Advances in electrical high current connections for electrical propulsion systems

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Abstract

Many countries strongly support electric propulsion for various fields of transportation, be it people or goods on land, at sea or in the air. Although electric drive systems appear much simpler than (internal) combustion systems, they exhibit their own challenging development tasks. This becomes obvious when an ever-increasing efficiency, performance or production rate is required, just to name a few.

The new challenges can be tackled with the help of new electromagnetic manufacturing processes. High speed processes with their well-known unique capabilities offer promising approaches. However, development is required in order to deliver the required performance.

High-speed forming with electromagnetic tools allows the production of sharp-edged battery housings. For body panels, sharp edges are mainly a design feature. For batteries, however, sharp edges allow for an almost ideally rectangular housing, enabling a higher energy density. Increases in the range of up to 10 % are achievable.

When it comes to packaging, the liquid cooling and heating of battery packs is of equally large importance. The channels for the medium must not consume too much space. The integration of channels inside the aluminium or steel frame of the battery pack is a promising approach. Due to the high welding speeds of up to 500 mm per second at optimum conditions and at the same time the ability to weld aluminium to aluminium or even steel without any loss in strength, electromagnetic pulse welding offers a promising solution.

The conduction of high electrical currents with for example the strong demand to save weight and thus use as little material as possible also requires new processes. Electromagnetic pulse welding of aluminium to aluminium and aluminium to copper is well known, investigated and already used in mass production. However, this is suitable for bus bars only. The connection of terminals to cables is mostly done by crimping. Using a pulsed force for crimping improves the compaction and thus the resistance of the joint, especially of cables with large cross sections. This allows for smaller connectors and reduced cable cross sections.

Keywords

electromagnetic pulse processes, electrical mobility, welding, crimping

1 Introduction

The transportation sector accelerated tremendously the development of electrical propulsion systems with all their subcomponents in the last couple of years. More and more applications enter the scope of the electrification starting with pedelecs up to commercial vehicles and ferries and in between the most prominent example, the passenger cars. With customer needs ranging from maximizing fun to maximizing payload they all have two things in common when stripping it down to the fundamentals, size and weight. When promoting electrified vehicles, manufacturers are used to talk about power density, range or load capacity. To maximize all these aspects and attract the most customers you have to minimize the weight and the needed space for your propulsion system while keeping the manufacturing costs at an appropriate level.

The topic about the weight is all about material and the way it is processed. For lightweight applications it is state of the art to use aluminium and its different alloys to lower the overall weight while keeping the strength at an acceptable level. The EMPT allows the designer to consider the original material strength for durability calculations even after the welding. The material properties won´t be harmed. In fact, they could be improved in the joining area and this will lead to further material savings because you don´t have to consider material weakening due to heat impact (Rebensdorf et al., 2016).

The power density is mainly driven by the efficiency of using the available space, besides the battery material itself. Minimizing the dead space between the battery cells by introducing an EMPT post-processing could provide a reasonable increase in usable volume inside of the battery housing for example. The absence of a punch and the enormous power of the magnetic field provide extraordinary calibrating possibilities.

Using high power makes it necessary to transport it from A to B with a minimum of losses. Big electrical engines and fast charging, to name only a few make it mandatory to increase cable cross sections and incorporate high-performance shields. Cross sections between 70 mm² and 150 mm² are widely used in industrial applications and commercial vehicles. Conventional manufacturing processes reach their limit trying to crimp these dimensions in serial applications. The EMP-crimping combines homogenous high compaction rates (= high electrical conductivity) for main conductor and shield and minimum crimping length (= minimum size = more space for other components).

2 Battery housings

Looking at the battery market reveals an ongoing contest between different rival types of batteries. There is no definite winner yet. Different vehicle manufacturers rely on different approaches. The most tangible advantage of vehicles powered by batteries is the range. Making the owner or user more flexible or as flexible as one could be with conventional power sources.

When it comes to prismatic cells the so-called packaging density based on the space needed for the battery is limited by the ***design*** of the battery housing. Prismatic cells are coiled or stacked layers of electrode foils and separators in between. This assembly is then put into a cubic metallic housing and gets ***sealed gas tight*** to protect it from external impacts.

Having these housings as a deep drawn part made of soft aluminium alloys like EN AW-3003 or 1050 make them perfectly fit to use EMPT.

2.1 Design

In general, such cubic housings are made by deep drawing. Since the process needs a punch and a die the design of the housing is restricted to their manufacturable dimensions. To create tools with economical reasonable lifetime they will have radii at each edge. (See Fig. 1)

Figure 1: Prismatic battery cell (PSTproducts)

With the help of EMPT you can reduce the radii to a minimum. After the deep drawing process, the EMPT “calibration” will be added to increase the final volume of the housing. Especially the stacked variants of this cell type will benefit from the small radii, since you can add additional stacks. Fig. 2 is highlighting the increased space of calibrated edges. Different tests show that it is possible to reduce the edge radii to less than 1 mm. Summing up the reduction of all edges leads to an increased range up to 10 %.

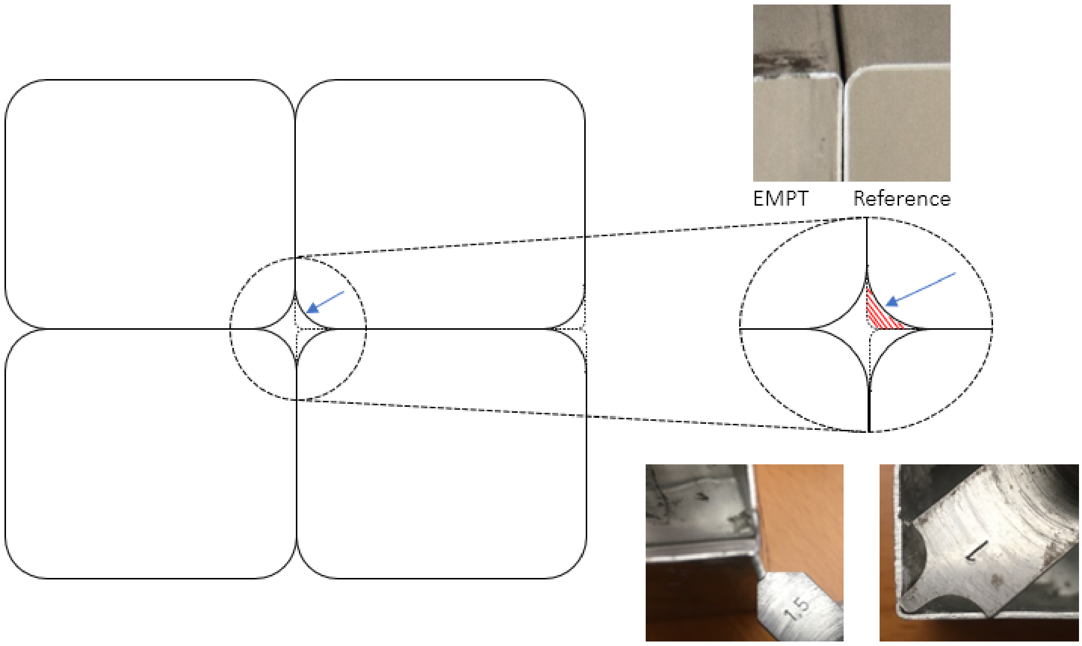

Figure 2: Decreased edge radius by EMPT (PSTproducts)

3 Battery cooling

3.1 In General

Lithium-Ion batteries are state of the art when it comes to battery types in electric cars. They are the decisive factor for the range of the car. From a physical point of view, this range is the usable capacity of the battery, also known as the "State of Health" (SOH). The actual usability of this capacity and its maintenance for as long as possible is influenced by many factors. In addition to driving behaviour, speed or the use of electricity consumers such as heating, it is above all the temperature of the battery. The correct temperature control determines the usable capacity and the service life of the battery, i.e., how many kilometres you can drive on one charge and does this value remains constant over the years. The thermal management of a modern electric vehicle must be able to absorb both the ambient temperature and the self-heating of the batteries during loading and unloading. It only reaches its full capacity in the temperature range in which people feel comfortable: between 20 and 40 degrees Celsius.

Various strategies are used in lithium-ion batteries to set the optimal cell temperature. The focus of the article is on housing cooling using liquids, whereby the designs shown can also be applied to other temperature control approaches. Liquid cooling is used when air cooling is no longer sufficient or when the available space requires a compact design. The heat transfer in such cooling plates is made up of heat conduction and convection, with convection here making the greater contribution to the removal of heat. The cooling plates must be placed as close as possible to the heat source, the battery, to facilitate heat transfer.

On the other hand, materials with a high thermal conductivity must be used and this is where the EMPT can show its strengths.

Today's economically viable materials with high thermal conductivity also have good electrical conductivity (see Fig. 3). Silver has the highest electrical conductivity of all metals.

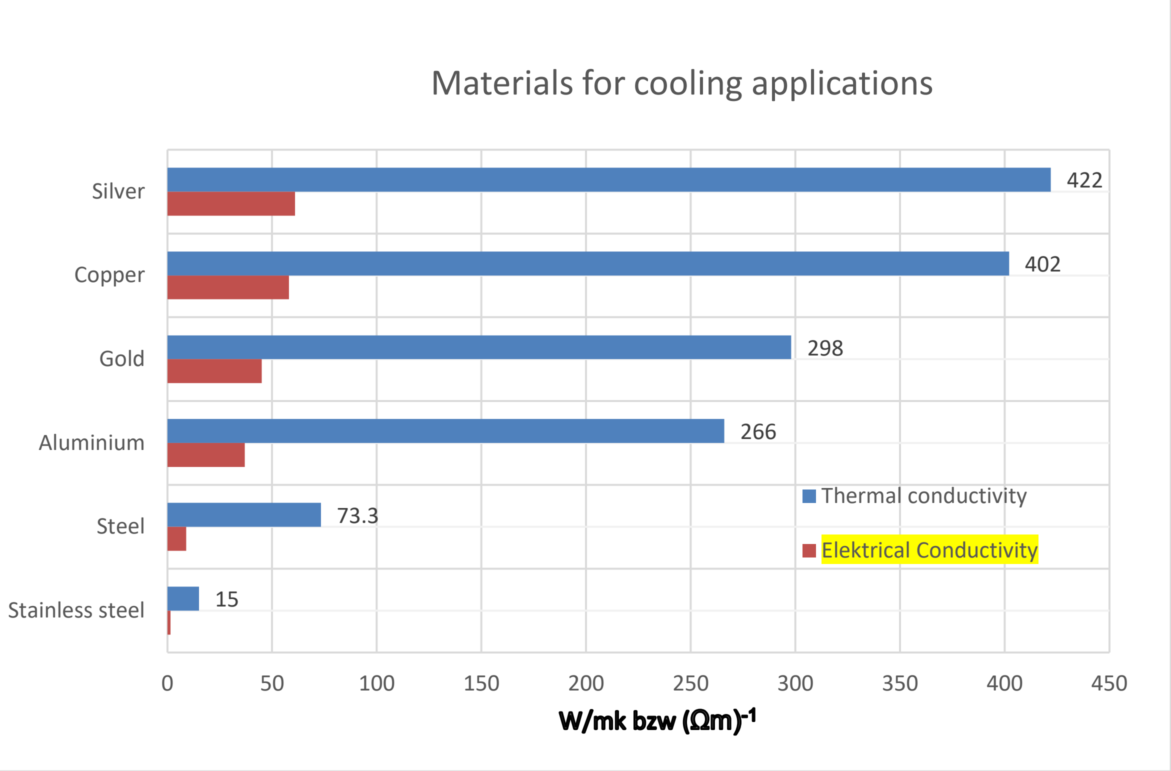

Figure 3: Overview of conductivities of different materials

This means that the EMPT is basically suitable for the production of cooling plates. The materials commonly used nowadays for cooling plates in the field of electromobility are aluminium and copper. Usually these are connected by brazing or friction stir welding. In contrast to EMPT, both processes involve thermal joining and its corresponding intermetallic phases.

3.2 EMP-welded cooling plate

The cooling plate itself is a single piece plate. By welding the preformed cooling plate directly onto the bottom of the battery carrier an enclosed volume is created. You will not only get rid of thermal insulating air gaps known from standalone cooling system placed additionally below or into the battery carrier, but will also benefit from the missing negative heat impact at the material strength.

The preformed cooling plate (e.g., EN AW-1050) shown in Fig. 4 is welded onto the bottom of the battery carrier.

Figure 4: Preformed cooling plate before welding

To create a gas tight circumferential outer weld the EMPT tool coil has to form a closed loop. Small leakages between the different channels are allowed providing the chance of creating simple channel designs by overlapping welding highlighted in red in Fig. 5.

Figure 5: Cooling plate after welding

The plates could be varied in size, material and thickness to meet the requirements from a small cooled module made of only some cells up to cooling of the complete battery carrier mounted in an electric vehicle.

4 Electrical Connections

Depending on the application a power supply (e.g., battery) and electrical consumers (e.g., electrical propulsion system) will be placed in an available design space considering several rivalling requirements. When dealing with vehicles you will find different locations for battery and electrical engines. High safety requirements lead to a low centre of gravity forcing the designer to put the battery into the bottom structures of the vehicle while the propulsion system is mounted at the front or rear axle. In addition to that a connection with the charging plug, the battery/charging management system and all the other electrical consumers has to be considered. The latest vehicles carry around several kilometres of cables and their connectors. These connections are facing increased requirements especially when connected with safety-related systems or in the near future with systems for autonomous driving. EMP joints can provide powerful, versatile and safe connections throughout the vehicle.

4.1 Cable Crimping

The EMP-crimp provides the following advantages compared to conventional crimping:

- High compaction rates (cross sections up to 200 mm²) lead to a high electrical conductivity at a minimum space (see Fig. 6)

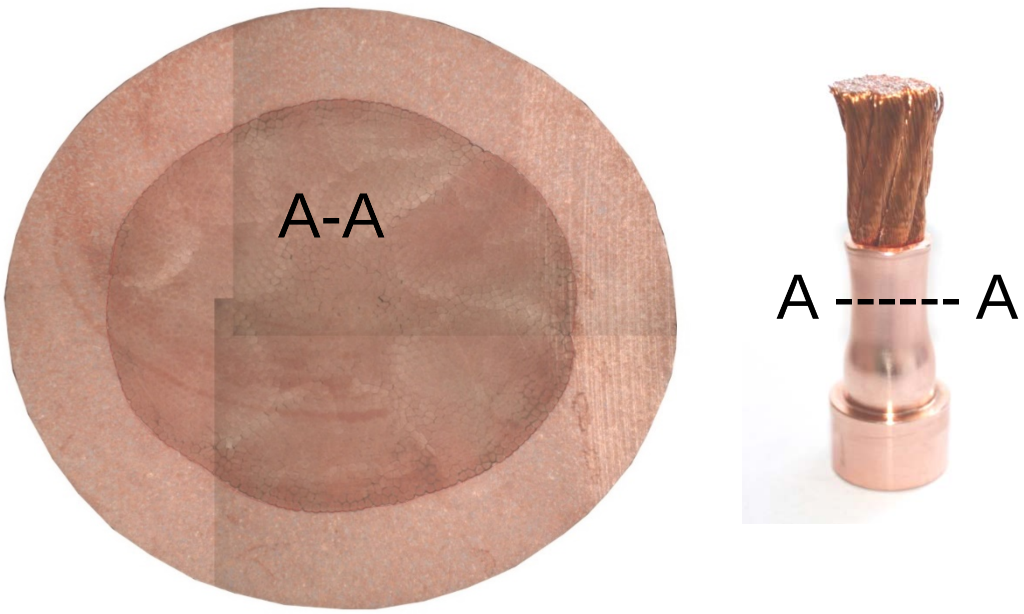

Figure 6: Microsection of a copper cable (PSTproducts)

- Due to the high deformation velocities of several 100 m/s and a so called "repressing effect"* the EMP crimp is almost without any spring back which leads to superior results in durability testing like pull-out force and bending tests (valid for new and aged cables)
- The demands at the current load capacity of the cable shields had increased due to the new applications of the e-mobility. The homogenous pressing of an EMPT crimp shows a much better contacting compared to polygonal crimps, leading to a higher permitted load capacity.

4.2 Busbar Welding

In areas where regularly unplugging is not necessary, electrical connections will be designed as permanent joints. Such a bonding will be welded to create a strong and robust connection with superior electrical characteristics.

Permanent connections can be found when connecting the battery electrodes with a consumer. The most prominent type of battery nowadays in propulsion systems is the Li-Ion battery. By using Lithium as active material the material of the underlying carrier is getting defined. The Lithium compound will be pressed onto the cathode. The cathode has to be made out of aluminium since copper will corrode. With the anode (e.g., active material = graphite) it is the other way around. It is made out of copper because aluminium would interact with the Lithium. This leads to two different materials at the battery poles, aluminium and copper. Depending on the main material for cables and bars within an application there is the need to weld aluminium to copper or vice versa. Creating such a weld with conventional thermal methods will lead to brittle intermetallic phases with very low electrical conductivity.

The EMPT welding, as a representative of the cold pressing procedures, avoids intermetallic phases. The result is a very strong and highly electrically conductive joint. Fig. 7 shows the typical failure of sample stressed in a tensile test. The damage will occur in the weaker base material and the welding area stays intact.

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* Based on the relatively low discharge frequencies of 10 – 15kHz of the cable crimping tools compared to other EMPT-coils the magnetic pressure is present longer, leading to better results of the crimps.

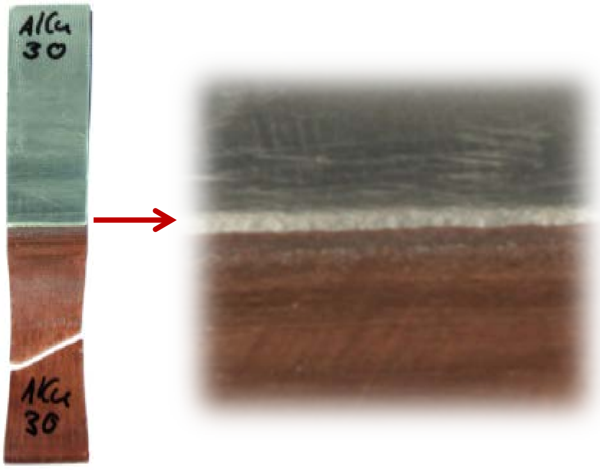

Figure 7: Al/Cu tensile test sample

Determining the electrical conductivity by a 4-point measurement reveals the superior electrical conductivity of the EMPT bond (Fig. 8). The electrical conductivity of the bond equals the mean value of the joining partners.

Ω/mOhm*	MP_1	MP_2	MP_3	MP_4
MP_1	0.001	0.105	0.181	0.280
MP_2	0.105	0.001	0.138	0.222
MP_3	0.186	0.141	0.001	0.185
MP_4	0.276	0.221	0.182	0.001

*Measured with Milliohmmeter Hioki 3554

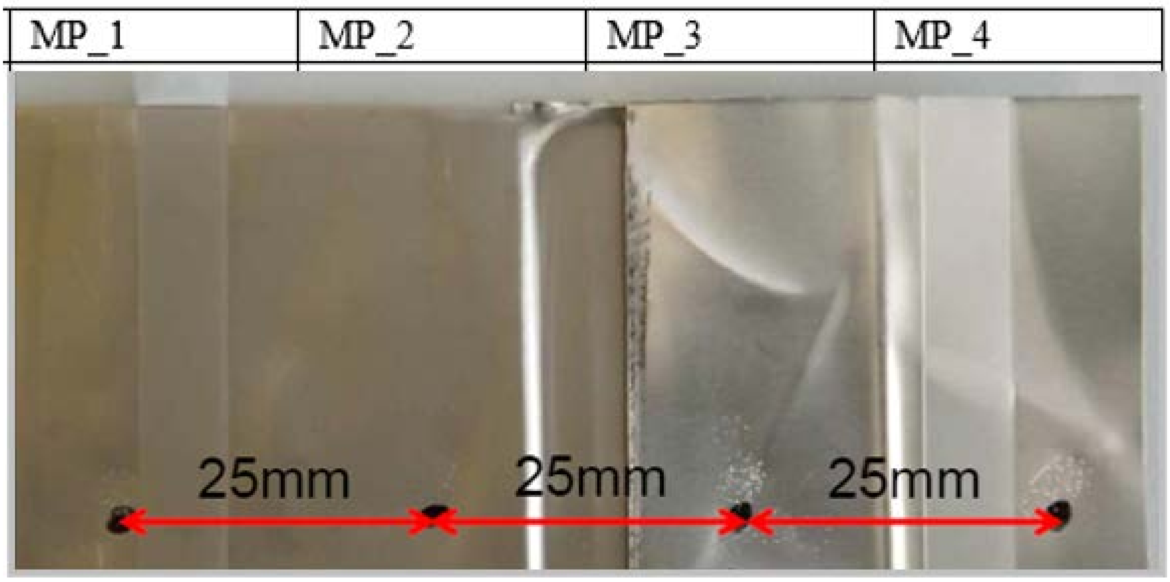

Figure 8: 4-point measurement of a EMP welded joining

5 Discussion

It has been shown that there are multiple applications within the field of e-mobility where the EMPT provides advantages compared to the conventional manufacturing methods. The absence of heat and direct contact paired with beneficial material behaviour under high-speed deformation leads to technical outstanding components.

Applications powered by batteries will always need cooling but the solutions seen at the vehicle market are still very different. Every OEM is following its own path and it is questionable if there will be a short-term agreement. Finding the right partner will be the key to gain a foothold.

The rapid market change from combustion to electrical engine could lead to a breakthrough of the EMPT crimping within the next couple of years. The bigger cross sections (>70 mm²) make it hard to oversee the advantages EMPT has to offer technologically and economically.

On the downside the potential customers faced with investments in a new technology when there are not many players on the market hesitate to take the risk and make the next step. From a geographically point of view the most promising markets are Asia and USA. The European mentality of thinking twice and verification above all hinder the widespread usage of EMPT.

References

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