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A Comparative Study on Cutting Electrodes for Batteries with Lasers

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Abstract

E-mobility is still one of the most discussed topics within the automotive industry. Electric powered vehicles can drive emission-free and present consequently the future propulsion. Nearly all global players in the automotive industry are making great efforts to develop cost-efficient electric drives, which are suitable for series production. The national governments support this evolution progressively. For example the mobility research programme of the Federal Republic of Germany looks at the production of Li-Ion cells in its entirety. Within this programme the cutting of electrodes for Li-Ion cells by lasers is an issue, too. This paper provides a comparative study on cutting materials relevant for Li-Ion cells with beam sources operating in a cw mode and a pulsed mode respectively.

Keywords: Laser Cutting; Remote Cutting; Battery Technology; Ablation; Pulsed Mode; cw Mode

1. Motivation / State of the Art

With respect to the mobility research programme of the Federal Republic of Germany one million e-cars are planned to appear on Germany's streets. In order to reach this aim one of the main issues to be solved is how to produce the enormous amount of batteries in a cost-efficient and sustainable matter. The production process of batteries is an accumulation of different manufacturing technologies in a great variance and complexity on a high level. Chemical, physical as well as engineering skills are required. Finding the right base materials and their mixture is equally important as choosing the right technology for building a battery by connecting the individual cells. Most of these techniques are well known from other sectors like the telecommunication industry. For example the production of Li-Ion cells for mobile phones is state-of-the-art in this sector. The transfer of this knowledge for manufacturing e-cars' batteries is not satisfying at all. Significant differences in capacities, geometrical dimensions and life times are only some of the reasons. However the automotive industry makes great efforts to get a competitive cost structure for battery production. Influenced by the worldwide rapid development the adaption of

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established manufacturing technologies is the main issue at the moment. Rather to set future trends even to improve the recent ones the Federal Republic of Germany supports the automotive industry with several government research programs. One of these projects is named “DeLIZ”, which is an acronym for a production-related demonstration centre for Li-Ion cells. Within this project the research facilities Fraunhofer IWS Dresden, the University of Technology Dresden together with the University of Technology Munich investigate alternative production processes and process controls. The whole production process from reel to cell is regarded. This includes coating the metal foils, cutting the electrodes as well as the separator, handling the components, joining the stacked foils, sealing the batch and connecting the cells to a whole battery.

This paper addresses one of the mentioned production steps in detail. It is the cutting of electrodes. Punching is state-of-the-art for this application. Short cycle times in mass production cause the dominance of this technology. Nevertheless Li-Ion cells for automotive applications demand high cutting qualities in terms of burr and particle free cutting edges. Both of them lead to short cycles and consequently to an undesired lifetime reduction of the highly stressed cells. In addition, the ceramic coating of the electrodes causes an increased tool wear. The punching dies become blunt and the cutting quality diminishes at the same time. Consequently the dies have to be reground very often. Laser cutting is investigated as an alternative production process in this paper. The non-contact processing with laser radiation guarantees a wear-free treatment. Furthermore the laser process is very flexible and different geometries can be adapted easily without making new cutting dies. In comparison to punching the main disadvantage of laser cutting are the relatively long cycle times. In order to overcome this limitation the potential of high dynamic remote cutting techniques is studied in this paper. Laser beam sources with both continuous wave (cw) and pulsed mode operation are used. Achievable cutting speeds and qualities will be determined. Based on these results the application areas for the two operating modes and for lasers in general are characterized.

2. Experimental

Besides the postulated cutting quality an average cutting speed above 1 m/s is generally required to compete with punching. Consequently conventional gas assisted laser fusion cutting is out of the question. The high inertia of moved masses of a typical flatbed laser cutting machine limits achievable cutting speeds on the contour [1]. Even state-of-the-art cutting machines with linear drives and light weight constructions are not suitable to achieve the requested cutting speeds [2]. Because of that laser remote cutting is the key aspect for this paper. For the two different operating modes of the laser the principal experimental set-up is almost similar. In both cases the laser beam is deflected high dynamically by preobjective scanning. Two scanning mirrors manipulate the collimated beam in order to reach each point within the working area of the scanning system. An f-theta objective keeps the focal plane constant. Using relatively long working distances slight movement of the mirrors cause great displacements and high speed of the focal point on the work piece’s surface. The main difference between the two experimental set-ups is the used beam source and adapted optical elements.

Materials to be cut were coated aluminium foils (cathode material) with a total thickness of 130 µm as well as coated copper foils (anode material) with a thickness of 120 µm. Both materials are composites consisting of three layers as drafted in Figure 1.

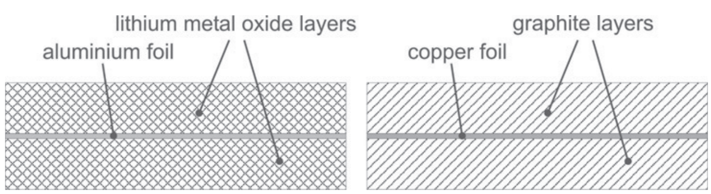

Figure 1. Scheme of the structure of the test materials, cathode (le.) and anode (ri.)

Concerning the cw beam sources several investigations for cutting metal sheets have outlined the great potential of remote cutting. Particularly thin foils can be cut with very high speeds in the requested range [3, 4, 5]. Instead of that it is interesting to learn, whether the achievable cutting quality is sufficient. For the realised investigations a fibre laser with an output power up to 5000 W was used. A spot diameter of 25 µm can be reached with the optical configuration. The general set-up shows Figure 2.

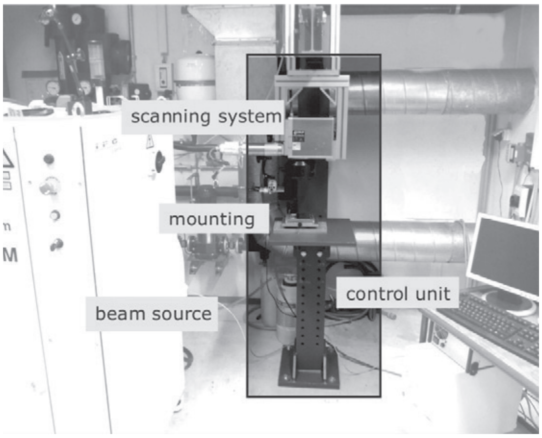

Figure 2. General set-up for remote cutting of electrodes with cw mode beam sources

Short pulsed lasers are widely utilized to realize high precision micro machining and material-independent cutting with minimal thermal damage (HAZ). The main challenge of the investigations is to upscale the cutting speed to the specified value while preserving the high cutting quality. First basic studies are carried out with q-switched lasers of two different wavelengths (355 nm, 1064 nm), output power up to 50 W and pulse length in the low nanosecond range. Depending on the laser and optical setup spot diameters of 10 µm and 25 µm respectively are achieved. Typical pulse repetition rates utilized in the tests were between 20 and 100 kHz.

3. Results and Discussion

3.1. Cutting Speed

In consideration of developing a mass production process the achieved average cutting speeds must not be below a critical value. This critical speed is defined as 1 m/s and 60 m/min respectively. When falling below this value the process becomes unattractive for mass production of lithium ion cells and cannot compete with punching.

Firstly achieved cutting speeds were determined as a function of the used laser power for the anode's as well as for the cathode's material for the cw system, see Figure 3.

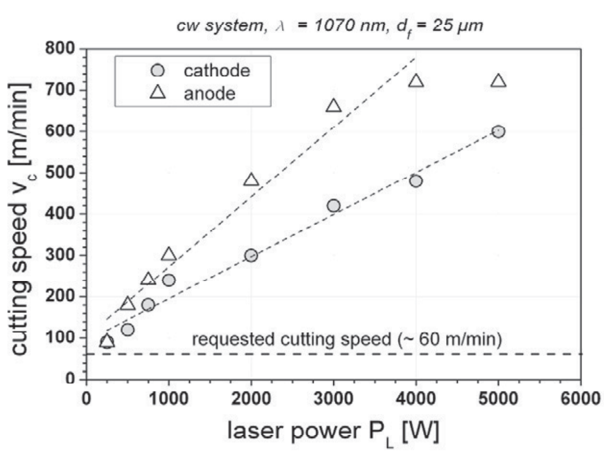

Figure 3. Achieved cutting speeds with the beam source in cw mode

As expected the cutting speed for both materials increases as the laser power increases. The degressive growth for the anode above 3000 W is caused by the dynamic performance of the used scanning system. In general cutting speeds for anode's material are higher than for cathode's material. In order to reach the requested cutting speed of 60 m/min a laser power up 1000 W is more than enough. Achieved cutting speeds for P_L = 500 W are 180 m/min for the anode and 120 m/min for the cathode. It is also possible to top the requested cutting speed by using 250 W. With respect to the process stability a laser power of 500 W is recommended.

Subsequent investigations were done with the different pulsed systems. To guarantee comparability the same wavelength as well as the same spot diameter was used likewise. The achieved cutting speeds as a function of the used laser power at 1070 nm and approximately 100 ns are illustrated in Figure 4.

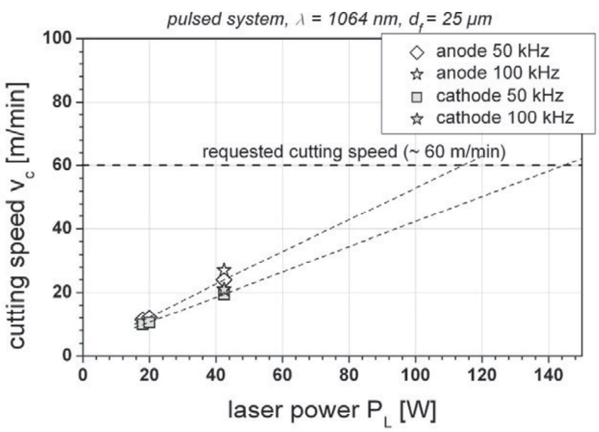

Figure 4. Achieved cutting speeds with the pulsed system

The graph shows the same behavior as before. The cutting speed increases as the laser power rises. At 42 W average output power two different repetition rates were investigated – 50 kHz as well as 100 kHz. The higher repetition rate allows slightly increased cutting speeds. The achieved values for anode's material are higher than the ones for the cathode, which is due to different material thickness and composition. What is evident from Figure 4 are the relatively low magnitudes for cutting speeds in comparison to the values of the cw experiments. The used laser power is obviously to low in order to reach the requested velocities. Hence an interpolation was done. The calculation shows that a laser power in the range from 100 W to 150 W is needed to cut the cathode at 60 m/min. These values are in accordance with the determined values for the cw system, where a laser power of 250 W results in a cutting speed of 90 m/min. Pulsed laser systems with comparable pulse parameters as used in the presented study but with higher average output power (200 W and above) are available in the market. Additional tests with a frequency tripled solid state laser at 355 nm wavelength showed similar results regarding cutting speed dependency. Due to the lower average laser power the achievable cutting speeds were lower (up to 7 m/min at 10 W at 30 ns).

Altogether the investigations show that a laser power in the range of several hundred watts is required to separate the tested materials at more than 60 m/min. The required laser power for pulsed systems seems to be lower than for the cw system. Using a pulsed system a power of 100 to 150 W appears to be sufficient to cut the material at 60 m/min.

3.2. Cutting Quality

To evaluate the cutting quality some criteria must be defined. Known from punching processes are problems caused by the appearance of the cutting edge. One issue is to avoid cutting edges smudged by the metal foils. In case of smudging the coating layer (lithium metal oxide or graphite) with the metal layer (aluminium or copper foil) an undesired short cycle is generated. Hence the cutting edges were analyzed by light microscopy as well as SEM. Within the whole investigated area for the cw system as well as for the pulsed system no critical defects were detected. Only some small and isolated droplets in the range of a few microns are apparent. Consequently the appearance of the cutting edge itself can be stated as uncritically. SEM images of typical cutting edges are depicted in Figure 5.

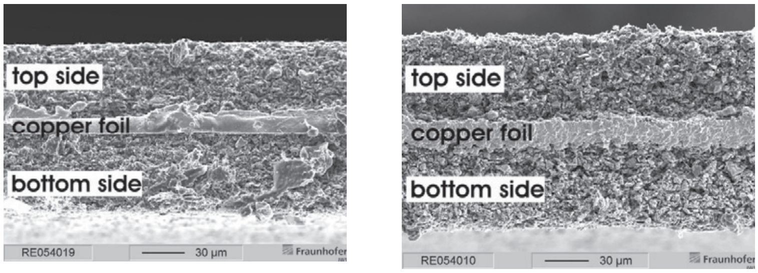

Figure 5. Examples of the typical appearance of the cutting edges of the anode for the cw mode beam source (le.) and the pulsed beam source (ri.)

Other aspects to compare achieved cutting qualities are the clearance width of the metal foil (ablation width of upper coating) and the frazzling width (protruding lower coating) of the coated material. Both characteristics were determined with the aid of digital light microscopy. A sample's top view offers the possibility to measure the mentioned values as drafted in Figure 6.

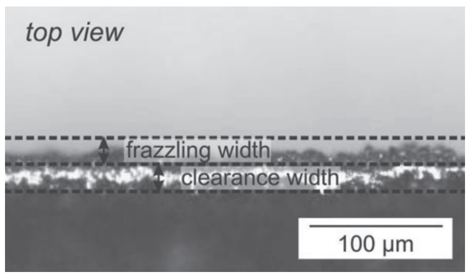

Figure 6. Scheme of the determination of characteristic values for the cutting quality with the aid of a top view of the cutting edge

Firstly the values of the clearance width as well as of the frazzling width were determined for the cw system. The measured values as function of the used laser power are plotted in Figure 7.

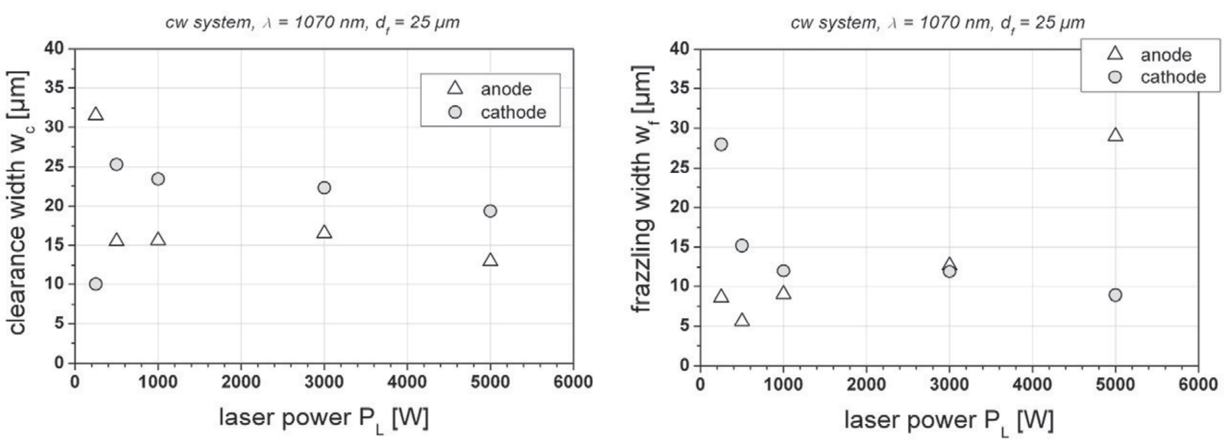

Figure 7. Clearance width (le.) and frazzling width (ri.) for the cw system

It is evident that the clearance width is nearly unaffected by the used laser power. This can be explained by regarding the energy input per unit length. As mentioned before a higher laser power results in higher cutting speeds. Hence the increase of laser power during the investigations by a factor of 20 influences the energy input per unit length only by a factor of 3. This slight change results in relatively small differences for the clearance width.

The values alternate between 13 µm and 17 µm for the anode's material and between 19 µm and 25 µm for the cathode's material. Generally the clearance width of the anode is lesser than the one of the cathode. Sole exception occurs at 250 W. In terms of frazzling widths best values appear at laser powers up to 1000 W. Determined amounts for the anode of 6 µm up to 9 µm are lower than for the cathode in this area.

With the short pulsed lasers comparably low cutting speeds were realized due to the limited output power. Therefore investigations of the edge quality were primarily conducted at maximum output power. On pulsed laser systems pulse energy, repetition rate and peak power as well as pulse duration are more interesting regarding their influence than bare output power. By varying the pulse frequency pulse energy and peak power can be influenced. Experiments showed that higher repetition rates and thus lower pulse energy resp. peak power are leading to slightly improved cutting speeds as well as a reduction in the overhang (clearance and frazzling). This can be demonstrated by the following selected measurement results using the example of anode material. Ongoing optimization of the process parameters is conducted to further improve these results.

Table 1. Achieved values of clearance width for the pulsed system on anode material

laser power and frequency	pulse energy [mJ]	clearance width [µm]	cutting speed [m/min]
42.5 W, 50 kHz	0.85	35 - 39	24.0
42.5 W, 100 kHz	0.42	26 - 28	25.5
19.5 W, 50 kHz	0.39	24 - 25	12.0

3.3. Summary and Conclusion

Altogether the investigations have shown that comparable results are achievable with both systems. Due to the high power range of the cw system slight advantages in terms of cutting speed for this system can be stated. A laser power of 250 W is sufficient to top the requested cutting speed of 60 m/min. Even at higher laser powers up to 5000 W cutting qualities in terms of clearance and frazzling width are acceptable. For moderate laser powers typical values of the clearance width are around 20 µm. The amounts of the frazzling width are close to 10 µm. Furthermore the investigations of the cutting edge itself show totally uncritical results.

In comparison to the cw system the pulsed systems offer more opportunities for further improvements of the cutting quality. Nowadays available pulsed laser systems provide an average output power up to 200 W. The studies have shown that this power range is sufficient to reach the requested velocities. Overall critical values of clearance and frazzling width must be defined by practical feasibility tests of the laser cut cell material in order to decide whether both systems can offer an appropriate production solution or only pulsed system are suitable.

References

[1] Morgenthal, L., Pfeiffer, E. & Beyer, E. (1999). "Laser-Konturschneiden von Elektroblechsegmenten." LaserOpto 31(2): 66-69.
[2] Bartels, F., Süß, B., Hauptmann, J., Wetzig & A., Beyer, E. (2010). "Ruck Zuck zum Bauteil." LaserTechnikJournal (3): 40-43.
[3] Beyer, E., Lütke, M., Himmer, T. & Bartels, F. (2008). "Cutting with high brightness lasers. "Proceedings of "Stuttgarter Lasertage 2008", p. 29 et seq.
[4] Lütke, M., Himmer, T., Wetzig, A. & Beyer, E. (2009). "Opportunities to enlarge the application area of remote-cutting." Proceedings of 28th ICALEO, Paper 608
[5] Zaeh, M., Musiol, J., Schober, A. & Oefele, F. (2009). "Heat induced distortion during remote laser cutting." Proceedings of 5th Lasers in Manufacturing, p. 227 et seq.