Introduction to Aluminum Use in Automotive

The Aluminum Association
Presenter

Russ Long

- Arconic
- Chief Engineer – Ground Transportation Products
**Day 1 AM Agenda**

- Objective: Provide introductory class on aluminum alloys and product forms typically applied in BIW and closure applications. Discussion and examples will compare steel applications to well designed aluminum applications. Specialty applications such as engine castings and transmission parts, aluminum cast or forged wheels, electrical distribution are not included.

1. Value of lightweighting
2. Common automotive aluminum uses
3. Potential weight savings
4. CAFE Overview
5. Current BIW and Closure applications
6. Alloy and temper designations
7. Corrosion
8. Aluminum Repair – “not harder, just different”
Day 1 PM Agenda

1. Aluminum Sheet Production – flowpath
2. Aluminum alloys commonly used for BIW and Closures
3. Sheet Properties
4. Yield, ultimate and elongations as received
5. Properties after paint bake
6. Natural aging
7. Formability measures
8. Joining – Spot welding, SPR, Adhesives, flow drill screws, etc.
9. Design example – aluminum hood, aluminum door
Day 2 AM Agenda

1. Extrusion process
2. Extrusion alloys commonly used in automotive applications
3. BIW components
4. Bumpers, crash boxes
5. Extrusion alloy properties
6. T4 versus T6 temper
7. Specialty alloys – crush, high strength for bumpers
8. Geometric limitations and guidelines for extrusion design
9. Design example – bumper
Day 2 PM Agenda

1. Foundry processes and castings evolution
2. Casting alloys and designation system
3. Foundry metallurgy essentials (101)
4. Permanent mold and die casting alloys
   - 356.2 series, 354, 355, 357, 359, 413
5. High Integrity Aluminum Structural Die Casting
   - Conventional vs. high pressure vacuum die castings
   - Case study
   - Requirements and factors affecting Thin Wall Structural Casting
   - Properties and tempers F-T4-T5-T6-T7
6. Joining
7. Modeling
8. Stress-engineering strain curves
Potential Weight savings with aluminum – D-class vehicle

- 10% reduction in curb weight gives a 6% improvement in fuel economy
- Initial customer focus is on advanced closure panels
- Customers now developing future aluminum intensive body structures due to greater mass savings potential

<table>
<thead>
<tr>
<th>Component</th>
<th>Steel (kg)</th>
<th>Aluminum (kg)</th>
<th>Typical Wt. Saving (kg)</th>
<th>% saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hood</td>
<td>16</td>
<td>8</td>
<td>8</td>
<td>50</td>
</tr>
<tr>
<td>Fenders</td>
<td>7</td>
<td>3.5</td>
<td>3.5</td>
<td>50</td>
</tr>
<tr>
<td>Deck lid</td>
<td>17</td>
<td>9</td>
<td>8</td>
<td>47</td>
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<tr>
<td>Doors</td>
<td>73</td>
<td>43</td>
<td>30</td>
<td>41</td>
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<tr>
<td>BIW</td>
<td>328</td>
<td>209</td>
<td>119</td>
<td>36</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>441</strong></td>
<td><strong>273</strong></td>
<td><strong>169</strong></td>
<td><strong>38</strong></td>
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</tbody>
</table>
All Aluminum Ford F-150 – Launched in 2015

Best in class gasoline fuel economy (19/26 mpg) – 2WD 2.7 L Ecoboost (6 speed)
2018 fuel economy (20/26 mpg) – 2WD 2.7 L Ecoboost (10 speed)

Best in class towing performance

700 - 890 lb lighter than 2014 steel model

America’s best selling vehicle for over 40 years

Contributes to CAFE improvement for the first time
2014 Steel F-150 VS. 2015 Aluminum F-150 Comparison

### Supercrew with 5.5 ft box
Length = 5890 mm
Wheelbase = 3670 mm

<table>
<thead>
<tr>
<th></th>
<th>Steel 2014 F150 (kg)</th>
<th>Aluminum 2015 F150 (kg)</th>
<th>Wt. Savings (kg)</th>
<th>% Savings</th>
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<tbody>
<tr>
<td>Hood</td>
<td>10.9 (Alum)</td>
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<td>3</td>
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<td>20</td>
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<td>60</td>
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<td>Tailgate</td>
<td>20</td>
<td>9.8</td>
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<td>51</td>
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<td>Doors (4)</td>
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<td>37.4</td>
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<tr>
<td>Cab</td>
<td>283</td>
<td>158</td>
<td>125</td>
<td>43</td>
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<tr>
<td>Cargo Box</td>
<td>105</td>
<td>60</td>
<td>45</td>
<td>43</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>524</strong></td>
<td><strong>294</strong></td>
<td><strong>231</strong></td>
<td><strong>44</strong></td>
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</tbody>
</table>


- Ford F150 is the largest selling vehicle in North America
- The P552 is a flagship vehicle
- Super Duty Trucks (F250, F350, F450) also in aluminum
Weight and Size History

- Vehicles have been getting larger, include more features and faster acceleration.
Fuel Economy Regulations – Worldwide

Conversion factor between fuel economy and CO₂ emissions:
- 8887 g CO₂ per gallon of gasoline
- 10180 g CO₂ per gallon of diesel
US Corporate Average Fuel Economy (CAFE) standards are size based

- How can auto OEMs get to 50 to 60 mpg? I don’t get near this fuel economy with my car!
US Corporate Average Fuel Economy (CAFE) – light truck targets

- What is a light truck?
Drivetrain Alone Cannot Provide the Fuel Savings Required by 2020

High Volume Auto Body Evolution

Evolution of auto design scenarios

MPG Requirements

Aluminum Intensive Vehicle
(Strength & ductility for safety, Robust joining)

Multi-Material

Steel & Aluminum Hybrid
(High scrap utilization, Steel to aluminum joining)

Aluminum Closures
(Increased formability for design/styling)

Tailoring Products
Closures

NA Penetration

Aluminum Closure Penetration

<table>
<thead>
<tr>
<th>Component</th>
<th>CY 2012</th>
<th>CY 2015</th>
<th>CY 2016</th>
<th>CY 2020</th>
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<tbody>
<tr>
<td>Hoods</td>
<td>50%</td>
<td>9%</td>
<td>50%</td>
<td>37%</td>
</tr>
<tr>
<td>Fenders</td>
<td>71%</td>
<td>29%</td>
<td>30%</td>
<td>23%</td>
</tr>
<tr>
<td>F Doors</td>
<td>5%</td>
<td>4%</td>
<td>7%</td>
<td>9%</td>
</tr>
<tr>
<td>R Doors</td>
<td>7%</td>
<td>7%</td>
<td>9%</td>
<td>7%</td>
</tr>
<tr>
<td>Trunk/Gate</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
<td>9%</td>
</tr>
</tbody>
</table>
Grumman LLV

US Postal delivery trucks

Began production in 1987:

Vehicle design life was 24 years and was extended to 30 years in 2009
Acura NSX

All aluminum – 1990-2005

2016 - present
2017 Ford Super Duty and Expedition/Navigator

Aluminum too!!
Audi Mixed Material Vehicles

Audi A8
Aluminum since 1994

Audi TT
Aluminum since 2008 (hybrid steel/alum)

Audi Q7 (hybrid steel/alum)
Aluminum since 2016

Audi R8
Aluminum since 2006
2016 Audi Q7 – Hybrid Steel/Aluminum

Body development – Lightweight design
Material mix details

- Al - sheet: 36%
- Steel conventional: 38%
- Al - casting: 12%
- Steel hot formed: 10%
- Al - extrusion: 4%

48% steel / 52% aluminum

Part based lightweight design to reach best efficiency.
Jaguar/Land Rover Aluminum Vehicles

- All Jaguar and Land Rover Vehicles will have aluminum BIW

Jaguar XJ
Aluminum since 2003

Jaguar XE
Aluminum since 2015

Range Rover Sport
Aluminum since 1970, 2013

Jaguar XF
Aluminum since 2008

Jaguar F Type
Aluminum since 2013

Jaguar F Pace
Hybrid steel/aluminum
Ferrari/Lamborghini Aluminum Vehicles

Ferrari 430
Aluminum since 1998

Ferrari 599
Aluminum since 2003

Lamborghini Gallardo
Corvette Stingray

Aluminum since 2013
Z series aluminum since 2006
Tesla Aluminum Vehicles – All Aluminum

Model S

Model X

Model 3

Hybrid steel aluminum BIW
Mercedes Benz – All Aluminum Vehicles

Mercedes Benz SL Roadster
Aluminum since 2013
110 kg lighter than steel body

Mercedes Benz AMG SLS Coupe
Aluminum since 2011
Mercedes Benz C-Class (2014 to present)

Material selection for add-on parts and outer skin

24.8 % aluminum
Mercedes Benz S-Class (2013 to present)

32% aluminum
Cadillac CT6 – Hybrid Steel/Aluminum

- 62% aluminum – 38% steel

Includes all aluminum closures
Chrysler Pacifica

Aluminum hood, sliding doors and liftgate (Mg cast inner)
2018 Jeep Wrangler

Aluminum hood and doors
2019 Silverado

Aluminum hood, doors and tailgate
RAM 1500

Aluminum hood and tailgate
Daimler Truck

Class 8 Cascadia cab
Aluminum since 1992

Business Class – M2 cab
Aluminum since 2001
True or False?:
1. US Government CAFE rules will result in all of us driving small cars.
2. US CAFE rules are more stringent than all other world areas.
3. Aluminum use alone can enable US fleets to meet all CAFE targets.

Will EPA/NHTSA dramatically reduce CAFE requirements?
2. What is a typical fuel economy reduction that can be achieved using lightweighting?
3. Are there vehicle classes that will likely use more aluminum?
4. Are aluminum cars as safe as steel cars in crash situations?
5. Do lighter vehicles improve overall fleet safety?
Questions?
Aluminum Alloy Designations

The Aluminum Association
Aluminum Alloy Classifications

• Aluminum alloys are categorized by two main groups
• Wrought alloys are further divided into two subgroups

Casting Alloys

Wrought Alloys

NON HEAT TREATABLE ALLOYS
Derive their properties from strain hardening (work hardening)

HEAT TREATABLE ALLOYS
Properties depend on age hardening
Some Examples of Alloy-Temper Designations:

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Temper</th>
</tr>
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<tbody>
<tr>
<td>1050</td>
<td>O</td>
</tr>
<tr>
<td>3003</td>
<td>H24</td>
</tr>
<tr>
<td>6111</td>
<td>T4</td>
</tr>
<tr>
<td>5052</td>
<td>H32</td>
</tr>
<tr>
<td>7075</td>
<td>T6</td>
</tr>
</tbody>
</table>

What does it all mean?
Let’s deal with alloy first....
Aluminum Alloy Designation and Nomenclature

- The Aluminum Association system was adopted in 1954

1. Alloy group
2. Identification of alloy, or aluminum purity
3. Modification of original or impurity limits
Aluminum Alloy Designation and Nomenclature

1. Alloy group

XXX

1xxx at least 99.00% aluminum (Al)
2xxx main alloying element is copper (Cu)
3xxx main alloying element is manganese (Mn)
4xxx main alloying element is silicon (Si)
5xxx main alloying element is magnesium (Mg)
6xxx main alloying elements are magnesium AND silicon (Mg and Si)
7xxx main alloying element is zinc, Zn (usually also magnesium, Mg)
8xxx alloyed with other elements (e.g. Fe, Li)

Non-heat treatable alloys
Heat-treatable alloys
The ‘catch all’ (mainly NHT, but some HT alloys also)
For the **1xxx alloys** (>99.00% Al) these two digits tell you the purity of the alloy.

The digits are the minimum Al content above 99%, examples:

- 1050  Al > 99.50%
- 1100  Al > 99.00%
- 1230  Al > 99.30%

For all the **other alloys** (non-1xxx) these two digits identify the alloy within the main alloy series, i.e. within 2xxx, or 3xxx, etc.

Generally arbitrarily assigned (although some alloys inherited the 2-digit alloy identifications existing prior to the Aluminum Association system adopted in 1954: 52S → 5052, 24S → 2024)
Aluminum Alloy Designation and Nomenclature

3. Modification of original or impurity limits

The first generation of the alloy is assigned the digit ‘0’
Example: 5083

The first modification of the alloy accepted by the Aluminum Association as being a substantive variation of the base alloy is assigned the digit ‘1’ Example: 5183

The next modification to the base alloy is assigned the digit ‘2’ and then the next again is assigned ‘3’ and so on: Examples: 5283, 5383, etc.

Note: If a variant of an alloy is not used for many years, it can be discontinued, and removed from the ‘Teal Sheets’
Aluminum Association ‘Teal Sheets’

### CHEMICAL COMPOSITION LIMITS

**Registered International Designation**

<table>
<thead>
<tr>
<th>Material</th>
<th>Fe</th>
<th>Cu</th>
<th>Mg</th>
<th>Zn</th>
<th>Ti</th>
<th>Ag</th>
<th>S</th>
<th>Si</th>
<th>Ga</th>
<th>Li</th>
<th>Pb</th>
<th>Al</th>
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<td>0.20</td>
<td>0.6</td>
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<td>0.1</td>
<td>0.1</td>
<td>0.03</td>
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</tr>
<tr>
<td>5086</td>
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<td>0.1</td>
<td>0.1</td>
<td>0.03</td>
<td>0.60</td>
<td>...</td>
<td>...</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>5454</td>
<td>0.01</td>
<td>0.1</td>
<td>0.1</td>
<td>0.03</td>
<td>0.60</td>
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<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
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</tr>
</tbody>
</table>

*Continued...*

**Others**

- **Excl.**
- **Total**
- **Min.**

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2018 Aluminum Association Design Seminar
Why So Many Alloys?

• Aluminum Alloy Development
• Answer: “Suitability for use”
  • Strength
  • Formability
  • Corrosion resistance
  • Toughness
  • Etc…
• Pure/commercially pure aluminum (1xxx) has many attractive properties and is used in many applications, but we add elements (alloying) to enhance properties, especially strength
• Blending the mixture of added elements (‘alloying’) can furnish the optimum combination of properties for the application (further enhanced by processing)
AA Temper Definitions

1050-O
3003-H24
6111-T4
5052-H32
7075-T6
AA Temper Definitions

Heat Treatable Alloy: “T” - tempers
“An alloy which may be strengthened by a suitable thermal treatment” 2xxx, 6xxx, 7xxx are heat-treatable. Examples: 2024-T3, 6061-T6

Non-Heat Treatable Alloy: “H” - tempers
“An alloy which can be strengthened only by cold work” 1xxx, 3xxx, 5xxx, and some 8xxx are non-heat-treatable. Examples: 3003-H19, 5052-H32
Basic Temper Designations

F  As-Fabricated (e.g. as-hot rolled, as-cold rolled)
O  Fully Annealed
Hxx Strain-Hardened  
   (NHT wrought products only)
W  Solution Heat-Treated (HT) and quenched (unstable)
Txx Thermal Treatment (HT)

F, O, and W are single digit temper designations, e.g. 6061-O, 7075-W, 3004-F

The H and T tempers have two or three further digits (and sometimes more) to describe the temper
Aluminum Alloy Temper Nomenclature: Non-Heat-Treatable Alloys

Most of these temper designations are in the form:

\[ H_{xx} \]

- **Strain hardened temper**

- **Condition**
  1 = Strain hardened only
  2 = Strain hardened and partial annealed
  3 = Strain hardened and stabilized
  4 = Strain hardened and lacquered or painted

- **Strength level**
  2 = Quarter hard
  4 = Half hard
  6 = Three quarters hard
  8 = Full hard
  9 = Extra hard
Heat Treat Temper Designations

F  As-Fabricated
O  Annealed
H  Strain-Hardened
    (wrought products only)
W  Solution Heat-Treated and Quenched
T  Thermal Treatment
    (Excluding F, O, or H)
The ‘T’ Tempers

- T1 cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.
- T2 cooled from an elevated temperature shaping process, cold worked, and naturally aged to a substantially stable condition.
- T3 solution heat-treated, cold worked, and naturally aged to a substantially stable condition.
- T4 solution heat-treated and naturally aged to a substantially stable condition.
- T5 cooled from an elevated temperature shaping process and then artificially aged.
- T6 solution heat-treated and then artificially aged.
- T7 solution heat-treated and overaged/stabilized.
- T8 solution heat-treated, cold worked, and then artificially aged.
- T9 solution heat-treated, artificially aged, and then cold worked.
- T10 cooled from an elevated temperature shaping process, cold worked, and then artificially aged.

Other digits may be added to signify additional processing:
e.g. Tx51 Stress-relieved by stretching
### OEM Specific Designations

- Most Auto OEMs purchase to one of their internal specifications
- For example: Ford

<table>
<thead>
<tr>
<th>Ford Spec</th>
<th>Typical Application</th>
<th>AA Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6EH</td>
<td>6xxx outer panel with enhanced hemming</td>
<td>6022, 6014</td>
</tr>
<tr>
<td>6DR1</td>
<td>6xxx exterior or interior</td>
<td>6022, 6016</td>
</tr>
<tr>
<td>6HS2</td>
<td>6xxx high strength</td>
<td>6111</td>
</tr>
<tr>
<td>6ST1</td>
<td>Alternative high strength</td>
<td>6061</td>
</tr>
<tr>
<td>5HF</td>
<td>5xxx High form</td>
<td>5182</td>
</tr>
<tr>
<td>5ST</td>
<td>5xxx standard</td>
<td>5754</td>
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</table>
OEM Specific Designations

- Most Auto OEMs purchase to one of their internal specifications
- For example: GM

<table>
<thead>
<tr>
<th>GM Spec</th>
<th>Typical Application</th>
<th>AA Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-S-6000-S-90</td>
<td>6xxx exterior panel</td>
<td>6022, 6014</td>
</tr>
<tr>
<td>Al-S-6000-IBR-100</td>
<td>6xxx exterior panel – improved paint bake</td>
<td>6022, 6016, 6451</td>
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<td>Al-S-6000-IH-90</td>
<td>6xxx exterior enhanced hemming</td>
<td>6014, 6016, 6022</td>
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<tr>
<td>Al-S-6000-HS-115</td>
<td>Alternative high strength</td>
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<td>Al-S-6000-R-110-U</td>
<td>6xxx reinforcement</td>
<td>6022-T4, 6016-T4</td>
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<tr>
<td>Al-S-5000-S-110</td>
<td>5xxx High form</td>
<td>5182</td>
</tr>
<tr>
<td>Al-S-5000-RSS-100</td>
<td>5xxx High form – reduced stretcher strain</td>
<td>5182</td>
</tr>
<tr>
<td>Al-S-5000-ST-90-90</td>
<td>5xxx Standard</td>
<td>5754, 5454</td>
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</tbody>
</table>
Aluminum Design Manual

- The aluminum design manual has useful information for design
- It is not set up for automotive design and does not include the alloys we have been discussing, it includes:
  - General bearing strengths,
  - Methods of calculating design allowables
  - Filler alloy selection guide
  - Typical welded joint strengths
  - Quick fatigue guides
## Table 7

**Nominal Densities of Aluminum and Aluminum Alloys**

Density and specific gravity are dependent upon composition, and variations are discernible from one cast to another for most alloys. The nominal values shown below should not be specified as engineering requirements but are used in calculating typical values for weight per unit length, weight per unit area, covering area, etc. The density values are derived from the metric and subsequently rounded.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Density (lbs/ft³)</th>
<th>Specific Gravity</th>
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</thead>
<tbody>
<tr>
<td>1050</td>
<td>0.975</td>
<td>2.705</td>
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<tr>
<td>1060</td>
<td>0.975</td>
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<td>1120</td>
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</tr>
<tr>
<td>2219</td>
<td>0.999</td>
<td>2.76</td>
</tr>
</tbody>
</table>

These values are not to be converted to the metric. X.XXX0 and X.XXX5 density values and X.XX0 and X.XXX5 specific gravity values are limited to 99.35 percent or higher purity aluminum.
### Table A.3.3M (Continued)

#### NOMINAL STRENGTHS OF WROUGHT ALUMINUM PRODUCTS

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Note (1): When worked cold (W.C.), S35S, or S65S alloy forfeit the listed properties for this temper. W.C. = work-softed cold.

Note (2): When worked cold (W.C.), S35S, or S65S alloy forfeit the listed properties for this temper. W.C. = work-softed cold.

Note (3): The mechanical properties at temperature 22°F (-30°C) are allowable in the quenched + tempered (Q+T) or T6 temper, as necessary, if the applicable 214 torsion property meets all of the respective T6 or T6S torsion property limits.

2018 Aluminum Association Design Seminar
# AA Design Manual – Selection of Weld Filler Alloys

## Table M.9.1: Weld Filler Alloys for Wrought Alloys

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1. This table is for structural application subject to normal machining conditions using GTAW or GMAW.
2. DNNW = Do not weld.
3. Filler in parenthesis are acceptable alternatives.
## AA Design Manual – Local Buckling Allowables

### Table B.4.2
BUCKLING CONSTANTS FOR TEMPER DESIGNATIONS BEGINNING WITH T5, T6, T7, T8, OR T9

<table>
<thead>
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<th>TYPE OF STRESS AND MEMBER</th>
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<th>SLOPE</th>
<th>INTERSECTION</th>
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<tr>
<td>Member Buckling</td>
<td>$B_r = F_r \left( 1 + \left( \frac{F_{cr}}{2250k} \right)^{0.2} \right)$</td>
<td>$D_r = \frac{B_r}{10} \left( \frac{F_{cr}}{E} \right)^{0.2}$</td>
<td>$C_r = 0.41 \frac{B_r}{D_r}$</td>
</tr>
<tr>
<td>Uniform Compression in Flat Elements</td>
<td>$B_r = F_r \left( 1 + \left( \frac{F_{cr}}{1500k} \right)^{0.2} \right)$</td>
<td>$D_r = \frac{B_r}{10} \left( \frac{F_{cr}}{E} \right)^{0.2}$</td>
<td>$C_r = 0.41 \frac{B_r}{D_r}$</td>
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<tr>
<td>Uniform Compression in Curved Elements</td>
<td>$B_r = F_r \left( 1 + \left( \frac{F_{cr}}{50,000k} \right)^{0.2} \right)$</td>
<td>$D_r = \frac{B_r}{4.5} \left( \frac{F_{cr}}{E} \right)^{0.2}$</td>
<td>$C_r = 0.80$</td>
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<tr>
<td>Flexural Compression in Flat Elements</td>
<td>$B_r = 1.3F_r \left( 1 + \left( \frac{F_{cr}}{340k} \right)^{0.2} \right)$</td>
<td>$D_r = \frac{B_r}{20} \left( \frac{6F_{cr}}{E} \right)^{0.2}$</td>
<td>$C_r = \frac{2B_r}{3D_r}$</td>
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<tr>
<td>Flexural Compression in Curved Elements</td>
<td>$B_r = 1.5F_r \left( 1 + \left( \frac{F_{cr}}{50,000k} \right)^{0.2} \right)$</td>
<td>$D_r = \frac{B_r}{2.7} \left( \frac{F_{cr}}{E} \right)^{0.2}$</td>
<td>$C_r = \left( \frac{B_r - B_r}{D_r - D_r} \right)^{0.2}$</td>
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<tr>
<td>Shear in Flat Elements</td>
<td>$B_r = F_r \left( 1 + \left( \frac{F_{cr}}{800k} \right)^{0.2} \right)$</td>
<td>$D_r = \frac{B_r}{10} \left( \frac{F_{cr}}{E} \right)^{0.2}$</td>
<td>$C_r = 0.41 \frac{B_r}{D_r}$</td>
</tr>
</tbody>
</table>

---

1. $k = 1.0$ ksi (6.89 MPa)
2. $C_r$ shall be determined using a plot of curves of limit state stress based on elastic and inelastic buckling or by trial and error solution.

**Figure B.5.1**
FLAT ELEMENTS SUPPORTED ON ONE EDGE

**Figure B.5.2**
FLAT ELEMENTS SUPPORTED ON BOTH EDGES
### Allowable Stresses

| Section | Axial Tension | Table 2-18W
<table>
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<tr>
<td></td>
<td>Allowable Stresses $F_{I/D} (k/in^2)$ for Building-Type Structures (Welded)</td>
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</tbody>
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#### Axial Tension

<table>
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<th>Section</th>
<th>Axial Tension</th>
<th>Allowable Stress $F_{I/D}$</th>
</tr>
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<tr>
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<td>on net effective area</td>
<td>15 k/in²</td>
</tr>
<tr>
<td></td>
<td>on gross area</td>
<td>15 k/in²</td>
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</table>

#### Shear or torsion

- **Shear or torsion rupture**
  - $G, H, 2$ : 7.4
  - $F_{I/D} = 15$ k/in²

- **Bolts or rivets on holes**
  - $J.3.a, J.4.6$ : 24.6
  - $F_{I/D} = 24$ k/in²

- **Bolts on slots, pans on holes**
  - $J.3.e.b$ : 16.4
  - $E = 10,100$ k/in²

- **Screws in holes**
  - $J.5.5.i, J.6$ : 16.0
  - $h_i = 1$

#### when welded with 5356 filler

<table>
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<tr>
<th>$k$</th>
<th>$F_{I/D}$ for $k &lt; k_h$</th>
<th>$F_{I/D}$ for $k_h &lt; k &lt; b$</th>
<th>$F_{I/D}$ for $k &gt; b$</th>
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<td>0.0085 + 10.5</td>
<td>333</td>
<td>51,350</td>
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<tr>
<td>0.0097</td>
<td>0.0085 + 10.5</td>
<td>333</td>
<td>51,350</td>
</tr>
</tbody>
</table>

#### Notes

- Allowable stresses for bolts, screws, and rivets are given for various combinations of axial and shear loads.
- The table includes formulas for calculating allowable stresses based on different sections and types of connections.
- The table also includes notes on material properties and welding specifications.

---

2018 Aluminum Association Design Seminar
### Minimum Bend Radii

#### Table 3-1

<table>
<thead>
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The radii listed are the minimum recommended for bending sheets and plates without fracturing in a standard press brake with air bend dies. Other types of bending operations may require larger radii or permit smaller radii. The minimum permissible radii will also vary with the design and condition of the tooling.
To Convert from Steel to Aluminum:

To Match Bending Stiffness:
- Since Modulus of aluminum is 1/3 of steel
  \[ I_{\text{alum}} = 3 \ I_{\text{steel}} \]

In most cases, the moment of inertia of aluminum parts can be roughly 2.5 \( I_{\text{steel}} \).
When was the last time you upgauged a steel part to reach a stiffness requirement?

To Match Bending Strength:
\[
S_{\text{alum} \sigma_y \text{alum}} = S_{\text{steel} \sigma_y \text{steel}}
\]
\[
S_{\text{alum}} = S_{\text{steel}} \left( \sigma_{y \text{steel}} / \sigma_y \text{alum} \right)
\]
- Density is 1/3, so significant weight savings are possible
Remember minor changes in section size can yield big gains

\[ A = bd - b1d1 \]

\[ I_{xx} = \frac{1}{12} \cdot ((bd^3 - b1d1^3)) \]

\[ I_{yy} = \frac{1}{12} \cdot ((db^3 - d1b1^3)) \]
Simple Example

Steel
- \( b = 60 \text{ mm} \)
- \( d = 40 \text{ mm} \)
- \( t = 2 \text{ mm} \)
- \( I_{xx} = 102272 \text{ mm}^4 \)
- \( I_{yy} = 193152 \text{ mm}^4 \)

Aluminum
- \( b = 60 \text{ mm} \) (hold because of packaging)
- \( d = 50 \text{ mm} \) (To increase stiffness – target 2x)
- \( t = 3 \text{ mm} \)
- \( I_{xx} = 241672 \text{ mm}^4 \) (2.36 x Steel)
- \( I_{yy} = 322632 \text{ mm}^4 \) (1.67 x Steel)
- Weight Savings = 45%
Rocker Example

Steel T=1.0

Moments of Inertia
\[ I_{xx} = 2360195 \text{ mm}^4 \]
\[ I_{yy} = 668175 \text{ mm}^4 \]

Aluminum T=2mm

Moments of Inertia
\[ I_{xx} = 5184127 \text{ mm}^4 \ (2.19 \ I_{xx} \text{ steel}) \]
\[ I_{yy} = 1451793 \text{ mm}^4 \ (2.17 \ I_{xx} \text{ steel}) \]

Weight savings = 35%

Moments of Inertia (Centroidal)
\[ I_{xx} = 5826014 \text{ mm}^4 \ (2.47 \ I_{xx} \text{ steel}) \]
\[ I_{yy} = 1835972 \text{ mm}^4 \ (2.75 \ I_{xx} \text{ steel}) \]
Roof Rail Example

Steel T=1.0

Moments of Inertia (Centroidal)
\( I_{xx} = 171111 \text{ mm}^4 \)
\( I_{yy} = 90610 \text{ mm}^4 \)

Aluminum T=1.5 mm

Moments of Inertia (Centroidal)
\( I_{xx} = 327830 \text{ mm}^4 \) (1.92 \( I_{xx} \) steel)
\( I_{yy} = 219817 \text{ mm}^4 \) (2.42 \( I_{yy} \) steel)

Weight savings = 45%
Questions?
Tell Us How We Did!

1. Open a browser on your laptop, tablet or mobile device

2. Visit: pollev.com/aasssociation001

3. Give us feedback!