

Aluminium – the light Heavyweight in Automotive

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ABSTRACT

During the past 30 years cars have grown in weight, although significant efforts have been made to reduce at least the weight increase. This is mostly due to increased safety requirements, both from legislation and customers, but also to the need for higher comfort and reliability.

Aluminium plays an increasing role in fighting against kilos, and has become the second most used metal in passenger cars. Prominent uses of this light metal are shown, the variety of different semi materials (e.g. sheets, extrusions and castings) and their preferred uses are discussed and latest developments with regard to material hybrids are shown. Finally, a study demonstrates that by intensive use of aluminium in modern cars a significant weight reduction without any compromise in safety can be obtained. Future legislation with respect to CO₂ emissions will be a driving force for lightweighting, as well as the brilliant recyclability of aluminium.

Key-words: aluminium semi materials, safety aspects, alumaximised car study, emissions' reduction, recycling, multi material design

INTRODUCTION

Cars are the most fascinating technical product for the public – they stand for flexibility and freedom. Upcoming legislation concerning emissions and consumptions ask for joint activities to meet these challenges, including combustion technologies, friction, drag and, last but not least, weight reductions. No other means of transportation has a similar importance for the people in EU 15, as can be seen in figure 1. The passenger kilometers per person and year, which are made by car, by far exceed the sum of all others.

HISTORY OF ALUMINIUM IN BODY IN WHITE APPLICATIONS

It was not until the early fifties before the first „high volume“ car was produced with an aluminium body, the Panhard Dyna in France. Amongst the range of cars within the Panhard group, the Dyna was relatively small. As all cars at that time, the Dyna was not more than a chassis and an engine; the aluminium sheet body was shoved upon it like a hat. The alloys used were all AlMgMn type (5xxx), due to the good formability and corrosion resistance. With its light body, the Dyna achieved excellent performance even with a relatively small engine. A few years later, the brand „Panhard“ vanished from the market, and the plants were taken over by Citroën.

The first and second oil crises in the early and mid seventies made people aware of the need for fuel-efficient cars. The US legislation enacted the CAFE (Corporate Average Fuel Economy) regulations; an additional „Gas Guzzler Tax“ was introduced to help accept higher production cost for light weighting and other fuel saving measures. Weight savings were intensively discussed within the automotive industry worldwide. But, these weight savings needed time for

development, and quick actions were asked for by the market.

To solve the problems, in the US hoods were identified as the best and fastest measures, using the same tools and gauges as for the steel parts. To overcome the problem of plastic denting (e.g. through hail) due to the lower Young's modulus of aluminium compared to steel, materials with high yield strength were considered. In many cases AA 2036 (AlCuMg type) was the alloy used, offering excellent formability with very high yield strength, even after the normal paint bake cycle. The joining method was the same as for the steel hoods, resistance spot welding, only the spot geometry and welding power source had to be changed.

This technique brought several advantages for the American automotive industry:

- additional tooling cost could be saved
- a high flexibility for the share of aluminium hoods was possible, equipping only those cars which had major weight problems through heavy options like air conditioners, sun roofs, electric seats etc.
- a quick re-conversion to steel was possible

But, as main disadvantage, a material dedicated optimisation could be made only for one material.

The European way to solve the problem was different. Cars were much smaller in outer size and thus lighter by tradition, and fuel was much more expensive historically through higher taxes than in the US. So the need for fuel-efficient cars had arisen already much earlier. Light components, like cylinder heads and gearbox housings of aluminium had been standard for new developments already before the oil crisis. Most of these developments were castings, nearly all of them only in the power train. Nevertheless, many light

weighting and other fuel saving techniques were developed as a consequence of the oil crisis, but due to the absence of national and/or European legislation these were frequently used only in applications for car exports to the US. For the first time the light weighting included a wider range of body and interior parts, such as hoods, seat shells and rails, catalytic converter heat shields, dashboard carriers, fenders and bumper reinforcements, to name only the most prominent ones. For all outer body parts the alloy was of a AlMgSi type (6xxx), because of its good forming behaviour, its good strength and excellent corrosion resistance. AlMgMn (5xxx) alloys were not used for the outer – visible – skin of cars because of their characteristic Luders or stretcher strain lines appearing out of metallurgical reasons at certain degrees of deformation with that type of alloys. Nevertheless, for inner parts 5xxx alloys in most cases were selected, because they offered the maximum formability. The American solution with AA 2036, on the other hand, was rejected by the European automotive industry out of corrosion-related reasons.

Audi started the development of a new door concept, which then appeared in series production with the 3rd generation of the Audi 100 in 1982. The concept of preassembling the inner door with glazing, locks and window levers to one unit and finally assemble this with the body in white required lightweight materials for easier manual handling. So the decision for using stamped aluminium sheets in a two shell design, joined together with a modified resistance spot welding, was only logical. A few years later, with the advent of the next generation of A80, the same concept was used, but the joining technology was optimized and thus clinching was introduced in modern car manufacturing technology.

Apart from these “short term developments” the oil crisis did initiate many more fundamental R&D projects within the automotive industry to find out possibilities and limits for future weight reductions. A very prominent example was the Audi 100 with all aluminium body as a concept car, first presented to the public at the Hanover Fair 1985 in Germany. The car was made in a monocoque design, more or less identical to the series production steel car. As an advantage the existing stamping tools could be used with the restriction that the gauges had to be identical like steel or only slightly above. In those cases, where an increased stiffness or strength was required, the parts were simply doubled. Another measure to compensate for the lower Young’s modulus of aluminium was replacing the typical resistance spot welding of steel monocoques through weld bonding and thus increasing the joining area.

Mercedes Benz revealed in 1988 an aluminium concept car as city car, being something like a very early predecessor of the now very successful smart. This

concept used one very early idea of fabricating the passenger cell out of only a handful of large castings – one for the floor group including firewall and A pillar and four for the top of the passenger compartment. In an ideal way using casting technologies many functions can be integrated into one part, reducing the number of parts and thus assembly costs significantly. For the prototypes, sand casting was the selected technology. For a small series production, low pressure die casting was considered. From today’s knowledge, for higher production volumes vacuum assisted high pressure die casting might be an adequate fabrication process, giving excellent strength and ductility properties. Conceptwise, the crash relevant front and rear parts consisted of wrought aluminium alloys, having superior ductility and strength properties. After the presentation of the project car to the public in 1988 the project was no longer followed – most probably due to lacking market demand.

Renault, finally, started a project for a light sportscar, the Renault Spider. Due to the planned low production volume, investment in tools should be low, accepting a slightly higher share for labour costs. Here aluminium extrusions were chosen for the body structure with a low tooling investment. Some of the extrusions were bent and subsequently machined, joining was done by MIG welding.

Different Aluminium Concepts

Today, there are several types of cars with an aluminium body on the market, covering production ranges from hundreds to more than 60.000 per year. Through aluminium’s variety of different semi materials and parts’ technologies (like sheet stamping, extruding, forging, casting in many different technologies etc.), for different production ranges different concepts make sense out of a technical as well as an economical perspective.

Some general remarks explain this:

Deep drawing tools for sheet material and the required press lines are extremely expensive. On the other hand, the deep drawing process itself is very quick, once the line and the tools are adjusted to the specific production lot. It is evident that for high production volumes a short production time dominates the costs, while for low numbers the high tooling and machinery investment dominate the parts’ costs.

Looking at extruded parts and taking into account that some additional manufacturing (like bending, end cutting, hydroforming, drilling, etc.) is required for a typical extruded part, one comes to costs for an average part which are significantly lower at low volumes (mainly due to lower tooling costs), but due to longer process times needed compared to sheet stamping the

cost degression is lower than for stamped parts. This makes it obvious why low volume cars are preferably designed with extrusions.

Looking finally at castings, and selecting here vacuum assisted high pressure die casting as an adequate process for thin walled body parts, the initial die costs are higher than the tooling for extruded parts, but castings normally go one step further and are, in many cases, through the possibility of integrating functions something like a subassembly, so that a typical cast part cost wise is relatively close to a typical subassembly fabricated of several extrusions. A major difference arises through the wear of the high pressure die casting tools, who have a limited lifetime and need to be renewed periodically, thus increasing the investment cost again.

Bearing this in mind, the fundamentally different concepts of Audi's A8 and A2 (with a mix of all the above mentioned technologies and medium production numbers), BMW's Z8 (using nearly only extrusions for the inner structure at low production volumes) and Ford's P2000 concept car (designed for about 200.000 cars per year or more, nearly completely as stamped sheet concept) are becoming more transparent now.

The Space Frame

The first Space Frame concept, developed in close cooperation between Audi and Alcoa, was the consequence of the experience made with the monocoque body presented 1985 and the economical considerations mentioned above. Simply said, the Space Frame is an intelligent mix of different semi materials, varied according to different production volumes.

For the first generation (the Audi A8), castings were used mostly as nodes, either to join several profiles at one point or changing geometry like with the front longitudinal member, coming from a circular shaped extrusion via a casting into a hexagonal extrusion. An additional advantage of the cast transition part is the possibility of varying gauges and adding ribs for stiffening purposes, thus enabling optimized lightweighting. The extruded profiles were either straight or bent and subsequently machined. Most of the Space Frame were extruded and cast parts, only a few stamped parts were used. As for the assembly, around 75% were joined manually for two reasons:

- The dimensional precision of the parts was not high enough to make seam welds without a tracking system, and robust tracking systems were not available on the market at that time
- For a planned production of around 15.000 units per year the investment costs should be kept low

Besides 70 meters of MIG welding, the BIW was joined through 1100 self piercing rivets, 500 spot welds and 180 clinches.

Through the positive experience with the first generation, a second generation with much higher production volume was developed. But it was not only a mere upscaling of the A8 concept, but a completely new design. For the higher volume the assembly had to be robotized, which required very low tolerances. Hydrocalibrating of the extrusions, including the piercing process into this process for cost reduction, was an important measure to get the precision required. Using laserwelding instead of MIG increased significantly the welding speed and reduced the heat induced into the components, thus remaining the geometry even after joining without any distortion. Instead of many small cast nodes in the first generation, the number of cast parts was reduced from 50 to 20 and they were growing in size, used even in crash relevant areas now, like the B pillar and the front longitudinals. For the assembly of the body in white more than 90% are joined by robot. This is a tremendous step for even higher production numbers and parallel cost reduction.

The new A8, appearing 2 years ago, took over many of the A2 technologies, but due to the lower production numbers tried to optimize the tooling cost by a reduced number of hydrocalibrated parts.

The Monocoque design

It has been Jaguar to introduce its new XJ in a completely new aluminium monocoque design, improving the stiffness versus the steel predecessor for approximately 60%. One of the reasons for this significant improvement was the introduction of the combination of adhesive bonding and self piercing riveting as BIW joining technology. Additionally, weight savings of 40% could be achieved.

It is no wonder that Jaguar intensively followed the monocoque concept – as daughter company of Ford the experience with this model might be introduced into much higher production volumes of Ford whenever needed in the future.

The Material Hybride / Multi Material Concept

For decades body applications were governed by the rule „all or nothing in aluminium“. This was mostly true due to joining reasons, but surface coatings, corrosion and repair played also an important role. Some attempts have been made in the past to mix materials in BIW applications, like Mercedes with its CL luxury coupe not some years ago, but these were only relatively small production volumes. It was only

2003 that BMW broke this rule with its new BMW 5 series, having an aluminium front structure with the rest of the BIW in steel (figure 2). The advantages are twofold: the aluminium front reduces the weight in general, thus being one of the biggest measures to make the car up to 75 kg lighter than its predecessor, and secondly the weight balance between front and rear is improved significantly and helps to improve the cornering properties of the car.

The introduction of this technology is even more impressive considering the production figures of more than 1000 units per day - historically similar giant progressive milestones have been made only with small production numbers at first. In the future, that technology offers specific lightweighting possibilities for all car makers, and additional cost reductions by growing experience can be expected.

OTHER ALUMINIUM COMPONENTS IN CARS

The first high volume applications of aluminium were the heat exchangers of Volkswagens first generation Golf, coming to the market in 1974. Here, a new joining technique, in combination with a new material (aluminium instead of copper) led not only to lighter, but also to cheaper parts. In the years to follow different types of heat exchangers were developed for different purposes (cooling of the engine, A/C, oil cooler, turbo charger, etc), and today more than 95% of the heat exchangers are made of aluminium and contribute significantly to light weighting efforts of all car makers.

Aluminium cylinder heads are found in nearly all modern cars, and all new developments of gasoline engine blocks are aluminium castings as well. This is true because aluminium does not only offer a large variety of different casting technologies for thin walled, hollow structures, but gives also due to its excellent heat conductivity a quick heating of the block, thus enabling the catalytic converter to be effective very fast.

Aluminium wheels started their triumphant advance 30 years ago. Technologies like low pressure die casting, forging, spin forging and stamping stand for a wide range of shaping possibilities, each having its specific advantages. The superior design of aluminium wheels in combination with weight savings makes them a 100% option for many cars.

Bumper beams were first developed in the early seventies for the risen safety requirements through the US legislation (8 mph impact speed). Europe was more hesitant in applying a strict legislation. Meanwhile, the development went from mere beams to complete systems including crash boxes, to protect the passengers on one side and offer affordable repair in case of accidents.

Roof rails, mirror housings, seats and backrests as well as many different interior parts – as daily new ideas are born a complete list of aluminium applications is not available. So, for example, curved extrusions are under development, enabling even more complex parts to be made. In the US, even torsionally extruded compressor wheels are in series production since many years and have proven their reliability in millions of cars.

Control arms in cast, extruded and forged versions are used in several cars even in high production volumes, improving the cornering properties and comfort of cars, as through their lower weight they offer lower unsprung masses and quicker response time.

THE ALUMAXIMISED CAR STUDY

As cars' weight is permanently growing since 30 years (figure 3), the question came up two years ago how light a modern car could be without any compromise in safety by intensive use of aluminium. Therefore, a study was made with fka (Parr et al) at Aachen university named "Alumaximised Car Study". For that purpose, a synthetic reference car in the "Golf-class" was created. This car was analyzed for the substitution potential into aluminium. Here, two steps were made: Primary weight savings, describing the potential weight savings through substitution of existing materials through aluminium, and secondary weight savings, describing the additional downsizing possibilities in brakes, powertrain etc due to significantly reduced loads to be carried after enlightening. To make the analysis more transparent, the primary weight savings were additionally divided into state-of-the-art technologies (e.g. existing and high volume proven) and latest-technology (e.g. existing, but so far only low volume proven).

The result was surprising: Starting with a reference car weight of 1229 kg, the primary weight savings led to 1003 and 928 kg car weight. Applying now the secondary weight savings, one can finally achieve 887 and 785 kg total weight respectively (figure 4). This means that the intensive use of aluminium might lead to cars with today's safety, comfort and environmental standards, but having a significantly lower weight and thus take over a significant contribution for achieving tomorrow's CO₂ standards.

THE CO₂ CHALLENGE

To fulfill the existing and upcoming legislation as well as the ACEA self commitment concerning the CO₂ emissions in the years to come several efforts have to be made, both by the automotive as well as the supplier industry. Several different measures exist for the

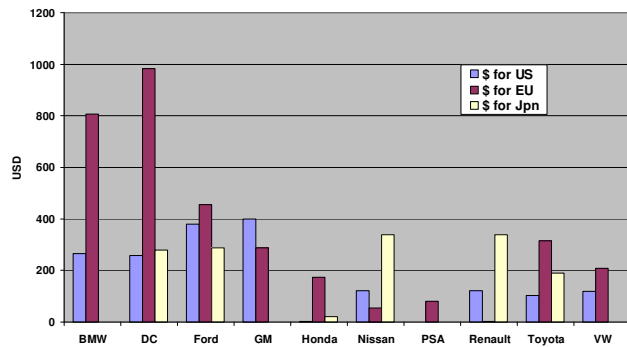


Figure 5: Estimated costs per car in USD in different world regions to meet the foreseen CO₂ legislation

CONCLUSION

To meet the challenges for future cars regarding emissions, safety and sustainability, aluminium is one prominent candidate to be increasingly used. The past has shown, that aluminium applications in modern cars have brought both, the automotive and aluminium industry, a big step forward concerning innovative technologies and attractive products.

REFERENCES

Austin, Rosinski, Sauer, le Duc; (2003); Sam & WRI (sustainable asset Management, Zürich & world resources Institute, Washington): Changing Drivers – The impact of climate change on competitiveness and value creation in the automotive industry

Parr, Wohlecker, Wynands; (2002)
Forschungsgesellschaft Kraftfahrwesen mbH Aachen:
Lightweight potential of an aluminium intensive vehicle