# Materials – Special materials production

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6 Special materials production

6.1 What to find in this section

The portfolio of light weight aluminium products comprises a great variety of long known or more exotic product lines which may be termed special due to their unique production technology or due to the specific application requirements, for which they were developed.

This section describes some of these special products and their production methods, which are already or will be used more readily in the future for special automotive components. You will find information on

- HF tube welding and tube materials,
- Production of metal matrix compounds (MMC),
- Aluminium-PP laminates,
- Various aluminium foam production methods,
and some initial information on
- Tailor welded blanks (TWB).

HF-welded tubes

SiC reinforced MMC
Cylinder liners from spray compacted materials: candidate for MMC

Floor panel from laminates (Hylite)

Aluminium foam filled extruded tube
Tailor welded blank stamping (Ford P2000)
6.2 Longitudinally welded tubes

See also:
- AAM – Manufacturing – 3 Forming > Bending
- AAM – Manufacturing – 3 Forming > Hydroforming (tubes)
- AAM – Products – 3 Automotive tubes > Available forms and thicknesses > HF-welded (incl. Clad)
- AAM – Products – 3 Automotive tubes > Available forms and thicknesses > Laser welded

6.2.1 Production of HF-welded tubes for structural applications

Longitudinally welded tubes serve as starting stock for structural applications, especially in the area of the chassis. Welded tubes were specifically developed to meet the requirements of hydroforming but are also suitable for other fabrication processes. Compared with extruded tubes, longitudinally welded tubes reflect the good material properties of sheet material concerning formability and very tight tolerances.

Two kinds of longitudinally welded tubes are available:
1. High-frequency-welded aluminium tubes
2. Laser-welded aluminium tubes

This section describes the manufacturing process for HF-welded tubes.
6.2.2 Production process for HF-welded tubes

Literature:

N.N.: Precision tubes, VAW alutubes GmbH, Hannover, 2001

Longitudinally welded tubes are made from rolled sheet metal coils in a continuous process at high speed.

The production sequence is as follows:
1. Coils are slit into suitably narrow strips by roller shears,
2. Strip edges are cleared,
3. Coil is formed into a split tube by multistage roll-forming,
4. Longitudinal resistance welding of the split tube occurs in a high frequency coil inductor under the pressure of upsetting rolls.
5. After welding, the external and, if required, internal weld bead is removed.
6. After exiting the cooling station the tube passes a multistage calibration station.
7. A flying saw cuts the tubes into the desired length.
8. The tubes are then put into racks by an automatic stracker for subsequent shipment or heat treatment.

![Production line for longitudinally welded tubes at VAW alutubes GmbH, Germany]
6.2.3 HF-welded tubes process – Technical data

Range and dimensions for large longitudinally welded aluminium tubes:

- Outside diameter range: Ø 40 - 152 mm
- Wall thickness range: 1.0 – 6.0 mm
- Mill lengths: 3000 – 6880 mm
- Tube welding speeds: 30-120 m/min
- Standard cut lengths: 100 – 3000 mm

Production line for longitudinally welded tubes at VAW alutubes GmbH, Germany
6.2.4 HF induction seam welding

Heating of the mating edges of the joint is achieved by a **Coil-Inductor** operating at frequencies up to 450 kHz.

![Schematic of HF induction seam welding process](image)

Because of the "skin effect" the welding current is concentrated on the surface, i.e. the depth of heating is small. Therefore, induction welding is preferred for applications of thin wall tubes.

**Characteristics of the process:**
- No mechanical contact; therefore no wear of the inductor,
- No filler required,
- Low heat input,
- Narrow heat affected zone,
- Little thermal influence on parent metal properties,
- Suitable for joining alloys sensitive to hot cracking.

The heat affected depth in HF induction welding depends inversely on the current frequency as shown in the diagram below.

![Heat affected depth as a function of HF current frequency](image)
6.3 Metal Matrix Composites

6.3.1 Metal Matrix Composites

See also:
 AAM – Applications – 2 Chassis > Brake system > Discs and drums

Aluminium-based Metal Matrix Composites (MMC) are increasingly becoming recognised as attractive alternative materials to aluminium alloys and other materials requiring increased stiffness, wear resistance, and strength.

Other attributes include alterations in mechanical behaviour (e.g. tensile and compressive properties, creep, notch resistance, and tribology). Physical properties of density, thermal expansion, and thermal diffusivity all can be an advantage in designing castings and extrusions from aluminium based MMC materials.

Typical reinforcements include aluminium oxide, silicon carbide, graphite, fly-ash, and aluminosilicates. All can be used in a wide range of aluminium alloys.

Main categories of aluminium metal matrix composites:
 Powder Reinforced Composites
 Fibre Reinforced Composites.

Methods of Manufacture
 Mixing/ Vortex
 Infiltration
 Rheocasting
 Powder Metallurgy
 Spray Atomisation/Codeposition
 In-Situ Production

These methods are briefly described in this chapter.
6.3.2 Methods of manufacture – Mixing/Vortex method

In the mixing / vortex method the filler phase is introduced in a stirred molten matrix and then cast either as a foundry pig or a DC billet for extrusion and or rolling.

The use of an inert atmosphere and or a vacuum is necessary to avoid the entrapment of gases.

Mixing can be done by an impeller, ultrasonically, or reciprocating rods.

Example:

AA 359 matrix with 20 vol.-% SiC

Source: Alcan
6.3.3 Methods of manufacture – Infiltration and In-Situ-production

Infiltration

This process involves the infiltration of a final-product-shape ceramic pre-form by a molten alloy. The pre-form is normally formed by pressing, slip casting, joining, or injection moulding. The molten metal infiltrates through the pre-form and oxidizes or chemically reacts with the pre-form material. The final composite phases consist of the oxidation (or reaction) products and the remaining matrix material.

The particle density depends on the pre-form density. Normally SiC is used for foundry alloys and aluminium oxide for wrought alloys.

In-Situ Production

Many processes can be used to produce in-situ MMC. Usually theses include the formation of compounds and their decomposition, phase changes, redox reactions, nucleation, and recrystallization.

A typical example is the addition of sand to aluminium producing a reaction to aluminium oxide.
6.3.4 Methods of manufacture – Rheocasting

Rheocasting is another stir cast method, whereby the particulate or fibers are agitated into a solidifying, highly viscous, and thixotropic dendritic slurry of the molten matrix. High shear rates are needed to bond the matrix and the filler. Extremely low viscosities are obtained. Consequently, only very low vol.-% of particles or fibres can be used in the process.

Example:

AA 359 matrix with 20 vol.-% SiC

Source: Alcan
6.3.5 Methods of manufacture – Powder Metallurgy

**Powder metallurgy** involves thoroughly mixing aluminium alloy powder with the particulate or fibre, compressing both into a billet and forging or extruding the product to shape.

The advantage of this route is that smaller particulate can be used and large particulate will allow greater vol.-% concentrations.

Methods of compaction are varied and can include:
- single compaction,
- double compaction, and
- mechanical deformation following hot pressing as well as hydrostatic and isostatic compaction.

**Example:**

AA 359 matrix with 20 vol.-% SiC

Source: Alcan
6.3.6 Methods of manufacture – Spray Atomisation / Codeposition

The Spray-Atomisation/Co-deposition process involves the incorporation of the fine ceramic particulate in inert-gas atomised droplets of the molten matrix. The matrix contains both the solid and liquid phases. This material is usually finely dispersed in droplets by the high-velocity spray of inert-gas jets. The solid mixture is usually collected on a non wetting substrate in the form of a reinforced composite mass. This process lends itself to a wide range of aluminium alloys.

The figure shows a schematic of the Ospray process.
6.4 Laminates / Sandwiches

6.4.1 Aluminium sandwich sheet (Example: Hylite™)

Sandwich Sheet
Hylite is a laminate material comprising two thin aluminium layers with a plastic layer in between. It was originally developed for non-load bearing car body parts (bonnet, boot lid, roof). However, the combination of considerable flexural stiffness and extreme lightness also makes it interesting for car body construction.

Choice of Material
Compared to steel sheet with the same flexural stiffness (0.74 mm) and aluminium (1.0 mm) Hylite is 65% and approximately 30% lighter respectively. This result has been obtained by uniting the best properties of aluminium and plastic in a single material, with the aluminium on the outside and a light plastic filling inside. Polypropylene (PP) was chosen for the filling.

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Hylite</th>
<th>Aluminium</th>
<th>SMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness (mm)</td>
<td>0.74</td>
<td>0.2/0.8/0.2</td>
<td>1.06</td>
<td>2.04</td>
</tr>
<tr>
<td>Weight (kg/m²)</td>
<td>5.8</td>
<td>1.8</td>
<td>2.9</td>
<td>3.9</td>
</tr>
<tr>
<td>Flexural stiffness (kNmm)</td>
<td>7.1</td>
<td>7.1</td>
<td>7.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Max. elongation %</td>
<td>36-40</td>
<td>18-20</td>
<td>20-25</td>
<td>-</td>
</tr>
<tr>
<td>Rel. dent resistance %</td>
<td>100</td>
<td>80</td>
<td>90</td>
<td>&gt;100</td>
</tr>
</tbody>
</table>

Comparison of mechanical properties based on equal flexural stiffness

Hylite Sandwich Properties
(1.2 mm thickness, soft aluminium outer layers)
Weight 1.8 kg/m²
Maximum stretch 22 %
Plain strain stretch 18 %
Peel strength 4 N/mm
Flexural stiffness 7.1 kNmm (equal to 0.74 mm steel and 1.06 mm aluminium sheet)
Aluminium yield point 140 MPa
Aluminium tensile strength 280 MPa
Shape retention to 150 °C (for 30 minutes)
Expansion coefficient 28*10⁻⁶/K
Heat conduction 0.3 W/mK
Deep drawing also possible on soft tools

With a view to the design processes currently used in the motor industry and the minimum steel thickness required, an aluminium layer of 0.2 mm has been chosen with an inner layer of 0.8 mm. The Hylite laminate can now be made in various gauges with a maximum width of 1540 mm and a maximum thickness of 2.5 mm. The manufacturing process is set up in such a way that the thickness ratio - and therefore also the stiffness, dent resistance and formability - can be adjusted depending on the application.
6.4.2 Application concept / roof panels

Hylite offers a unique integrated roof concept that consists of a sandwich panel of 2.44 mm thickness, adhesively bonded to the car structure as if it were a glass panel. A rubber strip for edge finish is injection moulded onto the finished part.

![Construction concept Hylite roof panel](image)

For the NedCar ACCESS concept car the 2.44 mm Hylite sheet (with aluminium skins of 0.22 mm) has been put into shape by stretch forming; for series production this will normally be done by conventional deep drawing.

The ACCESS roof has a net surface area of approx. 1.7 m² and weights only 5.1 kg. The stiffness of the roof panel is so high, that reinforcements are not needed. The weight of the 'traditional solution', which is a steel outer panel of 0.8 mm married with an inner panel, would be at least 15 kg. In addition the Hylite roof concept requires less tooling then the conventional solutions.

**Performance**

With this concept both an extremely high flexural rigidity and stiffness in the roof are achieved as well as very high torsional stiffness in the total body frame at very low weight. Also the very high dent resistance is a major feature of the Hylite roof concept.

![Diagram of Hylite roof panel](image)

**Production logistics**

A ready to assemble roof as sketched above fits extremely well in a space frame concept. The ideal is a concept where a completely pre-painted roof is added as a subassembly in one of the latest stages of assembly. This ensures a maximum accessibility of the interior of the car during assembly.

The production of the roof can be completed off-line, including addition of the interior lining.
Product Properties
Sheet thickness 2.44 mm
Al-skin thickness 0.22 mm
PP core thickness 2.00 mm
Structural rigidity 38.5 kNmm
Weight 3.0 kg/m²

Cost
Due to the simplicity of the roof concept and especially due to the reduced number of tools required, a considerable cost saving may be achieved.

<table>
<thead>
<tr>
<th>REFERENCE CALCULATION (ACCESS BODY)</th>
<th>Torsion Stiffness Body</th>
<th>Max Bending Body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body with 1.2 mm aluminium roof, welded with middle header</td>
<td>16167 100%</td>
<td>0.796 100%</td>
</tr>
<tr>
<td>Body without roof with middle header</td>
<td>12858 80%</td>
<td>0.809 101%</td>
</tr>
<tr>
<td>Body with 2.4 mm Hyllite roof, thickness of adhesive 2 mm, without middle header</td>
<td>14244 90%</td>
<td>0.811 101%</td>
</tr>
</tbody>
</table>
6.4.3 Examples

Examples of application of sandwich sheet in structural applications

Floor panel for compact-class car (see figure)

Material specification:
- Total sheet thickness 1.4 mm, aluminium skin 0.24 mm
- Deep draw quality
- Weight reduction 40%

Floor panel for small car (see figure)

Material specification:
- Total sheet thickness 2.0 mm, aluminium skin 0.2 mm
- Hard skin; flat application
- Weight reduction 45%

Hylite floor panel in space frame
6.4.4 Process development outer panels

From flat sheet to car bonnet in 10 operations

The process operations for the Hylite bonnet are very similar to those for steel. To produce the steel bonnet, 10 processing operations are required, which are determined by the complexity of the design. To make a well-defined hem in steel, it takes six process operations. In the case of Hylite it takes two preparatory ribbing operations, followed by four hemming operations.

The process pre-validation of Hylite was performed on the basis of 500 bonnets, engineered, built and installed using complete set of tools for this purpose.

1. Stamping blanks
The blanks for the bonnet were trimmed appropriately and supplied by Corus Hylite. The trimmed blanks form the starting material for processing.

2. Deep-drawing (figure 1)
The deep-drawing operation for Hylite and steel is essentially the same. For deep-drawing Hylite, the press settings have to be adjusted to lower pressing forces. The design of the draw beads has to be adjusted to the properties of the specific sheet material.

3. Ribbing (figure 2)
Ribbing makes it possible to achieve a sharp, excellently defined hem. The pad retainer and ribbing die are applied to the inside of the bonnet. The heated ribbing die (approx. 250ºC) is then pressed into the Hylite with a sliding motion. The ribbing operation takes approximately 20 seconds, which may be performed in the assembly line.
4/5 Trimming
The trimming operations are conventional. The cutting clearance is slightly less than with aluminium. The cut edge of Hylite is smoother than aluminium as there is less formation of burrs.

6/7 Flanging
The flanging operations are conventional.

8 Hemming (see figure 3)
The hemming operation is conventional.

10 Finished Bonnet (see figure 4)
## 6.4.5 Technical information

Hylite product information

<table>
<thead>
<tr>
<th>skin material</th>
<th>0.20 mm AA5182; soft-annealed (deep drawable) or full hard</th>
<th>core material</th>
<th>polypropylene</th>
</tr>
</thead>
<tbody>
<tr>
<td>total thickness (mm)</td>
<td>skin thickness (mm)</td>
<td>sp. weight (kg/m²)</td>
<td>E-mod.* (1000 MPa)</td>
</tr>
<tr>
<td>1.20±0.10 (soft skin)</td>
<td>0.20±0.007</td>
<td>1.82</td>
<td>28.7/11.2=23.9</td>
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<tr>
<td>1.40±0.10 (soft skin)</td>
<td>0.24±0.007</td>
<td>2.11</td>
<td>34.4/14.4=24.6</td>
</tr>
<tr>
<td>2.00±0.13 (hard skin)</td>
<td>0.20±0.007</td>
<td>2.54</td>
<td>29.8/12.0=14.9</td>
</tr>
<tr>
<td>2.40±0.13 (soft skin)</td>
<td>0.24±0.007</td>
<td>3</td>
<td>35.8/12.4=14.9</td>
</tr>
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</table>

### Hylite product information

#### Mechanical properties

<table>
<thead>
<tr>
<th>property</th>
<th>value</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td>skin-core adhesion</td>
<td>&gt;5 N/mm</td>
<td></td>
</tr>
<tr>
<td>durability skin-core adhesion</td>
<td>&gt;4 N/mm after wet exposure</td>
<td></td>
</tr>
<tr>
<td>aluminium yield strength (soft skin)</td>
<td>140 MPa</td>
<td>deep drawable Hylite</td>
</tr>
<tr>
<td>aluminium yield strength (hard skin)</td>
<td>280 MPa</td>
<td>full hard Hylite</td>
</tr>
<tr>
<td>aluminium tensile strength (soft skin)</td>
<td>350 MPa</td>
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</tr>
<tr>
<td>aluminium tensile strength (hard skin)</td>
<td>370 MPa</td>
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</tbody>
</table>

#### Thermal properties

<table>
<thead>
<tr>
<th>property</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>service temperature</td>
<td>-30°C to +90°C</td>
</tr>
<tr>
<td>linear thermal expansion coefficient</td>
<td>28 x 10-6/°C</td>
</tr>
<tr>
<td>flash point (core material)</td>
<td>300°C (DIN54836)</td>
</tr>
<tr>
<td>max. painting temperature</td>
<td>145°C</td>
</tr>
</tbody>
</table>

#### Electrical properties

<table>
<thead>
<tr>
<th>property</th>
<th>value</th>
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</thead>
<tbody>
<tr>
<td>DC resistivity (core material)</td>
<td>&gt;1015 S cm</td>
</tr>
<tr>
<td>electrical breakdown (core material)</td>
<td>25 kV/mm (DIN VDE 0303 T21 E)</td>
</tr>
</tbody>
</table>
6.5 Foam

6.5.1 Introduction

Aluminium foam is a fascinating material that has generated considerable interest in the automotive industry. New processing techniques that lower cost and provide reproducible quality foams will widen the spectrum of applications even more. Long term trends like weight efficient structures, increased passenger safety and recyclability favour aluminium foam over other materials like polymer foams.

Most promising future automotive applications:
- crash box, bumper components, foam-filled rails, pillars and other sections for increases strength, stability and crashworthiness,
- Head Injury Countermeasures including interior applications and hoods for pedestrian protection,
- other energy management applications.

Benefits over traditional solutions:
- increase in energy absorption with increased design flexibility resulting from lower weight,
- space saving component designs,
- improves the bending strength of a traditional hollow beam by a factor of 2 or more.

Biggest challenges:
- Bringing costs down,
- making production routes more robust and reproducible,
- guarantee acceptable quality of foam in production.
6.5.2 Processing routes overview

(from "Metal Foams: a Design Guide", see Literature)

**Metal foams are made by one of seven basic processes:**

- Bubbling gas through molten Al-SiC or Al-Al₂O₃. The ALCAN and CYMAT foams are made in this way.
- Consolidation of a metal powder (typically an aluminium alloy) with a particulate foaming agent (typically TiH₂) followed by heating into the mushy state when the foaming agent releases hydrogen, expanding the material. The expansion can be done in a closed mould giving structures of complex shape with a dense outer skin. The MEPURA / ALULIGHT and FRAUNHOFER foams are made in this way.
- By stirring a foaming agent (TiH₂ again) into a molten alloy and controlling the pressure while cooling. The ALPORAS foam, notable for its relative uniformity, is made in this way.
- Pressure infiltration of a ceramic mould made from a polymer foam precursor, which is burned out before the metal is injected. The resulting structure is regular and reproducible, has open-cells, and a typical relative density of about 0.1. The "Lattice Block" materials marketed by JAMcorp use this process, and the ERG foams are made by refinements of it.
- Vapor phase deposition or electro-deposition onto a polymer foam precursor which is subsequently burned out. The result is an open-cell metal foam with hollow cell edges. The INCO process works in this way.
- Expansion of an inert gas trapped in pores at high pressure when a powder compact is HIPed. The Boeing process works with titanium alloy powder and argon.
- Sintering of hollow spheres made by either a modified atomization process or by sintering of a metal oxide or hydride followed by reduction. Both the Georgia Tech and the MURILITE materials are made in this way.
6.5.3 Powder metallurgical processing: For example Alulight

Extruded foamable semi products

Characteristics of Powder Metallurgical Foam:

- Relative Density between 10-35 % (0.3-1 Mg/m³).
- Alloys: All aluminium alloys. Common alloys: 1xxx, 4xxx, 6xxx, 7xxx, i.e. AlSi12, AlMg1Si0.6
- Products: Panels, sandwiches and 3D shapes are common. Geometrical restrictions for 3D shapes are similar to castings due to foaming in steel moulds.
- Deformation mode depends on alloy: High-Si casting alloy foams deform by breaking of cell walls (brittle). Kneading alloys deform by plastically collapsing cell walls.
- Relatively expensive process, costs may be reduced by automatization in the future.
- Homogeneity of cell sizes throughout a part is a crucial parameter for quality.
- Automotive prototype applications: Karmann AFS panels, foam filled A-Pillar, Bumper, Crossmember, crash box.
- Automotive series application: Ferrari 360 Spider (Alcoa)
6.5.4 Melt-based processing: For example Cymat

Characteristics of Melt Route Foam:

▲ Relative Density between 5-20 % (0.13-0.54 Mg/m³).
▲ Made by stabilizing aluminium foam bubbles with solid particles. Most common alloys used: A356 with SiC, A380 with SiC, and 6061 with Al2O3.
▲ Possible alloys 1xxx, 3xxx, 5xxx, casting alloys.
▲ Products: Flat panels maximum dimensions 1.2m wide, 15.25m long and from 12.5mm to 100mm thick. 3-D castings using a low pressure casting technique (pat.pend.)
▲ Deformation depends on alloy but particle inclusions tend to cause brittleness.
▲ Relatively inexpensive process, automated continuous production capability exists. Future cost will tend towards that of the raw materials.
▲ Automotive future applications: Cymat is currently (2001) in a co-development program with automotive Tier 1 for a front end crash management system.
6.5.5 Mechanical properties: Uniaxial compression

Compression Stress-Strain Curves

The figure to the right shows stress-strain curves for powder metallurgic aluminium foam in compression. The density clearly determines stiffness, flow stress and energy absorption (formulas are given in the literature). Similar curves can be produced with a number of different alloys.

Typically, compression curves start (like tensile curves) with a linear-elastic region. Foams may show this behaviour but often the yield point is smeared out. This can be explained with certain cell walls yielding at lower loads than others because they are either thinner or oriented in a way to produce maximum local stresses in the walls. A consequence of this picture would be size-dependent flow stresses for foam parts. This is currently under investigation. The second region is a plateau with relatively constant flow stress, caused by buckling and yielding of more and more cells. At the end the macroscopic stresses raise due to densification of the foam.

Aluminium foam under compression: Influence of Density

Energy absorption is equal to area under the curves

Sources: Alulight
6.5.6 Mechanical properties: Stiffness vs. density

Literature:

Foam Property Charts

The diagrams on this and the next four pages are examples of Material Property Charts. They give an overview of the properties of metal foams, allow scaling relations to be deduced and enable selection through the use of material indices. All the Charts were taken from Ashby, M.F., et al. (1998).

Stiffness and density

The figure below shows Young’s modulus E plotted against density ρ for available metal foams. For clarity, only some of the data have been identified. The numbers in parentheses are the foam density in Mg/m³. The broken lines show the indices E/ρ, E^{1/2}/ρ and E^{1/3}/ρ. These are guidelines for minimum weight design at maximum stiffness of axially loaded parts, bending of beams and bending of plates, respectively. Metal foams have attractively high values of E^{1/3}/ρ, suggesting their use as light, stiff panels, and as a way of increasing natural vibration frequencies.

![Young's modulus vs. Density](Source: Ashby)
6.5.7 Mechanical properties: Compressive strength vs. density

Strength and density

The figure below shows compressive strength $\sigma_C$ plotted against density $\rho$ for currently available metal foams. For clarity, only some of the data have been identified. The numbers in parentheses are the foam density in Mg/m$^3$. The broken lines show the indices $\sigma_C/\rho$, $\sigma_C^{2/3}/\rho$ and $\sigma_C^{1/2}/\rho$. These are guidelines for minimum weight design at maximum strength of axially loaded parts ($\sigma_C/\rho$), bending of beams ($\sigma_C^{2/3}/\rho$) or bending of plates ($\sigma_C^{1/2}/\rho$). Metal foams have attractively high values of the last of these indices, suggesting their use as light, strong panels.

![Compressive strength vs. Density](image)

Compressive Strength vs. Density

Source: Ashby
6.5.8 Mechanical properties: Specific stiffness vs. specific strength

Specific stiffness and strength

Stiffness and strength at low weight are sought in many applications. Caution must be exercised here. If axial stiffness and strength are what is wanted, the proper measure of the first is $E/\rho$ and of the second is $\sigma c^2/\rho$. But if bending stiffness and strength are sought then $E^{3/2}/\rho$ and $\sigma c^{3/2}/\rho$ (beams) or $E^{3/2}/\rho$ and $\sigma c^{1.5}/\rho$ (panels) are the proper measures (see next screens).

The figure below shows the first of these combinations. For reference, the value of $E/\rho$ for structural steel, in the units shown here, is 25 GPa/(Mg/m$^3$), and that for $\sigma c/\rho$ is 24 MPa/(Mg/m$^3$). The values for 1000 series aluminium alloys are almost the same. Metal foams have lower values of these two properties than do steel and aluminium.

Specific Stiffness vs. Specific Strength for axial stiffness and strength.

Source: Ashby

Specific Stiffness vs. Specific Strength for bending or buckling of beams

This chart shows $E^{3/2}/\rho$ plotted against $\sigma c^{3/2}/\rho$.

Values for steel are 1.8 and 4.3; for aluminium, 3.1 and 6.2, all in the units shown on the figure.

Metal foams can surpass conventional materials here.
Specific Stiffness vs. Specific Strength for beams loaded in bending and buckling.
Source: Ashby

Specific Stiffness vs. Specific Strength for bending or buckling of panels

This chart shows \( E^{1/3}/\rho \) plotted against \( \sigma^{1/2}/\rho \). Values for steel are 0.7 and 1.8; for aluminium, 1.5 and 3.7, all in the units shown on the Figure.

Metal foams easily surpass conventional materials in these properties, indicating attractive fields for structural applications.
6.5.9 Aluminium foam products: Reinforcements

A2 rocker reinforcement (repair solution study)
Source: Alulight

Detail of A2 reinforcement
Source: Alulight

Foam reinforced swing arm (lower half of steel sheet shell and aluminum foam core)
Source: Alulight
VW Golf B-pillar reinforcement (study)
Source: Alulight
6.5.10 Aluminium foam products: Permanent cores

Cast wheel study with permanent core
Source: Alulight

Foam core of wheel with 5 spokes
Source: Alulight

Section through wheel showing position of cast-in core
Source: Alulight
Partially foam-filled engine cradle (hydroformed steel)
Source: Alulight

Casting cores and castings with permanent cores
Source: Alulight
6.5.11 Aluminium foam products: Panels

Flat panels: Foam only, Structured sandwich, flat sandwich (sheet on one or both sides)

Source: Alulight

Fire wall (study)

Source: Alulight
6.5.12 Panels, cores and 3-D shapes
(Cymat)

Cymat offers panels from their melt based process:
- 3 to 20% density foam
- 1/2" to 5" thick
- up to 50 ft long
- 2300 lbs per hour

Filling Tubes with Liquid Melt
- Minimum cross section 1" by 1 1/2"

3-D Shapes:
- Permanent molds and sand casts
- 20-30% density foam
6.5.13 Joining aluminium foams

Metal foams can be joined using techniques for wood: wood-screws, glue joints or embedded female fasteners. For higher temperature resistance welding and brazing are viable options.
Foamed-in inserts for fastening

Source: Alulight
6.5.14 Aluminium foam series application: Ferrari 360 Spider

Foam-reinforced frame side rail

This reinforcement previously consisted of a welded sheet. The foam solution provides low weight, high performance, low cycle time and (in this case) also cost reductions.

This part is the first component made of Al-foam ever introduced in series production.

Aluminium foam blocks in place inside side rail enhance bending stiffness

Source: Alulight / Alcoa

Aluminium foam block sawn in two for tight fitting montage

Source: Alulight / Alcoa

Ferrari 360 Spider space frame

In the area of the red circle two aluminium foam blocks give extra stiffness and crash energy absorption

Source: Alcoa
Ferrari 360 Spider
Source: Ferrari
6.6 Tailored blanks

6.6.1 Tailor-welded blanks – Introduction

A tailor-welded blank (TWB) is a multi-gauge and/or multi-alloy combination of automotive sheet to produce a blank that is more optimised in its use of alloy and gauge than a single gauge sheet.

The incorporation of a TWB in a closure or structure not only lowers the total weight of the component, but may also improve strength, stiffness, and performance. Other benefits include parts consolidation, reduced material handling, reduced stamping dies and assembly tooling, and increased design flexibility.

Aluminium tailor welded blanks can be produced by fusion welding of butt joints between mating blanks. The following pages give a brief account of the characteristics of applicable processes for production of TWBs (s. also section "Fusion Welding" of this Manual), which are:

- Laser beam welding
- Arc welding methods
- Hybrid processes
- Non-vacuum electron beam welding
- Friction stir welding
- Combination of processes

Most aluminium automotive sheet alloys are suitable for TWB applications. The Al-Mg alloys, e.g. EN AW-5754 and EN AW-5182, may be welded autogenously. The Al-Mg-Si alloys, for example AA6016 and AA6111, are hot-crack sensitive, and require a filler wire when fusion welded. The heat input into the fusion zone can have an effect on forming limits, static and fatigue strength properties and on degree of distortion, depending on the type of process used and on the quality of the weld.

Currently, the first application of TWB's in automotive structures can be reported, others are at a stage of development.
6.6.2 Methods for producing aluminium TWBs

Laser beam welding offers many advantages for aluminium TWBs: precise heat input, narrow weld bead with parallel fusion boundaries, narrow heat-affected zone, minimal thermal distortion, and high welding speeds (typically 6-12 m/min). Several lasers are suitable for aluminium TWBs: CO\(_2\), Nd:YAG, and high power direct diode.

Arc processes, such as Gas Tungsten Arc, Plasma Arc, and Gas Metal Arc (GMA) are suitable for welding TWBs. The wider heat input may cause larger heat-affected zones and increased thermal distortion, but offers good gap-bridging capability. In general, arc processes do not achieve the high speeds of laser (about 2-3 m/min).

Hybrid processes combine laser with arc; for example, laser-MIG and plasma-augmented laser. For aluminium TWBs, hybrid methods offer the best of both laser and arc: elevated speeds plus excellent gap-bridging capability and process robustness.

Non-Vacuum Electron Beam: NVEB is a high energy density welding method capable of speeds up to 20 m/min on automotive gauges. However, the welding apparatus and work piece must be enclosed in lead housing to encapsulate X-radiation.

Friction stir welding is a solid state process in which a specialised probe is used to effect plastic flow of the material across the joint by a stirring action. Since this process produces no fusion, it is suitable even for crack-sensitive alloys. However, the welding speeds are rather slow (less than 1 m/min).
6.6.3 Properties of TWB Laser seam welds

YAG welding of TWB at CORUS plant, Ijmuiden, NL

AA 6016-T4

Process parameters for TWB 2.7/1.3

- Laser: 4.5 kW Nd:YAG HAAS HLD4506
- Laser power used: 3.5 kW
- Filler: AlSi12
- Welding speed: 3.5 m/min
- Focus: Mono
- Shielding gas: Helium

Surface roughness and visual inspection of face and root are faultless. Roughness may change with different filler.

Cross section, face and root view of AA 6016 TWB

Source: CORUS, Ijmuiden

Quality tests:
(Joint quality acc. to EN 13919-2)
Reinforcement of joint face and root:
→ max. 0.2 mm
Hardness (HV0.2):
→ max. difference 20 HV
→ min. hardness 60 HV

Undercut:
THE Aluminium Automotive MANUAL

→ max. 0.05 mm

Tensile strength (transverse):
→ min. 150 MPa (related to cross section of thinner part)

Formability of TWB vs. shaped base metal

Note: Formability of TWB test piece is equal to the formability of the milled base metal with a 45° shoulder.

EN AW-5182-0

Process parameters for TWB 2.5/1.2

- Laser: 4.5 kW Nd:YAG HAAS HLD4506
- Laser power used: 3.2 kW
- Filler: none
- Welding speed: 5 m/min
- Focus: Mono
- Shielding gas: Helium

Surface roughness and visual inspection of face and root are faultless.
Quality tests:
(Joint quality acc. to EN 13919-2)
Reinforcement of joint face and root:
→ max. 0.2 mm
Hardness (HV0.5): s. figure below
→ max. difference 20 HV
Undercut:
→ max. 0.05 mm

Source: Corus, Ijmuiden
6.6.4 Application of TWB in the Lamborghini Gallardo: front inner wheel house arc

The figures document a commercial application of TWBs: the Lamborghini Gallardo front inner wheelhouse arc:
- Alloy: ECOLITE™ (AA 6016-T4)
- TWB: 2.7/1.2 mm
- Welding equipment: Nd.YAG Laser

Lamborghini Gallardo built with ECOLITE (TM) TWB
Source: Corus

ECOLITE (TM) TWB stamping for front wheelhouse arc
Source: Corus
ECOLITE (TM) TWB finished stamping for front wheelhouse arc
Source: Corus

Assembly of BIW with ECOLITE (TM) TWB stamping for front wheelhouse arc
Source: Corus

Front wheelhouse arc of Lamborghini Gallardo
Source: Corus
6.6.5 Stamping of aluminium TWBs

To avoid failures in the weld during stamping, TWBs are usually designed with the weld line in a relatively low strain region as shown in the figure at right. In addition, the stamping dies must be designed to accommodate the step(s) in the blanks due to the multiple gauges.

There is a wide variety of suitable applications for aluminium TWBs. Due to the weld line, TWBs would usually be used in automotive inner panels for closures or structures. Fulfilling the requirements of series production has been demonstrated in various prototype programmes.

Example are a liftgate inner, a hood inner, a door inner and a rear body side inner for the Ford P2000 concept vehicle, s. fig at right. In each case, the TWB assembly met or exceeded all OEM performance requirements.
TWB stamping for Ford P2000 concept vehicle
Source: Alcan