Products – Automotive tubes

Table of contents

3 Automotive tubes ............................................................................................................................................. 2
  3.2 Types of aluminium tubing ......................................................................................................................... 2
  3.3 Links to properties, processes and fabrication of aluminium tubing ........................................................... 4
  3.4 Available forms and thicknesses .................................................................................................................. 5
    3.4.1 Specialty vs. standard tubing .................................................................................................................. 5
    3.4.2 Extruded tubes ....................................................................................................................................... 6
    3.4.3 Drawn .................................................................................................................................................... 10
    3.4.4 HF-welded (incl. Clad) ......................................................................................................................... 14
    3.4.5 Laser welded ......................................................................................................................................... 21
  3.5 Mechanical properties ................................................................................................................................. 24
    3.5.1 Mechanical properties of extruded, MPE, drawn and drawn & coated tubes ........................................... 24
    3.5.2 Mechanical properties of HF-welded tubes (selection of alloys) ........................................................ 25
    3.5.3 Mechanical properties of Laser-welded tubes ....................................................................................... 26
  3.6 Testing and forming ....................................................................................................................................... 27
    3.6.1 Free Expansion Test (Burst test) ............................................................................................................... 27
    3.6.2 Mandrel Test ......................................................................................................................................... 29
    3.6.3 Automotive Tubes – Endforming Operations ......................................................................................... 30
  3.7 Corrosion properties ..................................................................................................................................... 31
    3.7.1 Corrosion resistance of automotive tubes ............................................................................................... 31
    3.7.2 Design against corrosion ......................................................................................................................... 32
    3.7.3 Long Life Alloys (LLA) ......................................................................................................................... 33
    3.7.4 SWAAT test ......................................................................................................................................... 34
3 Automotive tubes

3.2 Types of aluminium tubing

See also:
- AAM – Applications – 1 Power train > Liquid lines > Applications
- AAM – Applications – 2 Chassis > Structure and components > Subframe / Rear axle > Subframe – BMW 5 Series
- AAM – Applications – 1 Power train > Heat exchangers

Tubes are defined as hollow semifinished products with a uniform cross-section over the total length, which are supplied in straight lengths or coil. The cross-section contains only a single hollow with uniform wall thickness.

Cross-sections are either circular or oval round, square, rectangular, regular sided triangular or polygonic.

Hollow shapes with uniform cross-section over the total length, but with non-symmetric cross-sections and uniform or non-uniform wall thicknesses are called profiles.

Aluminium tubes are produced by the following methods:
- Extrusion (through porthole dies)
  - s. standard EN 755-1, -2, -8
- Extrusion (by mandrel, seamless tubes)
  - s. standard EN 755-1, -2, -7
- Extrusion and drawing
  - s. standard EN 754-1, -2, -7, -8
- HF-welding of rolled strip
  - s. standard EN 1592-1, -2, -3, -4
- Laser welding of rolled strip
- Brazing tubes are supplied with a clad braze alloy (HF-welded tubes)
- Tubes are also supplied with external and/or internal coatings.
- Multiport extrusions (MPE) are for special purposes, e.g. heat transfer.

Aluminium tubes for automotive applications may be divided into
- functional tubes, i.e. pressurised or non-pressurised gaseous or liquid media guiding tubes
- structural tubes for load carrying structural members
Functional and structural use of aluminium tubes
3.3 Links to properties, processes and fabrication of aluminium tubing

See also:
- AAM – Materials – 5 Wrought materials production > Extrusion
- AAM – Materials – 6 Special materials production > Longitudinally welded tubes
- AAM – Materials – 5 Wrought materials productions > Automotive sheet > From ingot to strip and panel > Production of Brazing Sheet

Tube Properties

Tube properties depend strongly on the production method used and on alloy composition and temper. Alloys are tailored to the respective production methods and application requirements, e.g. "Long Life Alloys" for heat exchangers.
- Mechanical properties of extruded, drawn and MPE tubes
- Mechanical properties of HF- and Laser-welded tubes
- Corrosion properties

Tube Production Processes

For a description of the production process of tubes and their dimensional size limits:
- Extruded tubes ---- s. Production of extruded shapes
- HF- and Laser-welded tubes ---- s. Longitudinally welded tubes
- Clad welded tubes ---- s. Automotive sheet production - Roll bonding

Fabrication of Tube Components

Almost invariably, tubes are subjected to cold forming operations, i.e.
- bending --- s. Bending of tubes and shapes
- expanding,
- shrinking,
- variable geometries ---- s. Hydroforming
3.4 Available forms and thicknesses

3.4.1 Specialty vs. standard tubing

See also:
- AAM – Products – 3 Automotive tubes > Mechanical properties
- AAM – Products – 3 Automotive tubes > Testing and forming
- AAM – Products – 3 Automotive tubes > Corrosion properties

Standard and specialty tubing

While for standard tubing of all production types, forms, dimensions and thickness the limits and tolerances are represented in relevant standards, automotive tubing is mainly characterised by specifically selected alloys, dimensions and tolerances, which have been optimised or developed for special automotive applications.

As a rule, special manufacturing and processing procedures and investments were necessary to meet the requirements of the automotive customer, which are reflected in special testing procedures and property profiles.

In the following subchapters informative data are collected for the main categories of automotive tubing:
- Extruded single and multiple hole tubes or profiles for heat management purposes (e.g. heat exchangers),
- Drawn and drawn & coated tubes for liquid lines,
- HF-welded tubes for functional and structural use,
- Laser-welded tubular blanks for structural purposes.

For each of these tubings mechanical properties are listed in a subsequent chapter and examples are given which illustrate the types of applications for which the tube materials have been developed.
3.4.2 Extruded tubes

General

See also:
- AAM – Products – 2 Extruded products
- AAM – Products – 3 Automotive tubes > Mechanical properties
- AAM – Products – 3 Automotive tubes > Testing and forming

Extruded aluminium tubes are produced essentially by the following two methods:

▲ Extrusion through porthole dies (Fig. 1)
(s. standard EN 755-1, -2, -8)
The essential features (including round tubes as drawing stock, hollow profiles and multiport extrusion (MPE) are
- longitudinal pressure welds (generated in the porthole die)
- close concentric tolerances (compared to seamless tubes)

▲ Extrusion by mandrel (Fig. 2)
(s. standard EN 755-1, -2, -7)
The essential features are
- seamless tube wall (no pressure welds, homogeneous microstructure)
- larger concentric tolerances compared to porthole die extrusion
- shapes limited to concentric cross-sections

Alloy selection of tubes
for structural applications: s. Extruded products
for functional purposes:
s. Round tubes
s. Multiport extrusions
Extruded Round Tubes (for heat exchangers)

See also:
  - AAM – Products – 3 Automotive tubes > Mechanical properties

Characteristics

**Alloys**
- EN AW-3103 (Europe) or AA 3003 (USA)
- long life alloys (LLA)
- EN AW-6106
- EN AW-6005

**Dimensions**
outer diameter is typically 6-10 mm

**Available forms/shapes**
Inner diameter can be either smooth or enhanced by internal fins.

**Application**
Primarily in various types of 'mechanical expanded' type heat exchangers (condensers and evaporators).

Source: Hydro Aluminium
Multiport Extrusions (for heat exchangers)

See also:
- AAM – Products – 3 Automotive tubes > Mechanical properties

Characteristics
- Large internal surface enhances heat transfer
- Wide variety in shape and size
- MPE's are divided into micro and macro profiles

Alloys
- Micro: EN AW-1050, EN AW-1100, and EN AW-3102
- Macro: EN AW-3003

Dimensions

<table>
<thead>
<tr>
<th></th>
<th>height</th>
<th>width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Micro</td>
<td>1.8 - 3 mm</td>
<td>15 - 30 mm</td>
</tr>
<tr>
<td>Macro</td>
<td>2 - 8 mm</td>
<td>16 - 105 mm</td>
</tr>
</tbody>
</table>

Available forms/shapes
- Design, dimensions, and tolerances are tailored to customer requirements

Application: Various kinds of heat exchangers.

Source: Hydro Aluminium
3.4.3 Drawn

**Drawn tubes**

See also:
- AAM – Products – 3 Automotive tubes > Mechanical properties
- AAM – Products – 3 Automotive tubes > Testing and forming
- AAM – Products – 3 Automotive tubes > Corrosion properties

**Drawing process**

The inner and outer diameter of the tube are reduced to achieve the desired geometry. Drawing of extruded tubes is more cost effective than extrusion of small diameter tubes.

**Characteristics**
- Fine tolerances
- High surface quality
  (combined effect of lubricants on the mandrels and dies)

**Alloys** (mostly similar to extruded tubes):
- 3xxx (EN AW-3003, EN AW-3103)
- 5xxx (EN AW-5049)
- 6xxx (EN AW-6005, EN AW-6101, EN AW-6106)

**Dimensions**
- OD = typical 2 to 25 mm
- WT = typical 0.3 to 2 mm

**Available forms/shapes**
- Round, oval, flat oval, polygonal, hexagonal, and D form

**Applications**
- Heat exchangers; inlet/outlet tube; power steering
Typical applications

See also:
- AAM – Applications – 1 Power train > Liquid lines > Applications
- AAM – Applications – 1 Power train > Heat exchangers > Others

Typical applications of drawn tubes for automotive use are liquid lines and mechanically assembled heat exchangers or coolers.
Drawn and coated tubes

Application of coated tubes and alloys:
- transport of air, fuel, other fluids (fuel lines, power steering, etc.)

Coating
- Protective poly-amide coating. Tubes are extruded and precision drawn. Coating is co-extruded.

Application Characteristics
- internal cleanliness
- corrosion resistance
- resistance against stone impingement

Alloys and Applications
- EN AW-3103 for low-pressure (e.g. fuel lines)
- EN AW-6106 for high-pressure (e.g. power steering)

Mechanical properties:
Rm > 290 MPa ; Rp0.2 > 200 MPa ; A10 > 7%

Temperature resistance (limited by coating):
PA12 from −50 to 150 °C

Available forms/shapes

Dimensions
- outer diameter 4 - 22 mm
- wall thickness 0.5 - 1.8 mm
- coating thickness 150 - 500 µm
- Typical tube length 100 to 6000 mm

Source: Hydro Aluminium, Hycot ®
Tolerances
According to DIN EN 747-7

Fabrication properties

Coating:
coating is resistant to the stresses of bending and endforming

Bending radius properties:
dependent on tube radius and thickness, but typical 2 to 3 x OD

Burst pressure:
dependent on tube radius and thickness, but typical 600 to 1000 bar (for straight tube)
3.4.4 HF-welded (incl. Clad)

HF-welded tubes for thermal management applications

See also:
- AAM – Materials – 6 Special materials production > Longitudinally welded tubes
- AAM – Products – 3 Automotive tubes > Testing and forming
- AAM – Products – 3 Automotive tubes > Corrosion properties

Process
- HF-welding of roll formed strip

Characteristics
- Core alloys available with inner and outer claddings give possibility to combine a low melting point brazing alloy with a high strength core, and if required a corrosion resistant inner cladding

Alloys for thermal management
- core alloy: 3003; 3005; Long Life Alloy
- inner cladding: 4343, 4045, 4004
- outer cladding: EN AW-7072
- cladding thickness: 8-12%

Thermal management applications
Heat exchanger tubes and manifolds; dimple tube to cover low flow applications, thin tubes for single row radiators, thicker walled tubes for oil cooler and manifolds, short tubes for heaters, and tall wide tubes for charge air coolers.
THE Aluminium Automotive MANUAL
HF-welded tubes for structural applications

See also:
- AAM – Products – 3 Automotive tubes > Mechanical properties > Mechanical properties of HF-welded tubes (selection of alloys)

**Typical product applications** include: rear axle subframes, prop-shaft tubes, and tubes for engine cradles and space frames. These examples best demonstrate the key criteria for using longitudinally seam-welded tubes. The requirements on rear axle tubes, for example, mainly relate to formability and geometrical tolerances; these determine the suitability of the product for hydroforming.

Tubes used for other applications require high formability for bending and flaring operations. In contrast, propshafts tubes, for example, must meet tight tolerances for vibration-free rotation.

**Typical shapes:**
Normally tubes used for hydroforming processes have circular shaped cross sections due to the shape of the hydroforming axial punches. But a lot of further tube cross sections are available. For example, square cross sections or profiles with integrated grooves.

![Examples of Typical Cross-Sections and Weld Seam Position](image)

**Source:** VAW alutube GmbH, Hannover

**Diameter and thickness tolerances**

A longitudinally seam-welded tube achieves the tolerances of a drawn tube but without additional processing costs. The reason for this is that the tube stock, aluminium strip, gains its mechanical and geometrical properties from the continuous cold rolling process. The HF-seam welding process is also continuous and ensures constant wall thickness and very tight tolerances.

<table>
<thead>
<tr>
<th>Outside diameter including roundness [mm]</th>
<th>Tolerances</th>
<th>Guaranteed [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø 40 - 60</td>
<td>± 0.20</td>
<td>± 0.12</td>
</tr>
<tr>
<td>Ø 60 - 90</td>
<td>No details available</td>
<td>± 0.15</td>
</tr>
<tr>
<td>Ø 90 - 152.40</td>
<td>No details available</td>
<td>± 0.15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean outside diameter (d_{\text{mean}}) / 2 [mm]</th>
<th>Tolerances</th>
<th>Guaranteed [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ø 40 - 60</td>
<td>No details available</td>
<td>± 0.06</td>
</tr>
<tr>
<td>Ø 60 - 90</td>
<td>No details available</td>
<td>± 0.09</td>
</tr>
<tr>
<td>Ø 90 - 152.40</td>
<td>No details available</td>
<td>± 0.15</td>
</tr>
</tbody>
</table>

**Source:** VAW alutube GmbH, Hannover
Materials for precision forming of HF-welded tubes

In principle, longitudinally seam-welded tubes can be made from all wrought aluminium alloys. For automotive applications, however, non-heat-treatable AlMg(Mn) alloys (5xxx series) and age-hardening AlMgSi alloys (6xxx series) are preferred.

Non-heat-treatable or "work-hardening" alloys offer better forming behaviour, especially when they are in the soft (-O) temper; this temper requires annealing subsequent to tube manufacturing. These tubes are excellently suited for hydroforming processes as well as for other cold forming operations.

The table shows only part of the product range.

HF-welded tubes for high-strength applications

At reduced annealing temperatures and annealing times, so-called "partial annealing" takes place to give tempers (e.g. H24, i.e. half hard) which allow a compromise to be made between formability and strength for the particular tube. With no annealing, fully hard tempers (H18 / H28) with the highest strength are achieved.

Work-hardening tubes are strain hardened during cold forming processes. Annealing the tubes at around 350°C can reduce this strain hardening; the material then has the characteristic values of soft temper (O) again.

---

### Table: Wall thickness and High-frequency welded tubes

<table>
<thead>
<tr>
<th>Wall thickness [mm]</th>
<th>High-frequency welded tubes Standard [mm]</th>
<th>Guaranteed [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 - 1.5</td>
<td>± 0.08</td>
<td>± 0.06</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
<td>± 0.08</td>
<td>± 0.07</td>
</tr>
<tr>
<td>2.0 - 2.5</td>
<td>± 0.08</td>
<td>± 0.08</td>
</tr>
<tr>
<td>2.5 - 3.0</td>
<td>No details available</td>
<td>± 0.09</td>
</tr>
<tr>
<td>3.0 - 3.5</td>
<td>No details available</td>
<td>± 0.10</td>
</tr>
<tr>
<td>3.5 - 4.0</td>
<td>No details available</td>
<td>± 0.10</td>
</tr>
<tr>
<td>4.0 - 4.5</td>
<td>No details available</td>
<td>± 0.10</td>
</tr>
<tr>
<td>4.5 - 6.0</td>
<td>No details available</td>
<td>± 0.17</td>
</tr>
</tbody>
</table>

### Table: Length and Straightness

<table>
<thead>
<tr>
<th>Length [mm]</th>
<th>Wall thickness [mm]</th>
<th>Straightness [mm / m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>L ≤ 500</td>
<td>± 1.0</td>
<td>1.6</td>
</tr>
<tr>
<td>L 500 - 1,000</td>
<td>± 1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>L ≤ 3,000</td>
<td>± 1.5</td>
<td>0.5</td>
</tr>
<tr>
<td>L &gt; 3,000</td>
<td>± 2.0</td>
<td>Available on request</td>
</tr>
</tbody>
</table>

***Tolerances, when gauge-optimised strip is used.

---

**Source:** VAW alutube GmbH, Hannover
### Tube materials in partially or fully strain-hardened and/or age-hardened tempers for high strength structural applications

<table>
<thead>
<tr>
<th>Alloy Designation</th>
<th>EN AW-</th>
<th>Temper</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlMg2Mn</td>
<td>5454</td>
<td>H14 / H24</td>
</tr>
<tr>
<td>AlMg3Mn</td>
<td>5454</td>
<td>H16 / H26</td>
</tr>
<tr>
<td>AlMg3.5Mn(*)</td>
<td></td>
<td>H14 / H24</td>
</tr>
<tr>
<td>AlSi1MgMn</td>
<td>6062</td>
<td>T6</td>
</tr>
</tbody>
</table>

*) non-standard, proprietary to VAW alutubes GmbH

The table shows only part of the product range.
Application examples

See also:

- AAM – Applications – 2 Chassis > Structure and components > Subframe / Rear axle
  > Subframe – BMW 5 Series

Pistons for Air Suspension Systems
(DaimlerChrysler S-Class)

HF longitudinally seam-welded tubes are chosen as the base material for the production of air suspension pistons, because their consistent geometrical tolerances make it easier to meet the tight tolerance requirements of the finished part.

The initial diameter of the tube is the mean of the maximum and minimum diameters of the finished part.

The final shape is achieved by multiple expanding, reducing and flaring operations on three forming stations.

Example:

Alloy: AlMg2Mn0.8

Tube dimension: 82 x 1.5 mm

Manufacturer: VAW alutubes GmbH

Source: VAW alutube GmbH, Hannover

HF longitudinally seam-welded tubes for drive shafts of passenger vehicles

On rear–wheel and four-wheel-driven cars with front-mounted engines, the drive shaft is usually comprised of different components. Connecting parts, for example forgings, are normally joined to the longitudinally seam-welded aluminium tubes by means of friction welding.

Properties:
- Outstanding dimensional tolerances
- High degree of roundness
High degree of linearity
Low eccentric tendency

Example: Drive shaft - BMW 5 Series
Alloy: AlMg3Mn
Tube dimension: 60.5 x 3.5 mm
Manufacturer:
Tube: VAW alutubes GmbH
Finished part: BMW AG

Source: VAW alutubes GmbH, Hannover

Rear-Axle Subframe - BMW 5 Series

The MIG-welded subframe basically consists of 4 hydroformed HF-welded tubes and several sheet metal attachments.

Manufacturing steps:
- Rotary draw bending
- Pre-forming
- Hydroforming
- MIG welding

Advantages:
- Optimum use of space afforded by sophisticated cold formed shapes of tubes,
- Fully automatic manufacturing process due to consistant tube qualities.

Weight: 11.3 Kg
Lightest rear-axle subframe in its class
Alloy: AlMg3.5Mn
Tube dimension: 60.5 x 4 - 95 x 3.5
Manufacturer:
Tube: VAW alutubes GmbH
Finished axle: BMW AG

Source: BMW AG
3.4.5 Laser welded

Laser-welded tubes

See also:
- AAM – Joining – 1 Fusion welding > Laser beam welding
- AAM – Products – 3 Automotive tubes > Mechanical properties > Mechanical properties of Laser-welded tubes
- AAM – Products – 3 Automotive tubes > Testing and forming

Literature:
- Schaik M. van., Kägi, B.: Soutube®, a new way of tube manufacturing, Tube Int., May 1999
- Rempe, W.: Seam welded tubes for hydroforming and other forming processes, Tube Int, September 2000

Characteristics
- Laser welded tube developed for hydroforming of structural components.
- Laser welds can be longitudinal, spiral, or radial

Alloys
- typical body sheet alloys such as
  - EN AW-5182-O,
  - EN AW-5754-O,
  - AA 6016-T4,
  - AA 6111-T4

Dimensions
- Extended D/t Ratio up to 250
- Diameter (40-250) mm
- Customized Length and Wall Thickness (t = 0.6 - 3.0 mm)

Applications
- A-, B-, C-Pillar
- Roof Rail
Tubular forms
- cylindrical
- conical
- oval
- tailored

Sill
etc

Source: Soutube

Source: Soutube
3.5 Mechanical properties

3.5.1 Mechanical properties of extruded, MPE, drawn and drawn & coated tubes

Source: Hydro Aluminium

<table>
<thead>
<tr>
<th>Alloy EN AW-</th>
<th>Composition</th>
<th>Temper</th>
<th>Rm [MPa]</th>
<th>Rp0.2 [MPa]</th>
<th>A 1 [%]</th>
<th>Extruded</th>
<th>MPE</th>
<th>Drawn</th>
<th>Drawn &amp; Coated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1050</td>
<td>A900.5</td>
<td>O/H18</td>
<td>80-95 / 245</td>
<td>&gt;25 / &gt;8</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1100</td>
<td>A900.7</td>
<td>F/H12</td>
<td>not specified / spec. acc. to agreement</td>
<td></td>
<td>X</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>1110</td>
<td>AlCu0.12</td>
<td>F/H12</td>
<td>not specified / spec. acc. to agreement</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>1197</td>
<td>AlCu0.45</td>
<td>F/H12</td>
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</tr>
<tr>
<td>3003</td>
<td>AlMn1Cu</td>
<td>O/H18</td>
<td>95-130 / 180</td>
<td>&gt;25 / &gt;145</td>
<td>&gt;25 / &gt;8</td>
<td>X</td>
<td>X</td>
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<tr>
<td>3102</td>
<td>AlMg0.2</td>
<td>F/H12</td>
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<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLA</td>
<td></td>
<td>F/H12</td>
<td>&gt;65</td>
<td>&gt;45</td>
<td>&gt;22</td>
<td>X</td>
<td>X</td>
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<td></td>
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<tr>
<td>5103</td>
<td>AlMn1</td>
<td>O/H18</td>
<td>95-130 / 180</td>
<td>&gt;25 / &gt;145</td>
<td>&gt;25 / &gt;8</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5096</td>
<td>AlMg/Mn0.8</td>
<td>O/H18</td>
<td>&gt;100 / &lt;100</td>
<td>&gt;80 / &gt;17</td>
<td>&gt;17 / &gt;2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6005</td>
<td></td>
<td>T6</td>
<td>260-300</td>
<td>240-260</td>
<td>8.12</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8101</td>
<td>AlMgSi1</td>
<td>F/T4</td>
<td>&gt;180</td>
<td>&gt;80</td>
<td>&gt;17</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8102</td>
<td>AlMgSi1</td>
<td>T6/2</td>
<td>&lt;320</td>
<td>&gt;8</td>
<td>&gt;8</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>8108</td>
<td>AlMgSi0.5</td>
<td>F/T4</td>
<td>&gt;180</td>
<td>&gt;80</td>
<td>&gt;17</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Hydro Aluminium
## 3.5.2 Mechanical properties of HF-welded tubes (selection of alloys)

### HF-welded tubes

Source: VAW alutube GmbH

<table>
<thead>
<tr>
<th>Alloy Designation</th>
<th>EN AW</th>
<th>TEMPER</th>
<th>Rm [MPa]</th>
<th>Rp0.2 [MPa]</th>
<th>AS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1Mg3</td>
<td>5754</td>
<td>O</td>
<td>60</td>
<td>180</td>
<td>26</td>
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<tr>
<td>A1Mg4</td>
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<td>O</td>
<td>90</td>
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<td>18</td>
</tr>
<tr>
<td>A1Mg5 Mini *)</td>
<td>5454</td>
<td>T</td>
<td>115</td>
<td>240</td>
<td>18</td>
</tr>
<tr>
<td>A1Mg4.5Mn0.4</td>
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<td>O</td>
<td>115</td>
<td>255</td>
<td>23</td>
</tr>
<tr>
<td>A1Mg4.5Mn0.7</td>
<td>5685</td>
<td>O</td>
<td>125</td>
<td>275</td>
<td>18</td>
</tr>
</tbody>
</table>

*) non-standard, proprietary to VAW alutube GmbH

### Tube materials in partially or fully strain hardened and/or age-hardened tempers for high strength structural applications

<table>
<thead>
<tr>
<th>Alloy Designation</th>
<th>EN AW</th>
<th>TEMPER</th>
<th>Rm [MPa]</th>
<th>Rp0.2 [MPa]</th>
<th>AS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1Mg5Mn0.4</td>
<td>5454</td>
<td>H14/H24</td>
<td>200</td>
<td>270</td>
<td>8</td>
</tr>
<tr>
<td>A1Mg5Mn0.5</td>
<td>5454</td>
<td>H13/H28</td>
<td>240</td>
<td>280</td>
<td>6</td>
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<tr>
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<td>5182</td>
<td>H14/H24</td>
<td>270</td>
<td>310</td>
<td>8</td>
</tr>
<tr>
<td>A1Mg5Mn0.4</td>
<td>5685</td>
<td>T</td>
<td>200</td>
<td>310</td>
<td>7</td>
</tr>
</tbody>
</table>

*) non-standard, proprietary to VAW alutube GmbH
3.5.3 Mechanical properties of Laser-welded tubes

Source: Corus Group

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Composition</th>
<th>Temper</th>
<th>$R_m$ [Mpa]</th>
<th>$R_s [Mpa]$</th>
<th>$A_{el}$ [%]</th>
<th>$A_u$ [%]</th>
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</thead>
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<tr>
<td>5051A</td>
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<tr>
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<td>O/H111</td>
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<td>100</td>
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<tr>
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<td>AlMg3</td>
<td>O/H111</td>
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<td>6083</td>
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<td>O/H111</td>
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<tr>
<td>5182</td>
<td>AlMg4.5Mn0.4</td>
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<td>110</td>
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</table>
3.6 Testing and forming

3.6.1 Free Expansion Test (Burst test)

Test Method

In the Free Expansion Test the tube is filled with a fluid, sealed, and pressurized (P). No axial force is given on the tube.

The radial expansion is defined as:

\[ S = \frac{(D-D_0)}{D_0} \times 100\% \]

The test was development[1] as a standard test for critical tubular products like automotive tubes.

Figure below:

Results of Free Expansion Test for different manufactured tubes in comparison with steel tubes

[1] developed in "Arbeitskreis: Materialprüfung in der IHU" at the TU-Darmstadt (PTU)

Burst Test Schematic
(Figure below)

Characteristics:

\[ \wedge \text{ Uniform elongation in circumference direction } \% \],
\[ \wedge \text{ Max. expansion in radial direction } S \text{ in } [\text{mm}] \]
Figure below:
**Samples** of Free Expansion tested laser welded aluminum tubes (d = 60 mm, t = 1,5 mm) with failure in the base metal (upper) and with failure in the weld (lower).

*Source: Corus*

**Free Expansion Test Machine for Tubes**
3.6.2 Mandrel Test

Mandrel Tube Test

Test for the evaluation of tube expansion capability and longitudinal weld quality in welded tubes.

The mandrel is pushed axially into the tube opening, and the maximum expansion without cracking is measured.

The result is expressed as expansion which is defined as

\[ \frac{(D-D_0)}{D_0} \times 100\% \]

Test standard acc. to DIN EN 10234

Test parameters
- top angle 60°
- sample height 80 mm
- pressure force 1000 kg

Schematic of test set-up and procedure: (below)

Test sample: (below)

Source: Corus
3.6.3 Automotive Tubes – Endforming Operations

To accommodate connections for automotive tubes, some form of endforming operation is typically required. Shown below are the most common operations; expanding, reducing, flaring, and beading.

The figure (below) shows some examples of typical tube endforms. Some endforms require multiple forming operations.

Source: Hydro Aluminium
3.7 Corrosion properties

3.7.1 Corrosion resistance of automotive tubes

Corrosion resistance of automotive tubes is one of the key requirements for their use in pressurised and non-pressurised liquid and gaseous media lines, such as heat exchangers, air conditioning systems. Especially in safety relevant applications like power steering and brake lines corrosion resistance is a prerequisite for safe life and reliability.

Aluminium alloy and coating systems have been developed to meet these demands.

The following examples described in this section illustrate the state of the art.

- Design of alloy systems for optimum corrosion resistance of brazed heat exchangers.
- Long Life Alloys developed for heat exchanger applications
- Coated tubes for liquid lines as tested by standard SWAAT test
3.7.2 Design against corrosion

In the design against corrosion of a heat exchanger the alloy composition of each of the components is tailored so as to direct corrosion attack to the least harmful part. In a heat exchanger the least harmful part is the fin and joint fillet, so these parts are designed to become sacrificial to the tube.

Figure (below): After 10 days of SWAAT test, there is no contact anymore between tube and fin in the poor corrosion design, whereas after 30 days the component is still intact in the good corrosion design.

![Corrosion Design Diagram](Source: Hydro Aluminium)

Figure (below): Individual components of a heat exchanger.
3.7.3 Long Life Alloys (LLA)

Long Life Alloys are developed to have improved corrosion resistance over conventional tube alloys, with other properties on a similar level.

Application:
- Automotive thermal management applications, to replace Zn sprayed or coated tubes.

Advantages:
- Avoid chromating (environmental issue)
- Cost saving by avoiding Zn spraying or coating
- Definition: withstand 20 days in SWAAT test

The improved corrosion performance is achieved by:
- Directing corrosion attack; lateral corrosion attack instead of pitting. See figures.

To make optimal use of the improved intrinsic corrosion resistance of Long Life Alloys, a good corrosion design is needed.
The figure (below) shows differences in corrosion behaviour between Long Life Alloy and standard EN AW-3103 alloy.

Source: Hydro Aluminium
3.7.4 SWAAT test

The SWAAT test is used for the ranking of corrosion performance of samples (tubes) or components (heat exchangers).

SWAAT is an accelerated test due to aggressive environment with a pH of 2.8 – 3.0 and a temperature of @ 50 °C.

For components the requirement of the automotive industry is to withstand 40 days (test conditions according to ASTM standard G85-A3).

Evaluation:
- mechanical properties;
- time to leak;
- metallurgical;
- pit depth;
- mass loss

Figure (below):
Typical coated tube sample before and after SWAAT test.

![Typical coated tube sample before and after SWAAT test.](Source: Hydro Aluminium)

Figure (below):
Typical bare tube sample before and after SWAAT test.

![Typical bare tube sample before and after SWAAT test.](Source: Hydro Aluminium)