NEW DEVELOPMENTS IN ALUMINUM FOR AIRCRAFT AND AUTOMOBILES

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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>Reduction</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>
</tbody>
</table>

Total: 100%
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

CAR WEIGHT/EMISSIONS

LESS WEIGHT = LOWER EMISSIONS
# Aluminum Strength/Weakness versus Competitive Materials

<table>
<thead>
<tr>
<th>Al Strength vs Steel</th>
<th>Al Strength vs Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight effectiveness</td>
<td>Lightweight effectiveness</td>
</tr>
<tr>
<td>Corrosion Resistance</td>
<td>Stiffness</td>
</tr>
<tr>
<td></td>
<td>Recyclable</td>
</tr>
<tr>
<td></td>
<td>Ease of repair</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Al Weakness vs Steel</th>
<th>Al Weakness vs Plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>Design options</td>
</tr>
<tr>
<td>Ease of manufacturing</td>
<td>Corrosion resistance</td>
</tr>
<tr>
<td>Cost</td>
<td>Dent resistance</td>
</tr>
</tbody>
</table>
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
  - Connectors
  - Wire harnesses
  - Motors
  - Vacuum tubes
  - Air conditioning systems
  - Fuel systems
  - Electrical systems
  - Body panels
  - Chassis components
  - Axle components
  - Braking systems
  - Suspension systems
  - Steering systems
  - Tires
  - Mufflers
  - Exhaust systems

- 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

Primary application:
- Inner
- Outer

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

- Yield strength after paint bake, MPa
- Total elongation, %

- 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
- 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 ~150 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><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><strong>2XXX-T3</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Being evaluated:</strong></td>
<td><strong>6013-T6</strong></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><strong>GLARE©</strong></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.

Constant $\Delta K$ Test:

Fatigue crack growth rate vs. crack length for C188-T3 and 2024-T3 alclad sheet tested at constant $\Delta K=25$ 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)
- 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>
<tr>
<td>2024 and 7475</td>
</tr>
<tr>
<td>Aramid and glass</td>
</tr>
<tr>
<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

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

( ) = Important, but not critical, design requirement

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

**Upper Cover**

<table>
<thead>
<tr>
<th>Commercial and Transport</th>
<th>High Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard:</td>
<td></td>
</tr>
<tr>
<td>7150-T6</td>
<td>7475-T73</td>
</tr>
<tr>
<td>7150-T61</td>
<td>7050-T76</td>
</tr>
<tr>
<td></td>
<td>2124-T8</td>
</tr>
<tr>
<td>Newly used:</td>
<td></td>
</tr>
<tr>
<td>7150-T77</td>
<td></td>
</tr>
<tr>
<td>7055-T77</td>
<td></td>
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<tr>
<td>Candidates for development:</td>
<td></td>
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<tr>
<td>DRA</td>
<td>DRA</td>
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<tr>
<td>Al-Gr</td>
<td>Al-Gr</td>
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<tr>
<td>Al-Be</td>
<td>Al-Be</td>
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<tr>
<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.
<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>
<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><strong>Being evaluated:</strong></td>
<td>8090-T8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7475-T76</td>
<td></td>
</tr>
<tr>
<td><strong>Possible candidates:</strong></td>
<td>ARALL</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>X7093-T73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Al-Li</td>
</tr>
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( ) = Important, but not critical, design requirement

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