Modern Extrusion Coating Die Technology

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ABSTRACT

New technology is being developed which may enhance the performance of extrusion coating dies. Processors require extrusion tooling that offers precise control of coat weight uniformity, trouble-free coating width variation, and the ability to minimize expensive edge trim waste. A novel concept will be presented that improves web stability and helps to reduce edge bead and neck-in effects. Laboratory trial results which demonstrate the potential of this emerging technology will be discussed.

INTRODUCTION

Processors who convert substrates utilizing extrusion coating and laminating techniques need to build into their cost structure varying degrees of edge trim waste. As tension is applied to the molten web it becomes narrower, or “necks-in”, in the air gap between the die lip exit and the coating nip. This narrowing of the web results in excess coating material building-up at the extreme edges of the coating web. The heavy edge zones of coating material are often called “edge beads”. Processors will normally coat past the edges of the substrate and then trim this “over-coat” away to keep the out-of-specification edge beads out of the savable converted product area. Since the over coated trim waste stream will include a small amount of substrate in addition to the edge bead, this material is usually not able to be recycled back into the process.

The root cause of the undesirable edge bead is the fact that the web necks-in. Given this, it would make sense to investigate measures that reduce the neck-in phenomenon in an effort to diminish the size of the edges and the width of the over-coat regions. Shortening the air gap distance is known to reduce neck-in. This, however, is an impractical remedy since a substantial minimum air gap is usually needed to yield enough oxidation of the web to promote adhesion to the substrate. Reducing the tension on the molten web would help but is also impractical since reduced line speeds will adversely impact production efficiency. Minimizing the draw ratio (the ratio of die lip gap to final coating thickness) can also assist in reducing neck-in but there are again practical limitations. If the lip gap is set too tightly, there will be excessive contact of the melt with the die lip faces. This would result in frequent contamination of the lips, or “plating-out”. This, in turn, leads to defect lines in the coating and would need to be addressed with frequent production shut-downs to clean the lips.
Due to the many practical limitations preventing us from significantly optimizing the parameters that affect neck-in in the air gap region, many die designers have focused their efforts upstream (inside the die) in an attempt to compensate for the edge beads. The well-known method which incorporates adjustable internal deckles has become the industry standard. These internal deckles comprise of a main quill on each end of the primary die channel along with a series of adjustable deckle blades. By moving the main quills and intermediate blades inward relative to the final lip area blades, the volumetric flow rate of material exiting the edge regions of the die slot can be reduced in comparison to the main flow for most of the die. As neck-in occurs in the air gap region, these initially thinned edge areas will thicken. The typical result is a reduced edge bead size and width leading to a narrower over-coat requirement. While this technology can effectively reduce edge trim waste when coating LDPE, there is room for improvement - especially for coating materials which have less melt strength, such as PP or HDPE.

It would be beneficial to develop devices that directly influence neck-in to assist classic internal deckle systems and achieve even more savings with regard to trim waste. One such technology under investigation is external edge guides. These are shaped extensions which hang from the die lips and shoulder the web at each side. Initial test results from laboratory trials have shown that neck-in can be reduced when using these edge guides. Further experimentation will be required to explore how effective these devices will be in a high speed production environment. Since the edge guides are devices which attack the root cause of the edge bead problem (which is the neck-in), we are encouraged to believe that a combination of edge guides with traditional internal deckles will provide more robust edge bead control.

**ESTABLISHED TECHNOLOGY**

Before discussing the development work underway, let’s review current coating and laminating die technology.

The flow channel within the die has the role of establishing fundamental flow distribution of the coating material. Basic channel designs can be completely constant across the die width. More sophisticated flow channels have a changing geometry to improve streamlining and distribution uniformity, or can have a changing geometry in the center with constant sections on each end. The constant geometry on the ends allows for adjustable internal deckles to be utilized.

Internal deckles provide streamlined width adjustment and can be tuned to reduce the size of the edge beads. External deckles are reliable and can be conveniently locked and unlocked, often with a single point adjustment to vary the sealing force. By using a die that combines these two types of deckle systems, processors can realize distinct advantages.

In addition to the basic shape of the flow distribution channel, the dimension of the land in the lip exit area of the die and the type of automatic lip adjusting hardware used are key features that help to improve the ultimate control of the coat weight uniformity.
The basic function of a die is to transform a molten polymer feed from a melt pipe or a coextrusion feedblock to a significantly wider and thinner web. To achieve this dramatic transformation, die flow distribution channels (often called manifolds) are designed to provide a nearly equivalent pressure drop for each polymer path along the width of the die. There are many manifold designs that can accomplish this uniform spreading of the melt. The simplest version is called a “T-die” that has a constant cross section and establishes relatively uniform flow distribution by generating a large pressure drop across the die lips, compared to a small pressure drop across the width of the die. Since the manifold is constant, the design is well suited to accommodate sliding internal deckles, as shown in Figure 1.

![Figure 1: Constant Cross Section Manifold with Internal Deckling](image)

Manifold designs with a varying cross section can offer more precise initial distribution, so less fine-tuning with the lip adjustments will be required. Many flow channel designs, as shown in Figure 2, are available that have a varying distributor section, or preland, to promote uniform flow distribution. Since the channel will vary across the entire length of the die, the design does not accommodate full internal deckles and is usually deckled externally.

![Figure 2: Manifold with Varying Geometry](image)
A distribution channel that combines a varying central channel section with constant end sections is illustrated in Figure 3. The manifold/preland interface in the center of the channel has a curvature that promotes lateral flow distribution. The constant sections on each end allow full deckle plugs to slide within the flow channel for streamlined width variation.

![Figure 3: Varying Central Geometry and Constant Geometry at Each End](image)

This flow channel design can distribute a wider variety of coating materials since it is compatible with standard and higher viscosity grades and can still be fully deckled internally.

**Coating Width Variation**

Deckles adjust extrudate width and have been used by the industry for decades. A version available with combined internal and external deckling is illustrated in Figure 4.

![Figure 4: Internal Deckles Combined with External Deckles](image)

The device shown in the figure is the deckle assembly that would mount to each end of an extrusion die. The bronze colored components are the internal deckle quills and blades that completely seal the ends of the internal channels. This approach eliminates
stagnation or dead areas in the channel. The silver-gray colored component at the bottom of the figure is an external back-up deckling system. External deckles are well known for their ability to provide highly effective sealing characteristics. By combining these two deckle systems, which were previously thought to be mutually exclusive, a significantly better approach to deckling has been developed. Just like the coextrusion of two coating materials leads to a higher performance product by combining the superior adhesive properties of one material with the superior strength properties of another, so does this new deckle concept lead to a dramatic performance improvement. Processors have found that die systems equipped with only internal deckles require a great deal of experience and skill to adjust without leakage problems. They also find that external-only deckle systems do not allow for edge profile control and are not as streamlined. A combined dual deckle system allows for simple, convenient width adjustment procedures, without leakage issues. The impact that a dual deckle system will have on a typical coating operation can be quantified by considering downtime due to leakage. Internal-only systems can be down on a weekly basis to address leakage problems, whereas dual deckle systems can run leak-free for several weeks. Typically, downtime frequency is reduced by a factor of 4 to 6.

**Edge Profile Control**

One of the chief goals in extrusion coating is to maintain a uniform coating thickness across the entire application width. This is not always easy. The common problem of edge bead – an increased thickness along both edges of the coating – makes it necessary to trim the edges to meet product specifications. Edge bead is particularly costly in extrusion coating because the scrap includes both coating and substrate. The edge beads are formed by the imbalance of forces that is created when tension is applied to the coating web. As the web becomes oriented in the machine direction, it necks-in resulting in a build-up of material on the edges. Adjustable internal deckle blade systems (Figure 5) allow the processor to minimize the width and size of the edge bead. The result is a minimal overcoat requirement (usually 5 to 7 mm per side instead of 15 to 20 mm per side for LDPE), so waste is significantly reduced. Too much thinning of the edges by deckle blade tuning for materials that have less melt strength, such as PP, can result in web instability - limiting how much bead reduction is achievable.

![Figure 5: Internal Deckle Blades Repositioned to Reduce Edge Bead](image)
Control of Coat Weight Uniformity

There are two key features that have been developed to maximize the amount of control the processor has over coat weight uniformity.

- Longer lip land lengths provide a significant response to an operator or gage control system adjustment.
- A thermally isolated automatic lip adjusting system provides extremely accurate product tolerance.

Many designs for internally deckled dies utilize a very short final lip land at the exit area of the die (only 3 to 5 mm long). Some die manufacturers do this to minimize the pressure generated in the lips, so that the die becomes less of a challenge to seal. Another possible reason to use a very short final land is if this final land area of the die will be left undeckled (the internal deckle devices end just short of the final land). This represents a compromise, however, since shorter lip lands will promote more die swell (which will result in more frequent lip face contamination). Also, the reduced lip pressure drop resulting from an undersized lip land provides less lip tuning control. Finally, an open-end final lip exit (that does not have a deckle blade in the land) can contribute to the edge instability problem.

A better approach is to provide an appropriate lip land length, with a good balance between the pressure drop across the lip land compared to the pressure drop across the whole die. Depending on the materials and rates to be processed, lip lands can be provided in a range from 10 to 25mm. Longer lands can allow a broader window of materials to be accurately distributed by one die, for example LLDPE and HDPE in addition to the normal LDPE.

Figure 6 shows an extrusion coating die with an automatic lip adjusting system which provides three key advantages over previously available systems.

![Off-Mounted Autoflex System on Extrusion Coating Die](image)

Since the translator blocks are mounted outside of the die body, there is significantly less heat transfer between the body and the blocks than with previous systems that were mounted within the die body. This eliminates much of the thermal “cross-talk”, so accurate gage control can be achieved more quickly.
The translator material is a beryllium-copper alloy, whose high thermal conductivity provides a rapid response to a control action. Also, due to a large coefficient of thermal expansion, the translators provide a great deal of stroke (+/- 0.38mm of automatic adjustment range).

Automatic profile control typically reduces profile variation from (+/- 4 to 5% with manual control) to (+/-1 to 2% with automatic control). Modern automatic systems when combined with appropriately designed flow distribution channels have helped to minimize the time that the system needs to recover from a process interruption. In some cases, tight tolerance steady state control can be re-achieved within 10 minutes of making a significant width change, for example.

**DEVELOPING TECHNOLOGY**

A new development effort is underway to investigate if use of external edge guides would benefit the extrusion coating process. External edge guides are contoured extension blocks that hang below the die exit and influence the edge shape and the total span of the melt curtain in the air gap region. While the initial results are very promising, further experimentation is needed at higher line speeds before any definitive conclusions can be reached. In addition, future work should include combining the edge guides with internal deckles to see if the synergy we expect is realized in practice.

The preliminary experimentation involved a 230mm laboratory die, without internal deckles as shown in Figure 7. The air gap distance was 220mm. A common extrusion coating grade of LDPE was extruded at 312 degrees C. The die lip gap was set at a constant 0.5mm across the width of the die. The coating thickness was 30 microns and the line speed was 15 meters per minute. At these conditions and utilizing conventional end plates that are flush with the lip exit, the coated width after neck-in was 157mm, so the neck-in amount per side was 36.5mm.

![Figure 7: Neck-In from Laboratory Die with Conventional Endplates](image)

Next, special extended and shaped end plates were installed on the same die and the process was run at the same conditions. As shown in Figure 8, the extensions were shaped such that they would create a wider final span for the melt curtain than would
have resulted from the normal neck-in trajectory. In this trial, the coated width after neck-in was 165mm. The neck-in amount per side was reduced to 32.5mm.

In addition to this preliminary finding of neck-in savings, we also observed that the edge guides needed to be controlled at a temperature near the melt processing temperature to be effective. If the guides were controlled at a significantly higher temperature than the melt then the web would break free from the guides prematurely, resulting in neck-in amounts that were similar to that observed with standard end plates. If the guides were controlled at a significantly colder temperature than the melt then the melt curtain would not fall freely and the material would begin to fold upon itself due to significant drag at the edge guide walls. If there was a close temperature match between the guides and the melt then the curtain maintained contact with and traveled smoothly along the guides.

If the edge guide concept continues to prove useful through further trials, it will be applied to extrusion coating and laminating dies as shown in Figure 9. The edge guides would fasten to the external back-up deckle and move together with the deckle assembly. Since they are detachable, specific sets of guide shapes and sizes could be installed to allow a wide range of coating materials and air gaps to be used. Cartridge heaters would be installed to control the guide temperatures. If the edge guides are eventually proven to help to maintain web stability and reduce neck-in at high line speeds, then we expect that processors would be able to more aggressively tune the internal deckle system to further reduce the edge bead size, even for materials with low melt strength.
CONCLUDING REMARKS

Extrusion die tooling continues to develop and evolve to meet increasingly stringent performance requirements. Modern die designs can provide processors with convenient coating width adjustment, a reduced overcoat requirement, and rapid coat weight precision control for a wide variety of coating materials.

It is likely that coat weight precision, edge trim savings, and process stability can be further improved by incorporating edge guide technology into the extrusion coating process. Further work is planned to develop the potential of this emerging technology.