Advances in Slot Die Coating Technology for Hot Melt Adhesives

Mark Miller ***Coating*** *Tech Slot Dies*

ISCST-20180919AM-A-CA2

Presented at the 19th International Coating Science and Technology Symposium,
September 16-19, 2018, Long Beach, CA, USA†.

INTRODUCTION

When it comes to fluid coating onto substrates, the equipment required falls into three areas-

1. Extrusion coating
2. Hot melt coating
3. Liquid coating

What makes these three coating methods the same and what makes them different?

Extrusion coating is typically non-tacky molten polymers being cast onto substrates with a nipped roll and a large air gap. In extrusion coating, the coating head is directly fed from an extruder. Hot melt coating is typically tackified polymer adhesives that behave similar to molten polymers, but engage with the substrate in a proximity arrangement. Hot melt coating heads are fed by a precision metering pump being fed by an adhesive melter. Liquid coating resembles the proximity arrangement of hot melt coating, but the fluid is flowing at room temperature. Unlike extrusion and hot melt coating, liquid coating requires some form of curing to solidify the liquid on the substrate. Extrusion coating utilizes cooling to develop a solid film coating, while hot melt adhesive coatings solidify from cooling or curing.

In pre-metered coating of extrusion, hot melt and liquid coating, the slot die design is very similar. If the rheological characteristics of the polymer, adhesive or liquid is identical, then the internal manifold cavity of the slot die would be identical also. So why does an extrusion coating head, a hot melt coating head and a liquid coating head look so different.

An extrusion coating head has adjustable internal deckle flags that allow the operator to tune the polymer melt curtain flowing out of the slot die over the large gap between the slot die exit and the roll nip. Without this tuning capability, the extruded polymer melt curtain would neck in and have heavy edge beads. This tuning deckle reduces, but does not eliminate, these edge beads. Because polymer melts need to exit the slot die and not hang up on the lip faces, sharp edges to the lip face geometry is helpful.

A hot melt slot die operates without the gap and nip arrangement of extrusion coating. This proximity coating arrangement, where the slot die lip faces are 1-2 times the coating thickness from the substrate, allow the slot die to operate without forming the edge bead and neck-in associated with extrusion coating. However, with the narrow gaps associated with proximity coating, different lip geometries may be needed for different coating thicknesses.

Liquid coating slot dies are operated at room temperature. So while the external design of the slot die is very different from a hot melt and extrusion coating die, the internal functionality is very similar. As the fluid enters the slot die, it is controlled by the manifold cavity to exit the slot die at the same pressure, velocity and volumetric flow rate across the entire opening. Because temperature does not influence the slot die operation, the equipment can be manufactured and maintained to set gaps and tolerances. So for an ambient temperature application a fixed design for the slot die bodies and utilizing a shim creates the best operating condition.

What happens if you add heat to the fluid? At some point, the metal starts to move. With the slot die body moving, an operator needs the ability to adjust the slot die back to the precise position that is required for precision coating operation. That is why the hot melt slot die and extrusion coating die are designed with a flexible lip design. Utilizing a flexible lip design for an ambient temperature coating adds variability that will make coating less precise. However, in a heated application, the lack of adjustability will not allow the slot die to provide the precision required.

So, for hot melt adhesive coating, you need to understand the proximity coating arrangement of liquid coating while adjusting the slot die similar to an extrusion coating application. With this added complication, why would a company opt for hot melt coating over liquid coating? Well, while hot melt coating requires additional process knowledge to operate effectively, liquid coating requires additional curing that can create a rate limiting step in the process. If the liquid is solvent based, there is the additional environmental concern and cost. In order to understand the details of implementing hot melt coating, more background is required.

ADHESIVE RHEOLOGY (VISCOSITY AND ELASTICITY)

In hot melt adhesive coating, we are fundamentally coating rubber bands. Unlike many liquid coatings, hot melt adhesives have both viscous and elastic characteristics. This means that the adhesive polymer melt doesn't just change the viscous flow characteristics with shear, but the adhesive may snap back after being stressed. This added effect can create unique coating defects not seen in liquid coating.

The adhesive may act one way when being stressed and another upon relaxation. This difference, or hysteresis, of the polymer melt can create die swell, edge beads or film split upon coating. The more rheological knowledge you can have regarding the adhesive the better. And I'm not just talking about simple, single data point viscosity. A complex polymer melt requires a more sophisticated study of the flow effects. Develop testing protocols for complex rheology that show viscous and elastic behavior of the polymer under stress and shear will help an operator understand the variation in coating that may occur as lot-to-lot variation of the adhesive is presented to the coating head. Remember, the adhesive takes a tortuous path to the substrate. We need to understand the effects of the stress and design for both the viscous and elastic nature of the polymer for both the equipment and the process settings required for an economically viable coated product.

Hot melt adhesives cover a wide range of applications, but the fundamental chemistries associated with EVAs, PURs and PSAs are all based off tackified polymers applied to substrates at elevated temperatures. Hot melt adhesives provide a functional character to the substrate for temporary or permanent bonding to a future surface after converting. These adhesives can be purchased or compounded in-house. These on-site compounds should be done with a word of caution. A slot die requires a consistent feed of adhesive with minimal lot-to-lot variability. If the adhesive and feed system is not consistent, the coating operator will chase the variation for the entire time the coating system is in operation. Until the volumetric flow and pressure of the adhesive delivery system is stable and the lot-to-lot adhesive chemistry is stable, the coating will vary.

In complex rheological studies, we gain an understanding of whether the viscous or elastic characteristics dominate. If there is a time dependence on the loss or storage modulus in the complex rheological study, then elasticity overpowers viscosity. With increased influence from the elastic nature of the polymer, more coating defects can occur including wrinkling, curling or voiding. If the adhesive has met the level of voiding, then the molecular structure of the adhesive has failed and the adhesive cannot be coated thinner. In other words, you have developed swiss cheese and there is no going back.

EQUIPMENT DESIGN

So how do you develop the best equipment for such a complex application? Computer modeling. To develop an understanding of this three dimensional equation of stress relaxation and viscosity response, finite element analysis can provide a window into handling hot melt adhesives properly. Without computer modeling, the manifold design will not take into account the complex nature of the adhesive rheology and internal flow characteristics developed in manifold geometries with a slot die.

Unlike ambient liquids that have self-leveling capability, hot melt adhesives need to be shaped and molded into the final application of a precision coated substrate. However, this shaping and molding needs to be gentle enough not to develop additional and unnecessary stresses.

The biggest variable controlling how the hot melt adhesive is shaped and molded is the lip opening. To reduce stresses on the adhesive, the lip opening needs to be wide enough to not place undue forces on the polymer melt, but narrow enough to distribute the flow evenly across the width of coating. The lip opening is the most powerful variable in coating because it is the only adjustment that is volumetric in nature. As the lip opening is changed the resulting volumetric flow has a cubic effect on forces acting on the fluid. All other equipment variables are linear.

That doesn’t mean that the other equipment variables should be ignored. External to the slot die, the gap between the slot die and the substrate needs to be maintained flat and even to maintain a flat and even coating appearance. Because heat causes the metal to move, die bending adjusters may be required to flatten out the front face of the slot die to match the flatness of the substrate or backing roll. As hot melt adhesives are coated and influence the other equipment, by heating the backing roll, the slot die flatness may need to be further adjusted to match the contours of the steady state position of the equipment. So, unlike ambient temperature liquid coating, hot melt coating may have more variation at start-up. The faster the equipment can get to steady state, the less waste will be developed.

OPERATION

So once the equipment is at steady state, what do you do if coating defects still persist? One common coating defect in hot melt coating is ribbing; where the adhesive is confused as to whether to stick to the substrate or the slot die. In this case, decreasing the gap between the slot die and the substrate may encourage the adhesive to follow the substrate path. If this isn’t enough, the attack angle of the slot die can be adjusted. The attack angle is the rotation of the slot die around the lower corner of the upper lip of the slot die. This rotation will allow the lip faces to have the desired effect of improved meniscus development without the interference of the slot die with other components.

When coating rubber bands, there are going to be some limitations to the ability to coat the rubber bands fast and thin. The current upper limit of speed that I am aware of is 3280 feet/min (1000 m/min). This speed limitation seems to be more associated with cooling capability, but the speed could be lower for a thinner coating because of the stresses involved in the take-away process. This is a multi-variable problem and as the thickness of the adhesive coating decreases, the top speed will decrease also.

The coating thickness of the adhesive is strongly connected to the internal strength of the adhesive. An adhesive chemistry can vary widely, and the effect on the ability to coat thin varies with the molecular character of the polymer. If fillers are added to produce a lower cost adhesive, the coating thickness achievable will rise. It is a balance between raw material costs and processability. For most adhesives, it is safe to assume that 1 mil (25.4 microns) or thicker can be coated. To coat thinner, tests should be run on the adhesive coating capability on a lab or pilot scale line to show proof of concept. I have seen some lower elasticity hot melts coat as thin as 0.5 mils (12.7 microns) successfully.

Hot melt adhesives coat thicker also, but there are three main levels that coating can be grouped-

1. > 3 mils (76.2 microns). In this region, a standard flexible lip slot die lip set should be utilized.
2. 1-3 mils (25.4-76.2 microns). In this region, a rotary rod lip set should be utilized.
3. < 1 mil (25.4 microns). In this region, a rotary rod lip set should be used, but is not guaranteed to have success.

In the thicker regime, coating with a standard lip set would allow for a proximity coating technique. In proximity coating, the slot die is positioned the coating thickness away from the substrate with a precision backing roll supporting the substrate. The tall lip faces of 0.15-0.30 inch (3.81-7.62 mm) allow the formation of a meniscus and the sharp lip edges allow for release of the adhesive from the slot die.

When the coating required drops below 3 mils (76.2 microns), a rotary rod lip design should be utilized to have streak free coating. Without the rotary rod lip design, the lip opening and slot die to substrate gap starts to narrow to the point that adhesive gels or char can develop streaks that are persistent. The way a rotary rod lip set works, the slot die lip face is actually pushed into the backing roll to develop a deflection in the roll. This deflection creates longer path for the substrate to follow, resulting in a slip phenomenon where the adhesive gel or char that would normally get stuck in the narrow gaps clears the path. The backing roll needs to be made of rubber to allow for this deflection. As a general rule of thumb, the thinner you coat, the harder the durometer the rubber should be. It is common to see a 70 Shore A durometer roll for 3 mils (76.2 microns) of coating and a 90 Shore A durometer roll for 1 mil (25.4 microns) of coating.

As presented in the explanation of the rotary rod lip design, the slot die itself is not the only equipment contributing to the ability to coat precisely. The backing roll, fluid delivery system and slot die positioner all provide some functionality to the success of adhesives coating. In addition, the web handling, tension control and stability of the roll-to-roll coating line can reduce variability or contribute to coating defects. For all equipment involved it is critical to maintain temperature evenly. Variation in temperature translates into variation in rheological characteristics of the adhesive. As the rheology varies, flow varies and the equipment needs to be adjusted to compensate. When at all possible, get to steady state and stay there as long as possible.

CONCLUSION

When it comes to fluid coating, there are three options to consider. If the application lends itself to hot melt adhesive coating, keep in mind that you are working in the one area that is the cross section of extrusion and liquid coating. This complex area of operation has a lot of potential, but you need to do your homework to be successful. Understand the limits of the adhesive. Understand the limits of the equipment. Develop the best adhesive for the application and then model the equipment to optimize performance. Hot melt adhesive coating is growing in popularity, so the more you can develop a knowledge base the farther ahead your company will be.