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Water-cooled small volume light weight motors

Simon Jahn[a], Steffen Dahms[a], Felix Gemse[a], Sabine Sändig[a], Pierre Köhring[b], Hartmut Voigt[b]

(a) Günter-Köhler-Institut für Fügetechnik und Werkstoffprüfung GmbH, Jena, Germany
(b) Hochschule für Technik, Wirtschaft und Kultur, Leipzig; Germany

ABSTRACT

Electric drives become more and more popular for vehicles, beginning with small cars up to high load trucks. To use the stored energy efficient, electro motors with small volume and low weight are required. Because of the specified short time overload capability an adapted cooling system has to be integrated. The heat sinks should add only less weight to the whole system and aluminum-alloys are the materials of choice. As process for joining of the disc shaped heat sinks, diffusion bonding without additional filler material is in use. In the paper the motor concept with integrated heat sinks as well as the joining process is presented.

Index Terms **–** diffusion bonding, e-mobility

1. INTRODUCTION

During the development of new motors for electric driven vehicles (electric only as well as hybrid driven) two decisive criteria are the reduction in size and weight. To achieve this, it is necessary to optimize the heat transfer inside the motor in order to avoid failures or damaging. With an integration of heat sinks direct into the motor as structural element, the requirements can be fulfilled.

2. E-MOTOR

2.1 Requirements

Beside the two main requirements, low weight and small volume; further criteria are a high efficiency and capability of short time overload. The last one is direct related to the cooling. With advanced cooling, the capability for short time overload can be higher. Another important factor to mention is that non rare material should be used, because of availability and costs.

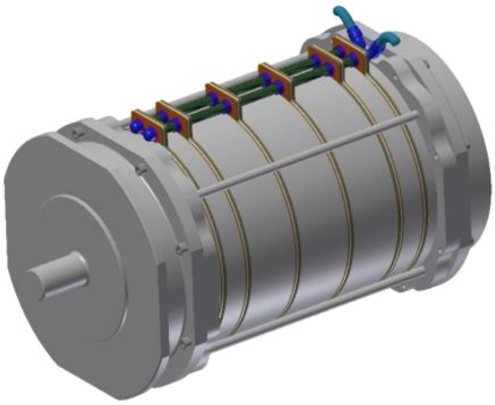

Figure 1: 3D-Modell of E-motor with integrated heat sinks

2.2 Design concept

In Figure 1 the design concept is shown. The water cooled heat sinks are integrated into the motor as structural part. Because of this, a material has to be chosen, which provides good heat conductivity as well as the necessary strength.

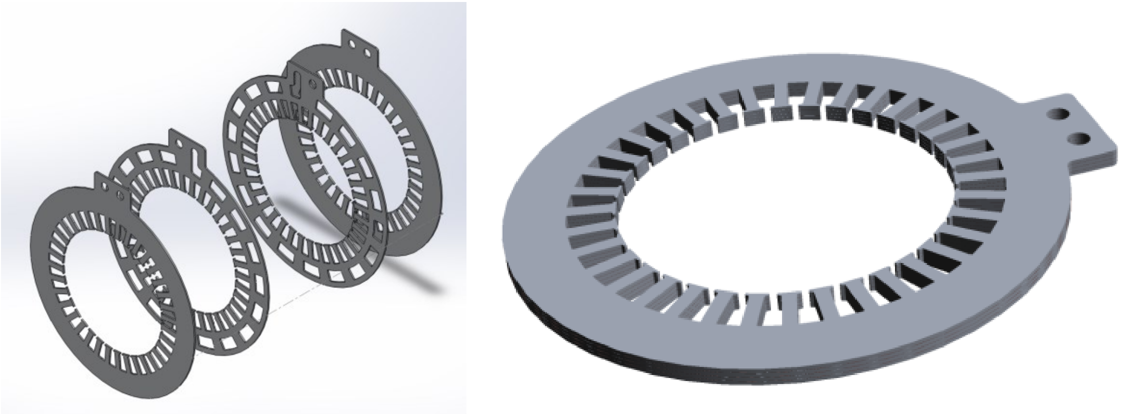

Figure 2: Single parts of the heat sinks assembly (left) and assembly (right)

The assembly of one heat sink consists out of 4 parts. But there are only two different shapes, because two single parts have the same geometry. With respect to series production, the geometry was set in such a way, that laser or water jet cutting as well as stamping can be used to get the single parts. With a laminated design of heat sinks, which have to be integrated into the motor housing, it is possible to get the heat out. In Figure 3 a comparison of different aluminum alloys is given. The value of technical pure Al 99.5 was set to 1.00.

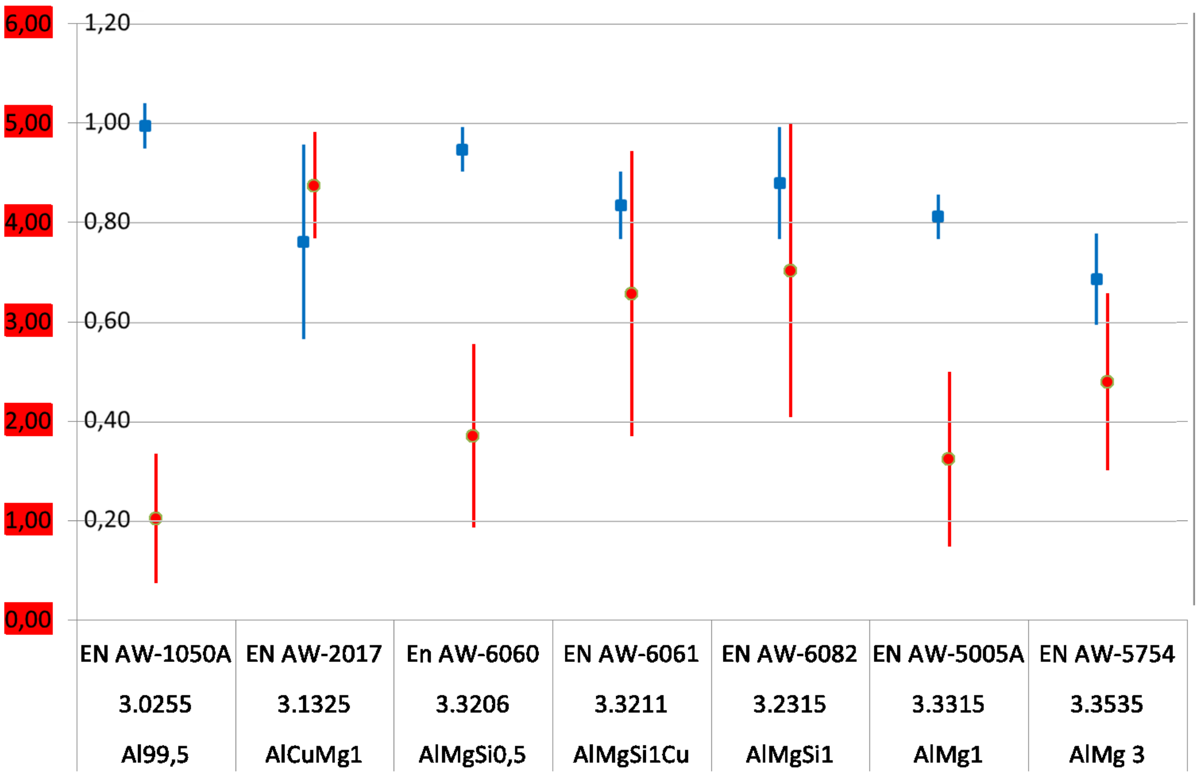

Figure 3: Comparison of different aluminum materials regarding ultimate tensile strength (red) and heat conductivity (blue)

As light weight material with high heat conductivity and required strength, the aluminum alloy 3.3535 was chosen. Because of the Mg-content, this alloy is difficult to join, at least if an areal bond is required. After testing different joining process, diffusion bonding has led to successful bonds within the required spec.

3. DIFFUSION BONDING

Diffusion bonding is a solid state joining process, which allows small as well as large scale planar joints. Materials of the same type or multi-material designs can be bonded below the melting respectively solidus temperature (about 50%-90% Tm respectively Ts). Because of the possibility to join large areas, it is in competition with brazing, especially furnace brazing.

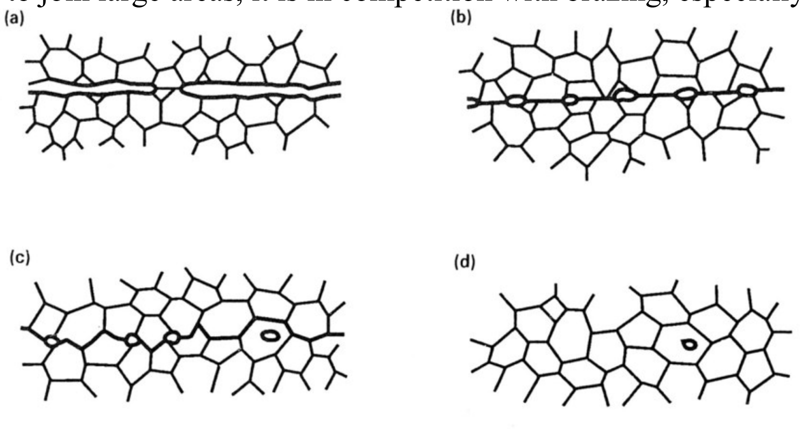

Figure 4: Diffusion bonding principle [1]

In Figure 2, the principle phases of diffusion bonding are shown. The parts have to be stacked (a) and then heated to the elevated joining temperature. An applied load is necessary to get the faying surfaces in close contact (b). Temperature and pressure driven, diffusion across the faying surfaces occurs as well as plastic deformation of surface roughness and creep. At the end of the process, the bond line is not visible any more in the case of similar material joining. To sum up, for the process it is necessary to heat the part, to apply load and in order to avoid undesirable reaction of the material(s), the process should be done in a protective atmosphere. Several different technical solutions are available for each of the three essential elements (heat, force and atmosphere). The diffusion bonding was carried out in a multi-purpose furnace system with integrated electro-mechanical press (shown in Figure 5).

Figure 5: Diffusion bonding system

After bonding, different test were done in order to qualify the process and the bonded parts. During development, destructive (strength testing, microstructure, etc.) as well as non-destructive testing processes (pressure test, leakage test) were chosen. During leakage testing the most important criteria was pressure drop. The part was pressurized up to 10 bar and the valve closed. Within 15 min no pressure drop was allow.

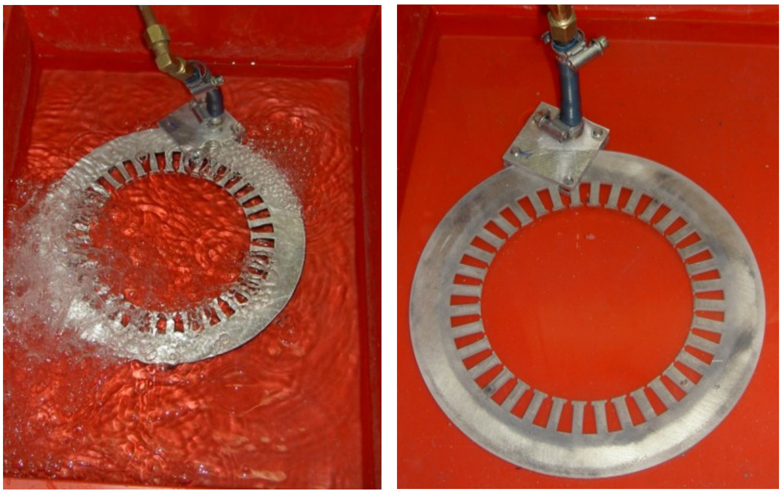

Figure 6: Leakage testing of parts; (bubbles indicate a leak on the left; tight part right)

4. RESULTS

Although the chosen Al-material had a high Mg-content, it was possible with diffusion bonding to obtain tight and high strength bonds. In Figure 7 an example of the heat sink can be seen.

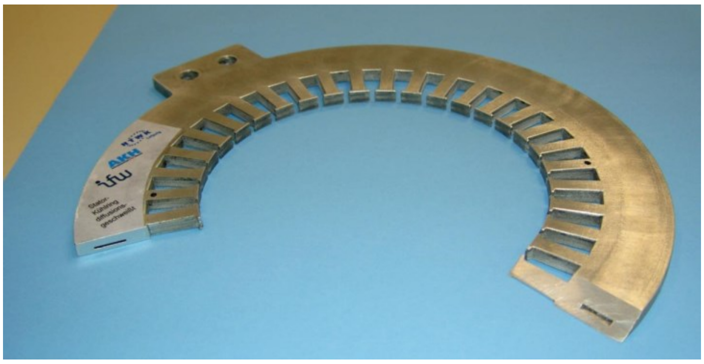

Figure 7: Bonded and cut heat sink

Several heat sinks were bond for the assembly of the motor prototype. During assembly the motor is shown in Figure 8 as well as during the test runs on a test bench. For the tested setup, six heat sinks had to be integrated into the heat sink. The specified and tested average power was 38 kW, whereas the tests on the test bench have power of 62 kW proven. Further, a short time overload capability up to 300% of the average design power was achieved. Compared to the traditional design with a water cooled casing around the motor, a weight reduction of 25% was achieved for the designed power of 38 kW. Beside the weight, the overall volume for the whole motor was minimized as well.

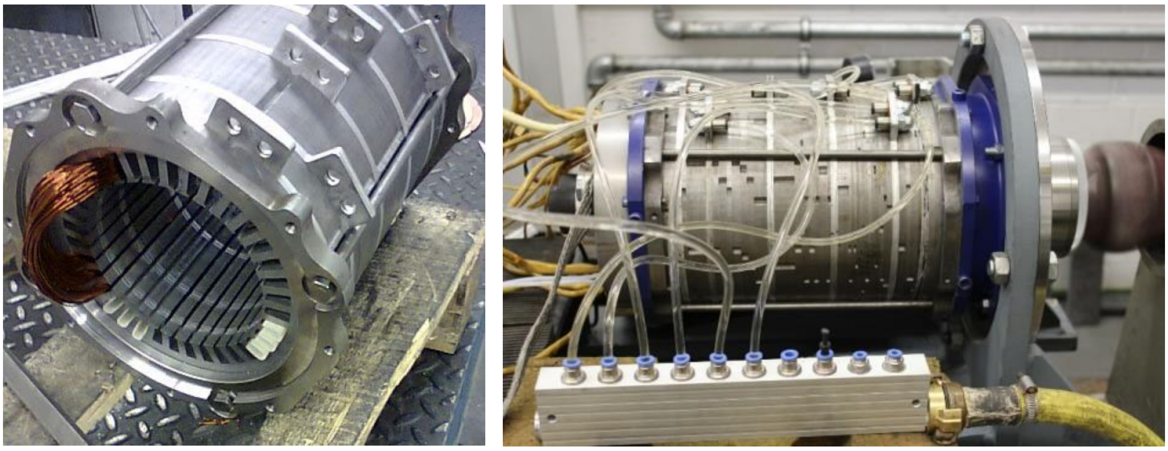

Figure 8: E-motor prototype during assembly and during test runs

5. SUMMARY

With the integration of heat sinks as structural parts direct into an E-motor it was possible to reduce the weight and the volume. Beside the test bench investigations the motor is in use in a 3.5 t class transporter. Main challenge was to get the areal bond of the heat sinks. Even if these consist out of four simple shaped parts only, the material (high Mg-containing Al-alloy) cannot be brazed reliable. With diffusion bonding the requirements were met and the whole system successful tested. The results regarding electrical properties and power led to another application of the presented motor design principle. Because of the high efficiency and high short time overload capability the motor design was used for test bench motor several times.

REFERENCES

[1] Owszarski, W.A. and Paulonis, D.F.: Application of Diffusion Welding in the USA, Welding Journal, 22, 1981

CONTACTS

For bonding process:

Dr.-Ing. Simon Jahn sjahn@ifw-jena.de

For motor design:

Prof. Dr.-Ing. Pierre Köhring pierre.koehring@htwk-leipzig.de