Light Metals 2014
Edited by: John Grandfield
TMS (The Minerals, Metals & Materials Society), 2014

Lightweight Construction for Electric Mobility Using Aluminium

Andreas Kleine, Marcel Rosefort, Hubert Koch
TRIMET ALUMINIUM SE, Aluminiumallee 1, 45356 Essen, Germany

1. Abstract

The worldwide growing demand for individual mobility with an increasing scarcity of fossil fuels and a rising need for sustainable environmental protection are the motivating factors for technology changes in automotive engineering. In this context lightweight construction is the big challenge in transportation currently and will remain so. Especially for electric mobility lightweight construction is essential due to range extension and the high weight of the battery. Besides constructional changes the intelligent use of material will be the solution to this task.

In this paper, in order to illustrate electro mobility lightweight construction by using aluminium, two innovative automotive components -wheel hub motor and oil pan for a range extender are mentioned. In the wheel hub motor part, the concept to reduce weight and the important tasks of this concept are introduced first. After that, the requirements of Al alloys to be the suitable material, especially the method to increase the heat conductivity are shown. Also the mechanical properties and the corrosion behaviour of the new optimised AlSi8.5Mg-Alloy are presented. Moreover, the production concept and approach for weight reduction of the stator are provided. In the oil pan part, the heat balance and the reduction of the noise emission lead to the motivation to develop a new oil pan. According to this, the implementation of heat insulation and damping capacity by closed foam structure during oil pan construction are described. Following this, the methods to form foam structure are discussed. In addition, some results of the characterization of the foam structure material are shown.

2. Introduction

For the future of the electro mobility lightweight construction is even more essential than for the conventional mobility. To realise an electric vehicle optimised range, best performances and highest comfort as well as a high battery capacity is necessary. For compensating the battery weight the car construction has to be as light as possible.

To realise such lightweight construction aluminium shows the best performance concerning cost and weight reduction. Combining this high lightweight potential with a multifunctional construction enables new advanced and innovative automotive components.

Selected examples of such components like a wheel hub motor and an oil pan for a range extender are mentioned below.

The following issues are focused on a number of aspects, such as the production of aluminium foam structures. Detailed information related to these topics can be found in [1+2].

3. Innovative Automotive Applications

3.1. Wheel hub motor

Wheel hub concept

The wheel hub motor, Figure 1, is the most consequent application of electro mobility.

The advantage of this electric drive concept in comparison to a conventional vehicle concept is that components like central motor and transmission parts can be totally omitted. As a result the gross vehicle weight is significantly lowered, whereas the weight of the unsprung masses is rising. This means that the weight should be as low as possible for increasing comfort, road holding, safety and driving dynamics.

The most difficult component regarding the part production is the stator of the electric wheel hub motor.

The most important tasks for the implementation of this concept are:

- development of a high pressure die casting alloy with an improved heat conductivity, high-temperature strength as well as a good corrosion resistance
- design concept for a lightweight-stator with an integrated internal cooling system suitable for high-pressure die casting

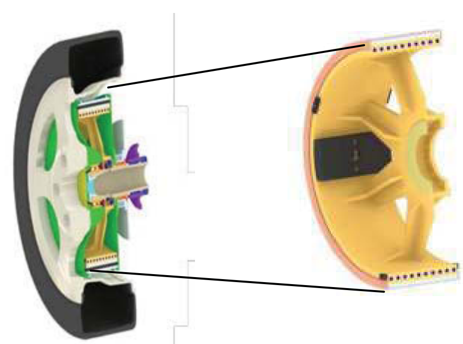


Figure 1. Wheel hub motor design (left: complete Wheel with motor; right: stator of the wheel hub motor), [3].

Material

To fulfil the requirements of an improved heat conductivity the aluminium alloy was optimised. Since the heat conductivity is correlated with the electrical conductivity according to the Wiedemann-Franz-Lorenz-law:

$$\lambda \cong \sigma * L * T$$

where:

λ : Heat Conductivity [W/(K·m)];
σ : Electrical Conductivity [m/(Ω·mm²)];
L : Lorenz Constant [WΩ/K²];
T : Temperature [K]

All optimisations of the electrical conductivity yield optimised heat conductivity.
As visible in Figure 2 the analysis of the aluminium alloy is essential. Low contents of alloying elements in general increase the conductivity. Especially Cr, Li and Mn should be lowered. This requires aluminium with a high purity. These elements cannot be used as alloy elements. For further optimisation of the electrical and thermal conductivity the elements Li, Ti, V and Zr should be removed from the melt via a boron treatment or in case of Li a chlorine treatment. As an example for the potential of the boron treatment the heat conductivity improvement of an AlSi7Mg-alloy is visible in Figure 3.

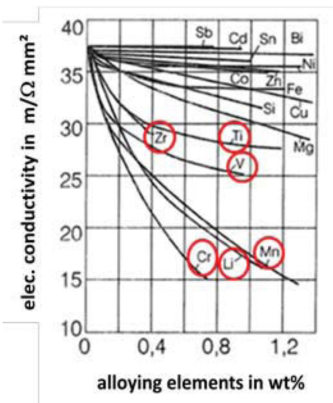


Figure 2. Influence of the alloying elements on the Electrical conductivity, [4].

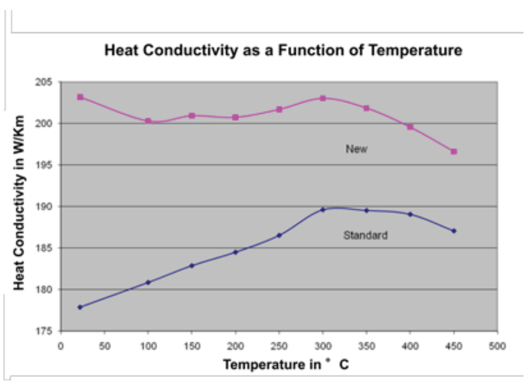
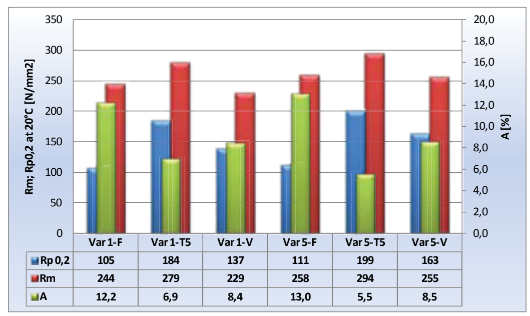


Figure 3. Potential of the boron treatment for the heat conductivity improvement (AlSi7Mg), [5].

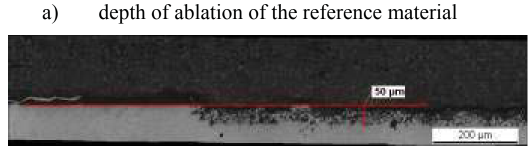
For the application of wheel hub stator an aluminium alloy of the type AlSi8.5Mg was used. To improve the heat resistance the influence of Cu and Ni was investigated. Additionally, the influence of Cu on the corrosion resistance has to be considered.
All alloying experiments were carried out with gravity permanent mould casting. To receive cooling conditions similar to high pressure die casting an optimised permanent mould and test bar geometry was applied. The variety of all alloying tests shows that a compromise is necessary to fulfil all requirements. The trials lead to an optimised AlSi8.5Mg-alloy with higher mechanical properties. Figure 4 shows the mechanical properties of the new, optimised AlSi8.5Mg-alloy.
To investigate the corrosion behavior an IK-test was carried out. The evaluation criterion is the depths of ablation. Significant for this test is that a sample is being exposed to a test solution for 2 hours. The evaluation was done by using metallographic sections. Figure 5 illustrates, that the corrosion resistance of the optimised AlSi8.5Mg-alloy is almost the same as that of the reference material, despite the addition of 0.15 wt% copper.



	Var 1-F	Var 1-T5	Var 1-V	Var 5-F	Var 5-T5	Var 5-V
Rp 0,2	105	184	137	111	199	163
Rm	244	279	229	258	294	255
A	12,2	6,9	8,4	13,0	5,5	8,5

Figure 4. Mechanical properties of the AlSi8.5-alloy (conventional [Var. 1] and optimised alloy [Var. 5]; F=as cast; T5=180°C/2,5h; V=180°C/120h)

a) depth of ablation of the reference material



b) depth of ablation of optim. AlSi8.5Mg-alloy

Figure 5. Comparison of the corrosion behavior

Production concept

In order to achieve a high performance regarding weight reduction the stator has to provide low wall thicknesses. This leads to the following requirements:

- high-pressure die casting method should be used for producing the stator and other components;
- the cooling channels have to be considered for the tool construction

The approach towards the tooling concept is a die casting mould with four sliders, which forms a one-side formation of the cooling channels, Figure 6.

Additional cores are integrated in these four sliders to form the internal cooling channels in the radius arms of the stator.
After the machining of the casting the outer cooling channels are closed via an additional aluminium sleeve.

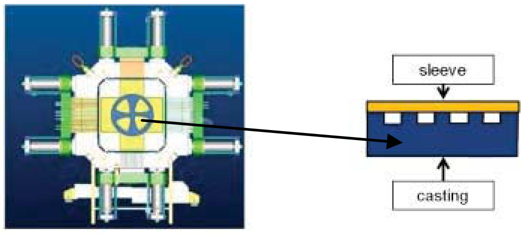


Figure 6. Die casting mould with four sliders which forms a one side formation of the cooling channels. (right: enlarged section of the outside area of the stator)

3.2. Oil pan for a range extender

The current function of a conventional oil pan is only to collect the engine oil. The motivation for the development of a new oil pan concept for a range extender is the difficult heat balance of a range extender. The combustion engine of the range extender is working only temporarily. This yields into a cooling down of the oil reservoir. For a good efficiency the oil temperature should be close to the operation temperature. Therefore the heat balance has to consider the following topics:

- Heat insulation while the combustion engine is stopped
- Heat exchanger for heat transfer from the oil into the vehicle air condition while combustion engine is running
- Heat exchanger for heat transfer from battery section into the oil when combustion engine is stopped (starting phase of the combustion engine). The same heat exchanger should be used for both heat exchange processes.

Figure 7 describes how a heat exchanger could be integrated into the oil pan construction.

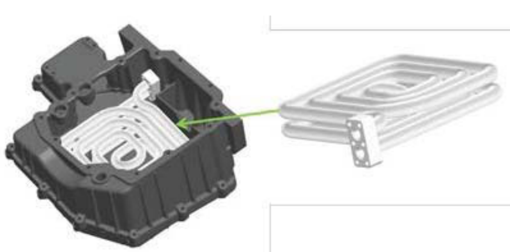


Figure 7. Examples of a new oil pan with an integrated heat exchanger [6]

The target of the material and process technology is to achieve an one-step process that leads to a casting with locally limited and external closed foam structure. Besides the heat insulation this structure offers the advantages of reduced noise emissions as well.

Basic investigations to produce cavities or foam structures

One possibility to manufacture cavities is offered by the space holder technique. In the present example, Figure 8, grains of salt are applied to hold the space for the cavities which have to be formed. For a better handling, the grains of salt have been connected into a stable core. Subsequently the trail has been made to fill the spaces between the grains of salt with aluminium melt by applying an underpressure.

Figure 9, shows the result after dissolving out the grains of salt with water. It is evident that the level of underpressure has to be increased to improve the quality of infiltration.

Figure 8. Example for a stable core consisting of bonded grains of salt.

Figure 9. Resulting aluminium structure after dissolving the grains of salt.

One technique for producing aluminium foam structures involves the addition of blowing agents into the aluminium melt. In principle titanium hydride (TiH_2) and magnesium hydride (MgH_2) can be applied. As shown in the reaction equations (1) + (2), these two substances release hydrogen due to a thermal decomposition.

$$TiH_2 \xrightarrow{\text{(ca. 600°C)}} Ti + H_2 \qquad (1)$$

$$MgH_2 \xrightarrow{\text{(380°C - 450°C)}} Mg + H_2 \qquad (2)$$

Fig. 10 compares the mode of action of MgH_2 with that of TiH_2. In the case of MgH_2 an intense decomposition reaction takes place immediately after it is being added into the aluminium melt. The rapid released hydrogen could not be used for a formation of a coherent network of pores. In contrast, using TiH_2, the reaction proceeds slower, so that it has basically been possible to enclose the released hydrogen into the solidifying aluminium. However, the size and distribution of the pores has to be improved. Furthermore, additional studies are required to transfer the findings into die-casting technology.

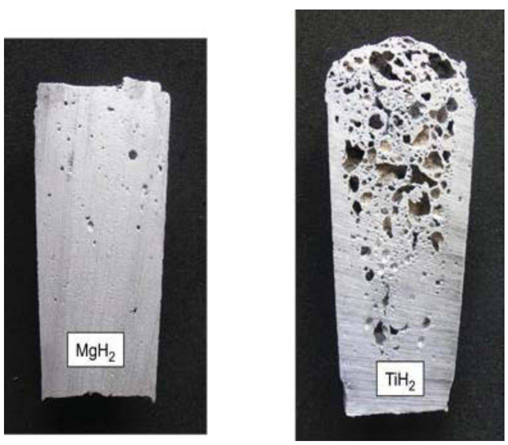


Figure 10. Examples of aluminium foam structures using MgH_2 and TiH_2.

Material characterization

Damping behavior

Damping is a material property which represents the energy absorption by the material. The damping behavior was measured on two samples having nearly the same shape. The two samples differ in that effect that sample A existed as a massive body, whereas sample B was made of an aluminum foam sandwich. Both, the massive body and the foam core were made of the same aluminium alloy. In order to determine the damping the Resonant Frequency and Damping Analyser (RFDA) was applied. Table 1 compares the characteristic parameters "Lost rate" and "Damping" of both samples. As shown, the damping of the aluminum foam material is larger by a factor of 21. Thus, the application of aluminum foam material is an effective measure to achieve a reduction of noise emissions.

Table 1: Comparison of the characteristic parameters "Lost rate" and "Damping"

typ of sample	Loss rate (1/s)	Damping
aluminium **foam material**	**8.1**	**0.000512**
aluminium **massive body**	**190.9**	**0.010832**

Insulation

For the evidence of improved thermal insulation effect of aluminium foam sandwich structures a comparative temperature measurement with a massive body sample of the same material as well as the same mass and surface was carried out. The samples were heated from below and the resulting temperatures on the opposite upper surface of the samples were recorded. The result is illustrated in Figure 11. The temperature rise of the aluminium foam sandwich material is delayed. Furthermore, in comparison to the massive body sample a lower temperature is achieved on the upper surface at the same time. This confirms the better thermal insulation effect of aluminium foam sandwich structures.

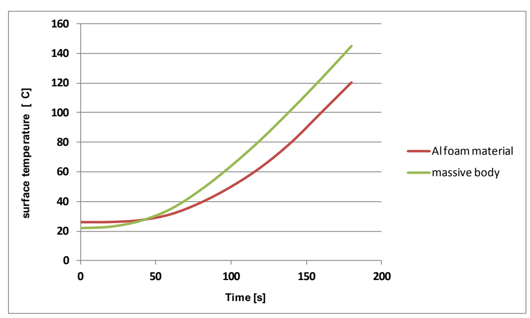


Figure 11. Comparative temperature measurement between a sample made of aluminium foam sandwich and a massive body sample

4. Conclusions

Aluminium is a modern lightweight construction material which offers a multi-purpose applicability at low costs, in particular if material, design and process perfectly match with one another.
The wheel hub motor and the oil pan concept for a range extender are perfect examples for an intelligent combination of lightweight material with innovative design. These parts are essential for the future development of the power train application in terms

of electric vehicles. Concerning a die casting alloy with improved heat conductivity, high-temperature strength as well as a good corrosion resistance, the optimised AlSi8.5Mg-alloy shows strong potential. Furthermore, in case of oil pans for a range extender aluminium foam sandwich structures are useful to achieve a significant reduction of noise emissions and a better thermal insulation effect.

5. Acknowledgement

This work has been funded by the federal state of Saxony-Anhalt (Germany) and the European Regional Development Fund (EFRE) within the promotional competition "ELISA".

EUROPÄISCHE UNION
Investition in unsere Zukunft
Europäischer Fonds
für regionale Entwicklung

Landesinitiative ELISA

References

[1] Integral Foam Molding of Light Metals: Technology, Foam Physics and Foam Simulation (Engineering Materials), Carolin Körner, Springer-Verlag; ISBN: 978-3-540-68838-9

[2] „PORÖSES ALUMINIUM“ Firmenprospekt der Exxentis AG in Wettingen / Schweiz

[3] Lehrstuhl Mechatronik / Institut für Mobile Systeme IMS / Otto-von-Guericke-Universität Magdeburg / Prof. Dr.-Ing. Roland Kasper

[4] Dr. Catrin Kammer: „Aluminium – Taschenbuch“ Band 1, Aluminium-Verlag, Düsseldorf 1995, 15. Auflage

[5] A.Kleine, M.Rosefort, A.Pithan, C.Matthies, H.Koch: Structure Optimization of Al-Si-Type Alloys for Thermal and Mechanical High Loaded Components, Proc. TMS 2013, The Minerals, Metals and Materials Society, San Antonio, USA, 2013

[6] T.Schwarz, Präsentation zum ELISA-Projekttreffen am 11.10.2013, WTZ Roßlau gGmbH