

Applications – Chassis & Suspension – Subframes

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1 Axle subframes

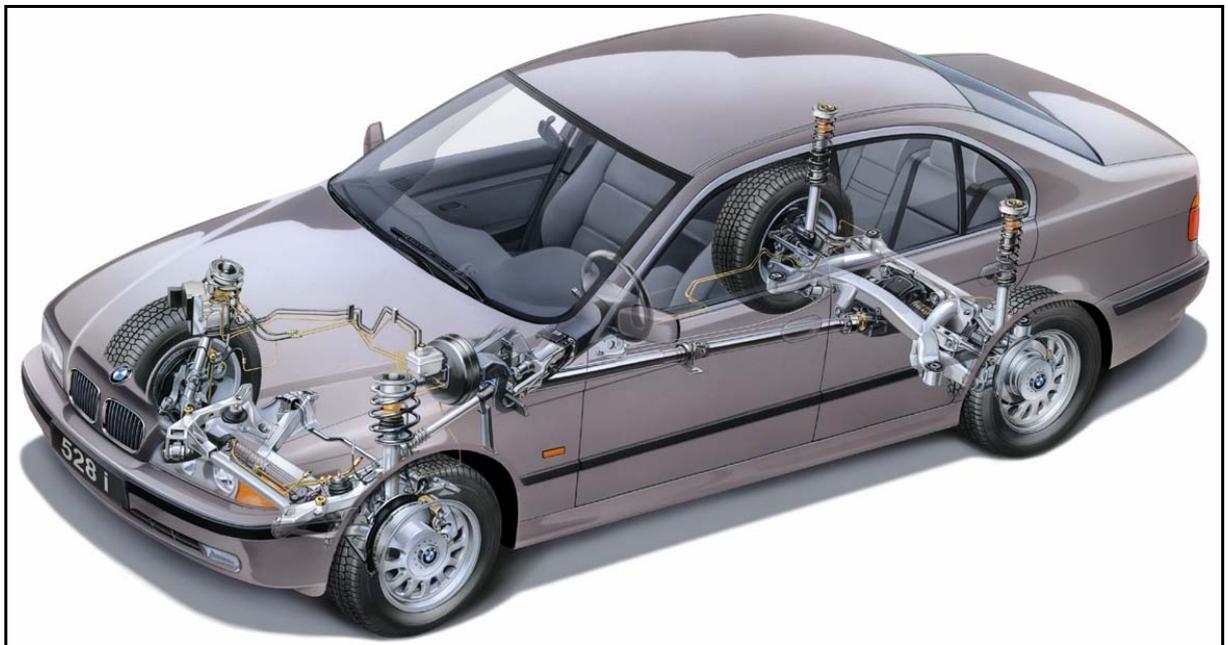
1.1 Introduction

Subframes are structural modules which are designed to carry specific automotive components such as the engine or the axle and suspension. The purpose of using a subframe in an automobile is to distribute high local loads over a wider area of the body structure (most relevant in thin-walled monocoque body designs) and to isolate vibration and harshness from the rest of the body. The subframes are bolted or welded to the vehicle body. Bolted subframes are sometimes equipped with rubber bushings or springs to dampen noise and vibrations. An additional benefit is that subframes can be separately assembled and integrated into the vehicle on an automated assembly line when required.

As a natural development from a car with a full chassis, separate front and rear axle subframes are used in modern vehicle designs to reduce the overall weight and cost. Axle subframes can have various forms and fulfill different functions:

- subframes for rear and front axles
- perimeter frames which carry both the axle and the engine (possibly including the transmission and the full suspension).

Simple axle subframes usually carry the axle, the lower control arms and, in case of the front axle, the steering rack. Subframes which also support the engine and possibly other components (e.g. transmission) would be particularly useful on front wheel drive cars. Such more complex, but also more expensive designs would result in better road isolation and less harshness since these components are not anymore directly connected to the main body structure. However, no specific examples can be shown.



BMW 5 series model with aluminium front and rear axle subframes

Source: BMW

Axle subframes must be stable to ensure excellent road contact, but also light to guarantee high occupant comfort regardless of surface unevenness. Therefore, they are most interesting components for the application of aluminium:

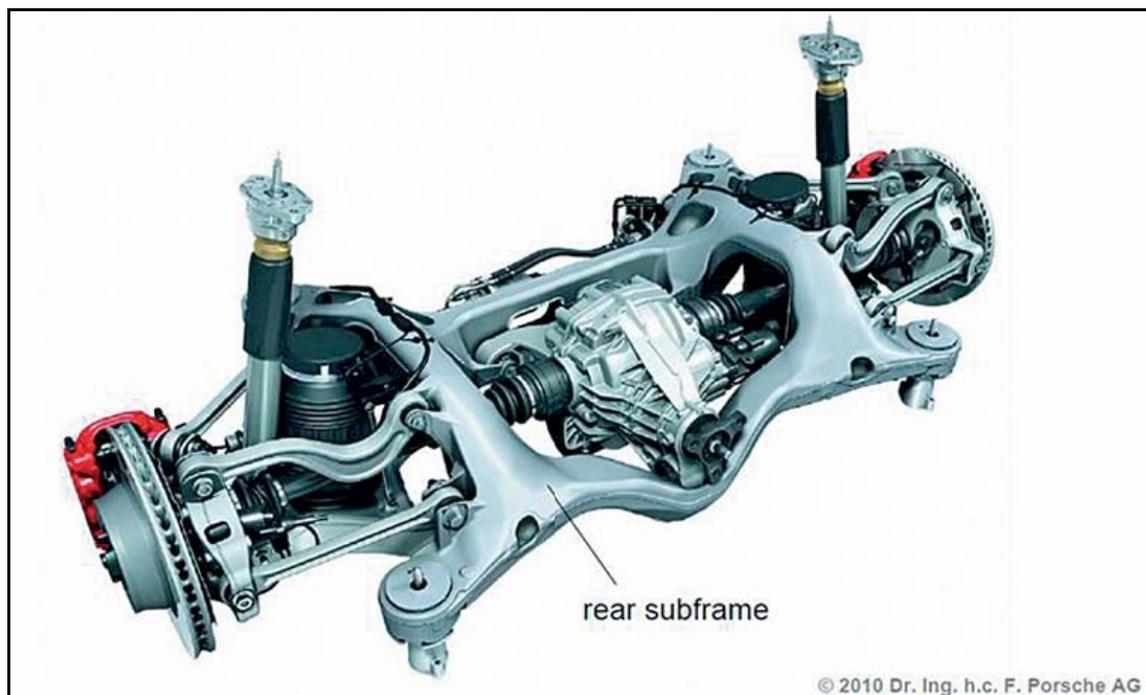
- Properly designed aluminium modules show the required strength and stiffness for axle subframes.
- In addition to the general lightweighting benefit, lightweighting of unsprung masses reduces the vibration forces and offers a smoother ride.
- The structural functionalities of axle subframes ask for fairly complex geometrical shapes and the need to integrate different attachment points. Consequently, the potential of the aluminium extrusion technology and the various high quality aluminium casting methods for the integration of additional functions into a structural part can be fully exploited.
- Depending on the production volume, the fabrication cost of aluminium subframes can be reduced by the application of properly designed high quality aluminium castings (reduction of assembly cost by part integration). Furthermore, the elimination/reduction of assembly joints improves the overall performance of the subframe.
- The possibility to assemble the aluminium subframe separately from the rest of the vehicle facilitates its integration into a steel or mixed material body.

Therefore, many different lightweight subframe designs have been developed using the various aluminium product forms, i.e. sheets, extrusions and castings. In the following, some aluminium axle subframes currently in series application will be presented. But also a variety of other aluminium designs which have been used in the past or have been developed up to the prototype scale are shown.

The market share of aluminium in this application is today still small. With the development and market introduction of dual phase steel grades and other advanced high strength steels, some promising aluminium projects for axle subframes and engine cradles have been stopped or delayed. Nevertheless, there is still significant growth potential for aluminium in axle subframes and engine cradles. The increasing demand for lightweighting, combined with the benefits of reduced unsprung masses, will clearly serve as a driver for future market growth.

1.2 Rear axle subframes

Aluminium rear axle subframes are particularly prominent for rear wheel drive cars with high demands on driving dynamics and comfort. The axle must hold the wheels on the road in order to ensure constant and even traction of the drive wheels. Thus it is important to create a structural module of especially low weight and high stiffness. In addition, severe package restrictions and the quality requirements of a safety functional chassis part represent further criteria to be considered. The complexity and size of the subframe combined with the high level of requirements represent a new dimension in the design of aluminium chassis parts for series application.



Rear axle of the Porsche Panamera
Source: Porsche

1.2.1 Rear subframe as a one-piece casting

An obvious solution for a lightweight aluminium rear axle subframe is a one-piece hollow casting. An early example (start of production 1998) is shown below. The relatively large casting (length 700 mm, width 1200 mm, height 250 mm) and a finished part weight of 16.7 kg has been produced by the Vacuum Riserless Casting (VRC) / Pressure Riserless Casting (PRC) technology developed by Alcoa. The wall thickness of the cast subframe varies between 5 and 25 mm, the A356 alloy is used in the as-cast state. The substitution of the original steel stamping by a cast aluminium subframe enabled a weight reduction of nearly 40%.



Rear axle subframe as a one-piece hollow casting produced by the VRC/PRC technology
Source: Alcoa

A more recent example, produced by Farsund Aluminium Casting AS using the low pressure die casting process (VRC/PRC), is the Porsche Panamera rear subframe. The rather small number of annual production units requires a production process which is economic for lower volumes. In order to limit cost, but maintain light weight, the subframe was designed as a one-piece casting with a high degree of functional integration. The selection of a casting technique offering maximum part performance enabled not only a complete hollow design with thin walls, but also to meet the high strength and stiffness demands of a highly stressed chassis part. With dimensions of 1200 by 710 by 335 mm, a nominal wall thickness of 3.9 mm and a weight of only 16 kg, the subframe component consolidates about 30 individual parts of the usual sheet panel design into one single casting.



**Rear axle subframe of the Porsche Panamera, produced as a one-piece hollow casting by low pressure die casting (VRC/PRC)
Source: Porsche**

But also other high quality casting methods such as aluminium sand casting can be used for the production of rear axle subframes.



**Prototype of a hollow aluminium rear axle subframe produced by sand casting in the alloy AlSi7Mg (final weight 17.1 kg)
Source: GF Automotive**

1.2.2 Rear axle subframe in aluminium sheet design

Non heat-treatable AlMgMn alloys are applied in large quantities as hot and cold rolled sheets due to their good formability which can always be re-established by interannealing during complex forming operations. They are highly suitable for the assembly of relatively complex chassis parts such as axle subframes because of their formability and strength, weldability and the fact that there is no need for quenching for age hardening (which would be detrimental for the required consistent geometrical tolerances).

A well established AlMg alloy for high strength and excellent formability is EN AW-5182 (AA5182). However, in 5xxx alloys containing > 3% Mg, the precipitation of β - Mg_5Al_8 particles at grain boundaries during long term exposure at temperatures > 80°C can result in a susceptibility to intergranular corrosion cracking. Thus, AlMg alloys with a higher Mg content must be used with caution in applications where exposure to elevated temperature cannot be excluded. The material of choice for chassis parts are therefore the medium strength alloys of the type AlMg3Mn (EN AW-5754) and AlMg3.5Mn (EN AW-5454).



Aluminium rear axles produced from AlMgMn aluminium alloy sheets
Source: Hydro Aluminium Rolled Products

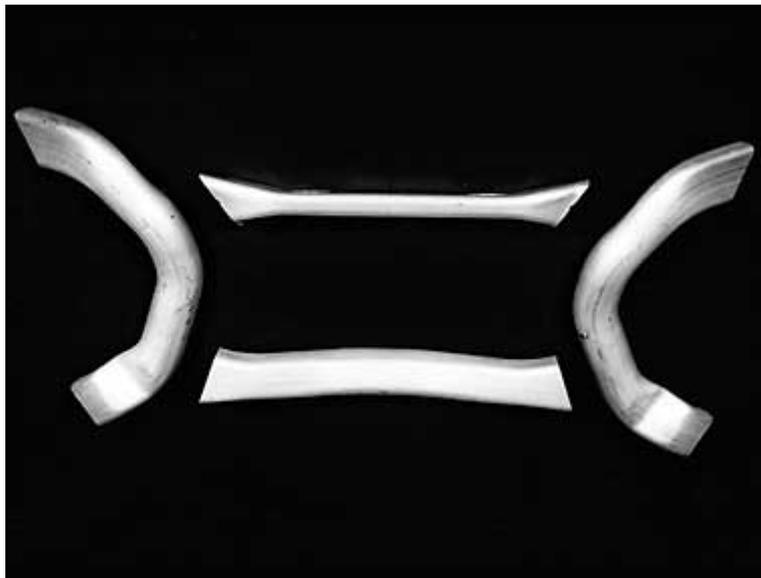
The rear axle subframe of the BMW 5 series models is a compact structural module consisting of hydroformed tubes and deep-drawn sheets which is assembled by MIG welding. With a weight of approx. 11.5 kg, it offers a weight reduction of about 40% compared to a steel solution. The hollow supporting tubes guarantee a high flexural and torsional stiffness which minimises the negative impact of the lower elastic modulus of aluminium on the vehicle's driving dynamics. Longitudinally seam-welded tubes (produced by HF welding) make up approx. 70 % of the subframe with the remaining 30 % comprised of cold-rolled and deep drawn sheets. The complex shape of the tubes in the required narrow tolerances is achieved by 3D-bending, suitable pre-forming and final hydroforming. The bearing bushes for fixing the plastic bearings are made from extrusions (cut-to-length) while the brackets for attaching the control arms are sheet-metal constructions. The wall thickness of the tubes and the sheet stampings is 3.5 – 4 mm, of the extrusions 3 – 6 mm. The EN AW-5454 (AlMg3.5Mn) alloy is used for the tubes and the sheet stampings, the extrusions are made of the alloy EN AW-6060 (Al MgSi0.5).

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Mechanical properties:	$R_{p0,2}$	R_m	Elongation
	[MPa]	[MPa]	[%]
Tubes (0/H111):	> 105	> 240	A ₅ > 18
Sheets (H24):	> 190	> 270	A ₅ > 8
Extrusions (T4):	> 60	> 120	A ₁₀ > 13



Rear axle subframe for BMW 5 series models
Source: Hydro Aluminium Rolled Products



Pre-fabricated tube parts for the BMW 5 series rear axle subframe
Source: Hydro Aluminium Rolled Products

Another fabrication method has been chosen for the aluminium subframe of the Mercedes S class. In this case, the rear axle subframe is a MIG welded assembly whose components are mainly made from deep-drawn aluminium sheet and a few cut-to-length extrusions. The respective longitudinal members and rear cross member consist of hollow structures which are manufactured by fitting half-shells together; the front cross member and brackets are of open sheet-metal design. The bearing bushes for fixing the plastic bearings are formed during the deep-drawing process. With a weight of 12.5 kg, the achieved weight reduction compared to a steel solution is also approx. 40%. Hot-rolled sheets of the alloy EN AW-5754 (AlMg3Mn) and extrusions with 3.5 mm wall thickness of the alloy EN AW-6060 (AlMgSi0.5) are applied.

Mechanical properties:	R _{p0,2} [MPa]	R _m [MPa]	Elongation [%]
Sheets (H0/111):	> 85	> 215	A ₅ > 17
Extrusions (T4):	> 60	> 120	A ₁₀ > 13



Rear axle subframe of the Mercedes S class
Source: Hydro Aluminium Rolled Products

1.2.3 Rear axle subframes assembled from different aluminium products

Whereas one-piece castings are primarily of interest for relatively small production volumes, the assembly of rear axle subframes from sheet stampings is rather a cost-effective solution for large series. Assemblies using different aluminium product forms (sheet stampings, pre-formed and/or machined extrusions and castings) may well be considered for medium production volumes.

The aluminium rear axle subframe of the BMW 7-series is a combination of hydroformed longitudinally welded tubes and cast components with a total weight of only 14.1 kg. The subframe is joined by MIG welding.



Aluminium rear axle subframe of the BMW 7 series
Source: Hydro Aluminium Rolled Products

A combination of a sheet stamping with a casting was also used for a prototype rear axle subframe which was designed for an upper class passenger car:

- Dimensions: (L / W / H in mm): 1130 / 675 / 265
- Finished part weight (in kg): 13



Aluminium rear axle subframe prototype consisting of a sheet stamping and a single casting (below, bottom view)
Source: Hydro Aluminium Rolled Products

The estimated weight benefit compared to the existing steel solution, which includes several stamped parts joined by numerous arc welded joints, was approx. 35 %. The choice of the aluminium solution mixing a cast part and a stamped sheet was guided by the wish to limit the number of joints. The proposed design allows to reduce the assembly cost and to balance the relatively poor fatigue behaviour of welded aluminium joints. The selection of a single cast part offers the possibility to integrate additional functions and to avoid several attachments. The weld has been placed near to the neutral axis of the part in order to reduce stress in welded area.

The thickness of the applied aluminium sheet was 3 mm, the alloy EN AW-6061 – T4. The wall thickness of the casting varied between 4 and 7 mm, alloy Calypso 61S (AlSi10Mg) – F. Low pressure die casting was foreseen for series production, the prototypes were made by sand casting. The casting alloy AlSi10Mg has been preferred over AlSi7Mg since it is more appropriate for large and thin parts. An AlMgSi (6xxx series) alloy has been chosen for welding compatibility with the casting alloy AlSi10Mg. It is used without any thermal treatment in order to avoid distortions that could occur during quenching and to avoid loss of mechanical properties during welding with the filler wire AA 4043.

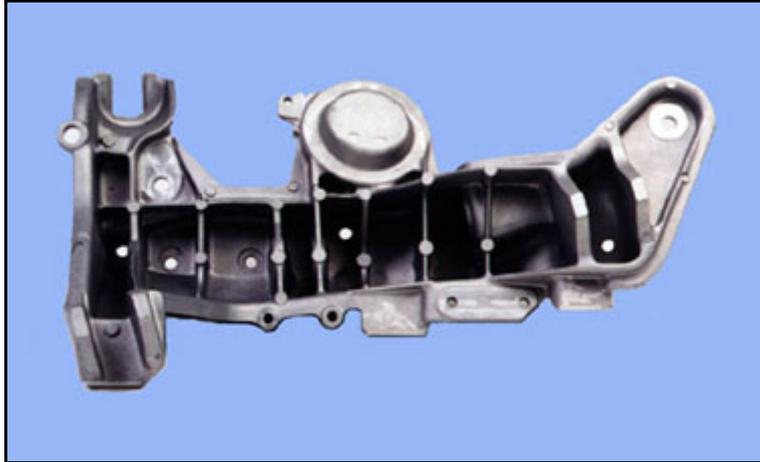
An assembled rear axle subframe consisting of extruded profiles (wall thickness 5 – 10 mm) and thixo-cast parts has been used in the Alfa Romeo Spider:

- Dimensions: (L / W / H in mm): 1270 / 630 / 280
- Finished part weight (in kg): 17.8

The straight extruded sections of the alloy EN AW-6061 in the T6 temper were only slightly machined. The thixo-cast component (Althix 67S1 (AlSi7Mg0.6) – T5) was produced by Stampal SPA. Thixo-casting was selected to manufacture the shaped component because it provides near net shape parts reducing the final machining needs and thus minimisation of cost. The components were joined by MIG welding.



**Rear axle subframe made from straight extrusions and thixo-cast components,
produced for the Alfa Romeo Spider
Source: Constellium**

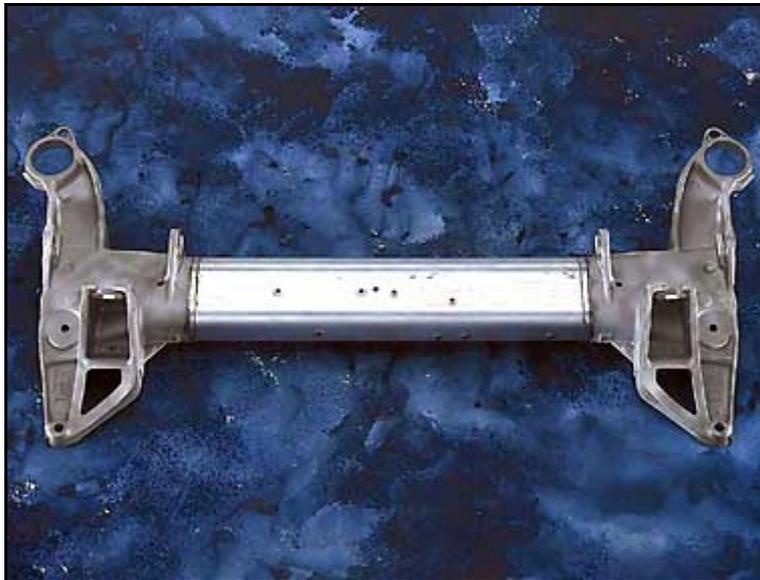


Thixo-cast arm (bottom view)
Source: Constellium

Also the rear axle subframe of the Citroën C5 was an assembly of aluminium extrusions and castings:

- Dimensions: (L / W / H in mm): 1260 / 570 / 220
- Finished part weight (in kg): 11.7.

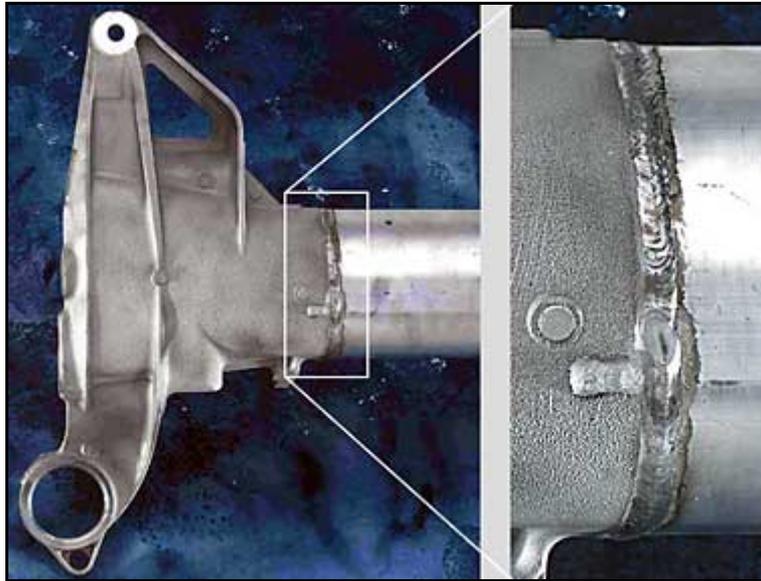
Compared to the former solution, a steel tube and two cast iron parts joined by machining and force fitting, the aluminium solution offered a weight reduction of 45%.



Rear axle subframe of the Citroën C5
Source: Constellium

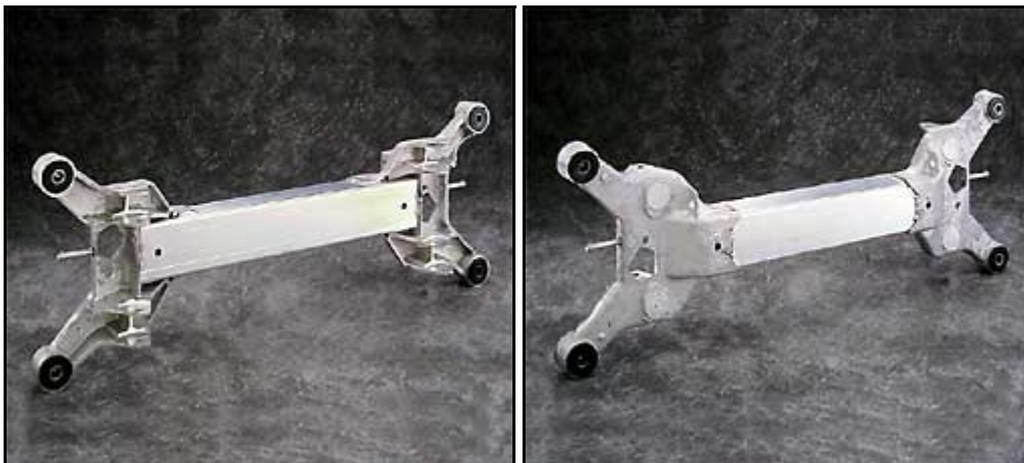
The wall thickness of the extruded section was 2.5 mm (alloy EN AW-6005A – T6), subsequent fabrication included cutting and piercing. The cast components with wall thicknesses between 4 and 15 mm were produced by permanent mould gravity casting using the alloy Calypso 67B (AlSi7Mg) – T6. The parts were then joined by press fitting and MIG welding. The joint is a butt weld on a natural support provided by the cast part (see photo

below). The assembly cost could be reduced compared to the earlier solution due to the elimination of the machining step which was necessary for force fitting of the steel tube onto the cast iron parts. The aluminium extrusion is just press fitted onto the cast parts and then welded.



Detail of the rear axle subframe of the Citroën C5
Source: Constellium

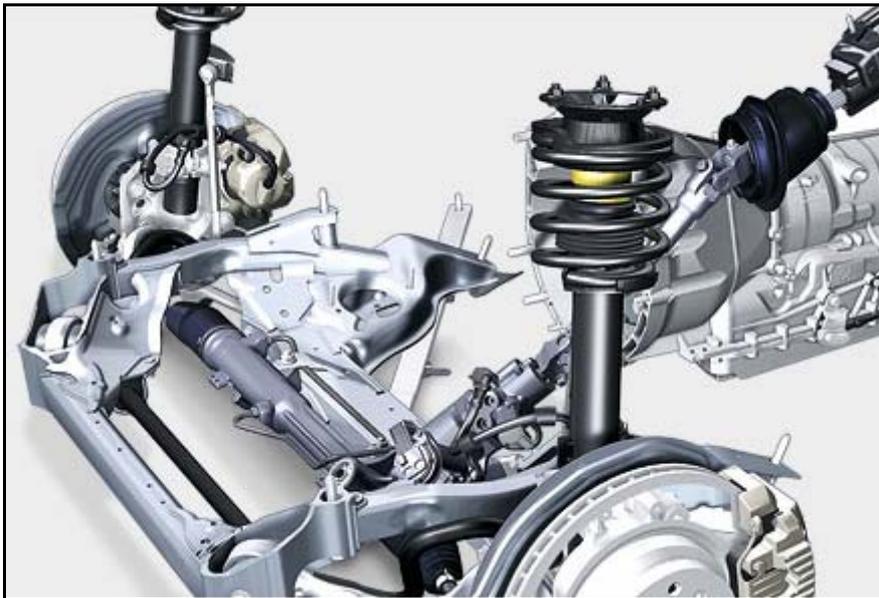
A similar solution consisting of two castings and an extrusion was chosen for the rear suspension crossmember of the Chrysler Concorde/Dodge Intrepid. Compared to the former steel solution, the aluminium design with a finished part weight of 5.8 kg offers a 30 – 35% lower mass, but doubles the lateral stiffness and even triples the torsional stiffness.



Rear suspension cross member of the Chrysler Concorde/Dodge Intrepid
Source: Alcan

1.3 Front axle subframes

Lightweighting is also a strong driver for the application of aluminium in the front axle subframe. An excellent example is the BMW double-joint spring-strut front axle which is constructed of aluminium. The use of aluminium leads to a weight reduction of 30% compared to a similar axle made of steel, minimising the unsprung mass of the vehicle. The application of aluminium delivers immediate results in the responsiveness of the suspension and steering systems. The lower the weight that has to be moved, the easier it is to control. At the same time, the aluminium structure is so stable that the front wheels always have optimum traction on the road surface, thanks to the highly rigid diagonal front axle subframe which also carries the steering gears, track control arms and push bars, as well as the anti-roll bar.



Aluminium front axle
Source: BMW

A different example is the front-axle subframe which was used for the lightweight version of the Volkswagen Lupo (“3 litre Lupo”). In this case, a very simple design consisting of a one-piece, folded sheet-metal structure has been used. Following a multistage deep-drawing and stamping process, the aluminium sheet is folded to give a hollow transverse member. The overlapping sheet ends are joined together by MIG welding. Collateral squeeze-cast aluminium brackets and forged control arms are attached to the transverse member.



Front axle subframe of the Volkswagen “3 litre” Lupo
Source: Hydro Aluminium Rolled Products

With a final weight of approx. 2.6 kg, the resulting weight reduction compared to a steel solution was approx. 45%. A hot rolled aluminium sheet of the alloy EN AW-5454 (AlMg3Mn) with a thickness of 3.5 mm was used. The mechanical properties are:

Mechanical properties:	R _{p0,2}	R _m	Elongation
	[MPa]	[MPa]	[%]
Sheets (H0/111):	> 85	> 215	A5 > 17



Intermediate fabrication steps
Source: Hydro Aluminium Rolled Products

The fabrication of the subframe includes the following steps:

- Two-stage deep-drawing
- Two-stage stamping
- Folding to a hollow structure
- Joining of the overlapping sheet ends by MIG-welding.