Lasers in Manufacturing Conference 2021

Laser technologies for battery pack production - a comprehensive overview with a focus on the structural components

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Abstract

The global mobility revolution is in full swing. The demand for components for electric cars and alternative drives is rising continuously. Many production approaches are making use of the benefits of laser technologies. It connects battery cells to form modules or packs. It ensures tightness and crash safety when joining battery packs and trays.
This paper offers an insight into the requirements of battery packs as well as the innovative joining technology solutions for the material specifics, which are made possible by the use of novel laser and system developments in industrial practice. Furthermore, the trends regarding the structural components of future battery packs will be presented. Finally, a spotlight will present the next generation of laser and joining technologies for use in battery system manufacturing and place them in the context of existing material-specific challenges, such as helium-tight welding of aluminum alloys.

Keywords: Battery pack; Structural components; Laser technologies; Laser manufacuturing; Battery electric vehicle; Laser welding

1. Introduction

The battery pack is the key component in electromobility and accounts about 40% of the added value of a battery electric vehicle (BEV), making it a key development area for automotive manufacturers. (German Federal Ministry for Economic Affairs and Energy, 2021). The expected high volumes of the battery pack confront the entire automotive market, including suppliers, with extensive new challenges in which a volatile market environment must be balanced with extensive technical requirements such as helium tightness (Pillot,

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2019). In this sense the importance of the battery pack for the sustainable success of battery electric vehicles (BEV) can be demonstrated by three main dimensions.

First, it is essential to emphasize that the battery pack is one of the key components on the road to future mobility, because for users, the range of a car as well as the total costs for the vehicle are the most important reasons why electromobility has not yet achieved a breakthrough (Nykvist et al., 2019). In the first step, technological developments must be made to develop a high-performance battery pack for long ranges.

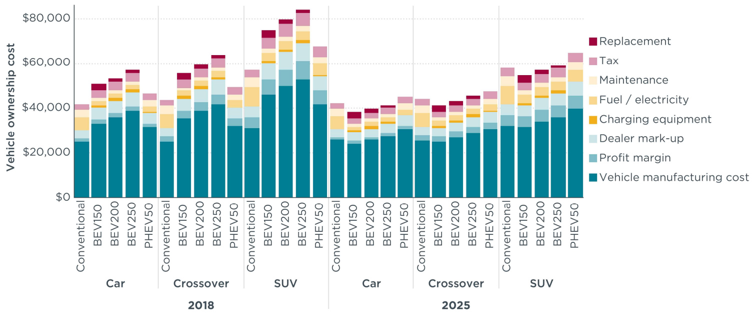

Fig. 1. Evolution of vehicle ownership cost composition for different car models from 2018 extrapolated to 2025 (Lutsey, 2017)

In the second step, however, the technology must be designed for mass production. Cost-effective production is particularly important for this. As can be seen from Fig. 2Fig. 1, vehicle manufacturing costs are still a major cost driver for BEVs. Moreover, Fig. 1 shows that the total costs of an ICE (internal combustion engine) are still much lower than a BEV. This justifies the focus on manufacturing technologies in this paper, because BEVs can only become competitive through cost-efficient further development of manufacturing technologies. The focus on the production of the battery pack in particular is based on the high proportion of the costs of the battery pack in relation to the total vehicle cost, which is still expected to be around 25% for a BEV car with 250kWh capacity in 2025 (see Fig. 2).

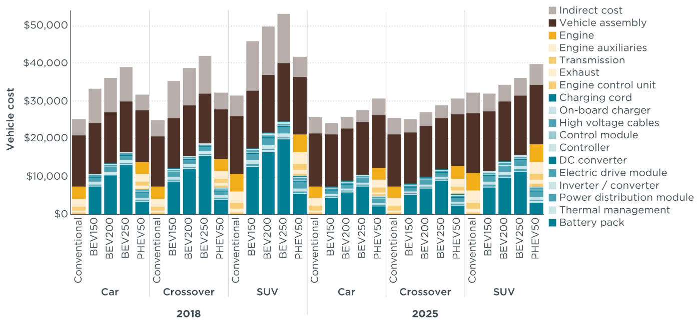

Fig. 2. Development of the vehicle cost mix for various vehicle models projected from 2018 to 2025 (Lutsey, 2017)

Thirdly, due to the increasingly short development cycles required in the further development phase of battery packs, a flexible production concept is the answer for rapid further development and advancement to market maturity (Schuh et al., 2020). In combination with the increasing number of vehicle derivates and battery pack variants, laser-based manufacturing technologies represent a great opportunity for the cost-efficient and flexible production of the structural components of the battery pack (Schuh et al., 2020).

For those reasons, the structure-giving components of the battery pack are introduced in the following. Based on this, laser-based key manufacturing technologies will be explained and assigned to the individual applications of the battery pack's structuring components.

2. State of the art

As Table 1 shows, the topics of efficiency and mass production play a major role in the relevant literature with regard to Helm et al., 2020 and Schuh et al., 2020. The main aim is to drive forward cost reduction, which, as already shown in the introduction, is still a major factor in the battery pack production according to Lutsey, 2017. In addition, Schuh et al., 2020 says shorter product life cycles require production flexibility to obtain a cost-efficient manufacturing. Finally, the last major aspect considered in the current literature is the robustness and resilience of the battery pack according to Arora et al., 2016. All these points emphasize the necessity of improved manufacturing processes over the whole production process chain. Laser-based manufacturing technologies can accelerate the cost-efficient and flexible production of a resilient battery pack. Due to the need to address these issues, this paper provides a comprehensive overview of relevant laser-based manufacturing processes for the battery pack.

Table 1. Excerpt of current studies for battery pack production

Source	Focus part of the battery pack	Thematic focus and manufacturing technologies	Critical factors mentioned for the battery pack in automotive
Zwicker et al., 2020	All components	ultrasonic welding, wire bonding, force fitting, soldering, laser beam welding, resistance welding, friction stir welding, tungsten inert gas welding, joining by forming and adhesive bonding	Capacity, resistance, cooling technology of the battery pack, suitability of a well-designed battery pack for mass production
Helm et al., 2020	Copper connectors and power electronics	Laser ablation with ultrashort pulsed lasers, laser beam welding	Short cycle times, high degree of automation and manufacturing efficiency, high quality electrical connections
Schuh et al., 2020	Structural components	Remote laser welding, resistance spot welding	Shorter product life cycles, increasing number of variants, high degree of flexibility and automation in mass production
Das et al., 2018	All components	Ultrasonic welding, resistance spot/projection welding, micro-tungsten inert gas welding, pulsed arc welding, ultrasonic wedge bonding, micro-clinching, magnetic pulse welding, laser welding, mechanical fastening	Producing joints with low electrical resistance, durable joint strength
Shui et al., 2018	Structural components	Design optimization of battery pack	Design optimization for lower weight and higher resilience
Lutsey, 2017	All components	Costs of BEV and battery pack	Cost reduction in manufacturing of the battery pack
Arora et al., 2016	All components	Challenges to large scale electrification of public and private transportation sectors	Robust and reliable battery packaging design

3. The structural components of the battery pack for automotive

3.1. Overview

The battery pack, as an integral unit of the BEV chassis, not only provides protection for the battery modules and the battery management system (BMS), but also protects the car and its passengers from battery leakage, vapors and fire, especially in the case of an accident or crash. Referring to this, Fig. 3 shows an exploded drawing of the individual components of the battery pack. Of these components, the structural components are explained and specified in sections 3.2-3.7.

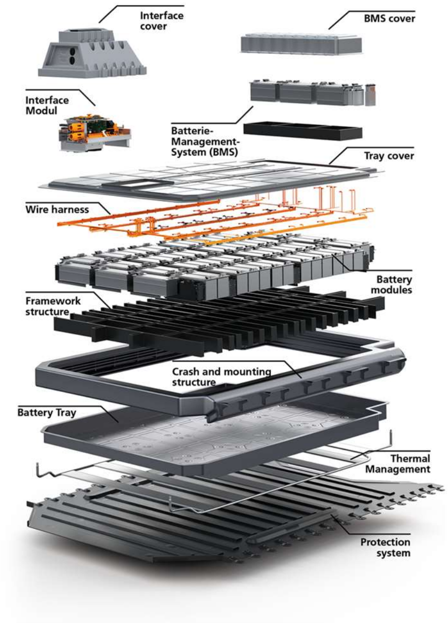

Fig. 3. Exploded drawing of a battery pack demonstrator (TRUMPF Laser- und Systemtechnik GmbH, 2021)

3.2. Tray cover

The tray cover encloses the battery pack with hermetic sealing and electromagnetic combability. For the manufacturing of the tray cover, for example, laser cutting is used for cutting the metal plates. Furthermore, paintings and oxide layers are removed by a laser-based ablation process (see Fig. 4). The tray cover is usually made of aluminum alloys (e.g., 5000 and 6000 series) or steel alloys and in special cases also as carbon-fiber reinforced plastics (CFRP) material or glass-fiber reinforced plastic (GFRP).

Fig. 4. Laser ablation of paint on the tray cover (TRUMPF Laser- und Systemtechnik GmbH, 2021)

3.3. Battery Tray

The battery tray is a protective housing for the battery modules, electronics, and cooling unit. The sheet metal for the battery tray can be cut by laser cutting (see Fig. 5). Furthermore, as can be seen in Fig. 5, after the bending process, a laser welding process can ensure gas-tight sealing and welding of the battery tray. In the majority of models, the battery tray is also made of aluminum (e.g., 5000 and 6000 series) or steel alloys.

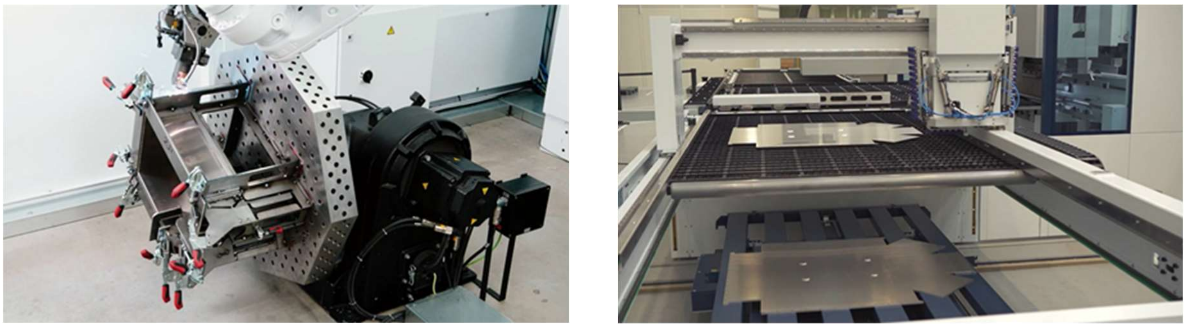

Fig. 5. (left) Laser welding of the battery tray (right) Laser cutting of the battery tray (TRUMPF Laser- und Systemtechnik GmbH, 2021)

3.4. Thermal management

The thermal management creates the optimum operating conditions for a reliable and high-performance battery pack. Depending on the cooling technology, several laser technologies can be used: laser structuring, laser welding, laser cutting. Laser structuring can be used to create precise structures in the thermal management of the battery pack, which later enables polymer connections. Laser welding and laser cutting can be used for cutting and welding of aluminum sheet metal, extrusion profiles, casted parts and tubes (see Fig. 6).

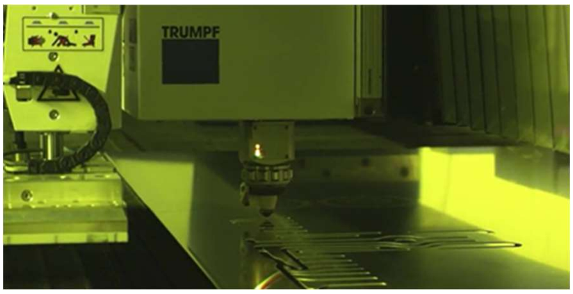

Fig. 6. Laser cutting of the thermal management (TRUMPF Laser- und Systemtechnik GmbH, 2021)

3.5. Crash and mounting structure

The crash and mounting structure absorbs high impact loads and dissipates the energy, especially in crash situations. Here, the structures must be particularly robustly manufactured in order to withstand high loads. For this purpose, metal profiles can be cut by laser cutting and welded by laser welding. Usually aluminum (e.g., 5000 and 6000 series) and steel alloys (e.g., roll formed and hot formed) are used.

3.6. Framework structure

The frame structure positions the battery modules in the battery carrier and mitigates deformation in crash situations. The joining process of the framework structure can be produced by (remote) laser welding, using beam forming and/or beam oscillation. The materials mainly used are aluminum (e.g., 5000 and 6000 series) and steel alloys (e.g., roll formed and hot formed).

3.7. Underride protection system

The protection system prevents damages to the battery pack from road debris. For the reinforcement structures remote laser welding can be used. For the protection system aluminum (e.g., 5000 and 6000 series) and steel alloys are used.

4. Key laser technologies for manufacturing

4.1. Overview

To meet tough cost, resilience and manufacturing flexibility, laser is a key technology for battery pack structural parts made of either aluminum alloys or high-strength steels. In sections 4.2.-4.7, the various key laser technologies for manufacturing the structural components of the battery are presented. First, the general areas of application of the technology will be shown, then briefly explained, and characterized. Finally, the technologies will be assigned to the various structural components of the battery pack.

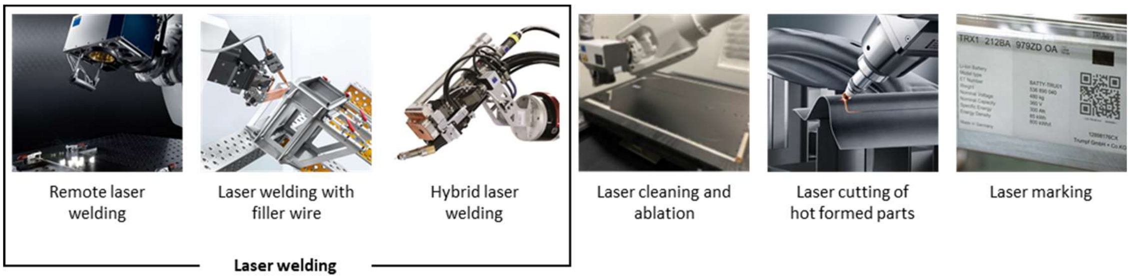

Fig. 7. Overview about key laser technologies for battery pack manufacturing (TRUMPF Laser- und Systemtechnik GmbH, 2021)

4.2. Remote laser welding

Remote laser welding is a widely used manufacturing technology in the automotive industry due to its extensive fields of application. The welding process is performed without moving the component or focusing optics what leads to a higher process flexibility and productivity. With remote laser welding, customized weld patterns with different shapes, orientation, and distribution can be manufactured in a flexible way. The technology is mainly used for large working pieces which require a high degree of precision and repetition accuracy. Based on this, remote laser welding is the preferred technology for welding the framework structure, protection system and the battery tray due to the large size of the components. Moreover, the technology is applicable for the welding of the battery modules because the seam must be precisely welded to ensure gas tightness.

4.3. Laser welding with filler wire

Laser welding with filler wire is used in the automotive industry for certain high alloy materials and difficult applications which require the use of filler material such as the welding of components with gaps (see Fig. 8). This technology is a multi-parameter process where the weld quality mainly depends on the following factors: laser beam and filler wire interaction, wire feed speed and wire feed angle. On the one hand, laser welding with filler wire is able to deliver good quality welds without cracking and material-adapted filler materials as well as optimized gap bridging. This is possible for gaps with up to 1 mm width. On the other hand, there is also an increasing system complexity combined with a reduced weld speed what adds more consumable costs. Depending on the application and design, laser welding with filler wire can be used for several structural components of the battery pack such as the battery tray or the protection system.

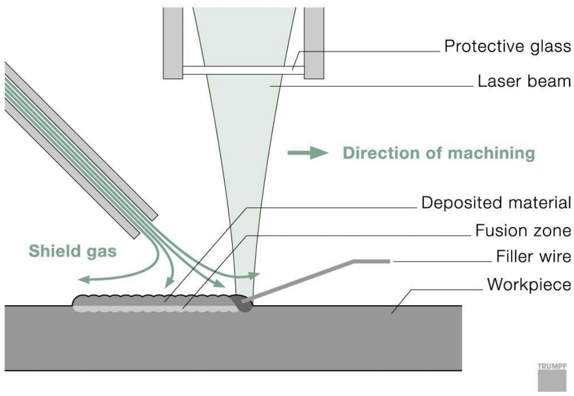

Fig. 8. Laser welding with filler wire (TRUMPF Laser- und Systemtechnik GmbH, 2021)

4.4. Hybrid laser welding

Hybrid laser welding names the process combining laser welding with arc welding in a common processing zone. The arc welding process has the ability to increase the gap bridging capabilities. The laser on the one hand supplies the high-power densities necessary for the deep welds and on the other hand stabilizes the arc to enable high welding speeds. The addition of filler wire not only effectively bridges the gap, but also directly influences the metallurgical properties to eliminate micro-cracks and enhance the toughness of the weld. This opens up a wide range of applications for hybrid laser welding, especially for 6000 series aluminum alloys and materials like extrusion profiles and casted parts. Therefore, hybrid laser welding is a suitable process for welding long seams on structural components that require gap bridging and have high strength, such as the crash frame or the framework structure, which require medium deep penetration and excellent metallurgical composition. Because the technology works well with 6000 series aluminum alloys, laser hybrid welding can be used extensively in the structural parts of the battery pack, such as the crash frame.

4.5. Laser cleaning and ablation

Laser cleaning and ablation is used to clean surfaces free of debris, oils, corrosion, or pain to ensure reliable welding and adhesive bonding processes afterwards (see Fig. 9). A typical laser cleaning system used in battery pack application consists of a nanosecond pulsed laser combined with scanning optics. The cleaning and ablation with laser technology is contactless and ensures a precise, selective, repeatable and chemicals-free process. Furthermore, there is no waste to sort afterwards and the tools must not be replaced or repaired. However, it should be considered that an exhaust system has to remove gases during laser ablation. For the battery pack, the laser cleaning and ablation is used for cleaning the surface prior to the welding or gluing processes in order to ensure to gas and water tightness. Moreover, cathodic dip paint on several parts must be removed for electromagnetic compatibility.

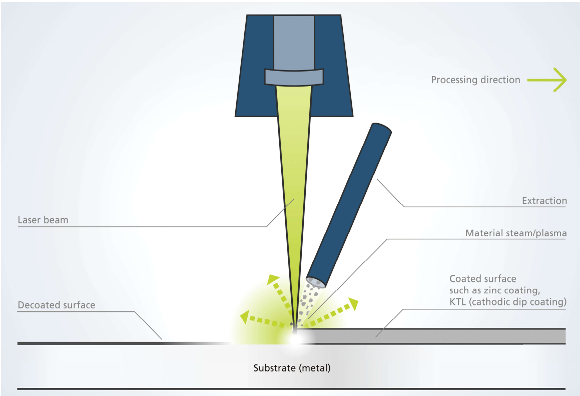

Fig. 9. Laser ablation (TRUMPF Laser- und Systemtechnik GmbH, 2021)

4.6. Laser cutting of hot formed parts

The basis for the laser cutting is a laser beam that is guided, shaped and bundled. Laser cutting can be used to cut many types of metal, with full flexibility in terms of cutting contours. The advantages of laser cutting are mainly the flexibility of the cutting geometries, which can be cut in 2D as well as in 3D. Furthermore, the process reliability as well as the precision of the method should be emphasized. However, laser cutting can only be used up to a certain thickness of approx. 20mm. Laser cutting can be used on all components of the battery pack where sheet metal is cut, such as the thermal management or the battery tray.

4.7. Laser marking

In laser marking, the marking is applied directly to the surface with a pulsed laser beam. The interactions of the focused beam with the surface lead to a change in the material - for example, discoloration, structuring, engraving or material removal. How the material changes depend significantly on the wavelength of the laser, the pulse duration and the irradiance of the laser beam. One advantage of laser marking is the flexibility, because different material and different patterns can be marked flexibly. Furthermore, a high process reliability is to be mentioned. The technology can be used in battery pack production, for example, to mark components. In times of global supply chains, traceability is becoming increasingly important. Furthermore, the components can be reliably and clearly identified, which simplifies tracking within the production environment.

5. Conclusion and Outlook

The profound transformation in the automotive industry continues. The production of the battery pack requires cost reductions and increased flexibility in equal measure. This paper has shown in which areas laser-based manufacturing technologies can support the flexible and cost-effective manufacturing of the structural components of a battery pack. The comprehensive overview emphasized the role of lasers as a key manufacturing technology in shaping the complex transformation to electromobility. Particular potential can be seen in the Battery tray. Due to the increasing number of variants for BEVs and battery packs, quickly adaptable and flexible production solutions are required, which makes remote laser welding the ideal production technology for the battery tray. Furthermore, laser cutting offers high flexibility at low cost. This means that all the structural elements of the battery pack that require sheet metal cutting can be manufactured by flexible laser cutting. In addition to laser technologies for joining and cutting, a quickly adaptable solution is also offered in the area of ablation through laser technology. Further research should focus on the role of laser technologies in the robustness of the battery pack. In particular, it should be technically investigated to what extent laser technologies can contribute to making the battery pack more robust and resilient. This topic is also frequently addressed, as the battery is still a safety-critical part of the BEV. Furthermore, it must be investigated to what extent the flexibility of laser technologies could be leveraged by smart factory solutions, because the rapid adaptability of production can only be achieved through interconnected manufacturing.

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