Applications – Chassis & Suspension – Suspension parts

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2 Suspension parts

The suspension includes the system of springs, shock absorbers and linkages which connect a vehicle to its wheels. The suspension supports the weight of the vehicle body and also protects the vehicle and any cargo from damage and wear. The purpose of an automobile's suspension system is two-fold: passenger comfort and vehicle control, i.e. the suspension system is the determining factor for active safety and driving pleasure. Comfort is provided by isolating the vehicle's passenger cabin from road bumps, vibrations, road noise, etc. Control is achieved by keeping the car body from excessively rolling and pitching, and maintaining good contact between the tyre and the road surface. These goals are generally at odds, so the tuning of the suspension system involves finding the right compromise.

Apart from the linkages, the fundamental components of any suspension are springs, dampers and stabilizer (also called anti-roll) bars. Some aluminium components are found in springs and dampers, but the most important aluminium applications are the structural suspension parts, i.e. knuckles (wheel carriers) and control arms. For unsprung masses such as knuckles and control arms, lightweighting presents additional advantages. Thus a reduction of the weight of the unsprung masses will also remain a most important driver for future developments.

2.1 Stabilizers

A stabilizer is usually a torsion spring that resists body roll motions. Its purpose is to prevent the car's body from "rolling" in a sharp turn. A stabilizer is generally constructed out of a U-shaped piece of steel that connects to the body at two points, and at the left and right sides of the suspension. If the left and right wheels move together, the bar just rotates about its mounting points and does not bend. If the wheels move relative to each other, the bar is subjected to torsion and forced to twist. Some high-priced cars have also begun to use "active" anti-roll bars that can be automatically adjusted by a suspension-control computer. The result is a reduced leaning of the body in turns while the rough-road ride quality of the vehicle is significantly improved. With respect to stabilizers, no specific aluminium applications are known or can be foreseen today.

2.2 Springs

Today's automotive spring systems are based on one of four basic designs:

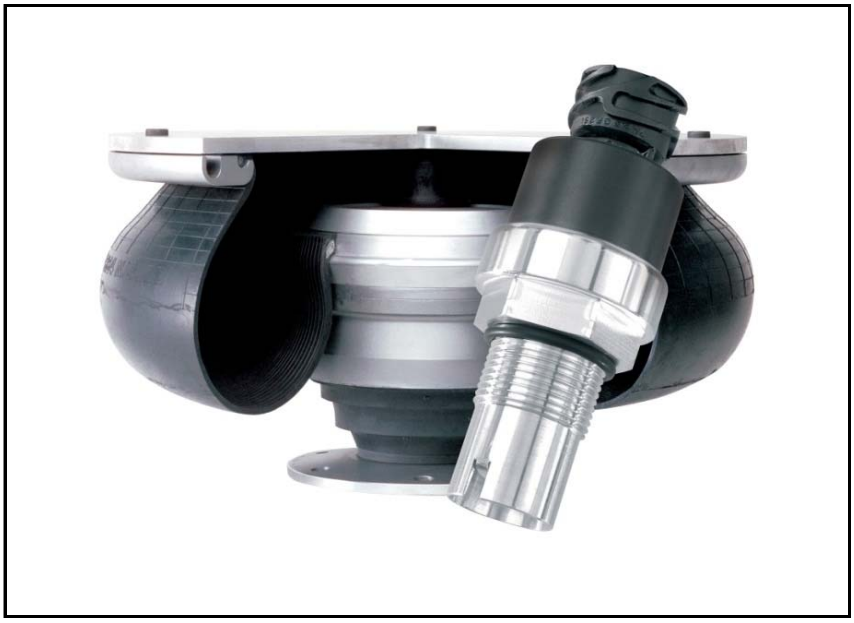
- Coil springs
- Leaf springs (seldom used today)
- Torsion bars
- Air springs

Torsion bar systems are most often found in the automobile. Torsion bars use the twisting properties of a steel bar to provide a coil spring-like performance. One end of the torsion bar is attached to the frame of the vehicle, the other end to a wishbone, which acts like a lever that moves perpendicular to the torsion bar.

Air springs consist of a cylindrical air chamber that is positioned between the wheel and the car body. Air suspension systems, which are typically found in the premium car segment, use compressed air as a spring. The air is pressurized by an engine-driven or electric air compressor. In terms of present and potential future aluminium applications, only air suspension systems have to be considered in more details.

Air suspension systems

The air suspension replaces the conventional steel spring system. Air suspension systems are able to automatically adapt the damping and spring characteristics of the suspension according to the preferences of the driver as well as to adjust the body level of the vehicle to changing driving conditions and loads. Due to their many advantages, air suspensions systems are more and more specified for future platforms. This is an important development trend as car manufacturers strive to improve gas mileage by weight reduction and thus utilize active suspension technology to maximize the car performance.



Electronically controlled air suspension system with electrically actuated valves and integrated height and pressure sensors

Source: ContiTech

Apart from different components in the control unit, aluminium applications in air suspension systems include the air reservoirs which make the compressed air centrally available, but also various connection pipes with integrated flanges. The currently applied pressure in air suspension systems ranges from 10 bar to 25 bar, but the components achieve bursting pressures of up to 100 bar. Aluminium air cells offer top functionality, high gas tightness, excellent corrosion resistance and low weight. Tight space requirements can be fulfilled by the customer-specific development and fabrication of air cells in highly complex geometrical shapes. A unique example for an innovative optimisation of the installation space is the triangular air cell of the Audi A6 which is installed behind the back seat.


Air cells for VW Phaeton (left) and Mercedes (right)

Source: SAG Motion AG

Air cell for the air suspension system of the Audi A6 (SAG Motion AG)

2.3 Dampers

Unless there is a dampening structure, mechanical springs would release the absorbed energy at an uncontrolled rate. In practice, the unwanted spring motion is dampened by shock absorbers which slow down and reduce the magnitude of the vibratory motions by absorbing or dissipating the kinetic energy of the suspension movement. Rubber bushings then absorb the rest of the vibrations. The sole purpose of the damper in any suspension system is to control the oscillations of the springs, the weight of the vehicle is supported by the spring system.

There are many types of shock absorber, but the most commonly used is the twin tube design which works with a hydraulic fluid (oil). It can be adapted to all types of suspension. The upper mount of the shock absorber connects to the frame of the car (i.e. the sprung weight), while the lower mount connects to the axle, near the wheel (i.e. the unsprung weight). The energy of the spring is transferred to the shock absorber through the upper mount into a piston which sits in the inner (pressure) tube filled with hydraulic fluid. Boreholes through the piston allow the fluid to leak through a series of compression valves as the piston moves up and down in the pressure tube. Since this process requires considerable force, there is a natural resistance to any rapid movement and the bouncing movement of the springs is dampened.The outer (reserve) tube stores excess hydraulic fluid.

Lightweight shock absorbers with tubular aluminium housings

Source: Aleris – ZFSachs

An automotive suspension strut combines the primary function of a shock absorber with the ability to support sideways loads not along its axis of compression, thus eliminating the need for an upper suspension arm. The most common suspension strut in an automobile is the McPherson strut (see next chapter). Each wheel is attached to the car body by a McPherson strut which combines a shock absorber and a spring in a single unit. Such an integrated shock-and-spring module offers better suspension tuning abilities and a lower vehicle step-in height because of the altered suspension geometry. This means that a strut must have a more rugged design, with mounting points near its middle for attachment of such loads. The substitution of steel by aluminium in the shock absorbers, which increasingly occurs in particular on car models with McPherson struts, saves 20-30% of the weight of the shock absorber.

Premium cars with air spring systems are fitted with electronically assisted pneumatic shock absorbers which allow the air spring pneumatic pressure to automatically optimize the damping action under varying load conditions. In addition to providing improved vehicle handling and driving comfort for different load conditions, this system isolates the chassis from the road and thus reduces the possibility of vibration damage.

2.4 Suspension control arms

The typical design elements of any modern suspension system – be it of the McPherson strut, trailing arm, multi-link or wishbone type - are the suspension control arms. The number of control arms in a vehicle depends on the type of suspension.

The McPherson suspension system, for example, consists of a wishbone (or a lower control arm stabilized by a secondary link) which provides a bottom mounting point for the hub of the wheel. This lower arm system controls both the lateral and longitudinal location of the wheel. The upper part of the hub carrier (or steering knuckle) is rigidly fixed to the strut. The strut suspension includes also a steering arm which connects to the knuckle. The whole assembly is very simple and, since it eliminates the upper control arm, also allows for more width in the engine compartment. Another common type of a front independent suspension is the double-wishbone suspension. While there are several different possible configurations, this design typically uses two wishbone-shaped arms to locate the wheel. Each wishbone, which has two mounting positions to the frame and one at the knuckle, bears a shock absorber and a coil spring to absorb vibrations. Double-wishbone suspensions allow for more control over the motion of the wheel. Because of these characteristics, the double-wishbone suspension is common on the front wheels of larger cars.

Suspension control arms are important safety-critical parts. Conventionally, these parts were made of steel. In comparison with a steel control arm, the mass reduction of an aluminium control arm may be up to 50 % and/or the structural rigidity and strength can be improved as well. Such a weight reduction potential is a strong driver for the application of aluminium, in particular because any reduction of the un-sprung masses offers significant additional advantages. Hence, suspension parts are a strongly growing market for aluminium.

The high quality requirements and the specific mechanical property of load-bearing control arms are best satisfied with aluminium forgings where the benefits of a fibrous microstructure oriented along the loading path can be exploited in addition. Highly automated forging processes starting from extruded or cast performs allow cost-effective large series production. Consequently, load-bearing control arms are the most important application of aluminium forgings in the automobile.

Forged control arms are produced in a variety of shapes

Source: Otto Fuchs

A wider range of aluminium processing technologies is available for the production of non-load bearing (guiding) control arms. Apart from forgings, also high quality cast parts (sand castings, squeeze castings, high pressure die castings, etc.), components produced using sophisticated semi-solid (thixotropic) processing methods and solutions based on sheets and/or extrusions are possible as well.

2.4.1 Forged control arms

Example 1

Source: Constellium

Production of this part started already in 1996, the current annual production volume is 400’000 parts (maximum annual production volume was 2 mio. parts). It is still used for some medium and premium VW/Audi car models.

Specifications:

Dimensions: (L / W / H in mm):	≈ 450 x 80 x 30
Finished part weight (in kg):	≈ 1.1
Weight benefit compared to a steel solution (in %):	30%
Replaced / Substituted steel parts:	steel forging

Material selection

Forging:	EN-AW 6082 - T6
Wall thickness:	10 to 30 mm

Example 2

Source: Constellium

This control arm is used for the front suspension of premium Mercedes car models (start of production: 2006, annual volume: 160’000 parts).

Specifications:

Dimensions: (L / W / H in mm):	≈ 500 x 100 x 100
Finished part weight (in kg):	≈ 1.7
Weight benefit compared to a steel solution (in %):	50%

Material selection

Forging:	EN-AW 6066 - T6
Wall thickness:	15 to 40 mm

Example 3

Source: Constellium

This control arm – shown in different manufacturing stages - is used for the rear suspension of premium Mercedes car models (start of production: 2006, the annual volume: 160'000 parts).

Specifications:

Dimensions: (L / W / H in mm):	≈ 450 x 120 x 20
Finished part weight (in kg):	≈ 0.6
Weight benefit compared to a steel solution (in %):	40 %

Material Selection

Forging:	EN AW-6082, T6
Wall thickness:	5 to 20 mm

Example 4

Source: Constellium

Production of this part started in 2004, the current annual production volume is 400'000. It is used for the front suspension of medium and premium VW/Audi car models manufactured in Europe and China.

Specifications:

Dimensions: (L / W / H in mm):	≈ 450 x 90 x 80
Finished part weight (in kg):	≈ 1.4
Weight benefit compared to a steel solution (in %):	50 %

Material Selection

Forging:	EN AW-6082 - T6
Wall thickness:	15 to 40 mm

Example 5

Source: Constellium

The start of production of the shown front control arm (annual production volume: 60'000) for BMW premium models (produced in Europe and in the US) was 2005.

Specifications:

Dimensions: (L / W / H in mm):	≈ 500 x 120 x 50
Finished part weight (in kg):	≈ 1.6
Weight benefit compared to a steel solution (in %):	30 %
Substituted part:	steel forging

Material selection

Forging:	EN AW-6082 - T6
Wall thickness:	15 to 50 mm

Example 6

Source: Constellium

The start of production of the shown front control arm (annual production volume: 300'000) for BMW premium models (produced in Europe and in the US) was 2006.

Specifications:

Dimensions: (L / W / H in mm):	≈ 300 x 300 x 50
Finished part weight (in kg):	≈ 0.9
Weight benefit compared to a steel solution (in %):	40 %

Material selection

Forging:	EN AW-6082, T6
Wall thickness:	5 to 40 mm

2.4.2 Control arms produced by semi-solid processing

Suspension parts have been a key market targeted by the various semi-solid processing technologies known under the terms rheocasting, thixo-casting, thixo-forging, etc. Semi-solid processing techniques make use of the specific properties of aluminium alloys at temperatures between the solidus and liquidus. They allow the production of net-shape or near net-shape components which approach the mechanical property levels of forged components using a shorter processing route (rather similar to that of cast components). There are different examples of suspension parts which have been produced using these processing methods. However, a real breakthrough has not yet been achieved for economical and technical reasons.

The following example shows a front axle upper wish bone which was produced by thixo-casting for series application. However, this production technology was later abandoned.

Source: Constellium

This part was produced by semi-solid forming (thixo-casting) for the Mercedes S class (SOP 1998) as a net shape component ready for assembly of the ball joint and the bushings, i.e. no additional machining operation.

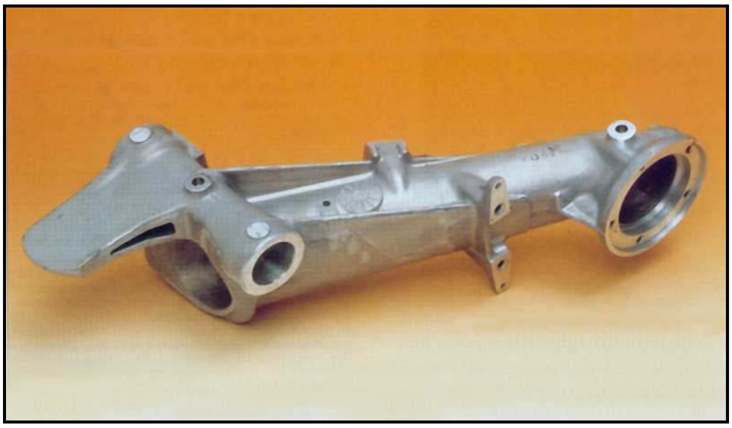
Specifications:
Dimensions: (L / W / H in mm): 350 x 260 x 70
Finished part weight (in kg): 0.960
Weight benefit vs. steel solution (in %): 30-40 (estimated)

Material Selection: SSM: A356–as cast

Wall thickness: 5 to 10 mm

2.4.3 Control arms produced by different casting methods

Example 1



Source: Constellium

The rear suspension arm shown above was produced as a permanent mould gravity casting for the Citroën XM model. The cost of the cast aluminium part was lower than the steel version because of its monolithic aspect compared to an assembly of numerous stamped steel parts.

Specifications:

Dimensions: (L / W / H in mm):	550x180x170
Finished part weight (in kg):	3.8
Weight benefit vs. steel solution (in %):	44
Replaced / Substituted steel parts:	Stamped steel assembly by welding

Material Selection:

Casting:	Calypso 67N – T6
Wall thickness:	5 to 10mm

Example 2

Source: GF Automotive

This sand cast rear control arm with a weight of only 2.6 kg is used in the Audi models A4, A5, Q5 and A8 (alloy: AlSi7Mg). The thin-walled aluminium sand casting offers an extremely lightweight solution. Fabrication steps: Casting, trimming, heat treatment, machining, assembly.

Example 3

Source: GF Automotive

The control arm shown above for the Porsche Panamera is produced by permanent mould casting
(alloy: AlSi7Mg). The fabrication operation includes the following steps: casting, trimming, heat treatment, machining and assembly.

2.4.4 Control arms produced from extruded sections

The specific characteristics of the aluminium extrusion technology also offer the potential for the cost-efficient production of control arms. An obvious solution is to simply cut appropriate slices from an extruded profile with a properly designed cross section. Extruded profiles which are subjected to little or no mechanical deformation (cold forming), have been used since the 1990ies in different car models. These extruded profiles can be both open or chamber sections, depending on the specific type of load, the applied alloy and the dimensions of the part. While this solution is clearly highly cost-efficient, it must be kept in mind that the determining mechanical characteristics are the mechanical properties in the transverse direction.

Some examples of such profiles are given below.

Extruded control arms (hollow profiles)

Source: Aleris

Left:

- Dimensions: (L / W / H in mm): ≈ 530 x 120 x 50
- Material: EN AW 6008

Right:

- Dimensions: (L / W / H in mm): ≈ 342 x 63 x 16
  ≈ 165 x 63 x 24
- Material: EN AW 6082

Extruded control arms are produced in open sections

Source: Aleris

Left:

- Dimensions: (L / W / H in mm): ≈ 486 x 52 x 15
- Material: EN AW 6082

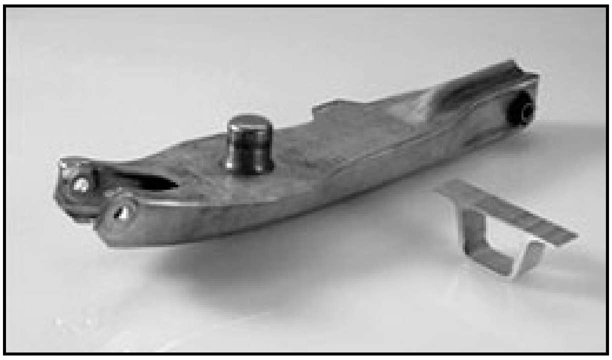
Middle:

- Dimensions: (L / W / H in mm): ≈ 457 x 60 x 21
- Material: EN AW 6082

Right:

- Dimensions: (L / W / H in mm): ≈ 325 x 63 x 24
- Material: EN AW 6082

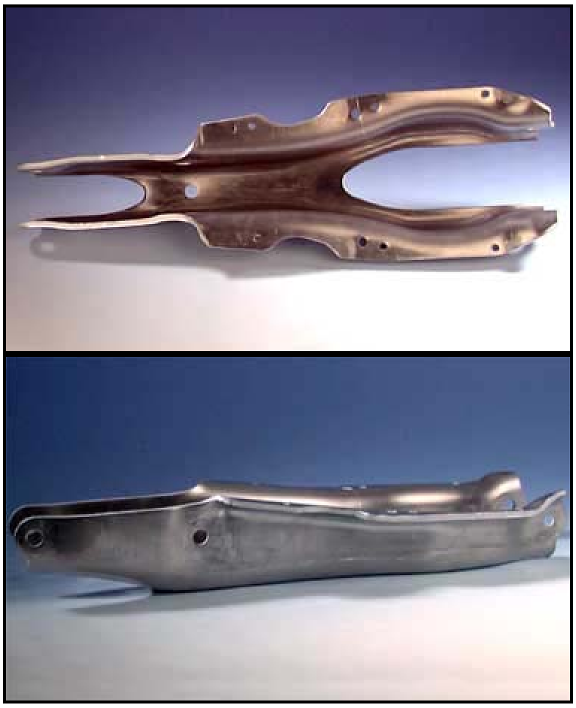
Another possibility is to subject a longitudinal segment of a specifically designed extruded section to an appropriate forming operation (see below).



Source: Raufoss Technology

The rear control arm shown above is produced in high volumes from an extruded section in an in-line process consisting of stretch bending cold forming, stamping, heat treatment and assembly. This innovative combination produces optimal lightweight solutions, setting new standards for weight reduction (weight: 1584 g, including all components, 40 – 50 % lighter than steel equivalent).

2.4.5 Control arms produced from rolled sheet



Transverse control arm in aluminium sheet design

Source: Hydro Aluminium Rolled Products

The transverse control arm shown above was designed for an upper class model as a deep drawn part. The minimum deep-drawing radius is around 12 mm (two times wall thickness) while the drawing depth is ~90 mm. The mounting points for the axle subframe, the wheel carrier and the fixture for the pneumatic suspension are integrated into the component. With a final weight of approx. 1.5 kg, a weight reduction of about 35% compared to the steel solution was achieved.

The starting material was a hot-rolled aluminium sheet of the alloy EN AW-5454 (AlMg3Mn), the sheet thickness was 6.0 mm.

Mechanical properties:	$R_{p0,2}$ [MPa]	R_m [MPa]	Elongation A_5 [%]
Sheets (H0/111):	> 85	> 215	> 17

2.4.6 Assembled control arms

A further possibility is to assemble the control arm from different aluminium product forms, e.g. stamped sheets and cit-to-length extrusions.

Trapezoidal wishbone as a welded aluminium module

Source: Hydro Aluminium Rolled Products

The trapezoidal control arm for an upper medium class model consists of three longitudinally seam-welded tubes and two extruded bearing bushes. The hollow structure of the components guarantees a high stiffness. It is therefore able to withstand the high bending and torsional moments, caused by braking and traction, without significant elastic deformation.

The weight of the assembled control arm is approx. 2.4 kg, representing a weight reduction of about 35 % compared to the steel solution. The longitudinally seam-welded tubes (HF welding) have a wall thickness of 4.0 mm, the alloy is EN AW-5754 – HO/111 (AlMg3.5Mn). The wall thickness of the extrusions is 4.0 – 6.0 mm, the alloy is EN AW-6060 - T4 (Al MgSi0.5). The fabrication process of the tubes includes machining, 2D-bending and forming, the extrusions are just cut-to-length. The applied joining method is MIG welding.

Mechanical properties:	$R_{p0,2}$ [MPa]	R_m [MPa]	Elongation
Tubes (0/H111):	> 105	> 240	A5 > 18%
Extrusions (T4):	> 60	> 120	A10 > 13%

2.5 Knuckles (wheel/hub carriers)

Aluminium knuckles produced by the Counter Pressure Casting technique

Source: KSM Castings

The knuckle attaches the wheel end braking components to the suspension. Knuckles are typically custom designed for each application per customer vehicle and loading requirements. The knuckle attaches to the suspension points, such as upper and lower control arms (via ball joints or pinch bolts), struts, and/or tie rod ball joints. The bearing and caliper are typically bolted to the knuckle. As a result of their relatively complex geometry, knuckles are generally cast and subsequently machined components. High quality aluminium casting methods must be applied in order to meet the stringent mechanical requirements.

2.5.1 Example 1 - Rear arm and hub carrier assembly

Source: Constellium

Rear arm /hub carrier assembly for the Peugeot 406 Coupé: The suspension arm, an aluminium permanent mould casting, was produced in high volumes (used for all 406 models). The aluminium hub carrier was a Cobapress™ cast forging (produced by Saint Jean Industries):

Specifications:
Dimensions: (L / W / H in mm): 620x250x120
Finished part weight (in kg): 3.2
Weight benefit vs. steel solution (in %): 50
Stiffness benefit vs. a steel solution (in %): 30
Replaced / Substituted steel parts: Hub carrier: cast iron
Suspension arm: steel tube + stamped steel parts

Material:
Casting: AlSi7Mg – T6

Wall thickness: 4 to 20 mm

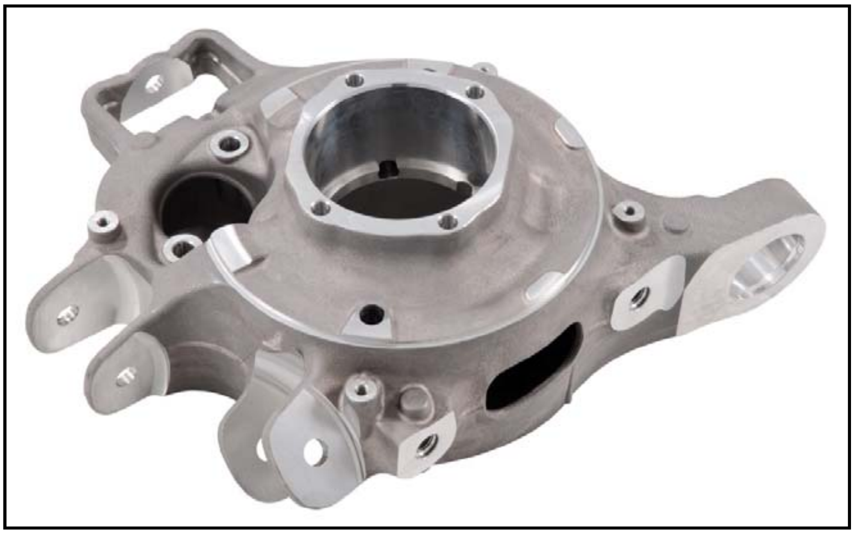
The Cobapress™ technology provides near net shape parts, allowing reduced machining and minimisation of costs. The forging operation during Cobapress process improves the fatigue behaviour of parts compared to standard gravity cast components.

2.5.2 Example 2 - Front knuckle produced by permanent mould casting

Source: GF Automotive

The shown front knuckle of the Porsche Panamera is an AlSi7Mg low pressure permanent mould casting (weight 4.2 kg). The fabrication operation includes casting, trimming, heat treatment, machining and assembly.

2.5.3 Example 3 – Permanent mould cast rear knuckle



Source: GF Automotive

The rear knuckle of the Porsche Panamera shown above is an AlSi7Mg permanent mould casting. The fabrication operation includes casting, trimming, heat treatment, machining and assembly. In spite of using the low pressure permanent mould casting process, a sand core is used to shape the hollow areas of the component.

2.5.4 Example 4 – Permanent mould cast knuckle

Source: GF Automotive

Permanent mould aluminium knuckle for the Audi A8 model (alloy: AlSi7Mg). The process chain includes beside of the pouring additional production steps such as trimming and heat treatment. Low pressure permanent mould cast aluminium components combine high strength and exceptional elongation. Both properties are crucial for lightweight safety components in the suspension.

2.5.5 Example 5 – Axle support machined from an extrusion

Source: Honsel

Axle supports can be cost-efficiently produced starting from a properly designed extruded aluminium section. The fabrication of the axle support shown above (applied in the Volkswagen Golf platform) just includes cutting to length and some machining. The alloy EN AW-6082 is applied.