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Integrated cut and place module for high productive manufacturing of lithium-ion cells

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ABSTRACT

A main reason for the high costs of lithium-ion cells is the complexity of the assembly process. Especially, creating the cell stack is an inefficient process due to an immature handling and aligning of the limp electrodes and separators. This paper focuses therefore on the methodical development of a functionally integrated assembly module that combines cutting and handling of electrode sheets to increase stacking accuracy, process reliability and productivity. Based on an analysis of requirements and functions, a technical solution has been identified and will be illustrated. At the end, the realized module is described and its performance is proven by experimental validation.

1. Introduction

Due to the global shortage of fossil resources the electrification of the power train becomes more and more the centre of attention for the automobile manufacturers [1]. The biggest challenge here is to develop powerful and cost-efficient energy storage systems [2]. In the short and medium term, lithium-ion batteries offer the greatest potential in this regard because of their high energy and power density [3]. Only their high price that is especially driven by the assembling of the single battery cells is currently hampering the successful breakthrough of electromobility [4]. At the moment, the assembly of single cells accounts for nearly 50% of the overall battery system costs [5]. In order to achieve the cost objectives of the automotive industry, it is necessary to improve the technologies used to manufacture the Li-ion battery cells. Increasing the productivity of the available facilities and an increase in yields in production are, above all, considered to be the most important factors on the road to success. At the same time, the highest quality requirements have to be fulfilled in order to avoid negative effects on the expected lifetime and capacity of the cells.

This article describes a possibility of increasing the productivity while at the same time reducing the cost for the assembling of lithium-ion pouch cells. Requirements for optimizing the cell stack creation are deduced from the deficits in the cell production according to the current state of the art. Based on this, the approach of the cut and place module and its technical implementation will be presented. After that, the realized setup and the findings for validating the approach are presented before finally discussing different alternatives for the overall system configuration.

2. Manufacturing of lithium-ion cells

2.1. State of the art

When assembling stack cells, the single functional layers which are still separate material webs at the beginning, have to be processed to form a proper cell stack. During this process, the extremely thin and limp anodes, cathodes and separators have to be put on top of each other always alternating and in a repetitive sequence until they reach a defined number of electrodes according to the desired cell capacity [6].

Four competitive procedures are known for the production of stack cells according to the current state of the art [7] which are illustrated in Fig. 1.

During *single sheet stacking* single sheet segments are cut out of the material webs which are then stacked in a pick and place process on top of each other. This production method is very complex and therefore costly but has the potential to create very high quality cells compared to other methods. The *flat winding* is a continuous cell stacking process during which the material

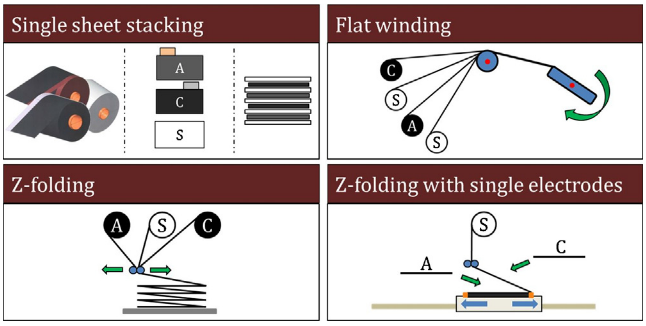

Fig. 1. The four stacking methods [7].

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webs of anode and cathode together with 2 separator webs are continuously wrapped around a flat core. This is a very fast and therefore cost-efficient production method. However, there are disadvantages to be mentioned: The small bending radii of the inner material layers as well as the mechanical stresses induced during the operation of the cell can lead to accelerated ageing of the cell. In case of *z-folding with one-sided coating*, the anode and cathode webs together with one intermediate separator are folded back and forth to form a *Z*. Similar to the flat winding; all materials are also continuously processed and therefore produced in a cost-efficient way. But a disadvantage comes up by the one-sided coating of the electrodes leading to a reduced power to weight as well as energy to weight ratio of the cell stack.

During the *z-folding with single sheets* only the separator is continuously processed as a material web. The previously separated electrode sheets are inserted between the intermediate layers of the *z*-folding [8]. The advantage of this procedure is the fact that also here no individual separator sheets have to be processed. However, especially ceramic separators tend to be damaged at the folding edges.

Regardless of the chosen method, the result of the stacking process is a cell stack (Fig. 2a) that consists of approximately 60–100 layers depending on the cell capacity.

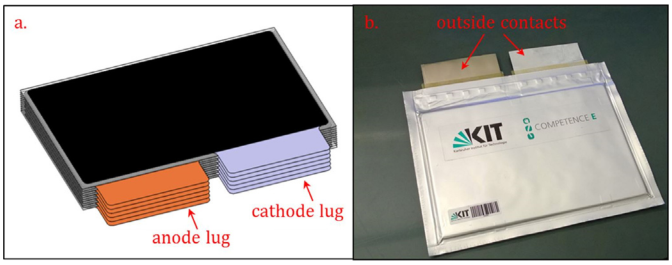

Fig. 2. (a) Exemplary cell stack at the end of the stacking process; and (b) finished cell.

At this point, conductor tabs have to be welded to the conductor lugs of the anodes and cathodes. The laser welding and the ultrasonic welding are currently used for this procedure. Later, these tabs will serve as the outside contacts of the cell [9,10]. For completing the cell, the stack is packed and filled with electrolyte and sealed. The external appearance of the battery cell can be seen in Fig. 2b. The last step of the cell manufacture is the formation which means the electric activation of the cell.

2.2. Challenges and objectives

In fully automated production systems, the stacking of cells represents the biggest challenge. In case of pouch cells for electric traction systems, the *single sheet stacking* is normally used. Thereby, the coated material web is processed to obtain single sheets by means of mechanical cutting methods or laser cutting. The cut sheet segments are subsequently stacked on top of each other by pick and place processes. This is done by using handling robots. They do not approach the target directly but always move in multiple axes and have to accelerate and decelerate the relatively heavy robot arms rapidly. This entails the risk that the sensitive single sheets could be deformed or even damaged [11].

Furthermore, a complex verifying and alignment procedure takes place after the gripping of each electrode sheet in order to ensure the precise positioning of the single layers during the assembly. For this purpose, camera systems are used. But their use in the production environment has the effect of limiting the cycle time and driving up the costs [12].

The combination of high quality requirements, sensitive materials and high demanded production rates has the consequence that in today's manufacturing plants on the one hand a high scrap rate is part of the day-to-day business while on the other hand the production of cell stacks is too costly for an industrial application due to inefficient plants. Therefore, also the end product – the lithium ion cell – is too expensive to be established as a successful and widespread solution for electrical vehicles.

In response to these challenges, the wbk Institute of Production Science at the Karlsruhe Institute of Technology (KIT) aims at developing a new approach for processing roll material to obtain cell stacks. The core of this approach has to be a machine module with low investment and running costs that provides high-quality single sheet electrodes and positions them with high accuracy for the downstream process of cell stacking by starting from the coated web materials. The costly test and alignment steps have to be left out. In order to reach a fast cycle time with high process reliability, only a few motion axes with the smallest possible masses and high repetition accuracy may be used. Furthermore, it has to be guaranteed that the single sheet electrodes are not damaged during the handling steps.

3. Design of the cut and place module

A first step in developing the required module involved a comparison of technologies at which the achievable cutting edge qualities of the different methods were compared with each other. Based on these results, numerous solution principles could be worked out which finally led to an overall design of the cut and place module. The final step was the installation and start-up of the module for validating the developed approach.

3.1. Cutting procedure

In order to achieve the high quality requirements when cutting single sheets, common cutting methods had been analyzed at first and then the results were compared with one another. Steel strip cutting, laser cutting and die cutting were the chosen technologies for analysis.

Fig. 3a–c shows SEM images of the cutting experiments that were carried out at KIT. They show the cutting edges of the used commercial automotive-qualified electrodes.

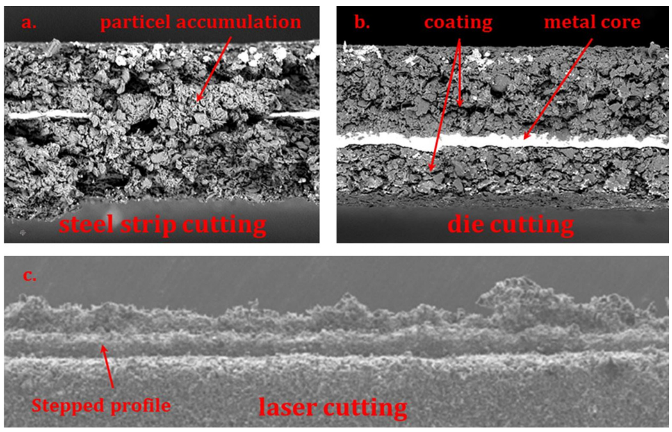

Fig. 3. Comparison of common cutting technologies applied in the lithium-ion industry by using the scanning electron microscopy.

Fig. 3a depicts the result of the steel strip cutting. In the centre of the image the metal core of the electrode can be seen to which the coating of the active material is adjacent at the top as well as at the bottom. The active material has detached itself from the coating in several places along the cutting edge and has accumulated in the form of particle collections in the cutting plane. Such collections can lead to short circuits in the cell later on and are therefore not tolerable. Fig. 3b offers the same view for the result of the die cutting process. The cutting gap of the selected die cutting tool measures merely 3 μm. Consequently, loose particle accumulations do not appear. The result of the laser cut can be obtained from Fig. 3c which provides a view onto the flat side of the electrode from above in the cutting edge area. This process produces a clean cutting edge without