Applications – Car body – Roof and trim

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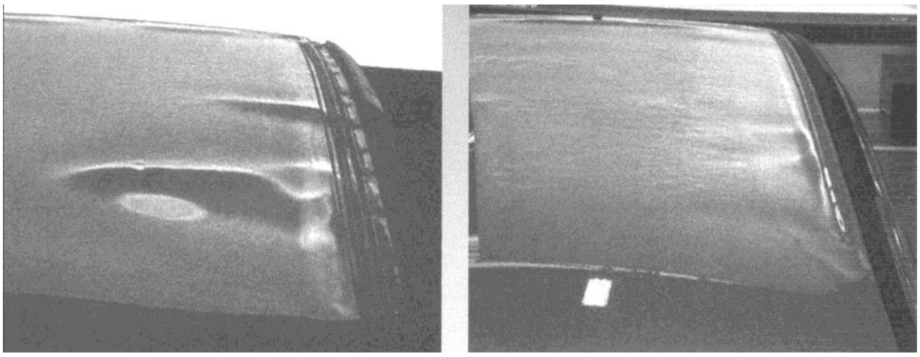
5 Roof and roof structure

The use of aluminium for the car roof is well established in all-aluminium car body designs (see chapter 3.3). But there are also significant aluminium applications in the roof of vehicles with steel car body structures. Weight reduction in the roof (i.e. lowering the centre of gravity) has always been a high priority topic in automotive design. However, the roof is generally an integral part of the body-in-white. Therefore, the integration of structural aluminium components into the roof of a steel body structure requires an in-depth consideration of different aspects (as outlined below).

5.1 Aluminium roof on a steel body

The substitution of the steel roof panel by a lightweight aluminium alloy roof panel is an attractive option to optimize the mass distribution in a car. However, if the remainder of the vehicle body structure continues to be fabricated in steel, two major hurdles have to be overcome. The first problem is the realization of a reliable joint between the different materials. Various technologies have been developed to join aluminium to steel; in most cases, adhesive bonding combined with a mechanical joining technique is applied, but also friction stir welding, soldering or fusion welding methods have been developed. If the mixed material joint is properly protected to avoid any danger of galvanic corrosion, a safe and durable joint is achieved.

The other problem is the different thermal expansion coefficient of aluminium and steel. The combination of the aluminium alloy roof attached to the steel body may create compressive stresses in the aluminium roof when the body is subjected to elevated temperatures such as those required to cure the paint applied to the assembled body-in-white. Visible thermal distortions of the roof panel, if any, are not acceptable. Such effects can be eliminated (or minimized) for example by the use of an aluminium alloy with a higher strength level, the selection of an appropriate adhesive, the application of proper joining procedures (e.g. optimized riveting position and use of jigs) as well as other suitable measures.



Effect of the alloy yield strength on the distortion of an aluminium alloy roof on a steel body after lacquer bake hardening: EN AW-6016 (left) and EN AW-6056 (right)

(Source: Constellium)

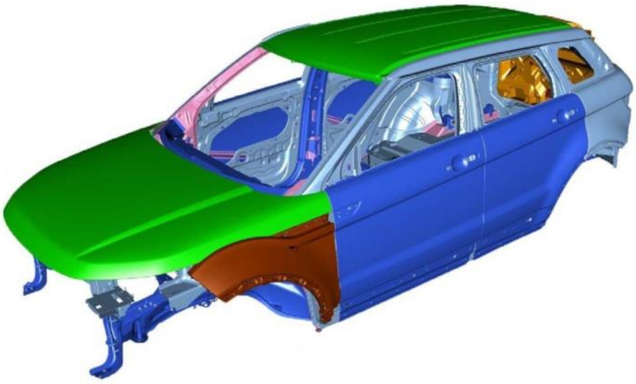
An aluminium roof contributed to the exemplary low weight of the Maybach bodyshell (in addition to some other large aluminium components: bonnet, doors and front wings). The large, but relatively flat component was produced by active hydromechanical deep drawing. In this variant of the of hydraulic deep drawing technique, the blank is pre-formed by an elevation of the pressure in the fluid medium in the opposite direction of the actual forming operation before the punch moves against the blank. The cold deformation by the prior hydraulic deep drawing step leads to an increase of the material strength and thus improves the mechanical stability of the roof panel.

Aluminium roof of the Maybach luxury car

(Photo: Maybach)

An aluminium roof on a steel body structure is also found on the Range Rover Evoque (L538) which was introduced into the market in 2012. The use of aluminium for the bonnet and the roof, thermoplastic fenders and a polymeric composite, one-piece tailgate helped to produce a vehicle weighing 100 kg less than the steel Freelander. Aluminium is used for the roof to help lower the car's centre-of-gravity and save about 7 kg against steel.

The roof of the Evoque is the first series application of Novelis' new high-strength aluminium alloy Anticorodal®-600 PX. The new high-strength aluminium alloy was chosen for the Evoque's advanced roof design on the basis of its superior strength and excellent formability. The aluminium roof is joined to the steel body structure by adhesive bonding and self-piercing riveting. The increased strength of Anticorodal®-600 PX provides the opportunity to reduce the sheet thickness by as much as 15 % compared to traditional aluminium car body sheet alloys. In this specific application, the increased strength not only contributes to the elimination of thermal distortions during the bake hardening process, but enables with a thickness of only 0.9 mm also the realization of an extremely lightweight roof solution. Adhesive bonding and self-piercing riveting is also used to fix the steel carrier of the optional panoramic glass roof.



Aluminium roof on a steel body (Range Rover Evoque)

(Source: Land Rover)

Most important was, however, an accurate prediction of the temperatures and the resulting distortions in the mixed steel/aluminium body shell at different locations during the paint bake. Thus it was possible to avoid thermal distortions by the implementation of suitable design changes and a careful consideration of the attachment methodology of the aluminium roof to the steel body structure.

Range Rover Evoque with an aluminium roof (alloy: Anticorodal®-600 PX)

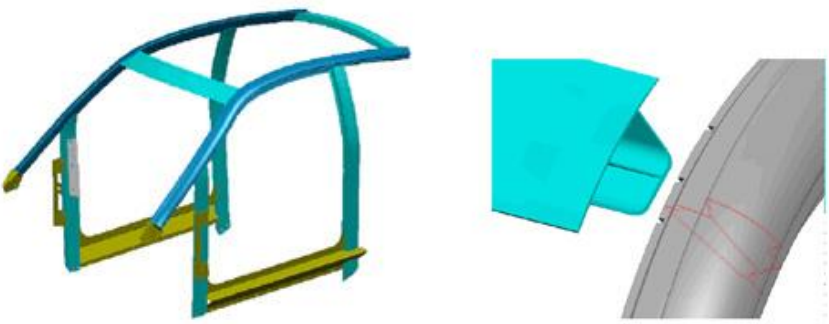
(Photo: Land Rover)

5.2 Roof structure

The integration of structural aluminium components into the roof of a steel car body was first attempted in the Ford THINK, a small electric city car. The cant rail of this vehicle, i.e. the structural member which runs over the top of the doors, is designed as a visible aluminium component. The extruded aluminium profile (alloy EN AW-6060) includes the A pillar and ends at the top rear end. The length of the beam is about 2.2 m, the profile has a hollow cross section with flanges and it is 3-dimensionally formed. The beam upper face is exposed to the atmosphere and the surface is untreated.

Ford THINK with an extruded aluminium cant rail

Also the transverse roof rails are bent extruded aluminium profiles (alloy EN AW-6060).



Complete frame (left) and details of the transverse and cant rail assembly (right)

Another visually attractive example of an aluminium roof substructure presented Renault in the Avantime model which was produced from 2001 to 2003 by Matra Automobile.

Body-in-white of the Renault Avantime

(Source: Matra Automobile)

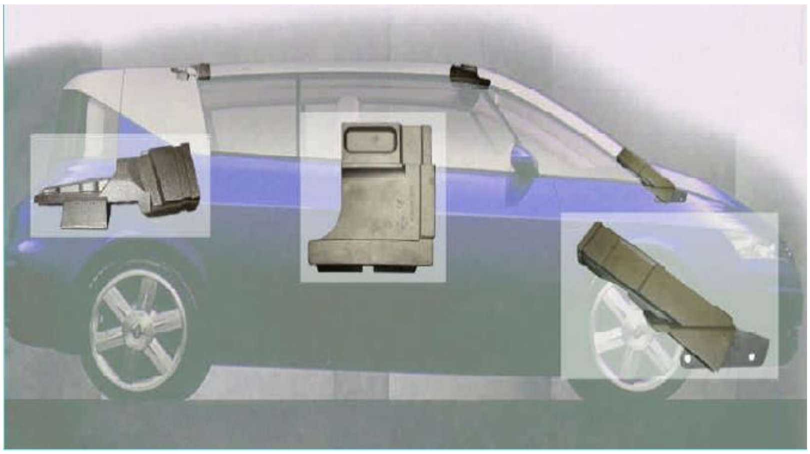
The Renault Avantime has a steel/aluminium body-in-white including:

- a steel chassis (carry-over part from the Renault Espace, green parts in the figure shown above),
- steel body panels (yellow parts),
- an aluminium roof structure (grey parts).

The weight of the aluminium roof structure is 18 kg (on a total BIW weight of 370 kg). As the Avantime does not have a B pillar, the roof structure is a safety critical part and contributes significantly to the crash performance of the vehicle.

The Avantime roof structure consists of three types of aluminium parts:

- Extrusions of the alloys EN AW-6106-T51 and EN AW-6060-T51 (46 % weight share); these alloys offer in the T51 temper a good compromise between formability and strength characteristics.
- Stamped sheet panels of the alloy EN AW-5182-0 (weight share 27 %).
- Cast parts of the alloy AlSi7Mg0.3-T5 (Calypso® 67S) with a weight share of 27 %. The castings are produced using the thixo-casting process which allows the realisation of high quality parts with low wall thickness and high dimensional accuracy which reduces the need for additional machining operations and provides a smooth surface.



Structural nodes produced by thixo-casting

The aluminium extrusions are formed by three-dimensional stretch-bending. This process allows minimising spring back effects and leads to component with good geometrical precision.

3D stretch bending of extrusions and welding of roof structure

(Source: Matra Automobile)

The aluminium components are joined by MIG arc welding; the welding sequence has been selected to minimise distortion of the parts. The aluminium roof structure assembly is then joined to the steel structure by adhesive bonding and self-piercing riveting.

5.3 Sun roofs

An automotive sun roof is an operable (tilting or sliding) opening in an automobile roof which allows light and/or fresh air to enter the passenger compartment. Sun roofs may be manually operated or motor driven, and are available in many shapes, sizes and styles.

Sun roofs, by historical definition are opaque and slide open to allow fresh air into the passenger compartment. The first sun roofs were folding sun roofs, i.e. the panel made of fabric folds back as it slides open. Today, however, most factory-installed sliding sun roof options feature a metal or - more and more - a glass panel. Top-mount sliding sun roofs have been a popular factory option in the past, but are now generally replaced by inbuilt systems. In top-mount versions, large glass panels slide open in tracks on top of the roof, with no loss of headroom. Inbuilt sun roof systems have a panel which slides between the metal roof and interior headliner, requiring some loss of headroom, but providing a full opening in the roof. Sun roof systems are available in many shapes, sizes and styles, and are known by many names:

- Pop-up sun roofs consist simply of a tilting panel. These panels are often removable, and must be stored when removed. The tilting action provides a vent in the roof, or a full opening when the panel is removed.
- Spoiler sun roofs combine the features of a pop-up with those of a sliding roof system. They tilt to vent, but can alternatively slide open.
- Panoramic roof systems are a newer type of large or multi-panel sun roofs which offer openings above both the front and rear seats and may be operable or fixed glass panels.
- Solar sun roofs have an inlaid photovoltaic solar insert which makes the glass totally opaque. While they operate identically to conventional factory-fitted glass sunroofs (tilting and retracting), the solar panel provides electricity to power the interior ventilation fans for cooling the car interior on hot days when the car is standing outside in the sunlight.

Sun roof for the BMW 7 series

(Photo: Webasto)

Lightweight aluminium components are a favoured solution for the design of the sun roof opening mechanism. Automobile companies generally use aluminium extrusions to make sun roof channels. Sun roof channels basically form part of a sliding system, i.e. the channels must have a smooth surface, show low friction and must be resistant to wear. Some manufacturers anodise the surface of these channels to produce a layer of aluminium oxide in order to improve the wear resistance. Furthermore, extruded profiles for sun roof channels have to meet high geometrical tolerances. Thus, a tight shape control of the extrusions is required.

Aluminium guide rails for sun roofs are typically made from EN AW-6060 extruded profiles. The extrusions are cut, bent, heat treated, punched, CNC milled, de-burred and finally surface treated.

Extruded aluminium guide rails for sun roofs

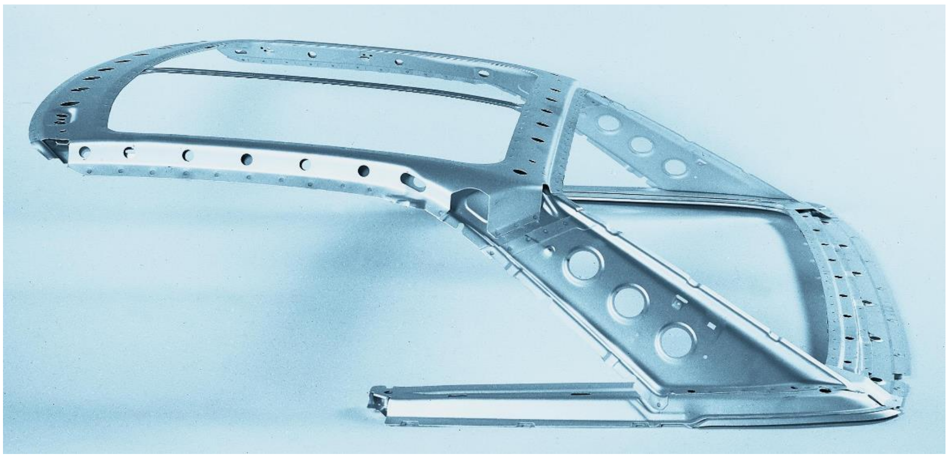
(Photo: Sapa)

5.4 Detachable hardtops

A convertible is a type of automobile that can convert from an enclosed to an open-air vehicle. In the past, some convertibles featured as standard or optional equipment fully rigid, manually installable hardtops. These hardtops provided acoustic insulation, but also required space-consuming off-season storage and a cumbersome two-person installation. Lightweight aluminium detachable hardtops facilitated the installation significantly compared to steel versions.

Aluminium hardtop for the second and third generations Mercedes SL

(Photo: Novelis)



Structure of the Mercedes SL hardtop

(Photo: Hydro Aluminium Rolled Products)

Nevertheless, with the development of metallic retractable roof systems (see 3.2.5.5), hardtops have practically disappeared from the market today. Storage and handling issues (the aluminium hardtop for the Porsche Boxter, for example, still weighed 23 kg) made their use inconveniently.

5.5 Retractable roofs

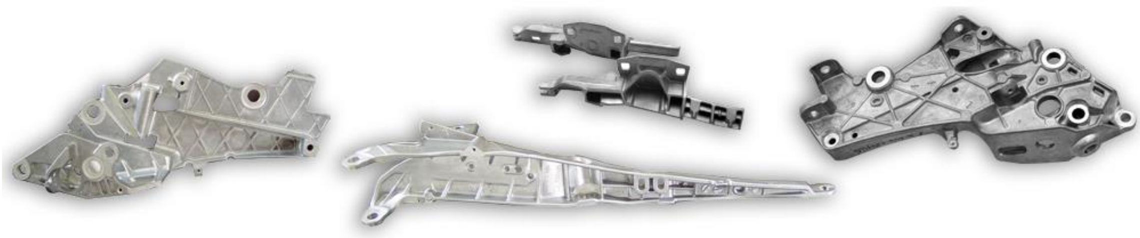
A prominent option for a convertible is the retractable roof. Retractable roof designs vary widely, but a few characteristics are common to all convertibles. The roofs are affixed to the vehicle body and are usually not detachable. Instead the roof is hinged and folds away, either into a recess behind the rear seats or into the boot of the vehicle. Consequently, the cargo space is severely constricted and in some cases, there is practically no boot space left when a retractable hard roof is stowed. The roof may operate either manually or automatically via hydraulic or electrical actuators. The roof itself may be constructed of soft or rigid material. Soft-tops are made of vinyl, canvas or other textile material; hard-top convertibles have roofs made from steel, aluminium, plastic or carbon fibre composites. Convertibles offer numerous iterations that fall between mechanically simple, but attention-demanding fabric tops to highly complex, modern retractable hardtops.

Retractable textile roof of the Audi A3

(Photo: Webasto)

Modern convertibles often include also wind deflectors to minimize noise and rushing air reaching the occupants. There are various wind deflector systems, e.g. rigid panels that folded up from behind the two seats, vertically retractable glass panels or other integrated wind controlling systems. In addition, some car models include a feature that routes a heating duct to the neck area of the seat (marketed as the "Air Scarf").
The collapsible textile roof which is supported by an articulated folding frame may include linings such as a sound-deadening layer or an interior cosmetic headliner to hide the frame. It may also include an electrical or electro-hydraulic mechanism for raising the roof. The erected top secures to the windshield frame header with manual latches, semi-manual latches, or fully automatic latches.

Lightweight aluminium designs are particularly suitable for the folding frame of retractable textile roofs. High pressure die cast aluminium parts are used for the functional components, aluminium extrusions are often used for the supporting frame connecting the functional nodes.

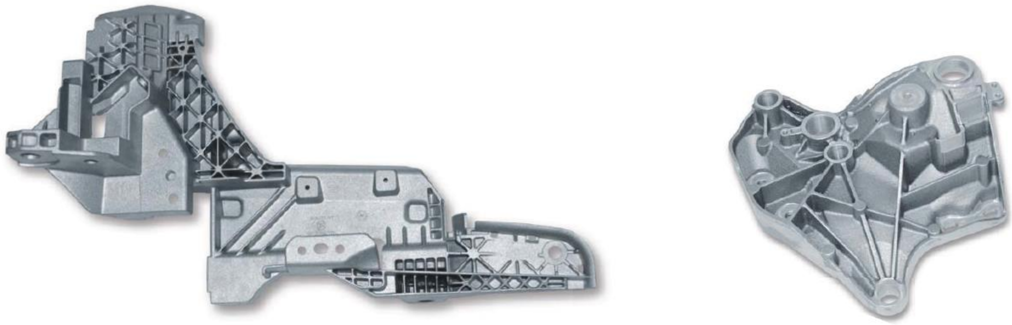


Swivelling bearings and struts and connectors (functional components) for convertible roof systems (VW EOS and BMW 3-series)

(Photo: ae group)

Reinforcement (left) and lever (right) for a convertible soft-top, high pressure die cast using the alloy Castasil®-37 (AlSi9MnMoZr)

(Photos: Aluminium Rheinfelden)



Base plate (left) and intermediate plate for a convertible soft-top mechanism (right), high pressure die cast using the Magsimal®-59 (AlMg5Si2Mn) alloy in the as-cast state

(Photos: Aluminium Rheinfelden)

A retractable hardtop is a type of convertible that forgoes a folding textile roof in favour of an automatically operated, self-storing hardtop where the rigid roof sections are opaque or translucent. The retractable hardtop solves some issues with the soft-top convertible, but has its own compromises, namely mechanical complexity, higher initial cost and more often than not, reduced luggage capacity. On the other hand, it offers increased acoustic insulation, durability and break-in protection similar to that of a fixed roof car model. Retractable hardtops can vary in material (steel, plastic or aluminium), in the number of rigid sections (two to five) and often rely on complex dual-hinged boot lids that enable the boot lid to both receive the retracting top from the front and also receive luggage from the rear along with a divider mechanism to prevent loading of luggage that would conflict with the operation of the hardtop.

Retractable aluminium two-piece hardtop of the Ferrari California

(Photo:Webasto)

As an example, the aluminium hardtop of the new Ferrari California can open in 14 seconds. It includes the use of proportional valve technology in the hydraulics, a sleek kinematics concept in order to optimize trunk volume, and a large number of aluminium structural components. The roof shell is constructed completely of aluminium. Further aluminium components include the main pivot brackets, cross members, frame, and the kinematics of the tonneau cover. The total weight of the entire roof system is 105kg, which is below the weight of a conventional textile retractable roof.

Three piece vario-roof of the Mercedes-Benz SL model

(Photo: Daimler)

Apart from the aluminium roof painted in the vehicle colour, the Mercedes-Benz SL model is also available with a transparent variant with a roller blind and a third variant where the glass roof switches to light or dark as required at the press of a button.

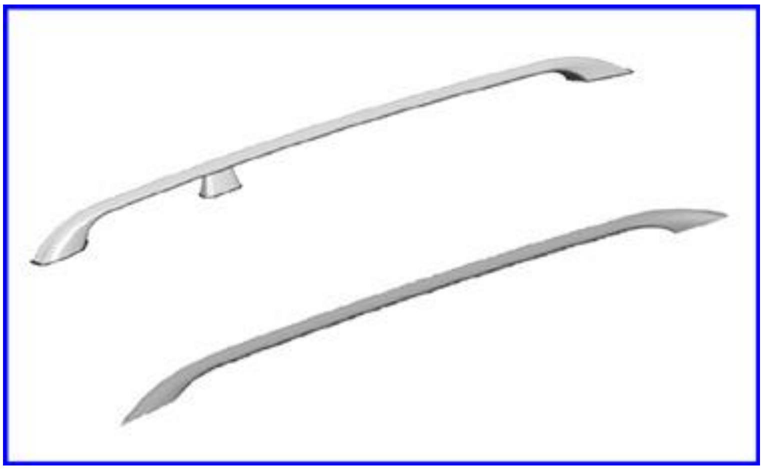
5.6 Roof rails

Another important application of aluminium extrusions are roof rails. Roof rails are placed on the top of the vehicle and are used to carry additional luggage and equipment. Aluminium extrusions are used for manufacturing roof rails because they enable visually attractive, low weight and high strength designs.
The length of aluminium roof rails can vary significantly, they are found on small cars as well as on station wagons and MPV's (Multi Purpose Vehicles). Roof rails have two principle functions; to enhance the design features of the vehicle and to carry extra loads placed on the roof, often with the help of another structure, e.g. transverse load bars or a roof box.

Roof rail for looks and extra load support

The typical roof rail has two cast supports with an extruded aluminium bar between them. It is also common to use an intermediate support for longer rails or where the design loads are high. The extrusion process provides almost limitless possibilities for the designer to choose a section that satisfies functional and esthetical demands. A subsequent stretch bending step offers additional design freedom. Casting offers similar freedom of design for supports.

Supports are typically joined to the extruded bar by mechanical joining or by adhesive bonding. By hydroforming the rail, it is also possible to integrate the end supports with the extrusion and thereby eliminate the cast supports thus reducing the number of parts and enhancing design.



Aluminium roof rail with cast supports at the ends and one in between (top) and a hydroformed rail with integrated supports (bottom)

A main design consideration is whether the roof rail is joined to the vehicle from the inside or from the outside of the roof. Joining from the inside enables the use of cast or hydroformed supports.

Cast end support designed for inside mounting

Joining from the outside calls for the use of a removable cover and also makes it difficult to take advantage of using hydroformed supports.

Roof rail support for mounting from the outside the vehicle with a removable cover

Apart from permanently attached roof rails, there are also roof rail variants which can be easily mounted when needed.

Removable aluminium roof rail

(Photo Constellium)

There are different possibilities for surface finishing of aluminium roof rails, in particular electrochemical polishing and anodizing. Depending on material and/or alloy, surfaces ranging from high-gloss to matt, from natural-colored to black aluminum are achieved by different processing options. Another possibility is powder-coating with matt or high-gloss lacquers.

Aluminium roof rails with different types of surface finishing

(Photo: WKW automotive)

Most of the new developments of roof rails are so called "flush rails". Flush rails are bent and machined extrusions which are integrated with the roof trim. There are no cast end supports, but only a bent and machined extrusion which is fixed flush to the roof trim. The alloy EN AW-6060 is generally used for the flush rails.

Alumiunium roof rail of the “flush rail” design

(Photo: Sapa)

Alumiunium “flush rail” are today found on several car models

(Photo: Sapa)

6 Trims

Trim is anything the manufacturer applies to the car to enhance its style and appearance. Decorative and functional strips around the vehicle are an integral part of vehicle design. Common exterior trim items include radiator grills, window frames, light rings, door handles, emblems and antennas. The demands of the designers must be realized in the same way as the functional requirements, e.g. in case of window frames, the necessities of window guide, cover and/or water management. But there are also different trim products which fulfil additional functions, e.g. door sill tread plates, boot finishers, division bars for side windows and side trims for A-C post. In these cases, there may be specific requirements which have to be considered in the material selection apart of the visual appearance (e.g. strength, wear resistance, etc.).

For decorative applications, metallic items were in the past usually nickel or chrome plated. Today, high quality trim components are generally made from aluminium sheets and extrusions (seldom forgings and castings). However, for pure decorative purposes, i.e. components without specific mechanical requirements, aluminized plastic parts are often selected as more cost-effective solutions. Apart from bright surfaces, also dark (black) trims − as featured by most cars made during the 1980s and 1990s − can be realized with aluminium using special anodization procedures.

The basis for a high-gloss surface is always the raw material. In practice, high purity aluminium (e.g. Al99.9 / EN AW-1098) or low alloyed AlMg alloys based on high purity aluminium are used for trim applications. Most important are also specific processing conditions, from molten metal treatment and ingot casting to the subsequent rolling or extrusion operations and the final mechanical processing (i.e. the machining, grinding and polishing operations). In specific cases, also structured surfaces are produced by special patterning processes. There are different possibilities available for the surface finishing of the mechanically machined parts. Exterior parts are mostly subjected to electrochemical polishing and anodizing for high surface perfection. The resulting hard and corrosion-resistant aluminium oxide surface layer provides an optimum protection and requires little maintenance. Depending on the applied alloy, the different processing options lead to surfaces ranging from high-gloss to matte and from natural-colored to black aluminum.

ALMINOX® extruded aluminium profiles for trim applications

(Photo: WKW automotive)

Bright anodized trim profiles for vehicle design lines and window frames

(Photo: WKW automotive)

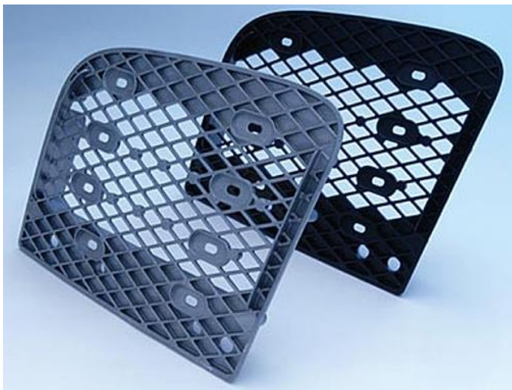
The high-gloss surface appearance of anodized strips underlines the top quality, dynamic design of the luxury and high performance vehicles. Therefore, "high gloss packages" are particularly prominent with upper class models and sport cars.

Popular are for example tread plates for the door sill. Tread plates are usually made from the extrusions alloys EN AW-6060 or 6063; the extruded profiles are cut, pressed, CNC-milled, scratch-brushed / polished and anodized.

Extruded aluminium tread plates for door sills

(Photo: Sapa)

Polished and bright anodized forged aluminium components as characteristic features: Audi TT fuel filler cap (left) an Audi S8 mirror housing (right)



Decorative cover for an air exit (Audi A8) produced by high pressure die casting

(Photo: DGS Druckguss)

Aluminium emblems and name plates

(Photo: Alanod)