# Cost attractive lightweight solutions through new Mg-concepts for the vehicle structure

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## Contents

## Abstract

The reduction of the vehicle mass is an important point in order to reach new milestones in reducing fuel consumption and emissions. Today's and future steel structure concepts still shows lightweight potential. But even more attractive potential for lightweight body in white structures could be realised by new multi material design concepts. The DLR (German Aerospace Center) Institute of Vehicle Concepts and Meridian Technologies Inc. are working on innovative and cost attractive magnesium A-pillar solutions. By using the topology optimisation a new design idea for the A-pillar area was found. This new design concept offers the possibility to integrate additional functions. The new design shows expedient crash behaviour. A developed solution has a weight benefit of more than 50% compared to a steel reference structure. Because of functional integration the magnesium part is very cost attractive. To achieve the requirements of corrosion prevention Magnesium parts need to be proper designed. Within the example of a serial production Front End Carrier (FEC) possible solutions will be shown.


## 1 Introduction

Worldwide $CO_2$ emission and therefore also the proportion attributable to traffic is considered to be one of the reasons of climate change. The Institute of Vehicle Concepts (DLR-FK) is working on the technology of low-emission vehicles of tomorrow. Research areas pursued by the Institute with the aim of achieving mobility with low or even zero $CO_2$ emission include:

Increasing energy efficiency:

- Secondary energy utilisation
- Alternative energy conversion

Reducing driving resistances:

- Lightweight construction strategies
- Multi-material design
- Hybrid design

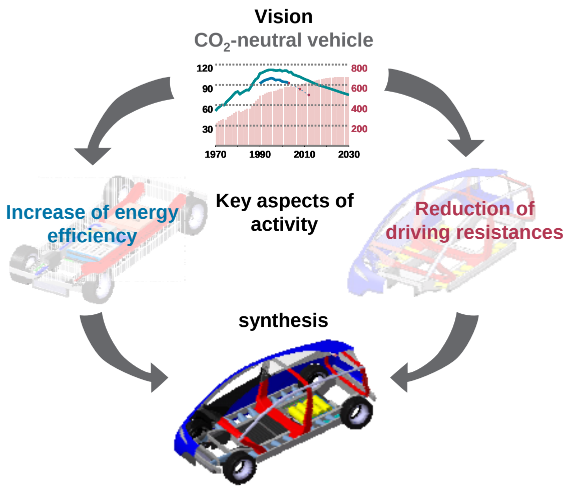


*Fig 1: Vision: a $CO_2$ neutral vehicle*

The results from the individual technologies make up a portfolio for a synthesis of new vehicle concepts primarily developed by the DLR-FK as a partner of the vehicle industry.

### 1.1 Potential of magnesium

Magnesium is a material with a great growth potential. The ‘Magnesium Vision 2020‘ study conducted by the United States Automotive Materials Partnership (USAMP) [1] demonstrates clearly that the magnesium components already implemented in vehicles today could be increased to cover a significantly higher proportion of vehicle parts. Every North American vehicle contains an average of approximately 5-6kg of magnesium at present. The weight of all the individual parts used however adds up to 190kg of magnesium. Examples of parts that have already been realised include seat structures, control panel mounting, gearbox casing and engine mounting systems. Obstacles nevertheless stand in the way of a broader utilisation of magnesium. At the moment one of these is the problem of magnesium extraction. The majority of crude magnesium is currently obtained in China. The method used is both energy intensive and environmentally damaging. A further challenge for successful utilisation of magnesium in vehicles is presented by the problem of corrosion of the material. In addition to this generally solvable criterion, there are other circumstances making it difficult for magnesium solutions to become widespread. The vehicle structures of today are often optimised for sheet metal shell constructions. New construction methods to suit the material are required to realise lightweight design using magnesium. Examples of structural parts made of magnesium conceived by the DLR Institute for Vehicle Concepts in conjunction with Meridian Technologies are presented below.

## 2 Topology optimisation of front end and concept design

### 2.1 Definition of design space requirements

The front end structure selected as a basis for development of a concept is a technologically challenging and particularly interesting area for lightweight construction. A topology optimisation was carried out based on the general requirements and load cases as well as the available design space. A lower middle range car was selected and the available design space was constructed using CATIA V5. In contrast to the standard practice in vehicles of today, the engine hood area was specified as potential load-bearing structure.

*Fig 2: Constructed design space for topology optimisation*

## 2.2 Topology optimisation

This 3D data record was then processed using the topology optimisation tool TOSCA. A total of 12 load cases (see below) were included in the optimisation.

Load cases:

- Torsion, left + right
- 1g compression (downward bend)
- Upward bend
- Curve motion, left + right
- Braking
- 40% front crash, left + right
- 30° inclined front crash, left + right
- Pole crash, front

Since today's topology optimisation tools are not suitable for optimisation of dynamic load cases, crash load cases were assumed to be equivalent static load cases. Since the illustrated design space only represents one part of the vehicle structure, special attention was paid to reproduce the behaviour of the non-represented remaining structure as realistically as possible. An elastic rather than rigid support was specified for the design space shown above for this purpose. Using the 40% front crash load case, a prescribed load distribution was set by adjustment of the individual spring stiffness values.

- 2 x A-pillar: 12.5% each
- 2 x Rocker panel: 25% each
- Transmission tunnel 15%
- 2 x Base: 5% each

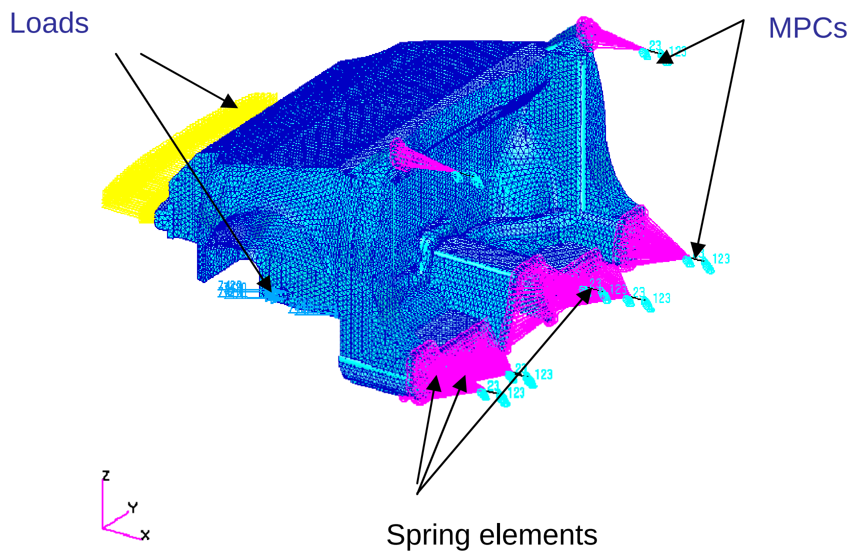


*Fig 3: Loads and supports for topology optimisation*

The importance of specification of the load distribution is clearly indicated by the table below. The first four columns show the respective absolute and percentage share of the load for the rigidly supported total model and the optimised result model. It becomes clear that 70% of the load is directed to the base during optimisation. The base of a real vehicle however takes up significantly smaller longitudinal forces. If the result was used for establishment of an optimal front end structure in this form, an incorrect result would be obtained. The four columns on the right of the table show the effect of the spring support. The optimisation allows allocation of realistic loads to the individual structural areas and thereby simulation of the stiffness of the missing residual vehicle structure.

| | Bauraummodell, fest fixiert | | Opt, 10 % Vol, fest fixiert | | Bauraummodell, feder in x | | Opt, 10 % Vol, feder in x | |
|---|---|---|---|---|---|---|---|---|
| | RFx | % | RFx | % | RFx | % | RFx | % |
| a-säule | -25588.623 | 12.79 | -28427.1758 | 14.18 | -24572.31 | 12.29 | -25749.66 | 12.87 |
| a-säule | -25399.9297 | 12.70 | -28889.274 | 14.65 | -24315.37 | 12.16 | -22944.7 | 11.47 |
| schweller | -16506.0645 | 8.25 | -0.625537 | 0.00 | -50697.52 | 25.35 | -49971.93 | 24.99 |
| schweller | -16237.5713 | 8.12 | -11.536131 | 0.01 | -50083.52 | 25.04 | -50298.9 | 25.15 |
| mitteltunnel | -19937.1484 | 9.97 | -50.073971 | 0.02 | -30119.36 | 15.06 | -30795.89 | 15.40 |
| boden | -47713.5664 | 23.86 | -71310.75 | 35.57 | -10144.56 | 5.07 | -10049.2 | 5.02 |
| boden | -48617.2813 | 24.31 | -71310.75 | 35.57 | -10067.55 | 5.03 | -10189.91 | 5.09 |
| | | | | | | | | |
| | | | | | | | | |
| Summe RFx | -200000.185 | | -200000.185 | | -200000.19 | | -200000.19 | |

*Fig 4: Load distribution with and without spring support of the design space*

The result of the structure optimisation is a structure with improved stiffness. This topology optimisation serves as a basis for further conceptual considerations. The aim of the project was to design a highly loaded magnesium structure with a high degree of functional integration. On closer inspection of the topology optimisation, it becomes evident that in contrast to the strut mounting concepts used today, no direct (in the direction of the spring effect) connection between strut mounting and the side member area is achieved. Instead a cantilever type of connection from the A-pillar forwards to the spring plate is obtained. This realisation gave rise to the idea of integrating the spring plate base in one large A-pillar cast node.

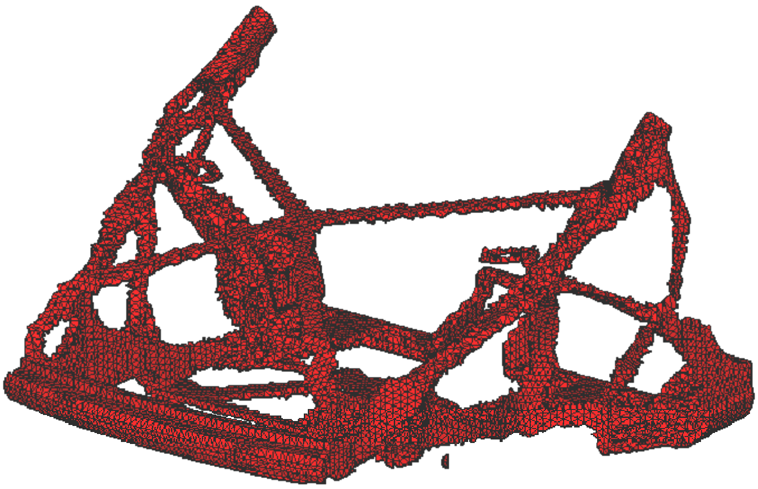

*Fig 5: Result of topology optimisation – View 1*

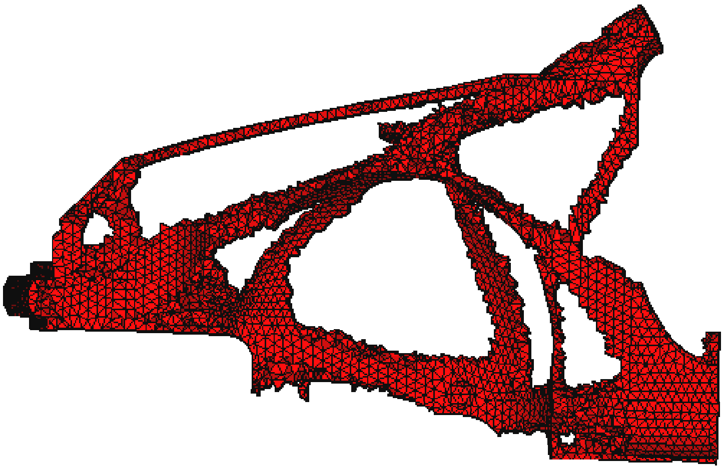

*Fig 6: Result of topology optimisation – View 2*

# 3 Detail development of the highly integrated cast Mg node

## 3.1 Construction and computed design of the A-pillar node

Starting with the topology optimisation results, a close-to-production preliminary development of the A-pillar node with integrated spring plate was carried out with the support of Meridian Technologies. The aim of this work was to determine the potential of magnesium for a highly loaded vehicle structure. Component specific load cases for this structural area were defined for this purpose. In addition to load cases at the strut mounting, door lowering load cases and a crash load case were included. The main load at the strut mounting was purposely exceeded by 1/3 in order to demonstrate scalability to higher vehicle classes.

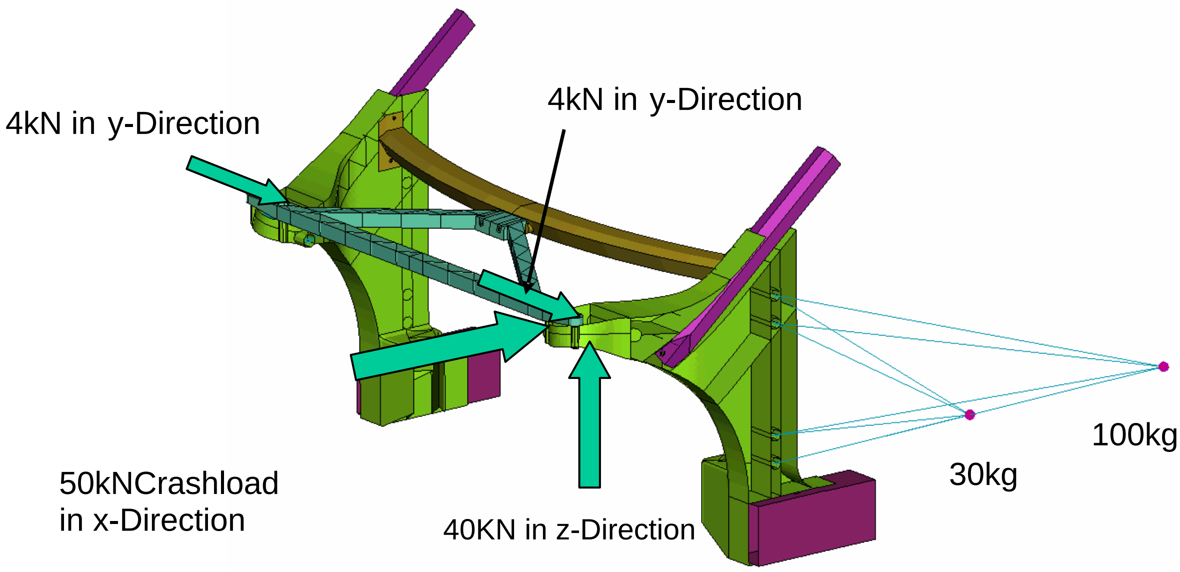


Fig 9: Design loads for the A-pillar node

A component specific topology optimisation in the available design space was carried out with the specified loads. This was then transformed into a rib pattern which was optimised by a topometry optimisation with reference to wall thicknesses. This work was conducted by Meridian Technologies in the European Development Centre in England.

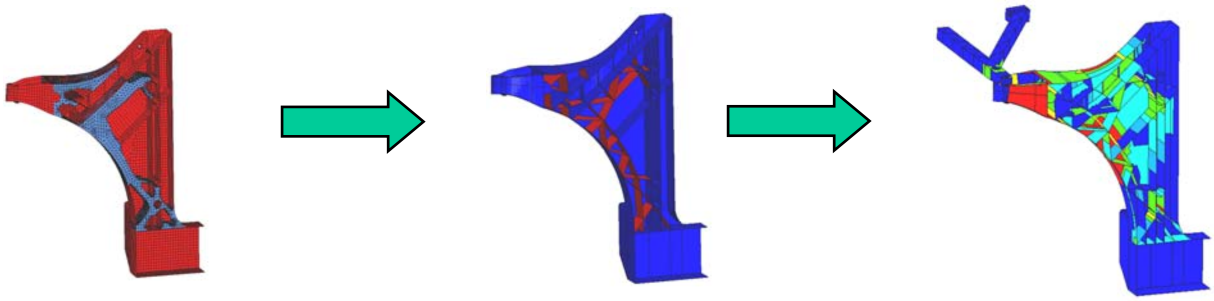

*Fig 10: Component evolution by topology and topometry optimisation*

A functional lightweight structure made of magnesium that meets the load case requirements including crash was developed using this procedure. Tensional forces of 130MPa are developed in the component during the crash load case. Component expansion remains below 6% so that no structural failure occurs.

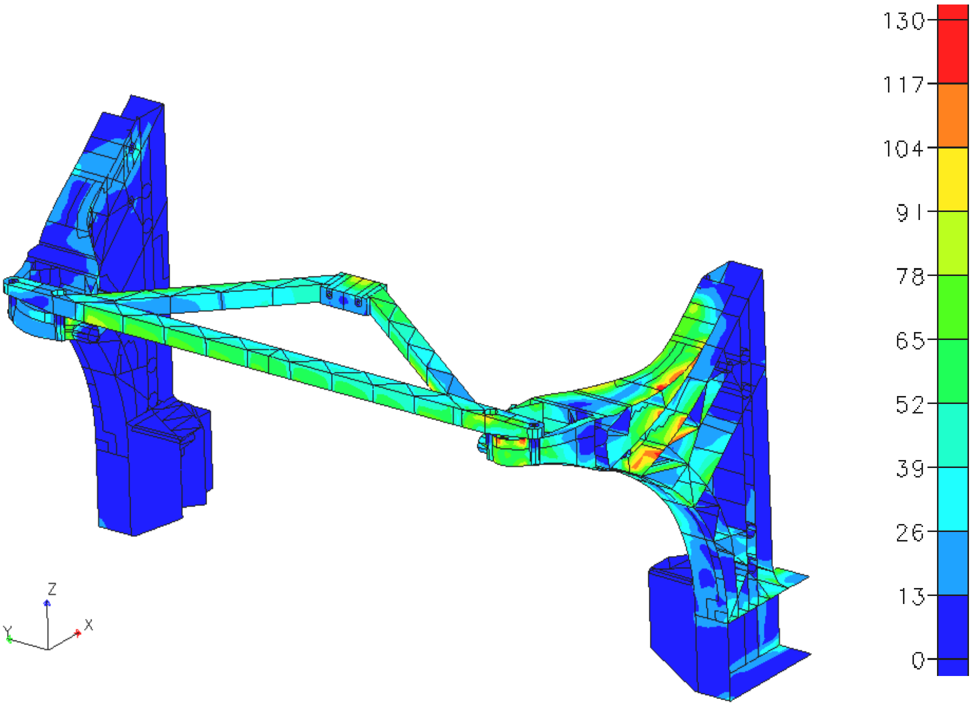


*Fig 11: Computed result for the ODB crash load case*

### 3.2 Cost and weight consideration

A weight saving of 43% was achieved with the developed design method in association with using magnesium as a material. With a modified two shell design of the part a weight saving of >55% have been achieved. Taking a lower middle range vehicle for comparison, 12 steel moulded parts were replaced with one casting. With regard to costs, it was estimated on the basis of data available at the Institute of Vehicle Concepts that production of a magnesium casting with the same degree of functional integration would be possible at the same price. The necessary corrosion protection is already taken into account here.

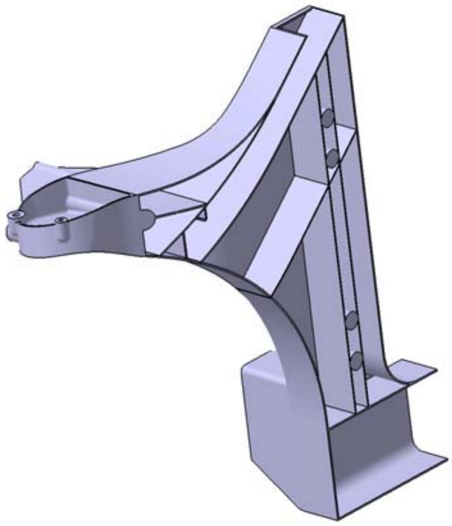

*Fig 12: Detailed view of the A-pillar node*

**Summary:**

- **Weight saving: 43% (5kg) proved by calculation**
- **Weight saving > 55% with a modified two shell design possible**
- **Component costs: Same than steel reference value**

# 4 Challenges and solutions for exterior magnesium applications

## 4.1 Example of a structural exterior magnesium application in serial production

Traditionally vehicle body structure front end modules have been either fabricated pressed steel assemblies, fabricated pressed aluminium assemblies or plastic / steel hybrids. Magnesium die cast technical solutions are now in series production (figure 1) which are either welded at the "BIW" stage or bolted in the body at the exterior trim stages of production.

The most evident advantage in using magnesium for a FEC is weight saving: a reduction of up to 9kg over steel system equivalent technology can be achieved [3]. Magnesium also offers good savings versus aluminium assemblies and in a minor extent over plastic steel hybrids. In addition to that, improvements to body structure performance and NVH can be achieved, together with enhanced geometric stability (fit and finish) advantages and integration opportunities (reduced complexity and cost) whilst satisfying durability, crash, corrosion and visual requirements. In addition, the reduced mass at the front of the vehicle triggers induced weight saving on the body in white.

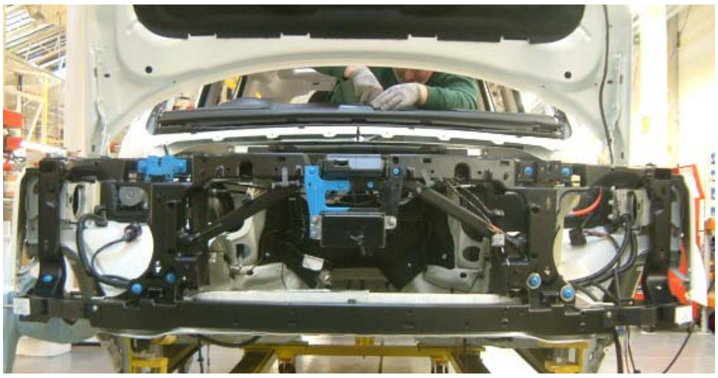

*Fig.13: Magnesium FEC example*

## 4.2 Corrosion prevention on exterior applications

The location of an FEC in automotive body structure results in the component experiencing a particularly harsh corrosive environment. In the past, the biggest issue facing the use of magnesium for exterior applications has been corrosion prevention and in particular galvanic corrosion.

Today galvanic and cosmetic corrosion requirements are achieved by proper design of component and fixings and proper choice of joint materials. Protection from galvanic corrosion is possible by avoiding the presence of electrolyte and by decoupling galvanic cells; hence two design principles are to respect. The first one is to insure a good drainage in fixing areas to avoid that mud and humidity get trapped.  The second is to separate Magnesium from steel by the introduction of an aluminium spacer: these spacers increase the length between the anode and cathode of the galvanic cell.

This way the reduction of corrosion is obtained respecting a simple design rule of a minimum distance of 10 mm between Magnesium and steel.

5000 or 6000 series aluminium for spacers are currently used. Figure 2 shows the relative compatibility series of different metal to magnesium.

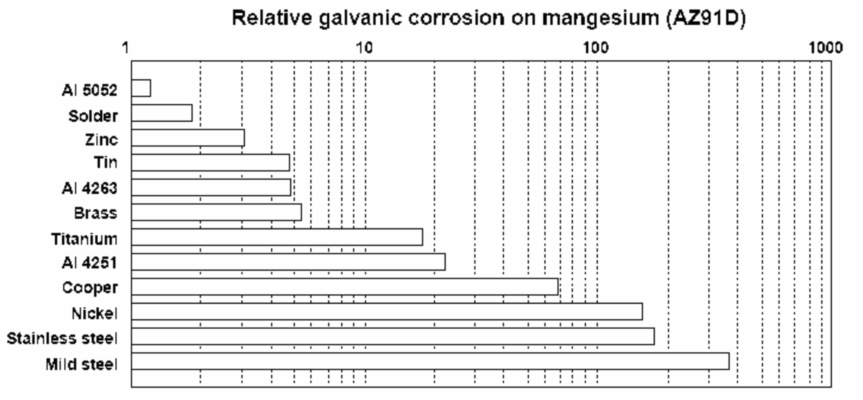


*Figure 14: relative compatibility series of various metals coupled to magnesium. Galvanic assembly immersed in 5% NaCl-solution. [4]*

Regarding fasteners, in recent years threadforming technology has become widely used in all magnesium component developments within Meridian Technologies Inc. including FEC's for attaching ancillary components. These fixings are fitted into blind holes which eliminates the potential for corrosion from the rear of the fastener. Examples of joint configurations are given in figure 3.

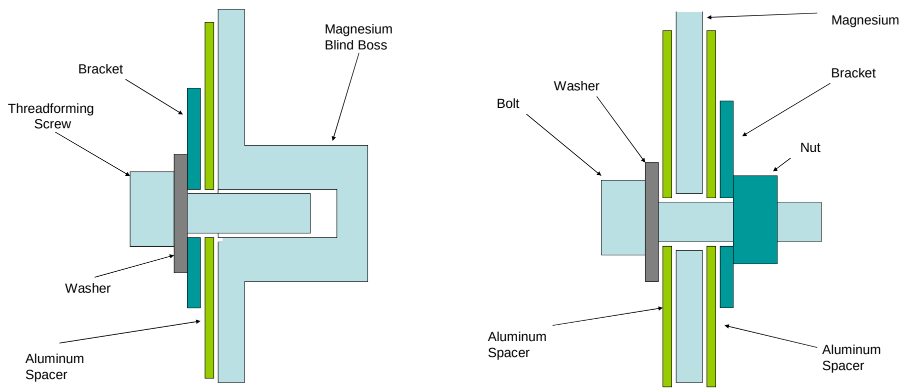


Figure 3 – Examples of  Joint Configuration

If parts have a cosmetic requirement then they need to be coated. Current solution consist of an acid etch – to remove surface iron particles that may have been transferred from the die tools in casting process or during handling / transportation post process – and a chemical conversion coating to insure the adhesion of the final top coat that is an epoxy base powder coating (see figure 4). This solution is capable of 1000 hours salt spray tests of ASTM B117 and of 12 weeks humidity salt spray tests (see figure 5).

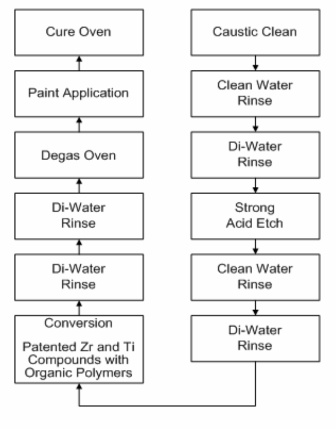


*Fig. 15: Example Of current Series Production coating system process*

*Fig.5 Example Test Panel*

## 5 Conclusion

The partners cooperating in this project have successfully demonstrated the high potential of magnesium in an innovative component. It was also shown that a design suitable for the material used is required in order to fulfil structural requirements. With integration of functions it is possible to design cost attractive solutions for the vehicle structure. With proper designed parts and joints corrosion protection for parts in exterior applications is possible.

# 6 References

[1] United States Automotive Materials Partnership (USAMP), Automotive Metals Division (AMD): “Magnesium Vision 2020: A North American Automotive Vision for Magnesium” (2004)

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[3] A. TIPPINGS, T. LAWSON, “Design and development of a High Pressure Die “FEC” (Front End Carrier) For Exterior Automotive Applications” 62$^{ND}$ Annual World Magnesium Conference, 2005

[4] Hydro Brochure “Corrosion And Finishing Of Magnesium Alloys” 10.1997.