Editors Note: This is Part I of a two-part series that discusses the forming of aluminum sheet for automotive products. Part II, to appear in the March/April 2013 issue of STAMPING Journal®, will discuss the lubricants used in aluminum forming.

Aluminum is used extensively for such automotive parts as hoods, trunk lids, and doors because of its light weight, workability, and recyclability, and its market share continues to increase.

**Commonly Used Alloys**
The 5xxx and 6xxx aluminum alloys are used most commonly for automotive applications. Their mechanical properties for automotive body sheets are listed in Figure 1, and their specific properties and main differences are shown in Figure 2.

The 5xxx alloys have ultimate tensile strength of 125 to 350 MPa and cannot be heat-treated. They have relatively good formability and are highly resistant to corrosion. However, 5xxx alloys are prone to the formation of Lüders bands during forming, so they are used mostly for inner-panel applications. 5182 and 5754 are the principal 5xxx series alloys used in autobody panels. 5754 also is recommended for elevated-temperature applications.

The 6xxx series alloys are heat-treatable to reach ultimate tensile strength of 125 to 400 MPa. The alloys, especially 6022 and 6111, often are used for outer panels since they are precipitation-hardened and free of Lüders bands.

**Design Guidelines and Requirements**
The key requirements for automotive closures are panel bending stiffness and dent resistance. The elastic modulus of aluminum (70 GPa) is about one-third that of steel (210 GPa). As a result, parts previously designed for steel need to be redesigned to achieve the same stiffness.

One way to improve stiffness in aluminum is to increase the ribbing used in the product or increase the part thickness. For closures and body-structure sheets, the thickness should be increased by a factor of about 1.45:\[ t_{aluminum} = \frac{3}{\sqrt{E_{steel} / E_{aluminum}}} = 1.44 \]

where: \( t = \) thickness
\( E = \) Young’s modulus
The resulting weight saving is about 50%:

\[ \frac{mass_{aluminum}}{mass_{steel}} = 1.44 \times \frac{YS_{steel}}{YS_{aluminum}} \]

Another important design criterion for aluminum alloys is dent resistance for static and dynamic conditions. To reach a static dent resistance comparable to steel’s, aluminum sheet should meet the following thickness requirement:

\[ t_{aluminum} \geq t_{steel} \times \sqrt{\frac{YS_{steel}}{YS_{aluminum}}} \]

Where: \( t = \) thickness
\( YS = \) yield strength

Figure 3 shows the aluminum sheet properties compared to those of steel, based on dynamic dent resistance studies. Figure 4 shows the weights of three different hoods made of mild steel, high-strength steel, and Al6016, respectively. For mild steel, the reduction in weight is limited by the dent resistance; for high-strength steel, it is limited by local stiffness. When the hood is made of Al6016, its weight can be reduced by 50 percent.

**Critical Material Parameters**
Some critical parameters are different for aluminum than steel, and they affect formability:
Elastic Modulus—With an elastic modulus one-third that of steel, aluminum parts experience more springback. This can be reduced by increasing the blank holder force, the amount of stretching, and sheet thickness. The forming operation must be optimized to ensure at least 2 percent stretch throughout the part (see Figure 5).

Friction—Friction between the tool and the aluminum sheet is expected to be higher compared to steel sheet because aluminum has a surface roughness (Ra) from 0.25 to 0.38 micron. In comparison, the Ra of steel sheet is about 0.63 to 0.88 micron. The smoother texture of aluminum requires dry, waxlike lubricants.

Formability—For the stamping of autobody parts, the lower formability of aluminum compared to steel can be offset to some extent by using technology such as advanced addendum design, local blank holder force control with multiple-point hydraulic cushions, or warm forming. Warm forming using heated dies and heated blanks has been investigated extensively, and recent studies have shown that the use of heated dies complicates the process and increases costs. Present R&D efforts are focused on heating the sheet to warm forming temperature while keeping the dies at room temperature.

Researchers hope to establish a practical and robust process that increases the formability of aluminum sheet for forming more complex parts with difficult geometries.

Tingting Mao is a graduate research associate and Taylan Altan is professor and director of the Center for Precision Forming (CPF) at The Ohio State University, 339 Baker Systems, 1971 Neil Ave., Columbus, OH 43210, 614-292-5063, www.cpforming.org and www.ercnsm.org.

Notes:

Automobile hood weight decreases substantially when Al6010 is used rather than steel. Source: Design with Aluminum (European Aluminum Association, 2011).

<table>
<thead>
<tr>
<th>Design Criteria</th>
<th>Specification</th>
<th>Mild Steel (YS = 200 MPa)</th>
<th>High-strength Steel (YS = 300 MPa)</th>
<th>Al 6016 (YS = 150 MPa)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dent Resistance</td>
<td>YS x t ≥ Cte</td>
<td>t ≥ 0.8</td>
<td>t ≥ 0.65</td>
<td>t ≥ 0.92</td>
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<tr>
<td>Local Stiffness</td>
<td>E x t ≥ Cte</td>
<td>t ≥ 0.7</td>
<td>t ≥ 0.7</td>
<td>t ≥ 1</td>
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<tr>
<td>Weight (kg)</td>
<td></td>
<td>14</td>
<td>12.4</td>
<td>6.1</td>
</tr>
</tbody>
</table>

* After Deformation and Paint Baking

Design Criteria Specification
Mild Steel (YS = 200 MPa) | High-strength Steel (YS = 300 MPa) | Al 6016 (YS = 150 MPa)*

Dent Resistance
Yield Strength x Thickness ≥ Cte

Local Stiffness
Young’s Modulus x Thickness ≥ Cte

Weight


Notes:

Automobile hood weight decreases substantially when Al6010 is used rather than steel. Source: Design with Aluminum (European Aluminum Association, 2011).