Managing the Die, Coating Gap and Coating Bead in PSA Hot Melt Slot Die Coating

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Pressure sensitive adhesive (PSA) tape manufacturers have several different coating method options available to them, with slot die coating being one method that many manufacturers utilize for precision hot melt coating of their tapes. The struggle that some of these companies have is low technical die knowledge - whether they are new to slot die coating and lack guidance internally, or have been slot die coating for some time but much of their technical knowledge has faded away as employees are promoted, move on, or retire. Possessing strong technical knowledge of die operations and setups is essential, as it enables plant engineers and operators to effectively diagnose coating problems and enhance the coating quality of their product. The goal of this paper is to provide insight and guidance on PSA hot melt slot die coating, so companies can equip their employees with the tools and understanding needed to fully leverage their existing and new equipment, ensuring consistent and high-quality outcomes in their PSA hot melt production.

Slot Die Flow Channel

In PSA hot melt coating, the hot melt is fed via a drum unloader, melter, or extruder to the die. It enters the die through a feed adapter, through the throat and into the manifold. The main goal of the manifold is to provide distribution from the center of the die to the ends. Having a well-designed manifold is critical to achieving even distribution throughout the die. The wider the slot coating, the more challenging it is to get even fluid distribution to the ends.

The manifold design is based primarily on rheology, and secondarily on process conditions. A slot die can be designed either for one rheology/recipe, optimized for a few different rheologies (while keeping other potential adhesives in mind), or with a balanced-design approach that aims to achieve uniform flow (through different lip gap profiles) for a multitude of low and high rheologies. Low viscosity hot melts flow easily, so a smaller manifold is generally sufficient. Conversely, high viscosity hot melts resist flow, requiring a larger manifold to deliver the volume needed to distribute the fluid before it reaches the pre-land. In a balanced-design for both low and high viscosity materials, the flow channel is typically a slightly smaller manifold than one normally used for high viscosity coatings.

Once the hot melt exits the manifold, it then enters the pre-land of the die. The pre-land is the transition area between the manifold and the lip land. It aids in maintaining an even distribution of fluid, ensuring a consistent flow rate and preventing variation in fluid flow. The fluid then moves to the lip land area where it guides the hot melt to the slot exit. The land area is where the fine distribution of the melt flow occurs. The length of the land contributes to the pressure in the die.

The lip gap, established by a machined gap or a body shim (if lane coating), can be adjusted and profiled across the slot to get as uniform of a coating thickness as possible. The lip gap has the most significant impact on the pressure and fluid velocity within the die. As the overall lip gap is reduced (for example, starting with a 0.015" (0.381mm) gap, instead of a 0.020" (0.508mm) gap, the pressure and velocity increases, and redirects melt flow to the ends. With a larger overall lip gap, the pressure and velocity decreases, and the melt flows heavier to the center. The overall starting lip gap used will be based primarily on the hot melt's rheology being coated for that run.

An overall lip gap change affects the pressure and distribution, but what about profiling at certain points across the die slot? The profiling of the lip gap, at any point of the slot, changes the pressure in that area back inside the manifold, by adding to or decreasing the resistance to flow. This change in flow resistance alters the fluid's velocity and redirects flow to different areas of the die. Once an adjustment to the lip gap is made, the change in pressure has to make its way through the closed system back to the pump to stabilize; therefore, it takes a little bit of time (approximately 30-60 seconds) to see the full effect of a profile change.

Though the change in pressure and flow occurs within 30-60 seconds, it is important for the operator to know that the change will not immediately show with the gauging scanner. It may take 10-15 minutes to see the full change, given that the scanner takes a composite of several scans to soften the machine direction variation and give a true cross direction profile.

It's important to train operators on both the 'profiling/pressure' and 'gauge scanner composite reading' delays because it's common for operators to want to make additional, unnecessary adjustments, after not seeing a significant enough change when they make an initial lip profile adjustment. As a result, the operator will need to make even more corrective adjustments and prolong the time it takes to get to a uniform coating.

Setting the Coating Gap

The distance between the exit of the die and the substrate is referred to as the coating gap. In PSA hot melt slot die coating, the substrate is usually supported by a temperature-controlled rubber backing roll. When coating PSA's, a high amount of applied force is often needed[1] to generate enough shear in the fluid to achieve a good wetting out. To attain the force needed, the die is pushed into the rubber backing roll. In this die-to-roll set-up, the hydraulic pressure (via the coating bead) establishes the coating gap. Therefore, the operating coating gap is equal to the coating thickness.

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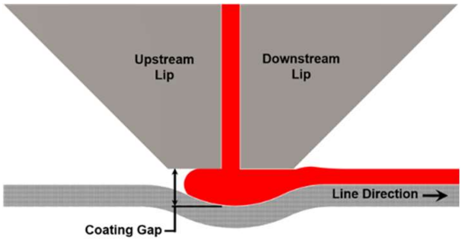
[1] Depending on fluid and substrate properties



Flush Lips

We typically recommend a set-up where the die pushes into the rubber roll approximately 0.002” (0.508mm). To set up the coating gap, we recommend positioning the die to the substrate to the point where you are unable to pull out a 0.002” (0.508mm) shim, and then backing the adjustment out slightly until the shim can be pulled out. When doing this (checking multiple spots across the die), the backing roll should be rotated often to prevent the continuous heat concentration, from the die, on a specific area in the roll.

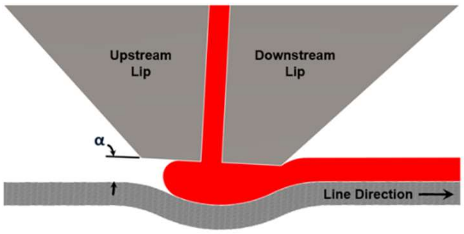
Since the coating gap is determined by the coating bead, it is nearly as critical as the lip gap in achieving a uniform coating. The coating may exit the die evenly due to lip gap profiling, but the coating gap either preserves this uniform profile or disrupts it. This makes the positioning of the die, the lip face straightness, and backing roll’s total indicated runout (TIR) all key factors in maintaining a uniform coating because they each affect the consistency of the coating gap across the slot.

Maintaining the coating gap uniformity during production presents an additional challenge. The coating gap can shift as the melt applies heat, beyond the substrate, to the rubber backing roll. That heat expands the steel (under the rubber) in the coating area; therefore, a backing roll that is temperature-controlled is used to minimize the amount of deflection that occurs. Typically, companies heat the roll up to 176° F (80° C), significantly lower than the melt temperature of their hot melt. To further combat the deflection that still occurs even with the temperature-controlled backing roll, the die can be mechanically adjusted on the ends (by the positioner) to facilitate an even coating gap across the die.

In addition to the delayed response tied to lip profiling and change in pressure noted earlier, there is another delay, and this one is linked to the profiling of the lip and coating gap. Once a lip profile/pressure adjustment change is made to coat thicker or thinner in one area, there is a change in the amount of hot melt coated in that area. As a result, the backing roll will slightly expand (when coating more material, producing more heat) or constrict (when coating less material, producing less heat) in the area where the coating thickness changed. This roll expansion/constriction then affects the coating gap, which then affects fluid flow in that area accordingly. This whole process can take as much as 20-30 minutes (depending on the size adjustment) before it’s fully worked out and seen in the gauging system profile.

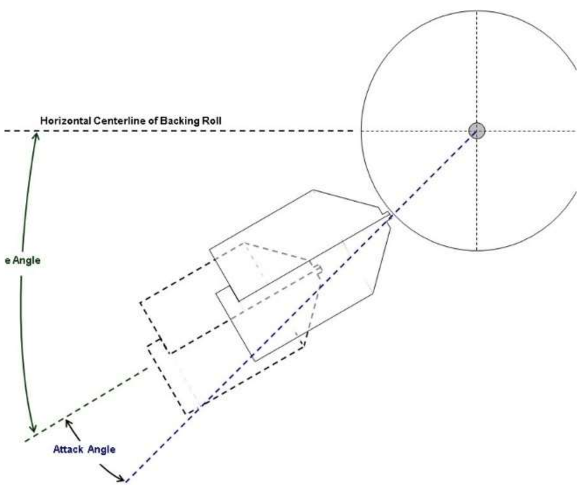
Utilizing the Angle of Attack

The angle of attack refers to the angle of the die lip faces in relation to the backing roll. The attack angle can influence the pressure and flow velocity in the coating gap. An attack angle is utilized on almost all PSA hot melt applications. Most of the time, a positive attack angle (with the downstream lip closer to the substrate) is used to increase the pressure and shear the PSA hot melt onto the substrate. This produces a glossy, smooth appearance. A smooth finish enhances adhesion to the final product by providing a larger surface area for bonding.



Converging Angle Of Attack α > 0

An ideal set-up of the die to the backing roll is to have the die's lower lip land, extended as a plane, passing through the center of the backing roll. This set-up is ideal because it's the most centralized point and limits the need to make additional adjustments as the attack angle changes. The axis of the rotation is at the apex of the lower lip land and its lip face. If the position of the lower lip exit isn't parallel and in line with the center of the backing roll, then either more or less angle is needed (depending on the direction).



We recommend utilizing the following formula for an <u>initial</u> attack angle and then adjusting as needed[2]:

*Wet lip face length (in.) / (backing roll diameter [in.] X .0175) = starting attack angle (degrees)**

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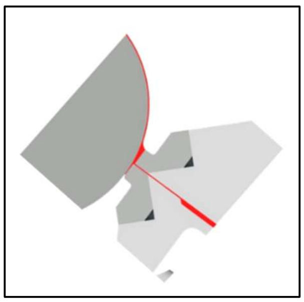
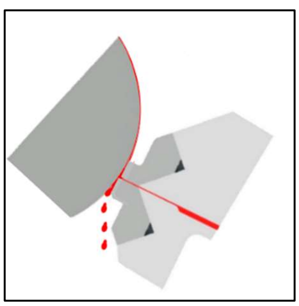
[2] These are general recommendations that are dependent on rheologies, surface tension of the fluid, surface energy of the substrate, and other fluid properties. The substrate also matters and can affect these settings. PET (polyester), paper, and foil can coat differently and have different substrate surface energies that affect the adhesion of coating and manifestation of defects.

**Formula for non-rotary rod style lip inserts and a rubber backing roll is multiplying the calculated "attack angle" by 2. The doubling of the attack angle for a rubber roll compensates for the compression of the roll.*
**For rotary rod style inserts, start with a 0-degree angle.*

Most PSA hot melt setups use a positive attack angle of 0.5°-2.0° but can be up to 5.0°. The angle of attack is an "on the fly" adjustment that should be adjusted slowly (by 0.1°) until the desired coating appearance is achieved. A negative angle of attack is seldomly used but may be utilized in conjunction with a low viscosity, ultra-thick coating. Coating ultra-thick requires a large coating gap, so the negative angle of attack supports the coating bead to prevent back-spill.



Too little of an attack angle (diverging angle, with the upstream lip closer to the substrate) can result in:
1) air entrainment given a lack of melt well on the dry lip
2) unstable coating results, like ribbing or chevrons
3) excessive wear on the dry lip
4) coating is likely to have a dull finish

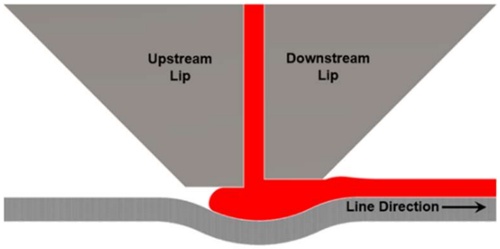


Too much of an attack angle (converging angle, with the downstream lip closer to the substrate) can result in:
1) back-spill by pushing the meniscus beyond the lower lip face
2) air entrainment due to the destabilization of the meniscus
3) excessive wear on the upper lip
4) unstable coat weight uniformity due to the loss of fluid spilling

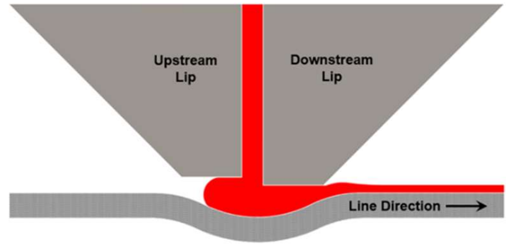
Utilizing Die Offset

Once the hot melt flows into the die, through the manifold, pre-land, and land area, it exits the die and forms a coating bead between the lip faces and the substrate. The positioning of that bead can occur by offsetting the die bodies. The offset is an adjustment that requires the die to be taken off-coating (unlike the coating gap and angle of attack, which can be adjusted on-the-fly while coating).

To create an offset, typically offset shims are used in conjunction with an offset block system to adjust the lip faces either parallel, "underbite" (with the lower body ahead of the upper body), or "overbite" (with the upper body ahead of the lower body).



Underbite Lip



Overbite Lip

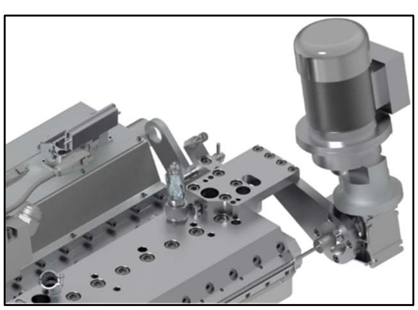
In our experience, an overbite can be helpful when coating thin PSA hot melt coatings. Thinner coatings are more difficult because the coating gap is so small, resulting in a small coating window. An overbite shifts the position of the meniscus on the dry lip and stabilizes the coating bead to allow for more material (a melt well on the dry lip) to be available to coat. This also helps avoid air entrainment and voids.

An underbite can be helpful when coating thicker PSA coatings. It allows for a larger melt well on the wet lip. This melt well enables the bead to clear but keeps the lower lip close to the roll, so you don't have back-spill past the dry lip.

We recommend starting with the lip faces flush, but if adjusting the coating gap and angle of attack doesn't resolve any coating or appearance issues, then the offset can be configured, starting with a 0.001" (0.0254mm) offset, to address inconsistencies by repositioning the coating bead. Once a 0.001" (0.0254mm) offset is used, we recommend trying different attack angles and coating gaps with that offset. Then if the issue is not resolved, then increasing the offset in 0.001" (0.0254mm) increments. Too much overbite or underbite can also cause coating issues. Too much overbite can cause back-spill due to pushing the meniscus beyond the dry lip face. If there's too much underbite, you could see some coating issues because the downstream coating bead might not have a clean release at the lip exit point (causing ribbing).

Utilizing a Rotary Rod

A motorized rotating rod located near the lips enables gels/char/contaminants to pass through the coating gap, minimizing streaks and die lines. It is typically recommended when coating 0.002" (0.0508mm) or less due to the small coating gap that occurs with thin coatings. The rotating rod can also help have a slight effect on the surface appearance.



The speed at which it rotates is subjective to the desired appearance. The recommended starting speed is 10 rpm and can be adjusted accordingly. If gels aren't passing well (resulting in streaks), then the speed can be increased. If you want higher shear, then you can slow down the rod to get a better surface finish. The aim is to produce a smooth surface finish while avoiding streaks. Typically, rotary rod lip faces are run flush because the rotary rod already extends out past the lips; however, an offset can be still utilized to resolve any coating issues that can't be resolved by adjusting the coating gap and attack angle.

General Set-Up

We recommend the following general sequence of steps when initially setting up the die:

1. Set the lip face offset
2. Set the initial lip gap (install deckle if used)
3. Set the angle of attack
4. Set the coating gap

After the initial setting, we then recommend the following steps to dial everything in:

1. First, address the appearance by adjusting the coating gap and attack angle. The goal is to use the largest possible coating gap with the smallest attack angle that will apply a smooth and glossy coating. Aiming for this goal, prevents leakage past the dry lip and promotes consistency and repeatability with the least amount of adjustment.
2. If there are still unresolved coating defects/quality issues, you can take the die 'off-coating' and adjust the offset accordingly.
3. Once you have a consistent wetting out and smooth surface finish, you can focus on the coat thickness uniformity by profiling the lip gap.

Conclusion

This paper sought to address the needs of both newcomers lacking internal expertise and experienced manufacturers facing the loss of technical knowledge. By providing comprehensive guidance and fostering a deeper understanding of die operations and setups, this paper aimed to empower companies to enhance efficiency and performance. Equipping employees with this technical knowledge and practical guidance ensures that manufacturers can optimize their slot die coating operations and maintain a competitive edge in delivering superior PSA tapes.

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