
- Growing environmental awareness
- Globalization of market
**BACKGROUND, AUTOMOTIVE**

1975 TO 1991 - SOURCES OF REDUCTION IN FUEL CONSUMPTION

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIRES</td>
<td>22.4</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>32.2</td>
</tr>
<tr>
<td>AERODRAG</td>
<td>34.7</td>
</tr>
<tr>
<td>POWER TRAIN</td>
<td>10.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
U. S. Car Weight/Fuel Economy Relationship

- Weight < 22%
- CAFE > 76% but down in last two years

Source: U. S. Environmental Protection Agency
Automotive

Why use aluminum?

• Weight reduction
  – Increased fuel economy
  – Decreased emissions
  – Increased performance
  – Increased cargo capacity

• Longer vehicle life

• Recycling capacity
Energy Cycle

LOWER WEIGHT = HIGHER MPG

![Bar chart showing miles per gallon (MPG) vs. weight in pounds (lbs.) with engines downsized proportionately. The graph indicates that lower weight correlates with higher MPG.]

CAR WEIGHT/EMISSIONS

LESS WEIGHT = LOWER EMISSIONS

![Bar chart showing CO2 emissions (X1000 lbs. over the life of the car) vs. weight in pounds (lbs.) with engines downsized proportionately. The graph indicates that lower weight correlates with lower CO2 emissions.]
Aluminum Strength/Weakness versus Competitive Materials

**Al Strength vs Steel**
- Lightweight effectiveness
- Corrosion Resistance

**Al Weakness vs Steel**
- Stiffness
- Ease of manufacturing
- Cost

**Al Strength vs Plastic**
- Lightweight effectiveness
- Stiffness
- Recyclable
- Ease of repair

**Al Weakness vs Plastic**
- Design options
- Corrosion resistance
- Dent resistance
Automotive

**Hang-on components**

- Outer panels
- Class A surface
- Corrosion resistant
- Y.S.
- U.S. and Europe: >207 MPa
- Japan: 138 MPa < Y.S. < 172 MPa
- Formable
  - Stretchable
  - Drawable
  - Hemmable
- Alloys
  - 2XXX
  - 6XXX
Automotive

Hang-on components
- Components
  - Characteristics
  - Hinge allocation
  - Thickness allocation
  - Material allocation
  - Manufacturing of parts
  - Assembly
  - Installation
  - Removal
  - Maintenance

- Inner panels
  - Formable
    - Stretchable
  - Drawable
  - Hemmable
- Alloys
  - 5XXX
  - 6XXX
Strength - Formability Relationships for Aluminum Auto Body Sheet Alloys

Yield strength after paint bake, MPa

Total elongation, %

Primary application
- Inner
- Outer

5182-O
2036-T4
Strength - Formability Relationships for Aluminum Auto Body Sheet Alloys

Total elongation, %

Yield strength after paint bake, MPa

Primary application
- Inner
- Outer
- Either

5030-T4
2008-T4
Strength - Formability Relationships for Aluminum Auto Body Sheet Alloys

Emerging materials for hang-on components
- Near term
  - 2XXX and 6XXX low bake temperature
  - 5XXX Luder-free
Automotive

Emerging materials for hang-on components

- Long term
  - Low cost
  - Formability, strength, weldability, and finish of best DQ steel
  - Corrosion resistance of best Al sheet

Automotive

Bumper components
This rendering of a generic spaceframe illustrates the use of less than 100 aluminum extrusions and interconnecting aluminum die cast nodes which are robotically welded to form the car body. A limited number of aluminum sheet components (i.e. inner fenders, floor pan) are then attached to complete the body.

Automotive

- Space Frame components
  - Strong
  - Tough
  - Corrosion resistant
  - SCC resistant
Automotive

**Space Frame components**
- Strong
- Tough
- Creep resistant
- Fatigue resistant

- Extrusions
  - Close tolerance 6XXX
  - Press quenched
  - Formed in T4
  - Aged to ~ 230 MPa YS
  - Crushable
Automotive

- **Space Frame components**
  - Strong
  - Tough
  - Corrosion resistant
  - SCC resistant

- **Extrusions**
  - Close tolerance 6XXX
  - Press quenched
  - Formed in T4
  - Aged to ~130 MPa YS
  - Crushable

- **Die castings**
  - Proprietary vacuum casting
    - < 5 ml gas/100g metal
    - Low porosity
  - High Si, low Mg
  - Fe to reduce die erosion and welding
  - SHT aged to T6
    - YS 115 to 140 MPa
    - 18 to 22% elongation
    - Crushable
Evolution of Aluminum Aerospace Alloys

New aluminum base alloys continue to be introduced

• 1920's - 2017, 2014
• 1930's - 2024
• 1940's - 7075
  • 1950's - 7178, 7079, X2020
• 1960's - 7175, 7475, 2124
• 1970's - 7050, 7150, 2324
  • 1980's - 2034, 2090, 8090, 2091
• 1990's - 7055, C188, ???
• 2000's - ???
Forces Shaping Future Aircraft Materials Needs
Many factors are driving change in 1990's:

- Aging commercial fleet
  - fatigue, corrosion

- Attention to cost effectiveness
  - procurement, inventory, manufacturing, operating

- Fuel prices ???
  - incremental weight savings
  - radical design/material changes

- Future supersonic commercial aircraft
  - radical design change, high temperature

- New competition
Property Requirements for Jetliner and Military Transport Applications

Material properties:

- Corrosion
- CYS = Compressive Yield Strength
- E = Modulus
- FAT = Fatigue

FCG = Fatigue Crack Growth
FT = Fracture Toughness
SS = Shear Strength
TS = Tensile Strength

( ) = Important, but not critical, design requirement

Fuselage skin: Corrosion, CYS, FAT, FCG, FT, SS, TS, (E)
# Fuselage

## Skin

<table>
<thead>
<tr>
<th></th>
<th>Commercial and Transport</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard:</strong></td>
<td>2024-T3</td>
<td>7475-T76</td>
</tr>
<tr>
<td></td>
<td>7475-T76 (thick)</td>
<td></td>
</tr>
<tr>
<td><strong>Newly used:</strong></td>
<td>2XXX-T3</td>
<td></td>
</tr>
<tr>
<td><strong>Being evaluated:</strong></td>
<td>6013-T6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2091</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8090</td>
<td></td>
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<tr>
<td></td>
<td>GLARE©</td>
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</tbody>
</table>
Toughness vs. Yield Strength:

Strength/toughness relationship for C188-T3 and 2024-T3 alclad sheet, 0.100 in. thick, T-L orientation. Toughness measured using 16 in. wide M(T) specimens.

Constant \( \Delta K \) Test:

Fatigue crack growth rate vs. crack length for C188-T3 and 2024-T3 alclad sheet tested at constant \( \Delta K = 25 \text{ ksi}\sqrt{\text{in.}} \), \( R = 0.1 \), T-L, high humidity (R.H.>90%) air.
Fiber/Metal Structural Laminates
(Typical 3/2 Lay-Up Shown)

Fiber/epoxy
0.009 in. (0.23 mm)

Aluminum sheet
0.012 in. (0.30 mm)

Fiber/epoxy
0.009 in. (0.23 mm)

0.054 in. (1.4 mm)

<table>
<thead>
<tr>
<th>Standard Constituent Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum sheet alloy</td>
</tr>
<tr>
<td>Fiber</td>
</tr>
<tr>
<td>Prepreg</td>
</tr>
</tbody>
</table>
Fiber-Metal Laminates

Benefit: Weight Reduction
Application: Fuselage Skin
Target: 20 - 25%

Weight Reduction Because of:
• Density Reduction (10 - 15%)
• Downgaging Sheet Thickness (10%)
• Part Elimination (Doubler, Tear Straps)

Downgaging Possible Because of:
• Superior Fatigue Properties
• Excellent Damage Tolerance
  (Residual Strength, Fracture Toughness)
Property Requirements for Jetliner and Military Transport Applications

Material properties:
- Corrosion
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- ( ) = Important, but not critical, design requirement

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Upper wing (Compression):
Skins: CYS, E, FAT, FT, (Corrosion, FCG)
## Wing

### Upper Cover

<table>
<thead>
<tr>
<th></th>
<th>Commercial and Transport</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard:</strong></td>
<td>7150-T6</td>
<td>7475-T73</td>
</tr>
<tr>
<td></td>
<td>7150-T61</td>
<td>7050-T76</td>
</tr>
<tr>
<td><strong>Newly used:</strong></td>
<td>7150-T77</td>
<td>2124-T8</td>
</tr>
<tr>
<td></td>
<td>7055-T77</td>
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<tr>
<td><strong>Candidates</strong></td>
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<tr>
<td><strong>for development:</strong></td>
<td>DRA</td>
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<td></td>
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<td></td>
<td>Al-Be</td>
<td>Al-Be</td>
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<td></td>
<td>CRA</td>
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</tbody>
</table>
Upper Wing Skin Plate Alloy/Temper Chronology

Schematic Illustration of Strength/Corrosion Resistance Improvements of the New Alcoa Aluminum Alloy 7055 Compared to Aluminum Alloys 7150 and 7050
The DMMC Material Microstructure:
The P/M processing route can produce a reinforcement that is well-distributed in the aluminum matrix.
## Wing

<table>
<thead>
<tr>
<th>Lower Cover</th>
<th>Commercial and Transport</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard:</strong></td>
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<tr>
<td>2024-T3</td>
<td></td>
<td>7475-T73</td>
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<tr>
<td>2324-T39</td>
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<td>2419-T8</td>
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<tr>
<td>2224-T3</td>
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<tr>
<td><strong>Being evaluated:</strong></td>
<td></td>
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<tr>
<td>8090-T8</td>
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<tr>
<td>7475-T76</td>
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<td><strong>Possible candidates:</strong></td>
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<tr>
<td>ARALL</td>
<td></td>
<td>X7093-T73</td>
</tr>
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<td>Al-Li</td>
</tr>
</tbody>
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- FT = Fracture Toughness
- SS = Shear Strength
- TS = Tensile Strength

Lower wing (Tension):
- Stringers: FAT, FT, TS, (Corrosion, FCG)