ALUMINUM EXTRUSION DESIGN AND THE ROLE IT PLAYS IN HIGH PERFORMANCE COOLING SOLUTIONS FOR POWER ELECTRONICS

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SAPA NORTH AMERICAN TECHNICAL CENTER
OUTLINE

● Introduction of Sapa Group

● Aluminum Extrusion Design
  ● Basic extrusion rules
  ● Extrusion tooling
  ● Heat sink ratio
  ● Surface finishing

● High Performance Cooling Solutions
  ● Friction Stir Welding
  ● Wide Heat Sinks
  ● Modular Heat Sinks
  ● Friction Stir Welded Liquid Coolers
SAPA GROUP

Sapa is the world leader in aluminium solutions – a new company that joined the aluminium extrusion businesses of Sapa and Hydro. Together, we are shaping a lighter future through a global reach and local presence within extrusions, building systems, and precision tubing. We have 23,000 employees in more than 40 countries, and our headquarters are located in Oslo, Norway.
Sapa Extrusions North America offers design, manufacturing, fabrication and finishing of aluminum extrusions through 23 facilities located across North America.
PROFILE DESIGN

What is the goal?
- Design the optimal profile that fulfills the demands of the application at the lowest possible cost.

To design the optimal profile, we must understand factors in production that increase costs.
PRODUCT DESIGN COST FACTORS

- Type of Profile
  - Solid
  - Semi-Hollow
  - Hollow

- Alloy / Temper
  - 6063 vs. 6061

- Wall Thickness
  - Thin? Thin to Thick?

- Tongue Ratio

- Tolerances
  - Standard AA vs. Tighter

- Cut Length
  - Long Lengths vs. Short Lengths

- Surface Finish
  - Anodize? Paint?
**PROFILES CLASSIFICATIONS**

- **Solid**
  - Low production cost
  - Low die cost

- **Semi-Hollow**
  - Tooling could break sooner
  - Higher material and die cost

- **Hollow**
  - Higher Material and Tooling Cost
  - Multi-Void hollows have the highest cost
CIRCLE SIZE DIAMETER
MINIMUM WALL THICKNESS

- Recommended minimum wall thickness for 6063 Alloy are shown in the guidelines. (Add 15% for 6061 Alloy)

- Sapa also offers specialty extrusions up to 5” diameter circle size with wall thickness as thin as 0.015” and as light as 0.007 pounds per foot.
GEOMETRY CONSIDERATIONS

- Symmetry
- Uniform wall thickness
- Large radii
- Tongue ratio reduction
- Incorporating useful features
  - ID Mark, drill points, screw slots, location/registration stops
GEOMETRY OPTIMIZATION

Creative improvements to tongue ratio

Ratio 4:1
Ratio 3:1
For Channel Widths Greater than .118 in.

Less Favorable
Good

Reduce the number of voids

Convert hollows to solid profile

Limit tongue ratio
HEAT SINK RATIO

- Fin height to gap ratio is typically limited to 16:1.
DAMAGED DIE
## SURFACE FINISHING

<table>
<thead>
<tr>
<th>Surface Treatment</th>
<th>Emissivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>As extruded</td>
<td>0.10</td>
</tr>
<tr>
<td>Clear anodize</td>
<td>0.78</td>
</tr>
<tr>
<td>Black anodize</td>
<td>0.85</td>
</tr>
<tr>
<td>White paint</td>
<td>0.90</td>
</tr>
<tr>
<td>Black paint</td>
<td>0.97</td>
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</tbody>
</table>
Aluminum heat sinks and liquid coolers have been widely used as cooling components in power electronics, LED lighting, computers, telecom devices, healthcare, automotive, etc.
ALUMINUM EXTRUSIONS

**Material Advantages**
- Recyclable and nontoxic
- Lightweight
- Strong
- Corrosion resistant
- **Thermally conductive**
- Reflective
- Electrically conductive
- Non-magnetic
- Non-sparking

**Process Advantages**
- Attractive
- **Finish options**
- Virtually seamless
- Complex integral shapes
- Easily assembled
- Weldable
- **Machinable**
- **Cost-effective**
- Short lead times
Copper (pure): 395 W/mK
EXTRUSION ALLOY VS. DIE-CAST ALLOY

Extrusion alloy 6063

Die-Cast alloy AlSi10
Friction Stir Welding is a solid-state joining method, which has been used in the welding of aluminum since 1991.
METHOD

- Weld tool probe
- Joint line
- Weld tool shoulder
- Work piece
- Weld path
- Exit point
FSW ALLOYS

Sapa alloys

Not heat treatable

Heat treatable

Not heat treatable

Heat treatable
APPEARANCE
CONFIGURATIONS
WELD STRUCTURE

- Fully re-crystallized fine grain micro-structure is created in the nugget by the intense plastic deformation at elevated temperature.
WELD STRENGTH

Mechanical properties

<table>
<thead>
<tr>
<th>SS-EN AW 6082</th>
<th>Yield strength $R_{p0.2}$ (MPa)</th>
<th>Tensile strength $R_m$ (MPa)</th>
<th>Elongation $A_{50,\text{mm}}$ (%)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>T6, parent material</td>
<td>291</td>
<td>317</td>
<td>11.3</td>
<td>ME, RS ³</td>
</tr>
<tr>
<td>Min. values for profile $t &lt; 5,\text{mm}$</td>
<td>250</td>
<td>295</td>
<td>6</td>
<td>SS-EN 755-2</td>
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<tr>
<td>Pulsed MIG</td>
<td>147</td>
<td>221</td>
<td>5.2</td>
<td>ME, RS ³</td>
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<tr>
<td>TIG</td>
<td>145</td>
<td>219</td>
<td>5.4</td>
<td>ME, RS ³</td>
</tr>
<tr>
<td>FSW, speed A ²</td>
<td>150</td>
<td>245</td>
<td>5.7</td>
<td>ME, RS ³</td>
</tr>
<tr>
<td>FSW, speed B ²</td>
<td>150</td>
<td>245</td>
<td>5.1</td>
<td>ME, RS ³</td>
</tr>
</tbody>
</table>

³ Mats Ericsson and Rolf Sandström, mean values of the results from their research report

² Speed A: 700 mm/min. Speed B: 1400 mm/min.

Fatigue strength

The above figure shows the results of the fatigue tests on MIG welds (●), TIG welds (●) and FSW joints (●).
HISTORICAL APPLICATIONS

- Structural panels
HISTORICAL APPLICATIONS

- Train Side Walls
ADVANTAGES OF FRICTION STIR WELDING

- No filler metal (parent metal conductivity)
- High tensile, fatigue, and bend properties
- Void free and leak proof
- Low thermal distortion and shrinkage
- Energy efficient
- Suitable for automation
- Cost Effective
WIDE HEAT SINKS

- FSW is used to join heat sink extrusions side by side to create wide heat sinks beyond our extrusion capabilities.
FSW MODULAR HEAT SINK*

*PATENT PENDING
FSW HEAT SINK VS. BONDED FIN HEAT SINK
METALLOGRAPHIC EXAMINATION
THERMAL TESTING SETUP
The thermal resistance of FSW modular heat sink is 8% lower than bonded fin design.

*The definition of thermal resistance: \( R_{th} = \frac{\Delta T}{Q} = \frac{T_{\text{hs base max}} - T_{\text{air inlet}}}{Q} \)
EXTRUDED FSW LIQUID COOLER*
METHOD

- The liquid cooler is sealed by friction stir welding the lids to the extruded body.
METALLOGRAPHIC EXAMINATION
PRESSURE TEST

- The liquid cooler can withstand burst pressure up to 90 bar.
THERMAL TEST SETUP

- Double-sided mounting with 1500 Watt per side
THERMAL RESISTANCE

![Graph showing thermal resistance vs. flow rate for water and water + glycol]
PRESSURE DROP

![Pressure Drop Graph]
SUMMARY

- FSW is used to join heat sink extrusions side by side to create wide heat sinks beyond our extrusion capabilities.

- High fin ratio heat sinks made by FSW provide very strong joints, improve product reliability, and deliver better thermal performance than bonded-fin heat sinks.

- Liquid coolers made by FSW and extrusion are an efficient and cost-effective means of cooling for high power devices.
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