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# Design of hybrid Mg/Al components for the automotive body - Preventing general and galvanic corrosion

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The hatchback of the new Mercedes-Benz E-Class T-Model is one example for a hybrid design with inner magnesium high pressure die casting liner and outer aluminium sheet. The hybrid rear door has to fulfil a variety of requirements in terms of dimensional stability, weight, stiffness, crash and corrosion performance. The hybrid concept in general as well as various interfaces and connecting points require a careful design to prevent galvanic corrosion. Critical connecting points are introduced and the design criteria are discussed by means of two examples (gas pressure spring and hinge). Finally the concept of corrosion protection measures and results of various testing trials of the component are presented.

**Introduction**

The use of magnesium has a long tradition at Mercedes-Benz and is designated by definition as material lightweight construction. Roughly, a reduction of 100 kg of the vehicle weight contributes to a fuel saving of approximately 0.3 to 0.4 l per 100 km corresponding to a reduction of 7 to 9 g $CO_2$ in the balance of the waste gas emissions.

Unfortunately, magnesium is not only the lightest, but electro-chemically the least noble metallic construction material available [1, 2]. As a component magnesium and its alloys are always used in combination with other materials. It is the combination of materials with different corrosion potential which represents the largest challenge for the construction and the associated manufacturing processes in the case of a corrosive exposure. The risk of galvanic corrosion is essentially important; hence it must be conceptually and systematically excluded over the entire development process of the whole assembly.

Prominent examples of the application of magnesium are for example the door inner part of the Mercedes-Benz SL (AM50) and the S-class Coupe CL (AM50) as well as the 7-gear-automatic transmission NAG2 (AS31) for various platforms. All components are manufactured by high pressure die casting and this tradition is now continued with the rear door of the new E-Class T-model featuring a magnesium hybrid rear door. Thus, all engineers involved in the development of the component, including design, production, quality control and foundry, based their work on a broad wealth of experience in development, manufacturing and customer driving operation. Furthermore external information about the electro-chemical compatibility between materials and coatings in direct contact with magnesium including experience in the field and laboratory tests was available [3-6].

**General description and specification of the component**

The hybrid construction method is a good alternative for multipart components of the automotive body. On the one hand the requirement of having large single parts with high function integration can be quite easily fulfilled using high pressure die casting as the production process. On the other hand the demand for an optically appealing surface can only be fulfilled by means of a conventional shell construction. However, if lightweight construction is required, the choice is a combination of a magnesium high pressure die cast component with a density of 1.8 g/cm³ for the inner liner and an aluminium sheet metal with a density of 2.7 g/cm³ for the outer skin [3]. Latter is used because today no magnesium high pressure die casting components or magnesium sheets are available in outer skin quality.

The aluminium-magnesium hybrid construction method for the rear door in the current T-model of the E-class S212 was introduced to mass production for the first time in autumn 2009. The production of the magnesium inner part with a weight of 7.1 kg is carried out in the company-owned foundry in Mettingen using a 4200 t cold chamber die casting machine. After casting, the accuracy to size is obtained by rough and fine blanking followed by grinding. The 1400 x 1100 mm large inner part has wall thicknesses ranging from 2 to 5 mm and is reinforced with ribs in several regions. The integration of the lamp pots is a demanding challenge both in moulding and casting to guarantee complete mould filling and save mould removing. The entire aluminium-magnesium assembly has a weight of 11.1 kg and offers a weight advantage of 5.2 kg in relation to a steel sheet construction.

Table 1: Mechanical properties of the alloys AMZ30, AM50 and AM60 produced by high pressure die casting [7, 8]

| alloy | $R_m$ (MPa) | $Rp_{0.2}$ (MPa) | A5 (%) |
|---|---|---|---|
| AMZ30 | > 200 | > 100 | >12 |
| AM50A | 200 | 110 | 10 |
| AM60A | 220 | 130 | 8 |

The fulfilment of the crash requirements in automotive engineering finally limits the choice of the possible magnesium alloys which can be used for the hybrid rear door. The combination of high strength and sufficient ductility is only fulfilled by the magnesium alloys AMZ30 and AM50 which have relatively low aluminium content (Tab. 1). The corrosion protection requires that the magnesium inner part is coated by cathodic electrodeposition (20 µm) and powder coat (80 µm), before the aluminium outer panel (AC170) is added by roll seaming and 2K adhesive bonding. Due to the low wall thicknesses of the high pressure die casting part, no direct screw connections between the two assembly parts are possible. Thus blind rivet nuts made of aluminium are inserted after the powder coating. After the seaming procedure the rear door together with the body in white passes through the finishing and paint shop. In the paint shop e-coat, seam sealing, filler, base-coat, clear-coat and cavity-wax-sealing is added.

**Systematics of design**

The typical product cycle in automotive industry amounts to approximately 7 years for nearly all manufacturers. At Mercedes-Benz, the total development time for the new E-Class was approximately 5 years. During the progress of the project, quality gates have to be passed, which mark important stages and which are embedded into the Mercedes-Benz Developing System (MDS), see Fig. 1 [9]. Already in the beginning of the project all functional requirements of corrosion protection must be defined in the component concept specifications. The corrosion performance is monitored and optimised throughout the project ending shortly before Job No. 1 (the start of production).

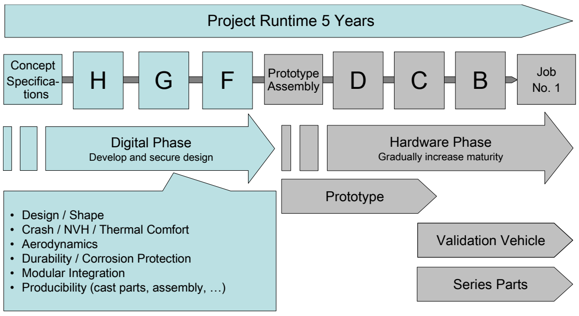


Fig. 1: The Mercedes-Benz Developing System [9]

Associated to the quality gates are prototype vehicles (E-vehicles) and validation vehicles (B-vehicles), which are submitted to a dynamic long-term corrosion test called MEKO-D (Mercedes-Benz corrosion endurance test - dynamic) for further validation. Individual components will be checked also in vehicle-independent testing called MEKO-S (Mercedes-Benz corrosion endurance test - static). For the aluminium-magnesium hybrid construction of the rear door an additional dynamic long-term corrosion test was performed already before passing quality gate E.

The required corrosion testing has to be embedded into a coordinated and systematic development process, while developing iteratively the corrosion protection. In the case of the rear door the high susceptibility of magnesium to galvanic corrosion has to be considered in more than 60 contact points (e.g. hinge, lock reinforcement, etc.) (Fig. 2). Most of the materials used in the automotive engineering (steel and coatings such as zinc nickel, zinc lamella etc.) lead to pronounced galvanic corrosion [6]. With the help of a particularly introduced interface management all critical points were listed including geometry of the part, material and coating. Each of the points was assigned to a corrosion exposure class (low, medium and high) and according to the requirements the material and coating selection was fixed. Thus it was guaranteed that each of the critical points was systematically monitored and optimised over the three-year development process.

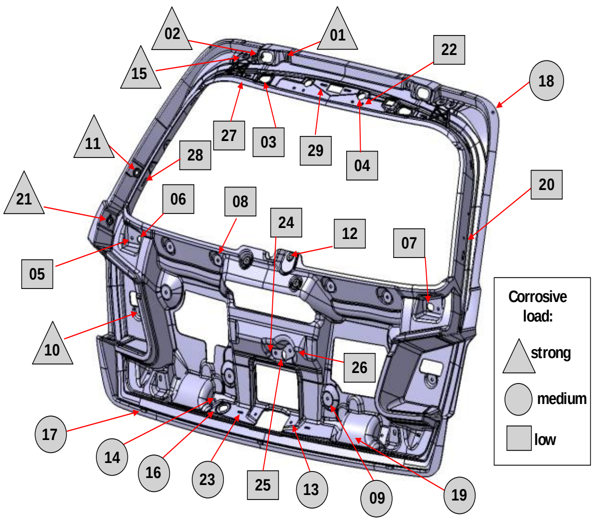


Fig. 2: Contact points of the magnesium inner part with indication of corrosive load - low, medium and strong

**Optimising the corrosion resistance of the uncoated component (general corrosion)**

In the total concept for the prevention of galvanic corrosion optimization of the uncoated component already plays a substantial role. Apart from using high purity alloys to minimise the general material corrosion, a defect- and contamination-free surface is required, in order to ensure a problem-free build-up of the corrosion protection layers. For this reason high pressure die casting as the selected production process and a pre-treatment before the actual coating build-up were included into the optimization process as well.

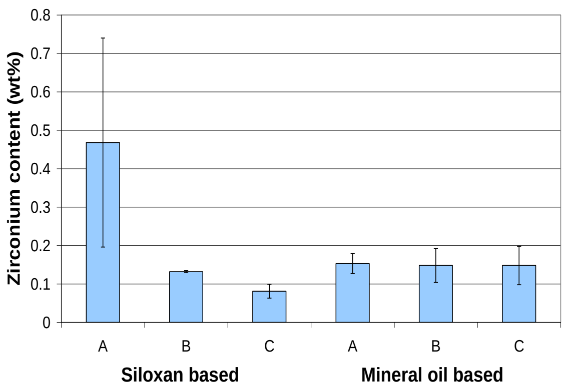


Fig. 3: Zirconium content of the magnesium inner part surfaces taken from three selected regions (A, B and C) after the conversion treatment, as an indicator for the quality and uniformity of the conversion layer. Comparison between two different mould release agents used in the high pressure die casting production step, which are based on the one hand on mineral oil and on the other hand on Siloxan. The zirconium content was determined by spark emission analysis and represents an average value over an analysis depth of approx. 0.15 mm.

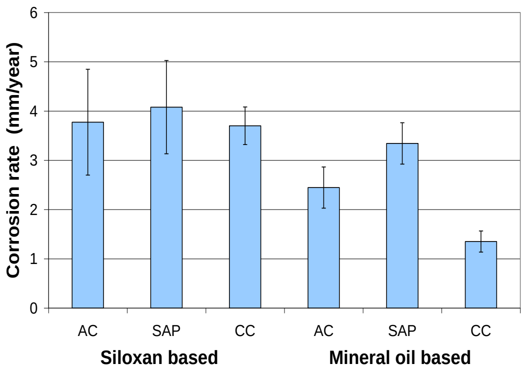


Fig. 4: Corrosion rate of test specimens exposed to neutral salt-spray (48 h, DIN 9227). The specimens were taken from Mg inner parts, which were manufactured either with mineral oil or Siloxan based mould release agents in the high pressure die casting process and after different pre-treatment steps (AC: as cast condition, SAP: sulphuric acid pickling and CC: Conversion treatment with $H_2ZrF_6$)

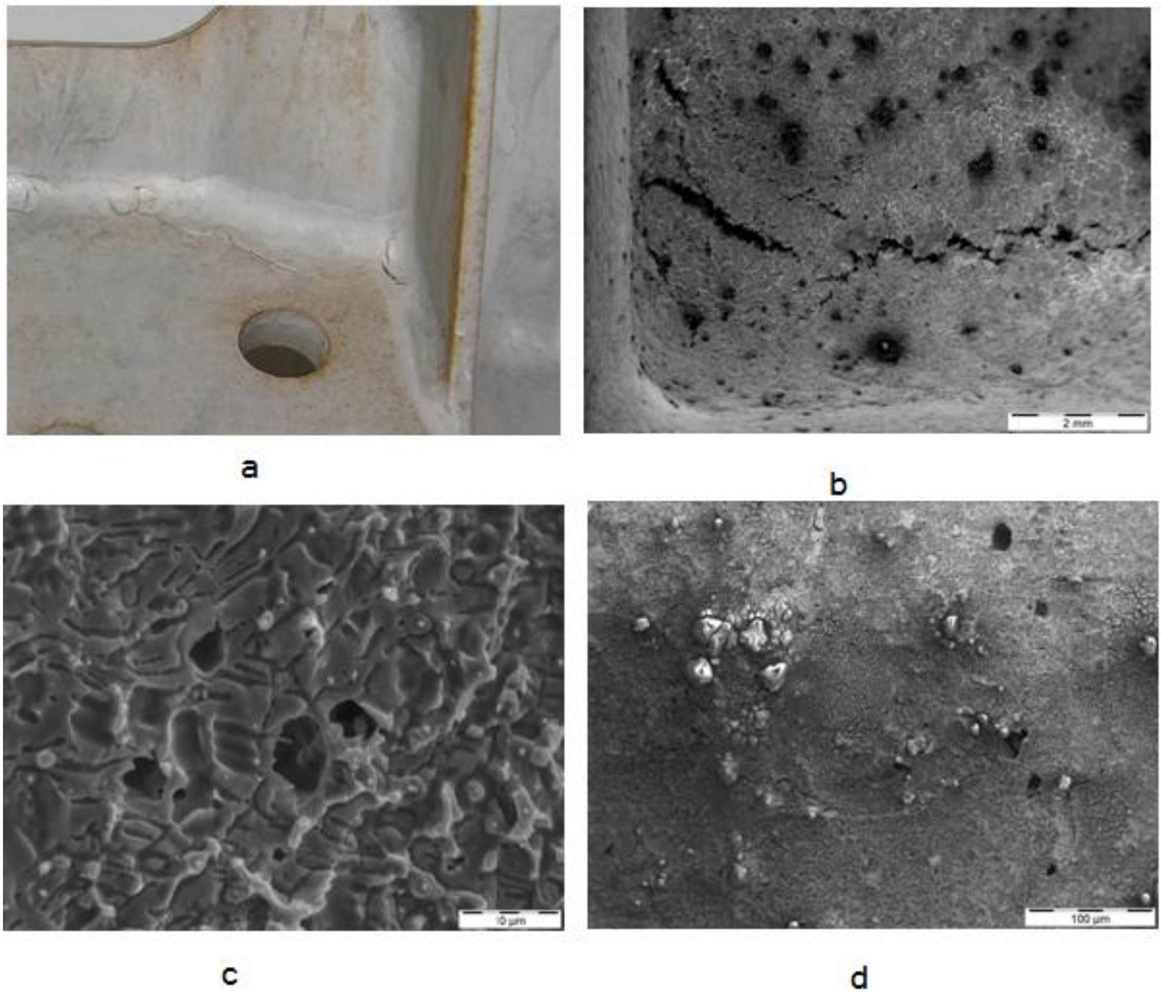


Fig. 5: Typical defects on the surface of the inner high pressure die cast part of the rear door: a) cold runners and cracks, b) solidification cracks c) micro porosity opened by the pickling process d) pores and adjacent region after the conversion treatment

Optimum corrosion protection requires a uniformly and reproducibly cleaned surface with defined composition. Only then a homogeneous conversion layer can be applied which - as a base for good adhesion of the subsequent build-up of the paint - can affect the corrosion performance of the final entire coating system. Possible interactions between the type of release agent/residues and the following cleaning and coating processes were examined very intensively, in order to identify and remedy problems in time. The following Fig. 3 is an example of how the choice of the release agent can already have a substantial influence on the cleaning and the formation of the conversion layer as a base for good adhesion. In this case a clear advantage exists, if in the high pressure die casting process a release agent is used, which is based on mineral oil instead of Siloxan. Effects of the release agent on the corrosion resistance of the uncoated component are still identified after each of the pre-treatment steps (Fig. 4).

Surface defects from the die casting process represent another problem for a coating. It is predominantly a question of cavities (deep cold runners), solidification cracks and micro porosity close to the surface (Fig. 5a - 5c), which are to a certain level typical for the high pressure die casting process. Residues from pickling and conversion solutions can remain in the defects causing an intensified oxide formation (corrosion) in adjacent regions and a reduced conversion layer formation (Fig. 5d). This may have negative effects on the adhesive strength and the sub-surface migration of a coating system. By systematically monitoring the surface finish and optimising the high pressure die casting process parameters, the defect density could be reduced to a non-critical level. Altogether the implemented measures led to an improved reproducibility and uniformity of the conversion layer formation and to a clearly improved adhesive strength of the layer system (e-coat - 20 µm and powder coating - 80 µm) build-up on top of it.

**Selected corrosion performance results of critical connecting points**

For a vehicle in service the integral acting critical climates (heat, coldness, humidity, salts) are overlaid by locally effective, constructed size dependent micro climates and dynamic loads. The respective interaction of all single influences under accelerated test conditions - the test collective – is reproduced by the dynamic Mercedes-Benz long-term corrosion test (MeKo-D). In contrast to the classical tests, e.g. salt-spray, the components are not permanently exposed to the electrolyte, but experience a realistic cyclic alternating load consisting of salts, dirt, humidity, different temperatures and mechanical influences.

Fig. 8 shows the assembled ball pin after MeKo-D testing. Severe corrosion was detected in spite of using AlMg3 for the blind rivet nut which is considered as galvanically compatible to magnesium [5].

Fig. 8: Connecting point of the gas pressure spring after 16 weeks dynamic long-term corrosion test run (MeKo-D)

Remarkable is the circular corrosion attack of the magnesium inner part around the bearing face of the blind rivet nut collar as well as the corrosion of the base material of the ball pin. The attack on the Mg inner part was so strong with severe galvanic corrosion causing material removal, blistering and coating delamination. The cross-section micrograph (see Fig. 9) revealed that the blind rivet nut penetrated the e-coat and powder coating during the riveting procedure resulting in direct contact with the magnesium inner part.

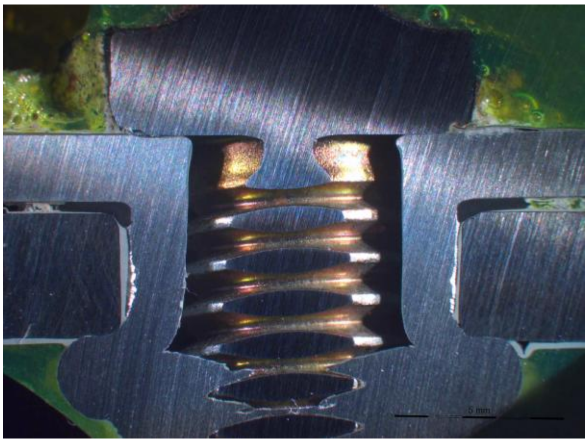

Fig. 9: Cross-section micrograph of the magnesium inner part with assembled blind rivet nut and ball pin after 16 weeks MeKo-D testing

The consequence was a galvanic contact element forming between the aluminium and magnesium part. The partially uncoated bearing face of the blind rivet nut collar thereby forms a relatively large cathode surface, which is in contact with a small bare, exposed magnesium surface. According to the area rule, indicating that the anodic partial current density is proportional to the area ratio of cathode to anode, a high local current density is generated. Fig. 10 shows the morphology of the corrosion attack, which begins underneath the aluminium collar bearing face and leads to sub-surface migration of the coating. Understanding the corrosion mechanisms helps to optimise or to prevent the local galvanic attack on the magnesium.


Fig. 10: Cross-section micrograph showing a section of the magnesium inner part assembled with blind rivet nut and ball pin after 16 weeks MeKo-D testing

**Solutions for critical connecting points (Galvanic corrosion)**

During a drive in rainy conditions, the humidity that comes down on the vehicle roof is drained off between the hinges and over the flanks of the rear door. Additionally turbulences in the rear of the vehicle provide an increased exposure of dirt and pollution. In consequence the ball pin of the gas pressure spring and the connection points of the hinges belong to the most critical components regarding galvanic corrosion attack. Due to the low wall thickness of the magnesium inner part the connection of assembly parts is not directly possible by using internal threads. Blind rivet nuts or bolt connections are used instead.

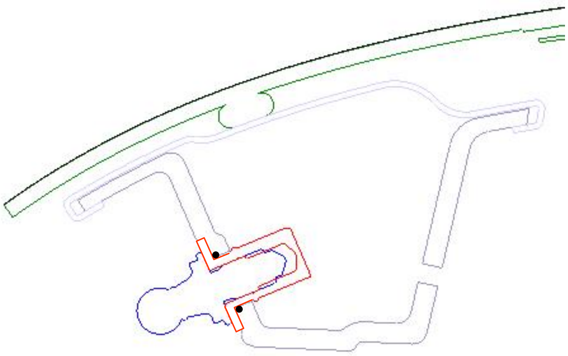

Fig. 6: Sectional view of the connecting point of the high pressure spring via the ball pin

On the sides the two gas pressure springs hold the rear door in the opened condition and are connected with the door by these ball pins. Thereby the ball pin is not directly screwed into the Mg inner part, but is inside a blind rivet nut with internal thread. The nut material is AlMg3 aluminium alloy. An additional e-coating of the aluminium blind rivet nut is necessary to provide sufficient protection from galvanic corrosion. Fig. 6 shows that the collar of the blind rivet nut exhibits a larger diameter as the bearing face of the ball pin, in order to avoid direct contact with the magnesium inner part. The riveting process takes place after powder-coating the magnesium, and an additional O-ring provides the leak-tightness.

Two hinges connect the rear door linked with the rear roof frame and are implemented as galvanized steel forging. The attachment is carried out as a bolt connection, whereby the nuts are tightened from the outside via holes in the aluminium sheet, which are covered later by a spoiler. The steel hinge sits on an aluminium plate (alloy AlMg1Si1.5) in order to avoid the direct contact of the magnesium part with the steel. According to Fig. 7 the plate exhibits an overlap and it is fixed to the magnesium part with aluminium pop-rivets. An additional e-coating of the vibratory grinded aluminium plate and of the pop-rivets is used to prevent galvanic corrosion.

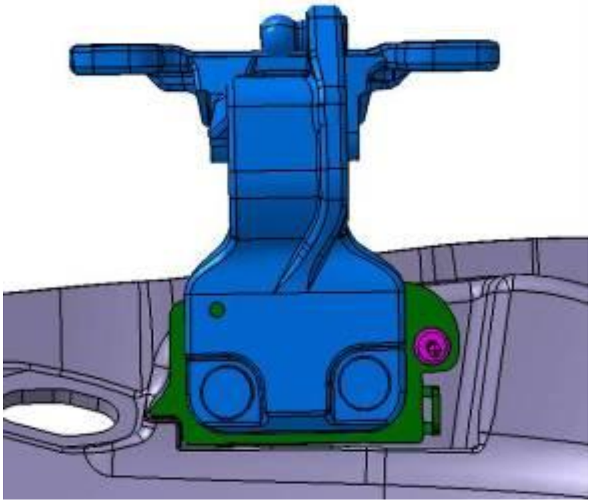

Fig. 7: Attachment of the steel hinge to the Mg inner part via an aluminium plate

**Summary and conclusions**

Within the framework of developing the rear door it was possible to protect a functionally highly integrated magnesium pressure die casting component in a hybrid construction with aluminium from galvanic corrosion attack.


Fig. 8: The rear end of the Mercedes-Benz E-Class T-Model featuring the hybrid Mg-Al hatch back

All requirement profiles of magnesium had to be fulfilled simultaneously. This included more noble materials which promote galvanic corrosion as well as corresponding mass production technologies, such as casting and assembly. This was successful only, because all critical connections of the magnesium inner part were accurately listed, systematically monitored and tested during the entire development phase. This requires a close co-operation between design, material- and process-engineering as well as quality management. The final result of the development is shown in Fig. 8.

Due to this innovative light weight construction approach a weight reduction of approx. 5.2 kg was reached in comparison with a conventional steel rear door shell construction. Thus, this measure is a significant contribution to the overall $CO_2$ emission reduction of the new Mercedes-Benz E-Class T-Model.

**Acknowledgements**

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**Literature**

[1] Blawert C., Hort N., Kainer K.U.: Automotive applications of magnesium and its alloys, Transactions of the Indian Institute of Metals, Vol. 57, 4, 2004, 397 – 408

[2] Kainer K.U., Srinivasan P.B., Blawert C., Dietzel W., Corrosion of Magnesium and its Alloys, In: Shreir's Corrosion, 4th edition, Vol. 3, Edited by T. Richardson, B. Cottis, R. Lindsay, S. Lyon, D. Scantlebury, H. Stott and M. Graham, Academic Press, Elsevier, 2009

[3] Schreckenberger H.: Korrosion und Korrosionsschutz von Magnesiumwerk-stoffen für den Automobilbau – Proble-matik der Kontaktkorrosion, Fortschr.-Ber. VDI Reihe 5, Nr. 613, VDI Verlag, Düsseldorf, 2001.

[4] Boese E. , Göllner J., Heyn A., Strunz J., Baierl Chr. und Schreckenberger H., Materials and Corrosion, 52, 2001, 247-256

[5] Schreckenberger, H., Papke, M., Eisenberg, S.: The magnesium hatchback of the 3-Liter Car - Processing and corrosion protection. SAE Technical Paper No. 2000-01-1123, Detroit, 2000.

[6] Reinhold, B., Kopp, J., Klose, S.G.: Korrosionsschutz bei Leichtmetallver-schraubungen: Tagungsband DVM-Tag 1998 - Bauteil 98 - Konstruktiver Korrosionsschutz. Berlin, 06.-08.05.1998, 59-71

[7] ASTM B94 – 07 standard

[8] Daimler Benz delivery specification

[9] Kellermann, H., Tritschler S.: The New E-Class, EuroCarBody, October 2009, Bad Nauheim, Germany