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How contamination affects EV battery performance

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Introduction

The global drive towards electrification of transport and consequent growth of the EV vehicle market has put a spotlight on scarcity and cost of its key materials.

The EV battery industry is under pressure to achieve highest process yields combined with the best performance and contamination is becoming recognised as a major cause of defects and degraded performance.

The types of contamination typically found by battery manufacturers together with information on the defects associated with such contamination is presented here.

Finally, contamination removal methods specific to EV battery manufacture, such as contact cleaning, are outlined together with key process steps where contamination removal is particularly beneficial.

In many high-technology manufacturing processes, Ionic and particulate contamination is a major issue for process yield even when processing is carried out in a cleanroom /controlled environment.

This is because processing the materials is creating the contaminants. Their removal at key stages in the manufacturing process is required to minimise the impact on the finished product.



CHARGE TRANSFER MECHANISM

– The key to performance

At its most basic level a battery cell is an electrochemical circuit with four components, two electrodes, a separator to keep the electrodes apart and an electrolyte containing the ions which migrate from one electrode to the other depending on whether the cell is charging or discharging (figure 1).

Several cells are then stacked together to provide a finished battery.

The performance of the battery is defined by the charge transfer mechanism, which is the number of ions which can migrate from one electrode to the other and how fast they migrate.

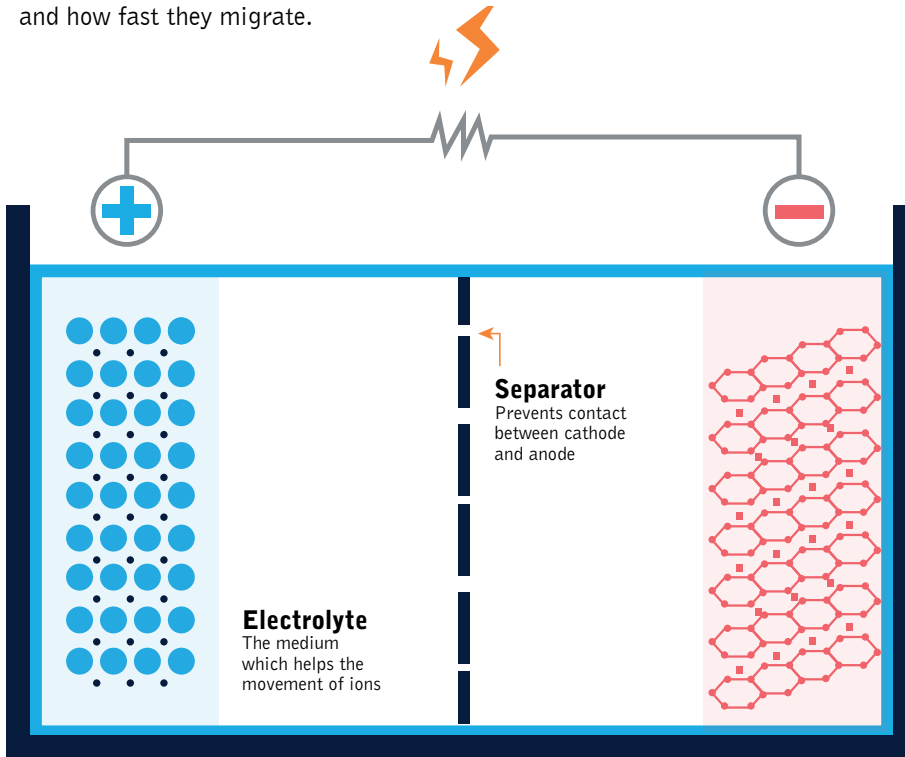


Figure 1 - Basic battery cell structure

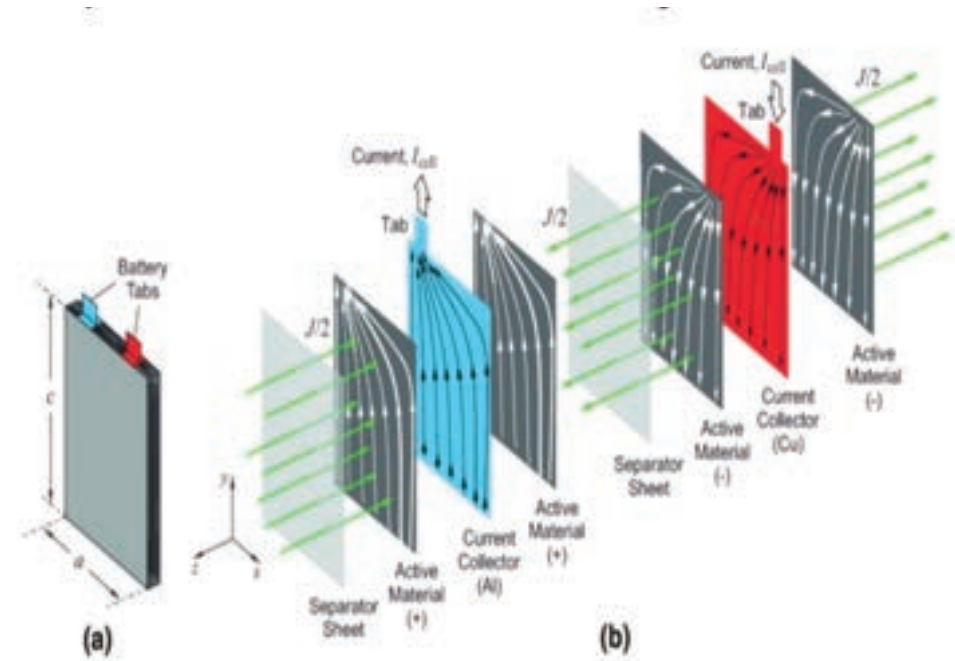


Figure 2 - Battery cell construction

From a user perspective the requirements are for lots of power i.e. energy density, long life defined by the number of charge/discharge cycles it can support and fast charging. These parameters are embodied in the design of the charge transfer mechanism of the battery cell.

Contamination is a major contributor to variations in the charge transfer properties resulting in defects and poor performance.

CONTAMINATION ASSOCIATED DEFECTS

There are several types of contamination within the battery manufacturing process. Particles which can be either metallic or insulative are most common.

These particles can be generated by battery materials being processed such as slitting of foils, by operators or by the environment itself.

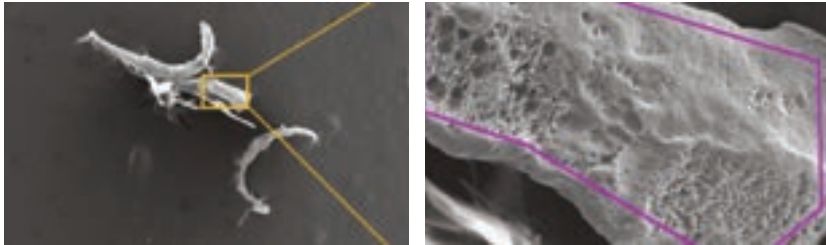


Figure 3 - Typical particles found on cathode

The most widespread types of contaminants reported by manufacturers are metallic and oxide particles such as chrome, iron, nickel and cobalt, all of which are generated during processing.

Research has shown that most particles are distributed evenly across 50 microns with over 2% of the electrode surface area being contaminated with around 400+ particles (figure 4).

Metallic particles are active materials and can create self-discharge or other faradaic reactions, especially at the cathode. Moreover, they are quite hard and are well known to generate short circuits when the electrodes and separator are pressed together during assembly and the particle pierces through the separator allowing the two electrodes to make electrical contact. These particles can cause a major short circuit in the battery resulting in thermal runaway, known also as “venting with flame” (figure 5) and a subsequent explosion or fire. A small, short circuit will only cause an elevated self-discharge which impacts the battery performance. Little heat is generated because the discharging energy is very low.

If enough microscopic metal particles converge on one spot, a sizable current will flow to the area of the particles due to the local change in the electrical resistivity. This causes the temperature to rise, leading to a thermal runaway. Lithium-ion cells with cobalt cathodes should never rise above 130°C (265°F). At 150°C (302°F) the cell becomes thermally unstable, a condition in which flaming gases are vented.

During a thermal runaway, the high heat of the failing cell can propagate to the next cell, causing it to become thermally unstable as well. In some cases, a chain reaction occurs in which each cell disintegrates. A pack can be destroyed within a few seconds or linger on for several hours as each cell is consumed one-by-one. To increase safety, packs are fitted with dividers to protect failing cells from conducting heat to neighbouring cells.

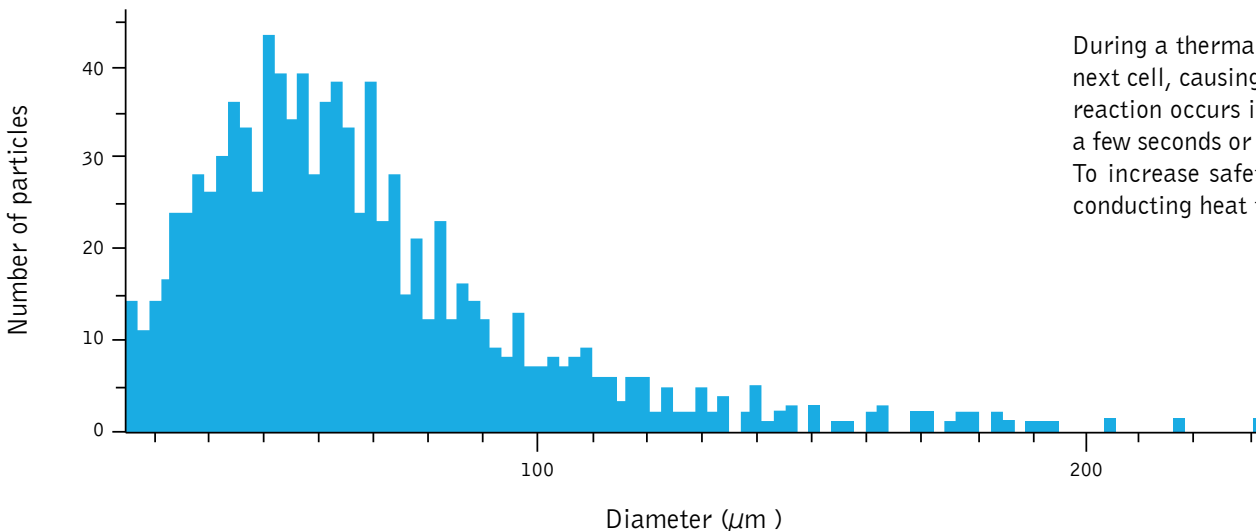


Figure 4 - Contaminating particle sizes

In battery performance high charge capacity and long life are parameters which customers value. For optimum performance the charge transfer between the electrodes and through the electrolyte must be completely uniform over the whole cell area. Variation in the charge transfer mechanism caused by particles of contamination results in a reduction in both charge capacity and in the number of charge/discharge cycles the battery can sustain resulting in a shortened battery life.

Particles may not always cause instant failure but can result in defects which are only detected when the battery fails in operation with the end user. These latent defects which cannot be identified during final inspection are a particular issue in safety critical applications and can result in reputational damage.

For Ionic contamination the main contaminant is moisture. Moisture contamination remains one of the most studied defects because it has such a detrimental effect on the battery performance. Water, H_2O reacts with $LiPF_6$ salts in electrolyte generating Hydrogen fluoride (HF). Several papers report the correlation between HF generation during battery cycling with capacitance fading either at the positive or negative electrodes. The nature of the fading depends on the nature of the materials. In the case of positive electrodes, dissolution of active material by HF occurs and a more pronounced performance degradation is observed.

The risk of Ionic contamination is highest during mixing of the chemicals which form the active matrices and the electrolyte which should be supplied fully filtered and desiccated. Care must be taken at the coating stage to prevent moisture from the air being incorporated into the active matrices at the coating head. No wet processing can be carried out due to this moisture sensitivity.

Any type of contamination on the electrodes can cause dewetting of the electrolyte resulting in charge transfer variation.

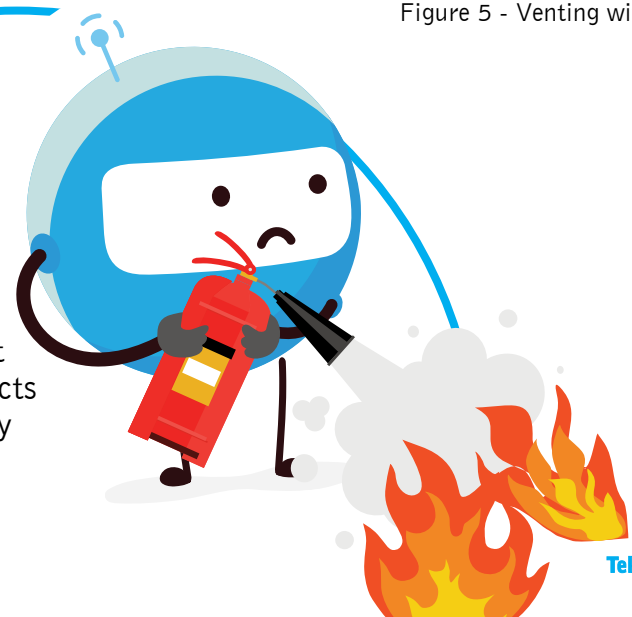


Fig 7 - Venting with flame

Figure 5 - Venting with flame

Tekkie fact:

Particles don't always cause instant failure but can result in latent defects that can degrade battery performance or failure for the end user.



CONTAMINATION CONTROL IN BATTERY PRODUCTION

Having assessed the risk of contamination related defects throughout the the roll to roll (R2R) production process (figure 6), it is necessary to identify a suitable technology to eliminate both particulate and Ionic contamination.

Because of the various sensitivities of the battery manufacturing process the cleaning techniques which are available are limited.

The moisture contained in air prohibits the use of air-based cleaning systems such as air knives. Even vacuum systems draw air over the surface of the materials and increase the risk of Ionic contamination. Particles trapped within brushes of a brush cleaner can damage sensitive materials and result in defects degrading battery performance.

The cleaning technology often used in battery manufacture is called "Contact Cleaning". In this technique specially formulated elastomer rollers run in contact with the surface to be cleaned, picking up loose particles. To ensure the elastomer rollers are always clean they run-in contact with a pressure sensitive adhesive roller which permanently captures the particles of contaminant leaving the elastomer rollers completely clean to avoid recontamination when touching the sensitive surface.

The cleaning efficiency of various technologies at different particle sizes as tested by a Japanese company is shown in figure 7. The data shows contact cleaning is most efficient and ideal for contamination removal in battery manufacturing where elastomer cleaning rollers remove even submicron particles without scratching.

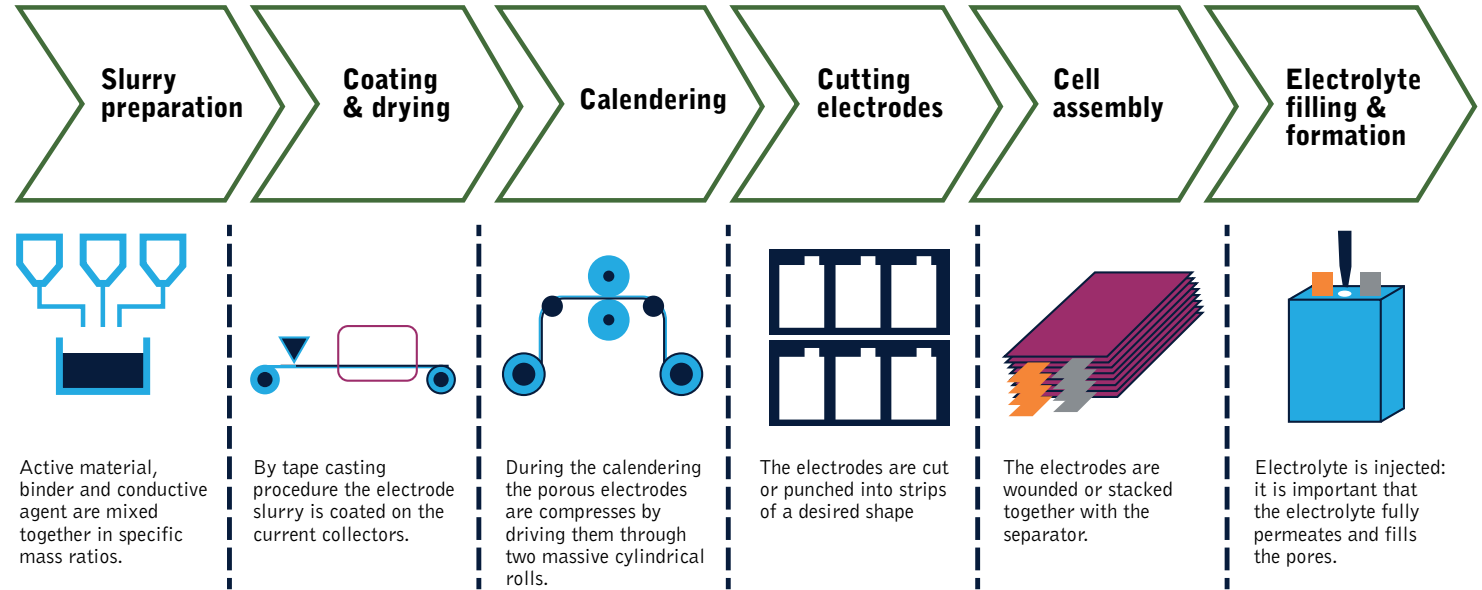


Figure 6 - Battery manufacturing process

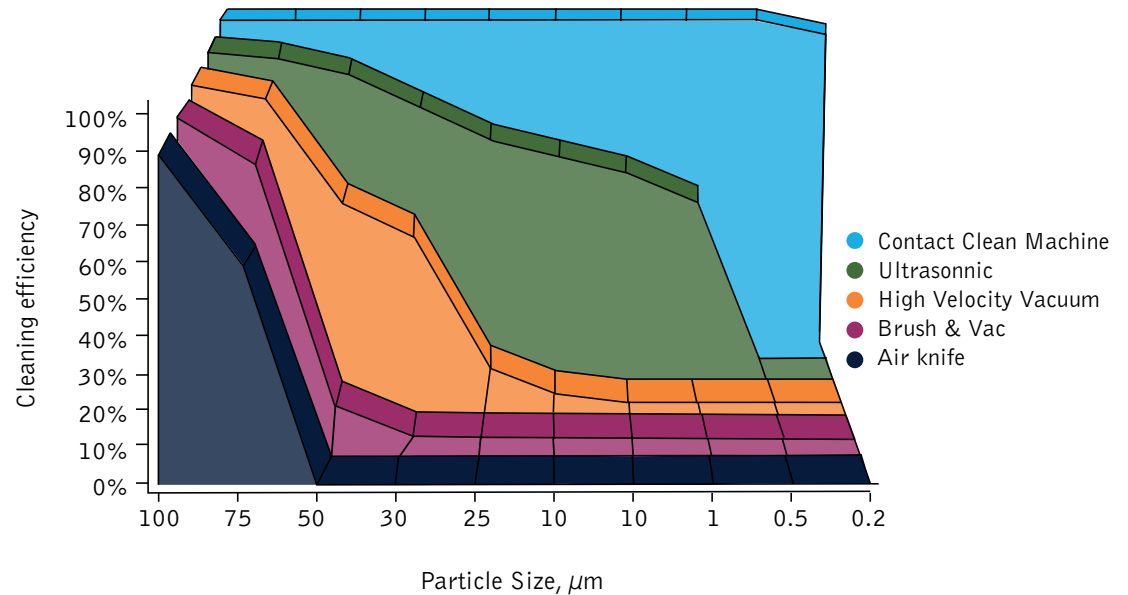


Figure 7 - Cleaning technology efficiency

ELECTRODE MANUFACTURE

The electrode fabrication step is an area where contamination is a major risk because it contains many potential contaminants such as particles from slitting and cutting foils to metal debris from rollers. Cleaning at all stages of electrode fabrication brings significant benefits both to yield and performance. For example, cleaning during electrode fabrication can reduce self-discharge defects by up to 40% giving batteries a more consistent, longer life.

There are two main components in each electrode namely the current collector foils and the active material layer (figure 8). The current collector foil is used to collect all the charges and transfer them into or out of the battery. Then there is the active material layer which provides the chemical functionality of the charge transfer system.

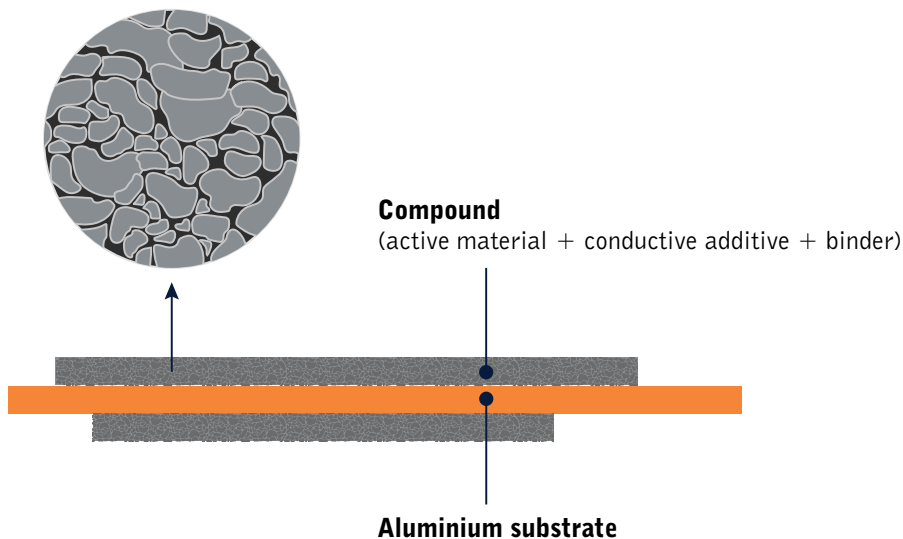


Figure 8 - Electrode construction

For the cathode the active material is a porous coating of a metal oxide coated on either copper or aluminium foil which is between 8 and 18 microns thick. For the anode it is usually a 10-micron copper foil coated with a carbon-based active material which is a resin filled with conductive particles chosen for the specific design of charge transfer mechanism. The base collector foils are often treated to improve adhesion of the coating and in recent developments the copper foils are also micro structured to improve the speed at which the electrolyte can be filled into each cell and to improve the wetting performance of the electrolyte to the electrode.

Cleaning before coating is an important step in battery production. Slitting of metal foils can generate particles of fine swarf with sharp ends that present a high risk of penetrating the separator film and causing short circuits. This swarf must be removed before coating. Particulate contamination also causes dewetting and variation in the charge transfer characteristic of the electrode.

Cleaning of the raw foils for both the anode and cathode should always be carried out. Figure 9 shows a Teknek double sided web cleaner on collector foil.

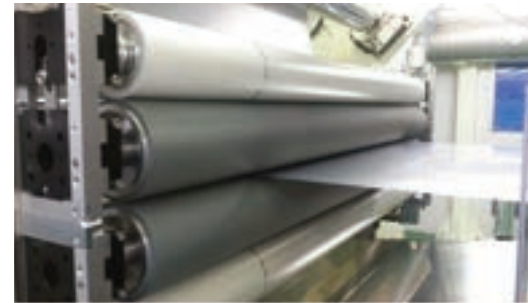


Figure 9 - Teknek machine cleaning both sides of collector foil

The active materials are incorporated in a polymeric binder together with conductive additives. To find a workable compromise between high energy density, operational safety and good current delivery, manufacturers of lithium-ion batteries can mix the metals in the active matrix coating of the electrode. Typical cathode materials are cobalt, nickel, manganese and iron phosphate.

For optimum performance the finished compound has to have a defined degree of porosity of around 20% to allow the ions to pass through to the collector foil. This is achieved by a combination of filler particle size combined with calendaring the coated foil.

The most common method of applying the active material matrix to the collector foils is by R2R coating. A variety of coating methods can be used with Slot Die, Flexo Printing and Gravure being the most common. The active matrix deposit is pattern coated as shown in figures 10 and 11 to give the cell its conductive area while allowing an uncoated area on the sides for welding the cell together. The active matrix coating operation gives rise to a variety of defects (figure 12).

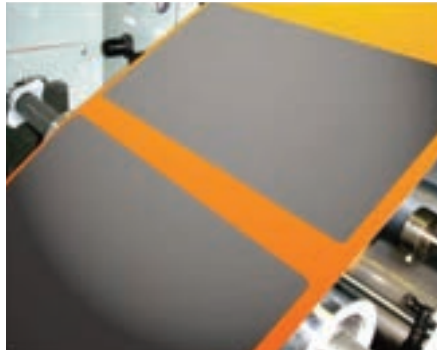


Figure 10 - Pattern coating of electrode*

Figure 11 - Stripe coating of electrode

As moisture is an issue in degradation of the active materials, new developments include the electrostatic application of dry active powder onto the charge collecting foils. This powder is then hot calendered onto the foil to melt the binder and fuse the active matrix onto the foil. If the amount of binder in the dry powder matrix is too low, then poor adhesion can result in particles of the matrix becoming detached resulting in conductive contamination which disturbs the charge transfer mechanism.

A key focus for reducing particulate contamination comes during the electrode manufacturing process. Because moisture degrades the performance of the active matrices much of the process must be carried out in an extremely dry environment. This dry environment, in turn, results in very high static charges in the process which attract particles to the charged surfaces making cleaning, combined with static control, even more important.



Figure 12 - Types of coating defects

Any particles on the surface of the coated electrodes before calendaring will be forced into the active matrix material by the high pressure of the calendar. This surface inclusion will affect the wetting of the electrolyte and inhibit charge transfer. Cleaning should be done on the dried coating before this process. Figure 13 shows a Teknek Double Sided Narrow Web unit fitted to the inlet of a calendar



Figure 13 - Cleaning before calendaring**

After the electrodes are slit down to cell width, they should be cleaned to avoid slitting dust being trapped when being laminated with the separators.

SEPARATORS

Traditional separator films are polymer-based films with a thickness of 20-25µm. Films are microporous to allow ions from the lithium based liquid electrolyte to pass through. blocks the pores in the separator film can disrupt the charge transfer system that in turn causes reductions in both charge capacity and the number of charge/discharge cycles the battery can sustain resulting in a shortened battery life.

Another battery structure, for polymer batteries, uses gel as a separator that also forms the electrolyte. This type of structure is particularly sensitive to metal particle contamination due to the softness of the gel.

More recent battery developments use a ceramic film with controlled structure either as a separator or as a combined separator and electrolyte. The ceramic reduces the risk of short circuits through piercing by metal particles.

Controlled porosity throughout the battery cell structure is key for performance. Pores blocked by contamination cause significant levels of defects and both sides of the separator film should be cleaned in the process.

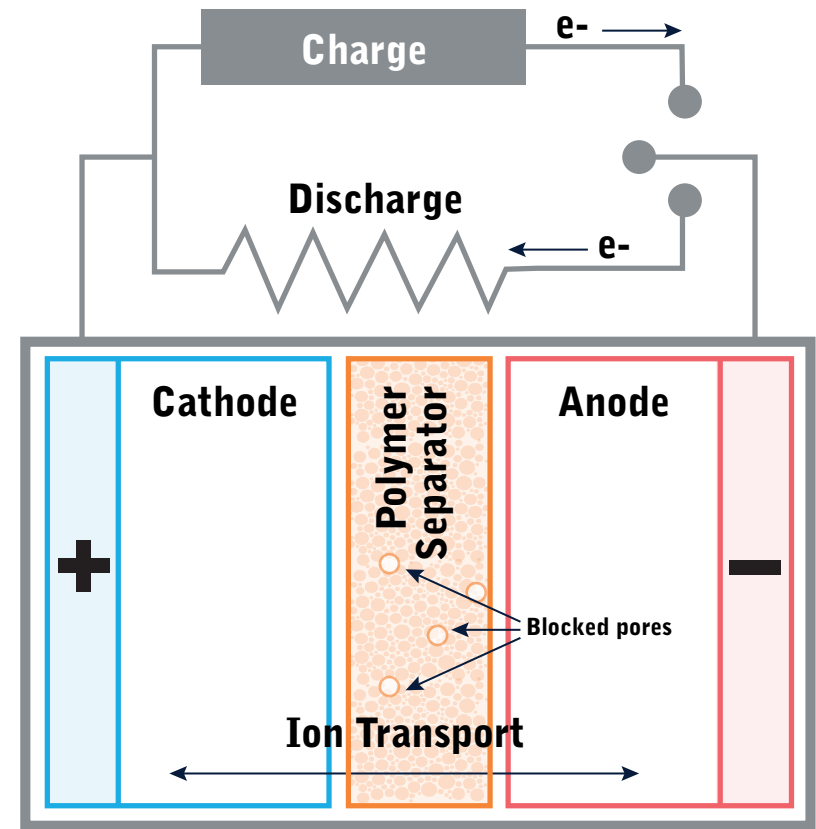


Figure 14 - Basic battery cell structure with blocked separator pores

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Tekkie fact:

Particles of contamination that block pores in the separator film can disrupt the charge transfer system and result in a shortened battery life for the end user.



ASSEMBLY

There are two main types of assembly processes, one using electrodes in sheet form, the other using electrodes in web format called Z folding

The electrodes are then either crosscut into sheets in figure 15, or the web is Z-folded. The sheets of anodes and cathodes are then assembled into stacks with the separator sheets in a subsequent operation.

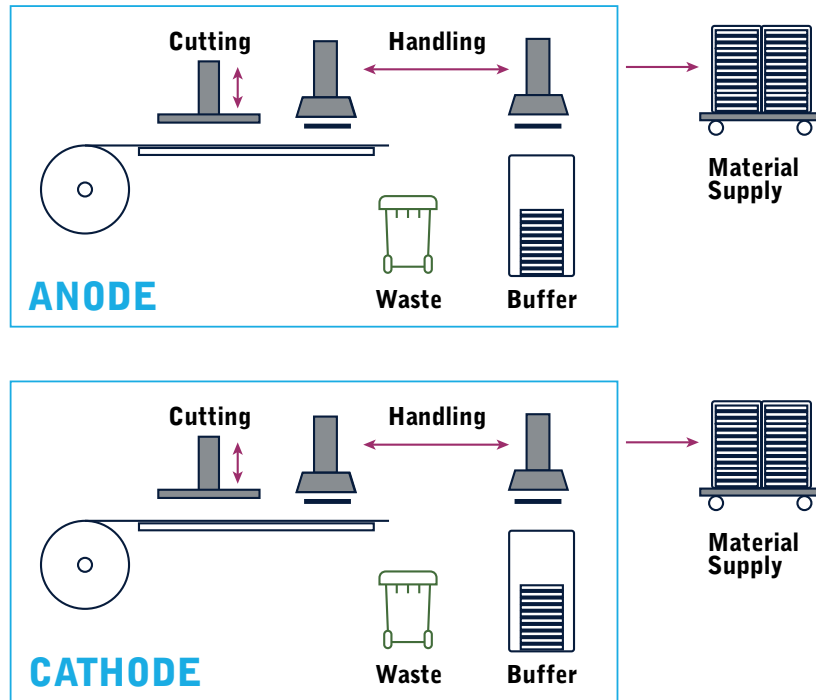


Figure 15 - Assembly process using sheets

To improve performance, both electrodes and the separator should be cleaned before stacking, winding up, interleaving or laminating.

Cleaning of the electrode and separator materials during Z folding assembly is one of the most common applications of contact cleaning with web machines automatically cleaning both sides of the materials.



Figure 16 - Teknek cleaning machine with calendaring equipment

PROCESS EQUIPMENT

A final area to consider is the process equipment itself. Transport rollers can pick up contamination from the environment and from microslip on contact with the foils. This contamination can transfer onto the backside of the electrodes causing defects in the subsequent processes. If calendaring rollers have particles of contamination on them, they can impress the shape of the particle into the coating reducing the active matrix thickness and porosity level while the backing rolls in the slot die process can cause imprints on the collector foil. All these defects will cause variation in the charge transfer mechanism and rollers should be regularly cleaned.

CONCLUSIONS

Electric Vehicle battery manufacturers worldwide are having to focus heavily on improving yields and to eliminate defects that degrade performance.

Removal of contaminants which cause both production and latent defects has become essential. Contact Cleaning Machines are used by major battery manufacturers throughout the world, improving yields, performance and safety.



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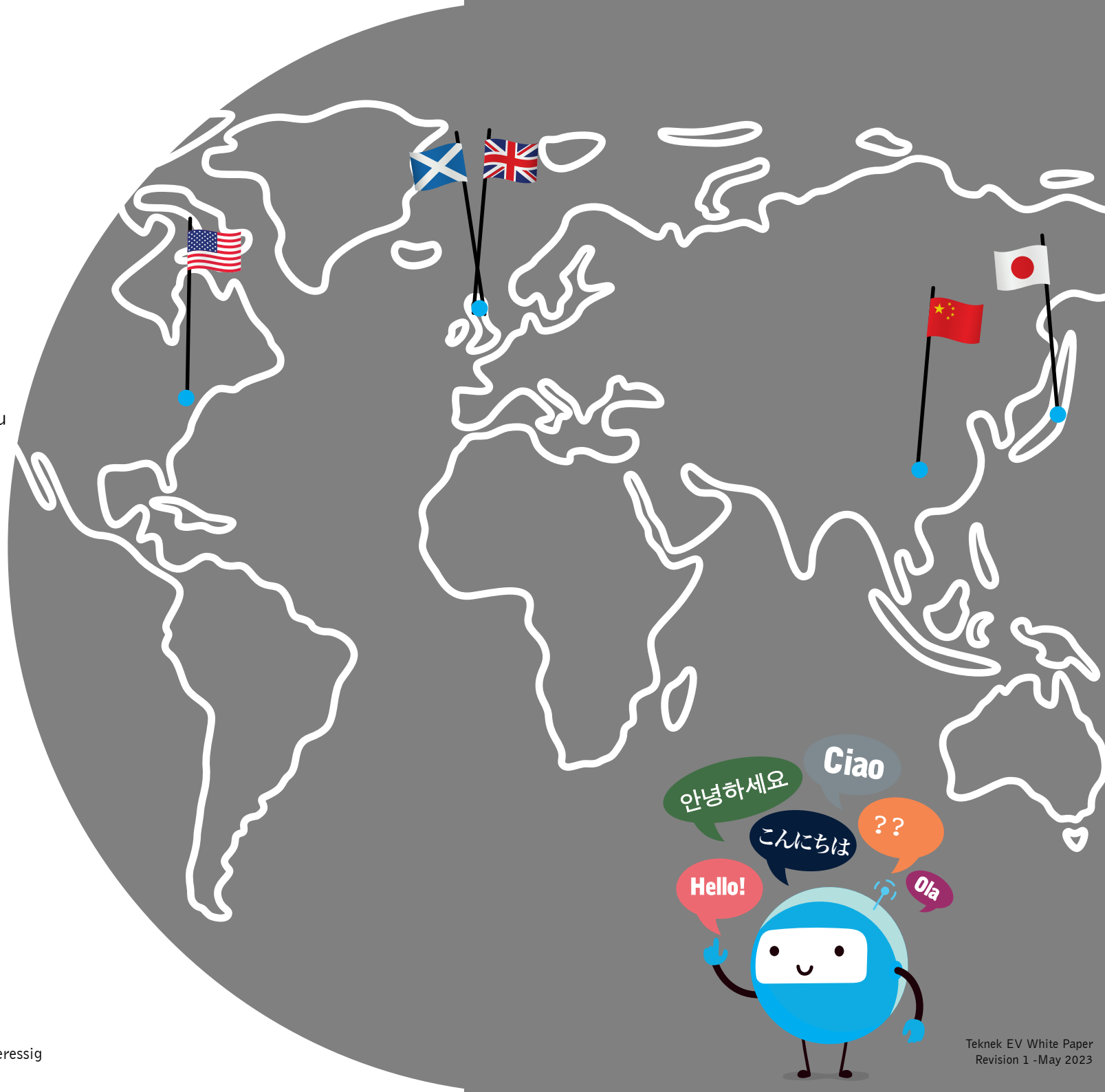
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