EUROPEAN LI-ION BATTERY ADVANCED MANUFACTURING FOR ELECTRIC VEHICLES

Electrode foils stacking and welding

Putting it all together ...
Electrode foils stacking and welding

*Putting it all together ...*

Only robust and reliable production and handling processes enable cost-effective mass production in the highest quality.

**Analysis of the Initial Situation**

The long, thin webs of the coated electrode sheets and the separator foil are to be implemented by the arrangement in layers to establish a large contact area and active area within a confined space. In addition, the flow of electrons to the conductor electrodes needs to be guided at right angles to the contact area and discharged from the enclosure of the chemical cell. For the draft of a cell, a decision is required as to whether the available installation space in the cell is to be used in favor of the thickness and ampacity of the metallic electrodes and thus an increase in the electrical maximum output. Alternatively, the space can be used for larger active areas, thus increasing the amount of storable energy.

For this distribution of the space, there are more influencing factors, resulting from the manufacturing engineering applied for the production of the cell. The geometric precision of all production and handling processes accounts for the necessary spatial undersizes for ensuring the feasibility of assembly. This space is lost for the cell function. The space for attaching the foils to the conductors and the space for sealing ultimately reduce the active area.

The two main functions for creating the foil stack before it is enveloped are stacking and the joining process. These processes are therefore particularly important in terms of the product design and production quality. They are supplemented by further processes, such as the drying of the foil, the supply of individual parts for joining and the fixation of the foil stack. It makes no difference whether this is the pick and place stacking of individual sheets or Z folding. However, the focus is on flat stacks, as opposed to wound stacks.

Fig: Different stacking types:

- flat wrapping
- pick and place
- Z-folding

The organization of the production plant for creating foil stacks from the individual foils must meet a wide range of requirements for creating cells in top quality, reliably, and efficiently at high output with a low level of resources, work and investment costs. The availability, i.e. the ratio between production time and overall time, plays an important role. The availability of an entire plant can be increased if long parts of the plant with rigid connections are decoupled from each other by buffers, thus preventing them from mutually slowing down due to machine malfunctions.
A number of research approaches are derived from these observations and a vision is developed for the optimum production of pouch cells.

The key is the joining process using ultrasonic welding. It must ensure the connection of the individual foils. To develop the process, the target variables and quality criteria need to be defined first. The development of the process is supported by the development and application of diagnostic methods for understanding the inner process flows. A clamping concept is then to be developed for fastening the components in the joining process and the other process steps. Precision and dimensional accuracy are lost when clamps are changed. For the consistency of the clamping concept for the overall process, a workpiece carrier system is also to be developed.

To decouple the cutting process, the drying process and the stacking process, an efficient magazining system is to be developed for buffering the individual sheets at high speed. These individual aspects are then to be taken into account to develop a comprehensive system concept. The following draft was made as a vision, which is to be developed in the following chapters.

The economic potential resulting from the approaches described above were identified compared to the BatPac reference model. It results in improved availability. The calculated parallelization of stations makes better use of the availability of the machines. Unnecessary handling steps are dispensed with and system space is saved. This project does not take the option into account of automating the manual process of fastening the adhesive strips on the cell stacks.
Joining Work Packages

Methods for Measuring the Joining Quality

A number of requirements are placed on foil welding, that are to be documented with the test methods as far as possible.

- Geometry of the weld optimized in terms of the installation space (= narrow weld area)
- Sufficient strength, ensured on a long-term basis
- Good electrical conductivity of the joint
- Minor mechanical impairment of the foil material
- Minor transfer of heat to the foil material and the battery cell module
- Process-consistent, including: sufficiently large process window
- Cycle time reduction compared to existing processes

The weld samples created as part of the development of the process are to be assessed in terms of the required welding quality according to suitable criteria. Inspection methods are to be selected and applied for this. The favorable selection and application of the inspection methods is for supporting the fast development of the process.

Methods and procedures used for measuring and assessing the test welds are:

- Visual inspection
- Strength analysis
- Microscopic inspection and 3D measurements
- Metallographic examination

Visual inspection

Visible weld faults and imperfections belong to the external characteristics.

Examples from process development:

- Wrinkles: several upper or lower foils have been deformed (wave shape)
• Cracks: one or more upper foils were cut off in longitudinal direction and precisely at the weld area border ("cut out", "punched out"). Both on the narrow side of the weld area and also on the long side.

Tensile test:

The strength characteristics of the test welds to be examined are determined using tensile shear tests. For this, a precise method for clamping the specimens needs to be developed.

The test data can thus be saved and the maximum tractive force assessed:
Microscopic inspection and 3D measurements:

The test welds can be examined using the digital microscope, Keyence VHX-2000 (location: screw-driving laboratory, 2nd floor). The use of a digital microscope provides many options. Sidelight emphasizes the surface structure of the weld area. 3D analyses and 3D measurements are also possible.

For the microscopic inspection, the topography of the welded area (e.g. tool impressions in the foils and in the conductor sheet) and its surrounding area (e.g. deformation of the foils; wrinkles and cracks in the foils) are of interest. The welds can be examined with a magnification of up to 200 times. After the conduction of tensile tests, the fracture pattern of the welding samples can also be assessed more accurately using a microscope.

Example: Micro-fissures in the topmost foil

Ground sections of foil stacks:

The metallographic ground section is for the visualization of weld faults, on the one hand. Statements can be made on the presence, the frequency and the distribution of defects (e.g. cavities) in the joining zone. On the other hand, the structure of the entire welding zone can be examined. The quality of a weld joint can thus be assessed and the optimization of welding processes supported. The challenge is the preparation of thin foils, without changing the result in the process.

The ground sections are assessed according to the following:

- Joint (weld) of foil stack and conductor sheet: material bonding, without gaps
- Connection of the foils: without gaps
- Foil tearing
- Deformation of the foils
• Thermal damage to the foils due to over-welding
• Forming of the weld nugget: geometry, structural change

Example from process development:

Development of Diagnostic Methods
By observing the phenomena and characteristics during the welding process, relevant knowledge is to be acquired for the application and a better comprehension of the process achieved. For these process diagnoses, suitable methods are to be selected, tested for the specific process and applied.

Thermography provides information on the distribution of heat in the direct environment of the process. It cannot look into the process.

The ultrasonic wave propagation in bodies can result in heat developing due to movement and friction at points where this is not intended. This can be detected with this option. The following figure shows how a point on the sonotrode heats up opposite the component.
High-speed recording can be used to monitor the process excellently from the outside. A high-speed camera is used for this. Due to high short shutter speed, a powerful light is required. The size of the picture depends on the image frequency. If one selects an image frequency higher than a vibration frequency of 20 kHz, the section becomes very small, but the individual vibrations can be followed. Larger pictures provide a better overview of the situation.

The films show the development and flying away of particles, the sonotrode penetrating the stack and possibly the separation of the topmost foils, and the surging and tearing of the foils. One can also see that sticky material can be forced out of the joint, which then represents tinsel.
Piercing attempts during the recording of the vibrations revealed that the sonotrode could become stationary and the vibration generators have an effect on the anvil. For this, a clearance-free system was created for non-contact distance measurement.

Example: Data record for Samples Ultrasonic Weld. There can be seen a basic oscillation. The shift is due to the lowering of the sonotrode. A chance in the amplitude is the welding oscillation itself.
Further Development of the Ultrasonic Welding Process

To ensure a sufficient and reproducible supply of samples with foil stacks for the basic tests, a foil winding device has been designed and built. In particular, the constantly good clean condition of the foils before winding was aimed at. A cleaning module was developed for this purpose, for removing dirt in the form of grease layers, oil residue and loosely adhering particles. The cleaning effect is essentially achieved by the continuous application of ethanol, followed by the separation of the residue dissolved in the ethanol on a microfiber cloth.

Two welding machine manufacturers were examined: Telsonic and Branson

Ultrasonic welding machines, UW20LHP/Versagraphix and M4000/SG22-x/MPS4

Welding stations were set up around them:
<table>
<thead>
<tr>
<th>Features</th>
<th>Branson Ultraweld UW L20HP (High Power)</th>
<th>Telsonic M4000</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Branson</td>
<td>Telsonic</td>
</tr>
<tr>
<td><strong>Generator/controller</strong></td>
<td>US generator with controller, single board computer incl. Versa Graphix software</td>
<td>US generator SG22-5000-3 (8PZT) and control module MPS4 in combination with SE2040 (not SE2050A)</td>
</tr>
<tr>
<td><strong>Sound transformer / converter</strong></td>
<td>Piezo</td>
<td>Piezo</td>
</tr>
<tr>
<td><strong>Operating frequency</strong></td>
<td>20 kHz</td>
<td>20 kHz</td>
</tr>
<tr>
<td><strong>Vibration direction</strong></td>
<td>Longitudinal / linear</td>
<td>Longitudinal / linear</td>
</tr>
<tr>
<td><strong>Maximum power output (generator)</strong></td>
<td>5.5 kW</td>
<td>5.0 kW eff.</td>
</tr>
<tr>
<td><strong>Frequency control</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Amplitude control</strong></td>
<td>Yes</td>
<td>+/- 3% from idle state to rated load and in the case of system fluctuations -10%/+15%</td>
</tr>
<tr>
<td><strong>Load compensation</strong></td>
<td>Automatic</td>
<td></td>
</tr>
<tr>
<td><strong>Welding modes</strong></td>
<td>Time, energy and path control, energy control with path compensation</td>
<td>Time, energy and path control</td>
</tr>
<tr>
<td><strong>Booster (mech. amplitude transformer)</strong></td>
<td>Material: titanium</td>
<td>Material: titanium</td>
</tr>
<tr>
<td><strong>Translated welding amplitude</strong></td>
<td>20(\mu)m &lt; A &lt; 40 (\mu)m</td>
<td>20(\mu)m &lt; A &lt; 40 (\mu)m</td>
</tr>
<tr>
<td><strong>Power module / electr. connection</strong></td>
<td>32 A (min. 25A) / 400V</td>
<td>400 V (50/60 Hz)</td>
</tr>
<tr>
<td><strong>Short-circuit and overload protection</strong></td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td><strong>Welding force generation</strong></td>
<td>Pneumatic</td>
<td>Pneumatic</td>
</tr>
<tr>
<td><strong>Pneumatic cylinders</strong></td>
<td>D=100mm (max. 4712 N)</td>
<td>D=100mm (approx. max. 4000 N)</td>
</tr>
<tr>
<td><strong>Closing force</strong></td>
<td>Max. 5500 N / min. 100N</td>
<td></td>
</tr>
<tr>
<td><strong>Welding path control</strong></td>
<td>Position sensor</td>
<td>Electronic measurement of displacement</td>
</tr>
<tr>
<td><strong>Press force or pressure control</strong></td>
<td></td>
<td>Electronic force and trigger sensor (100% =4000N)</td>
</tr>
<tr>
<td><strong>Air supply</strong></td>
<td>Max. 6 bar</td>
<td>Max. 8 bar</td>
</tr>
<tr>
<td><strong>Lower stroke position of welding press</strong></td>
<td>Mech. adjustable limit stop</td>
<td>Mech. adjustable limit stop</td>
</tr>
<tr>
<td><strong>Upper stroke position of welding press</strong></td>
<td>Mech. adjustable limit stop</td>
<td>Limit stop, not adjustable</td>
</tr>
<tr>
<td><strong>Max. stroke of welding press</strong></td>
<td>48 mm</td>
<td>25 mm</td>
</tr>
<tr>
<td><strong>LxWxH [mm]</strong></td>
<td>352x279x334</td>
<td>240x585x445</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>38 kg</td>
<td>70 kg</td>
</tr>
<tr>
<td><strong>Total price (Euro)</strong></td>
<td>Approx. 33,000.00 (net)</td>
<td>Approx. 39,000.00 (net)</td>
</tr>
</tbody>
</table>

Table: Comparison of features of Ultrasonic welding machines; based on [BRA] and [TEL]
The decisive adjustment parameters at the US welder for the US welding of metal foil stacks for Li-ion cell applications are: welding energy, trigger force and welding load or pressure and amplitude. The vibration frequency is determined by the design type of the US welder. For each toll to be tested an each variation of the setup, this set of parameters had to be optimized.

<table>
<thead>
<tr>
<th>Adjustment parameter</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welding energy</td>
<td>Since a time that is too short for the creation of the joint reduces the quality of the joint significantly, welding should preferably be stopped when a given welding energy value is reached instead of after a specified welding time. &quot;Power welding&quot; mode also has the benefit that the application of heat to the joint can be controlled in a relatively reproducible manner and thus be limited, which is particularly important for Li-ion cell applications. A welding energy that is too small will result in poor welding results/joint strengths, as the joint creation threshold is not established. If the welding energy is too high, that will disrupt, crack and destroy the partner to be joined. In the case of severe contamination of the partners to be joined, e.g. by grease layers, the reduced friction resistance poses a risk that in &quot;power welding&quot; mode, the power value is only established after an (untypically) very long time, that would disrupt the partners to be joined due to the continuous vibration load. For this reason, the specification of the control variable should be linked to the specification of a maximum process time, which results in welding being stopped with a corresponding error message when this time is reached.</td>
</tr>
<tr>
<td>Trigger force or trigger pressure</td>
<td>The trigger force is required to create the prerequisite for creating the joint by the surface contact of the joining parts and ensure the mechanical connection between the welding tools and the parts to be joined. Establishing a minimum force is the prerequisite for a good weld. The trigger force determines the ultrasonic trigger time and is activated before the actual welding load, i.e. at this time the sonotrode is engaged in the part to be joined on the sonotrode side. The trigger force must always be smaller than the force of the set welding pressure.</td>
</tr>
<tr>
<td>Welding load or welding pressure</td>
<td>When the trigger force is reached, the machine switches over to the welding load. This is normally done in synchronization with the effective ultrasonic time and the parameterizable holding time (cooling time). The welding load is decisive for the joint creation period, as it ensures the mechanical bond between the joining parts and the welding tools and the correction of the welding tools or the leveling of the surfaces of the partners to be joined during the joint creation phase with increasing deformation of the joining parts. The optimum welding load is determined by the materials to be welded, their hardness and deformation capacity and by the size of the joining area and the resulting surface contact pressure. It is normally set directly via the pressing air pressure or pneumatic cylinders of the US welder.</td>
</tr>
<tr>
<td>Vibration amplitude</td>
<td>The vibration amplitude has a decisive impact on the intensity of friction between the partners to be joined. Establishing a minimum amplitude is the prerequisite for a good weld. Typical values are between 20µm and 40µm. If they are exceeded, the workpieces will be damaged irreparably due to excessive alternating stress. The amplitude must be adapted to the corresponding materials and dimensions of the</td>
</tr>
</tbody>
</table>
parts to be joined.

| Vibration frequency | The vibration frequency is determined by the type of US welder. Machines with 20 kHz are used. For applications with very few metal foils, machines with a vibration frequency of 40 kHz are also used. |

Table: Adjustment parameters for US welding, based on [ADA]

The very precise investigations also revealed a previously unknown effect on the welding result, which was not mentioned by the machine manufacturer. Based on the initially inexplicable deviations in the welding quality, the Telsonic machine was examined in more detail.

The result was that the precise tightening torque between sonotrode and vibration system and the condition and absence of oil on the contact areas are of special importance.

For this, a special torque wrench was built for the 100 Nm tightening torque, to achieve the necessary reproducibility.

The clamping screws of the bearing rings must be tightened to 20 Nm.
The optimum tool shape was examined in great detail. It determines how to engage in the foil stack, how the vibrations are transferred and to what loads the topmost foils in particular are exposed to. An aligned pyramid shape has proven to be ideal. The alignment of the sonotrode and the anvil is also important, however.

The original intention of welding one long seam in one go had to be abandoned, because the available machine capacity is not sufficient. Therefore, four separate weld seams were planned.
In addition to the actual joint, the tool shape also has a significant influence. To avoid any deformation of the foils, the intervention zone needed to be offset more.

The following settings and welding processes were determined. Both welding machines would be capable for the process. Finally, the target process was developed with the machine with which there was the most experience.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Copper welding</th>
<th>Aluminum welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude</td>
<td>64%, 25.9 µm</td>
<td>50/20.0 µm</td>
</tr>
<tr>
<td>Energy</td>
<td>430 Ws</td>
<td>250 Ws</td>
</tr>
<tr>
<td>Welding pressure</td>
<td>1.35 bar</td>
<td>0.8 bar</td>
</tr>
<tr>
<td>F Trigger</td>
<td>650 N</td>
<td>450 N</td>
</tr>
<tr>
<td>Welding time</td>
<td>0.310 s</td>
<td>0.424 s</td>
</tr>
</tbody>
</table>

The optimized tools for both processes are the two-row pyramid chain for the sonotrode,
and the anvil according to the seam width

The intensive analyses have shown that this truncated pyramid shape represents a good optimum. The conversion to two pyramid rows was carried out to reduce the width of the weld seam.
The process is also OK to a large extent in the event of deviations of the parameters. The different welding depths and deformation of the component are to be seen.

A minimum throat thickness of 2.7 mm was achieved. The result according to the following sketch is a computational increase in the active area by \( \frac{2.3 \text{ mm}}{137 \text{ mm}} = 1.7\% \).
Alternative Joining Methods

Ultrasonic welding is very well suited for mixed aluminum and copper compounds. In the case of compounds of the same type inside the cell, other methods are also possible. A problem of laser welding is the variety of surfaces and the air included in a stack. Resistance welding would therefore appear to be more productive.

Research has shown that the flow of current in the foils can be concentrated using studs. The tests were carried out with a 20 kHz Matuschek system. The welding parameters are determined in the standard manner in terms of force, current intensity and pulse time without special considerations.

To achieve narrow welding zones (Elibama requirement) an attempt is made to give them a longitudinal shape.

An attempt was made first to create a longish stud by stamping, which was however flattened during the process, i.e. a stud must be made out of the solid. Massive forming or chip removal would also be possible. Wire pieces were placed underneath. They were melted into the underside.

A copper sheet with the copper foils could be welded onto the surface with foils. The stud is for concentrating the current. The top electrode made of tungsten prevents the melt from escaping and seals the joint.

A copper sheet with the copper foils could be welded onto the surface with foils. The stud is for concentrating the current. The top electrode made of tungsten prevents the melt from escaping and seals the joint.
For aluminum, it was necessary to attach a sandwich cover sheet next to the stud to prevent the aluminum from being welded onto the electrode. It could then be welded well, however. The surrounding solid material prevents the melted mass from escaping. The individual foils are all well connected. There was only a solidification cavity in the center of the weld nugget, which is not critical.

All tensile tests were above 300 N. These results mean that there is also a solution for joining pouch cells with the reliable resistance welding method. However, the design requirements shown here must be complied with.

**Stacking Work Packages**

**Development of a Work piece Carrier and Clamping System**

The local clamping system in the direct vicinity of the processes for cutting the foil ends and joining the conductors has a direct impact on dimensional accuracy and the joining quality.

Various different clamping principles are tested first, then a concept is developed:

It is important to clamp the foils next to the anvil and the sonotrode, but still to maintain sufficient distance to the process in order that the foils can also vibrate during the process, without tearing.
The process chain at the joint consists of the steps: clamping, cutting, inserting the conductor and then welding the conductors together with the foils. The workpiece carrier developed during the stacking WP should be the basis. The requirements were stacking capability, not applying too much force to the individual foils, the automatic firing of the carrier, good fastening of the foils to protect them from slipping, protection of the foils and consistency through all process steps.
The basis is the integrated part carrier. The foils are stacked there directly in the stacker. One thus has the alignment precision there that can be achieved.

This unit should be stackable and it should also be possible to transfer it in transport boxes.
For the positioning of the conductors, this unit must be inserted in a further carrier. The necessary adjustment options for alignment are included.

This carrier itself is inserted in the individual stations in the corresponding process tables and aligned with the adjustment screws enclosed for the cutting or joining process.

Welding:
Development of a Foil Buffer

The foils are provided from a continuous cutting process and need to be stored temporarily in a magazine without damaging the edges or the active coating.

The foils then need to be removed individually from the magazine and provided in the correct position for the lithium-ion cell assembly process.

The cycle of the cutting unit is 30 – 60 parts/min. The cycle of the assembly unit is 30 parts/min, i.e. the foils must be decelerated and accelerated in a non-destructive manner.

The requirements for a solution are:

- Gentle handling of the foils without any damage
  (no relative movements, the edge is guided by a belt running synchronously)
- No contamination of the foils due to non-contact handling (floating)
- Two-sided image processing inspection option (top and bottom sides, edges) as an option
  (inspection of the top side on the outfeed conveyor of the cutting unit, inspection of the bottom side during the "floating process")
- Position tolerance for the provision of the foils ±0.1mm (or less)
- The cutting and assembly processes take place in the dry space, suitable components have been selected
• All process stations are easy to access manually for maintenance, process monitoring, tool change, etc.
• Both the cutting process, as well as magazining, storage and provision can be carried out in a controlled atmosphere (suitable enclosure and air ducting possible). A dry room atmosphere must be kept as small as possible due to energy costs.

Ultrasound-based floating from the semi-conductor technology should be used as the technology for non-contact handling. The effective principle of the ultrasonic bearing is based on repulsion by the air vibrations of the ultrasonic sonotrode. Holding from above is achieved by the application of a vacuum.

Many handling tasks require the simultaneous application of attractive and repellent forces, e.g. gripping at the top. In these cases, the repellent effect of ultrasound is combined with attractive vacuum forces. This technology enables the simple handling of workpieces, which corresponds to conventional gripping at the top (with mechanical contact). In addition, flexible components can be smoothed without contact to the handling tool, their geometry stabilized and held in position.

The test plant creating has an incoming conveyor for catching the cut foils to deposit them in the first magazine. The second magazine serves as a demonstrator of the stacking device, in which the foils from the first magazine are rearranged. In addition, there is a drop box for separating foils not okay. The inspection with line scan cameras was not illustrated here. The feed motion is established by a small driver, which does not damage the sensitive foil however, due to the air suspension.
For the qualification of the process, the magazine prototype was made of aluminum. For the series production process, a cost-effective alternative is to be developed, for example made of plastic, because a large quantity is required to be able to buffer different output volumes. For the standard magazine, a suitable enclosure is also to be taken into account for protection from environmental influences.

Magazine with foils inserted  Magazine with elevated base in operating position

**Development of a Comprehensive Plant Concept**

Before a new plant concept can be created, the various requirements need to be analyzed. Possible design conflicts need to be revealed and a decision made for an optimum concept.

Dried electrode and separator materials are hygroscopic. It therefore needs to be ensured that after drying the intermediate products, they are then only transferred and processed in defined climatic conditions. These conditions are to be ensured in the rooms in which the dried intermediate products are processed and transported. This does not only apply to the normal process, but also to process interruptions and troubleshooting. If these conditions are not complied with, the intermediate products are to be marked as not okay and removed, i.e. the drying of the intermediate products should take place as late as possible. Individual process areas should be encapsulated to minimize rejects due to the violation of the climatic conditions.

The working rooms for workers and the process rooms have different air conditions. Exhaled air impairs the dry air condition and increases the dew point. Increased energy is necessary in order to retain a dry air condition in the room. That means strictly separating the rooms for dried intermediate products and the rooms in which the workers need to move. Dry room specific climatic conditions for these movement areas should be as low as possible, and small, encapsulated process rooms provided to prevent too many rejects in the event of manual fault elimination.
A dry air condition in the dry room must also be ensured in the event of malfunctions and downtimes. The required climatic conditions must also be retained in the event of production downtimes if there are intermediate products in the rooms for which air conditioning is required. Alternatively, the relevant intermediate products are to be marked as not okay.

In particular the extraction of cutting dust requires high filter technology expenses (extraction of particles versus dry room condition). These expenses will increase the higher the dew point is, due to the static charge of the particles. The particle properties and the available filter technology can and do result in part of the air flow being discharged via the roof after filtration. The higher the dew point of the process air is, the more energy is required for the air to be supplied, i.e. cutting the materials and the extraction of the particles should take place, if possible, before drying, and cleaning of the electrodes before drying, if possible. Encapsulation and separate supply air for extraction at the separator intersection. Encapsulation and separate supply air for extraction for cutting flags, encapsulation and separate supply air for extraction during welding.

All plant components and conveyor systems in the production area should be encapsulated, due to the high dryness requirements in the production process. For the atmosphere within the plant, the following conditions are to be complied with. Compliance with the atmosphere within the plant modules has the highest priority. Therefore, current plants are run with slight overpressure to ensure the required dew point. (Intermediate) products may only be moved through the plant in the required atmosphere. If the dew point is exceeded, the relevant intermediate products are to be marked as parts that are not okay and removed. That cannot be avoided, in particular when eliminating malfunctions. Compartmentalization concepts are to be applied to attempt to reduce the number of intermediate products that become not okay parts.

In addition, the drying processes at the lines respond sensitively to plant downtimes and intermittent processes, i.e. buffering is not only for increasing availability, but also for improving the quality. In addition, the clamping concept developed above should be applied consistently.

The encapsulation should also be retained for the transport processes of all partial products. Manual transport vehicles or automatically guided vehicles could be used between the stations. The atmosphere in the transport container must be monitored. The stations must be equipped with removal systems for loading and unloading in a dry atmosphere. The transport cycle times can be reduced if the stack capability of e.g. 5 work piece carriers is exploited. At an estimated cycle time of 1 minute per stack, that would be one transport operation every 5 minutes. The benefit of automatically guided vehicles is that access to the systems is given simultaneously, and one does not have to cross conveyor belts that produce dirt using stairs. No multipurpose tool magazines should be provided in the stations, as that would only increase their complexity. A fast change of the magazines is more efficient. The complete parallelization of the station is to be preferred.

It would appear to be practical for the Z folder to roll up the material again after drying for decoupling. Discontinuities in the separator should be possible in the Z folder by automatically removing a double layer. With a pick and place system, that would be the removal of a sheet. The electrode sheets should be cut first and only then dried.

In addition, the complete data relating to everything that occurs in the system and all process steps needs to be recorded. All workpiece carriers, magazines and rolls are to be equipped with ID technology and the stations with readers in order that everything can be traced.
A view of the integrated overall concept is given below.
Production of Demonstrators

The designed stations have been manufactured and assembled. By producing demonstrators the concept could be verified.

The taped stack were taken from series production and entered into the work piece carrier. The position was aligned by mechanical corners. In series production the accuracy would derive out of the z-folder. The closing lid of the workpiece carrier and the clips are designed to be automated.

The concept to be able to measure the stack dimensions uses a light barrier with referenced edges of the fixture.

The clamping blades are part of the 2nd carrier are lowered and it can be transferred into the cutting station.
After inserting and clamping the conductors the unit is be transferred into the welding station. Shifting to the side positions it according to the seam positions.

The build demonstrator:

References

[DVS 2216-1] DVS 2216-1 Ultraschallschweißen von Kunststoffserienteilen – Prozessbeschreibung, Maschinen und Geräte, Einflussgrößen, Konstruktion, Qualitätssicherung
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