Intermittent Coating

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ABSTRACT

The world has gone patch coating crazy! Batteries, pharmaceuticals, even adhesives. The interest in reducing waste and providing functional coating that can be used right off the coating station is very high. With this increased interest in intermittent coating we also have to consider the technical challenges.

Every coating process has a start and stop. In patch coating, this occurs more often than at the beginning and end of a roll. Of course the steady-state continuous flow in between starting and stopping has been discussed at length and has its own issues to deal with. But what special issues are associated with the start and stop of a coating head? For this discussion we will concentrate on slot die patch coating. Any shape can be coated – as long as it is a rectangle!

In the start-up and stop flow analysis, the challenge is to reduce waste and defects associated with the transition from fluid flow to not. The considerations of start-up include wetting of the fluid on the substrate, pump control of fluid dynamics, and physical position of the coating equipment to the substrate.

Wetting: The ability of the fluid to displace air at the fluid/solid interface in coating is critical to reducing defects. If the surface tension of the fluid and the surface energy of the substrate are not compatible the start of the coating bead may be delayed or jagged. This would lead to an improper “head’ of the coated patch. Surface energy modification may be required to produce a solid patch.

Pump Control: There are many techniques for intermittent coating, with the most widespread technique using valve control of the fluid and physical movement of the coating head. The valve acts as the immediate start/stop of fluid flow, while the mechanical movement of the coating head breaks the wetted bead. The timing of the valve control with the mechanical movement can

produce a good head or a poor start that includes poor bridging of the fluid, streaks, or a heavy "head."

Physical Position: Where the coating head sits in relation to the substrate can determine the output flow of the fluid "head." As a liquid surface approaches a substrate, the liquid boundary layer has vapor molecules that begin to adsorb to the substrate surface. This adsorption forms bridge when the concentration is high enough. If the bridge occurs with a concentration that is even across the coating width, the coating will be uniform for the "head" or beginning of the coated patch. If the concentrated vapor is too far away, the substrate surface too rough, or the concentration of the fluid fluctuates, the coating will create a curved coating "head" to the patch.

The considerations of stopping are similar to start-up, but need to consider fluid reaction to mechanical and rheologic behavior. The resultant "tail" of the coated patch are a function of the timing between the valve for fluid control, mechanical movement of the coating head, and wettability of the substrate by the fluid.

There is not just one way to coat patches of fluid onto a substrate, but as long as you are aware of the coating fundamentals, you will be successful in your intermittent coating operation.

INTRODUCTION

Intermittent coating (or patch coating) is coating with a start and stop shorter than the length of the full roll and defined by an uncoated border. In the case of slot die intermittent coating, the shape is always a rectangle. Intermittent coating can be completed in full web or lane coating, creating rectangles downweb from the coating source. The limit is based off patch control and reaction time.

Why would someone be interested in coating a discrete patch of coating instead of full web continuous coating? Money. The most common example is in the world of battery coating. When coating an anode or cathode, fuel cells and lithium-ion batteries require an uncoated border to reduce the chance of a short circuit in the final construction. What this experiment was designed to evaluate, is the limits of the coating width and spacing allowable with slot die coating technology. The application of lithium-ion battery technology, along with the product specifications, provided the outline for the experimental procedure and conclusions.

PATENTS

One of the earliest know patents regarding slot die technology and intermittent coating is credited to Edward Choinski (US Patent 4,938,994) from 1990. This patent describes the basis of intermittent coating required for printed electronics based off flow control and mechanical movement. This patent also describes multilayer fluid coating to allow for more than one fluid to be coated simultaneously on the same side of the substrate.

Further information (and the patent closest to the current arrangement) is described by a 3M patent (US Patent 5,360,629), where a pattern of discrete patches are spaced on a moving substrate. These coatings are created with a slot die and metering pump where a valve directs the fluid to either the slot die or a holding tank. The three-way valves is important to most intermittent coating applications today. Description of the PLC control provides insight into the process utilized in this experiment.

Another patent application from Watanabe et al. (US Patent 5,824,156) describes a physical reduction in flow (shut-off bar positioned within the slot die) to eliminate flow through a position within the slot opening. This shut-off bar is located internal to the slot die, while some non-patented applications have considered a shut-off bar external to the slot opening.

SPECIFICATIONS

For lithium-ion battery applications, the following data set is common, and was the basis for the experiment-

1. Coat width = 340 mm
2. Coat length = 680 mm
3. Intermittent coating capability required up to 10 mpm (30 mpm in further study) with maximum 3 mm tail allowed.
4. Crossweb variation tolerance based off weight (5 +/-0.15 mg/cm^2).
5. Required coating speed: at least 10 mpm for a slurry with loading of 6 mg/cm^2 and 50 solid %.
6. Coating edge quality to match crossweb coating variation capability.
7. Tension control improvement to match downweb coating variation capability based off weight (5 +/-0.15 mg/cm^2).

HEAD & TAIL DEVELOPMENT.

The initial start and final stop flow control is what is considered the "head" and "tail" of an intermittent coating patch. Following industry protocol, the goal was to reduce this increased or decreased thickness to a maximum of 3 mm in length when coating a discrete patch at 10 mpm. The head and tail occur for reasons of typical start and stop phenomenon (crossweb caliper control, velocity gradient, pressure gradient, and volumetric flow).

EDGE EFFECTS.

When the anode or cathode is coated onto a foil (aluminum and copper, respectively), besides the start and stop phenomenon of the head and tail, we also have to deal with edge effects. When assembling the final battery cell, any significant variation in coat weight will cause issues in the battery performance. Edge effects occur for three main reasons: surface tension, film stretching, and die swell.

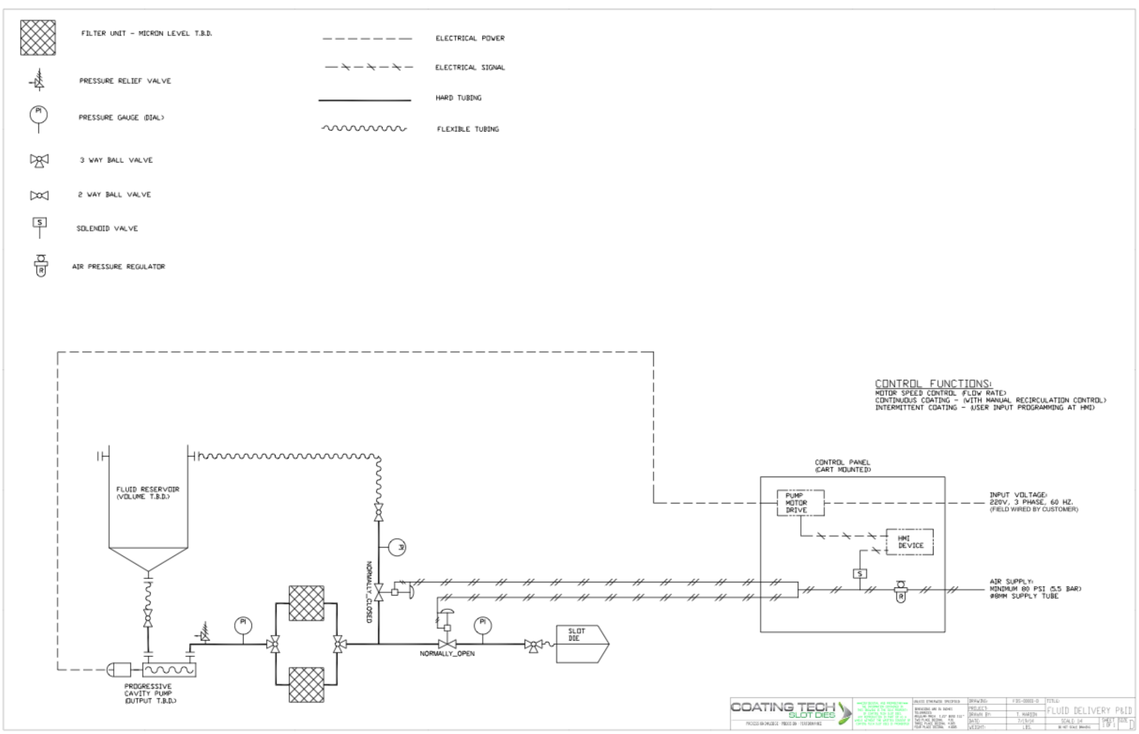
The combined head and tail effects with edge effects may seem small in the coated and calendared product, but the stack of multiple layers can increase the variation by millimeters and cause unevenness, wrinkling, folding, and power differentials. None of which is allowable in energy storage devices. This current distribution variation is recognized, in the worst case, as a spike in energy with run-away heat. Heavy edges increase battery cell volume and decrease energy density.

PATCH CONTROL

There are 2 fundamental methods for creating discrete coatings on continuous web: flow control and mechanical movement. The response time of each is critical to the resulting patch quality. This is the realm of computer control, electrical response and programing know-how. The intermittent programing logic needs to control as much as the die positioner movement, valve start and stop, web control, and possibly vacuum for fluid pinning. The response time of the valve and the time required for physical movement are the controlling factors of the patch length.

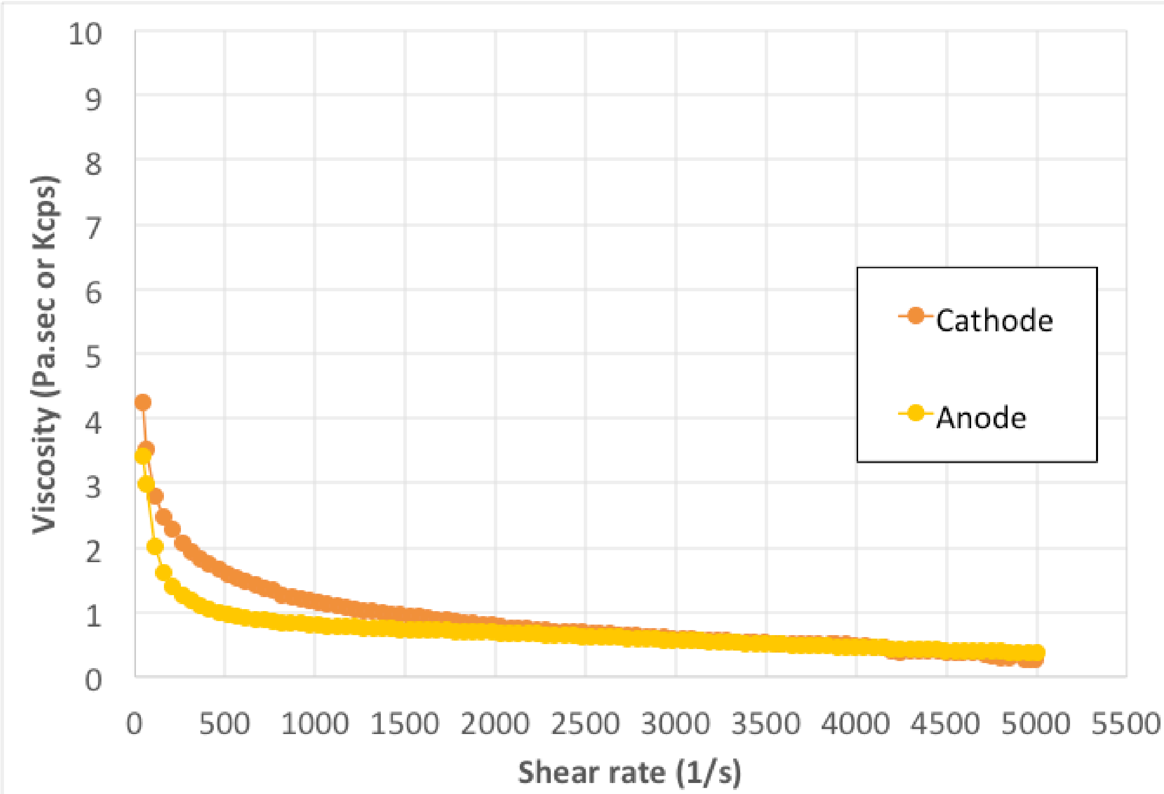
***FLOW CONTROL*.** In a typical arrangement, a 3-way valve controls the flow of fluid towards and away from the slot die. Flow control includes valves that work within the closed slot die system to allow for flow that is diverted when not needed for coating, and shut-off bars within and external to the slot die to keep internal fluid flow within the slot die from escaping.

***MECHANICAL MOVEMENT*.** If the fluid flow control is not enough to break the bead, then mechanical movement of the equipment is required to create clean starts and stops for the rectilinear patch. The mechanical movement can include moving the slot die away from the substrate or moving the substrate away from the slot die. This movement can be controlled by pistons that react with air or mechanical positioning. Another option is to utilize a cam for controlled motion with valving to match the cam motion.



EXPERIMENTAL

Water-base anode and NMP-based cathode slurries were utilized with aluminum and copper substrates for coating understanding. These raw materials are typical for lithium-ion battery applications. Rheological data shows shear thinning behavior for both fluids across the shear rate range experienced in slot die coating (1-5,000 sec^{-1}).



After anode and cathode were coated, cut-outs and cross sections were taken and analyzed to determine the relative heights to the average crossweb profile. These are final dried profiles, and not wet.

The slot die was of uniform dimensions for all applications-

- Offset = 0
- Lip face (upstream and downstream) = 762 micron (0.030 inch)
- Shim thickness = 500 micron (20 mil)
- Coating gap = 25 micron (1 mil)
- Coating width = 340 mm (13.38 inch)

RESULTS AND DISCUSSION

It is damaging to the final battery cell assembly if the head, tail, or edges of coating differ in height in comparison to the bulk of the coated anode or cathode slurry. In addition to height variation, the width of the unwanted bead and the parallel nature of the coated line is important.

What was found in experimental results was that the parallel line is a function of line speed. As line speed increased, the parallel nature was less difficult to maintain. This is a combination of the wetting effects of the shear thinning fluid and the reduced pulsation at the higher line speeds.

Another important phenomena is the effect of obtaining steady-state flow conditions for the fluid prior to engaging the slot die. The critical concern is making sure the flow rate is smooth at the exit and air is not trapped in the system. In the "head" of the coating, if there is a pressure overshoot, then the fluid comes out as an increased velocity. Even if the pressure is stabilized, air in the system will allow the fluid to flow excessively. Measuring and balancing pressure within the slot die valve system improved head and tail development.

In edge effects, whether considering surface tension, film stretching or die swell, stresses are imparted in the fluid from the slot die. These stresses develop a draw ratio D, which is defined as a ratio of the substrate speed ($v_{\text{substrate}}$) to the fluid speed (v_{fluid}). The edge height is taller by a factor of the draw ratio ($D^{1/2}$). Proper mechanical design of the slot die for the rheology and similar fluid to substrate speed improved edge effects.

CONCLUSIONS

Intermittent coating continues to be an important and growing field in the world of slot die coating technology in general, and the flexible electronics and energy storage industries in particular.

With lithium-ion battery coating applications, the ability to meet the current production requirements for a simultaneous dual-sided, intermittent coated anode and cathode are possible in the 10-30 m/min range. The question is where the upper limit is and what advances need to be developed for higher production speeds and improved energy density.

Fluid control and physical movement were investigated for this experiment. Utilization of both seemed to create the best effects for reduced head/tail development, reduced edge bead, and improved parallel edge effects. Surface modification and vacuum were not considered for this work. Developing a deeper understanding of raw material rheology, process limitations will provide the framework for new developments and breakthroughs in the intermittent coating industries.

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