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>Source</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 the relationship between weight and miles per gallon.](chart1)

Less weight = lower emissions

![Bar chart showing the relationship between weight and CO2 emissions.](chart2)
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
  - Connectors
  - Clamps
  - Fasteners
  - Washers
  - Screws
  - Bolts
  - Nuts
  - Fastening devices
  - Seals
  - Gaskets
  - Adhesives
  - Cramps
  - Rivets
  - Pin connectors
  - Locks
  - Hinges
  - Bumpers
  - Air vents
  - Mergers
  - Connectors

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

Total elongation, %

Yield strength after paint bake, MPa

5030-T4
2008-T4

Primary application
- Inner
- Outer
△ Either
Automotive

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
- Corrosion 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

- 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

<table>
<thead>
<tr>
<th>Skin</th>
<th>Commercial and Transport</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard:</td>
<td>2024-T3</td>
<td>7475-T76</td>
</tr>
<tr>
<td></td>
<td>7475-T76 (thick)</td>
<td></td>
</tr>
<tr>
<td>Newly used:</td>
<td>2XXX-T3</td>
<td></td>
</tr>
<tr>
<td>Being evaluated:</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>
</tr>
<tr>
<td></td>
<td>GLARE©</td>
<td></td>
</tr>
</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.

![Toughness vs. Yield Strength Graph]

Constant ΔK Test:

Fatigue crack growth rate vs. crack length for C188-T3 and 2024-T3 alclad sheet tested at constant ΔK=25 ksi\sqrt{in.}, R=0.1, T-L, high humidity (R.H.>90%) air.

![Constant ΔK Test Graph]
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)

0.054 in. (1.4 mm)

Standard Constituent Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum sheet</td>
<td>2024 and 7475</td>
</tr>
<tr>
<td>Fiber</td>
<td>Aramid and glass</td>
</tr>
<tr>
<td>Prepreg</td>
<td>Unidirectional and cross-ply</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
- CYS = Compressive Yield Strength
- E = Modulus
- FAT = Fatigue
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Upper wing (Compression):
- Skins: CYS, E, FAT, FT, (Corrosion, FCG)

FCG = Fatigue Crack Growth
FT = Fracture Toughness
SS = Shear Strength
TS = Tensile Strength
**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>
<td></td>
</tr>
<tr>
<td><strong>Candidates for development:</strong></td>
<td>DRA</td>
<td>DRA</td>
</tr>
<tr>
<td></td>
<td>Al-Gr</td>
<td>Al-Gr</td>
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<tr>
<td></td>
<td>Al-Be</td>
<td>Al-Be</td>
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<tr>
<td></td>
<td>CRA</td>
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</tr>
</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>Standard:</td>
<td>2024-T3</td>
<td>7475-T73</td>
</tr>
<tr>
<td></td>
<td>2324-T39</td>
<td>2419-T8</td>
</tr>
<tr>
<td></td>
<td>2224-T3</td>
<td></td>
</tr>
<tr>
<td>Being evaluated:</td>
<td>8090-T8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7475-T76</td>
<td></td>
</tr>
<tr>
<td>Possible candidates:</td>
<td>ARALL</td>
<td>X7093-T73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Al-Li</td>
</tr>
</tbody>
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Lower wing (Tension):
Stringers: FAT, FT, TS, (Corrosion, FCG)