The Application of Simulation in Co Extrusion Processes

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ABSTRACT

This paper shows how simulation was used to help improve our understanding of some flow phenomena that are unique to coextrusion processes. The paper shows how simulation was used to help explain experimental observations and to quantify them so that the problems could be avoided in future trials or new equipment designs.

INTRODUCTION

Coextrusion provides the ability to combine the desirable properties of several materials into one structure. This is generally done to produce a structure at a lower cost or with properties that can not be obtained from a mono-layer product or blend.

Flow simulation, or computational fluid dynamics (CFD) provides us with the ability to better understand what is happening within a process by studying the relationship between material properties, equipment design and processing conditions. CFD is like a “window” into the process whereby we can “see” what is the relationship between the material and the equipment through the analysis of various flow field characteristics such as Pressure Drop, Velocity, Shear Rate, Shear Stress, Temperature, Residence Time, etc. In fact, simulation can provide information that would be impossible, or at least extremely difficult to physically measure.

This paper will describe some situations in which simulation was used to help understand and ultimately solve some problems related specifically to coextrusion. The reader is referred to the literature for another paper that shows how simulation was used to study other extrusion flow problems [1]. The simulations in this paper were performed with the FLOW 2000 Extrusion Simulation Software [2].

The examples of application of simulation to coextrusion deal primarily with flat (cast) film (or sheet) extrusion or extrusion coating. A good review of this technology was provided in presentations by Jerdee [3] and Christie [4].

NEW PRODUCT DEVELOPMENT

A company wishes to produce a new 3 layer product using their flat die and 3-layer feed-block. They initially selected a Polyester for the Top Layer, as polyolefin for the bottom layer and a suitable adhesive. Figure 1 is a sample of the sheet that was produced during of the initial trials.

Figure 1 Three layer sheet sample with poor layer distribution and distortion

The sample suffered from poor layer distribution and distortion (waviness). Many attempts were performed to determine stable operating conditions and several materials were also tested with no success. The reason for the initial failure can be easily explained through some analysis of the rheology and the flow fields.

Figure 2 compares the shear viscosity of the 3 materials that were used in the initial experiments.

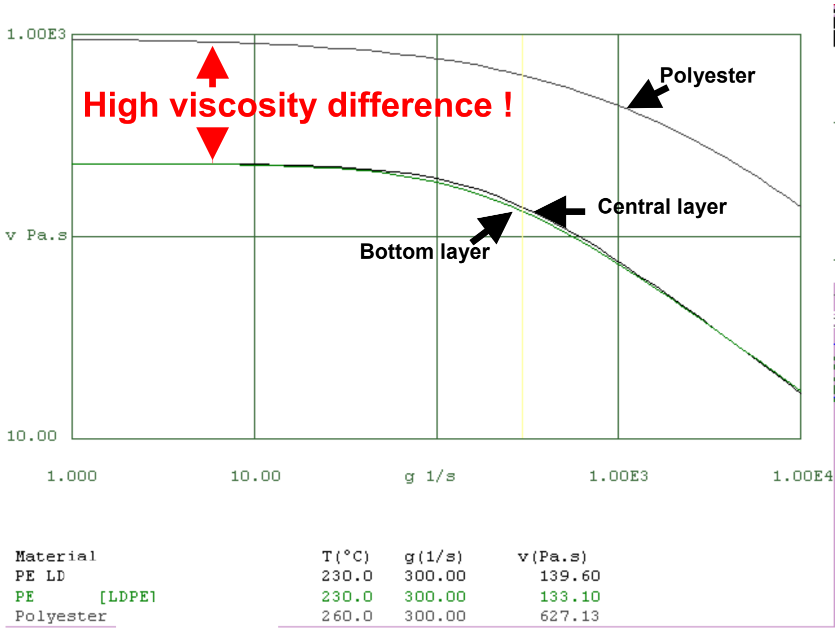

Figure 2 Comparison of shear viscosity for materials used

From figure 2, it is quite obvious that the Polyester has a much higher viscosity than both the LDPE and LDPE based Adhesive which, have similar viscosities. One might suspect that this large viscosity difference may cause a problem during coextrusion but it is not immediately obvious as to how much of a viscosity difference is tolerable. Simulation can help quantify the effect of the large viscosity difference on the flow field.

Figure 3 is a representation of the flow field that was studied in the simulation.

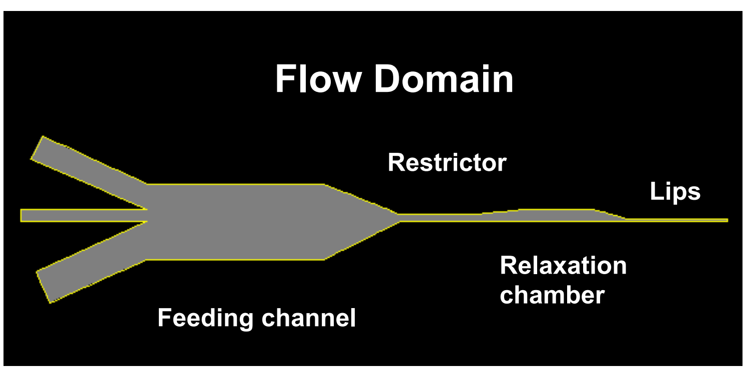

Figure 3 Cross section of flat die flow field

Figure 3 is basically a cut along the centerline of the die with the 3 channels at the left representing the inlet from the feed-block. Since this analysis is focused on the coextrusion flows within the flat die, a detailed feed-block analysis is not necessary.

A 2D Finite Element Method (FEM) flow simulation was performed on the above flow field. Figure 4 shows the calculated velocity profiles that result in the Manifold and in the Die Lips based on the flow rates and shear viscosity of the materials.

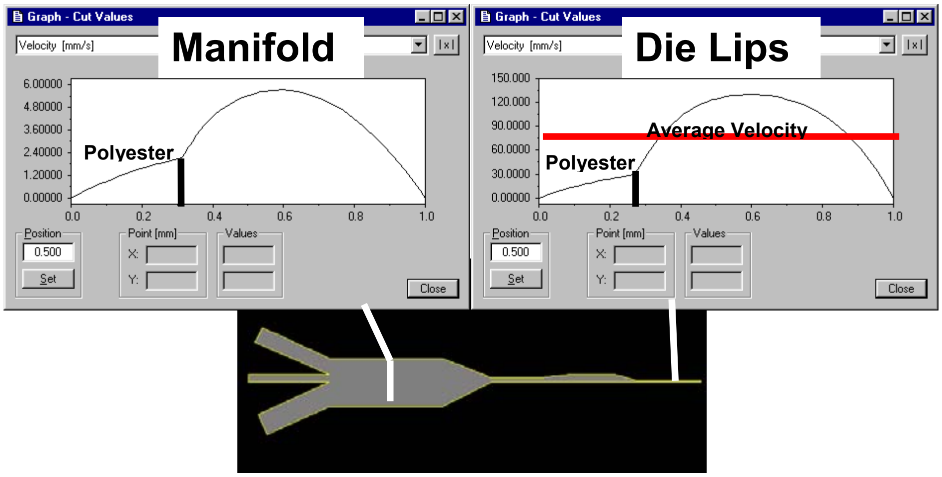

Figure 4 Velocity profile in Manifold (left) and Die Lips (right)

The high viscosity of the Polyester layer results in a large asymmetry on the flow velocity profile. In the manifold, the lower viscosity material will try to encapsulate the high viscosity material resulting in some layer non uniformity; especially at the edges. In many cases, this determines how much edge trim must be removed and generally reduces the amount of saleable product that the line produces. However, if the velocity profile too asymmetric, then it becomes difficult to produce any saleable product at all.

The right image in figure 4 shows the velocity profile at the die exit lips. The high viscosity polyester takes up a disproportionately larger amount of the flow channel allowing it to have an lower average velocity than the LDPE (and adhesive) layers. This means that when this flow stream exits the die, it will want to bend towards the polyester. However, the material will be pulled by the nips and the velocity will be forced to re-arrange so that all of the materials will flow with the same average velocity. This means that the polyester will need to accelerate while the LDPE will need to slow down. When this velocity re-arrangement becomes too large, the sheet starts to distort making it impossible to create good product. The solution is to find materials that have more similar viscosities so that the velocity re-arrangement is less severe and more symmetric.

FEED-BLOCK DESIGN

A feed-block combines multiple streams of polymer into a single structure (sandwich) as shown in figure 5.

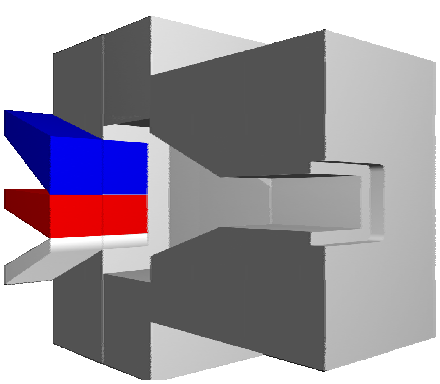

Figure 5 Combination of 3 layers in a feed-block (no vanes) [3]

While the material flowing in each layer does fill the entire channel as show in figure 5, the actual velocity profile that occurs in each channel is not as obvious.

Consider 2 layers merging as show in figure 6, which is a 3D FEM flow simulation in the merge region of a feed-block. (The simulation uses an axis of symmetry across the centre and at the bottom.) The left image shows the pressure along the channel while the image on the right shows the velocity contour at the merge point.

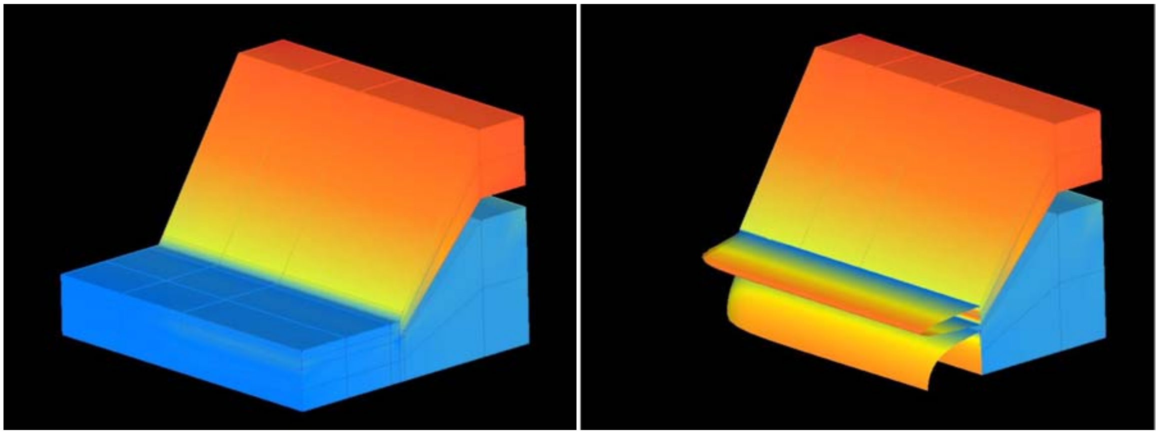

Figure 6 3D FEM simulation of two layer feed-block; pressure (left), velocity at merge (right).

Figure 7 shows two additional views of the flow field with a ring to emphasize the velocity contour that exists near the edge wall. While the velocity in the center of the

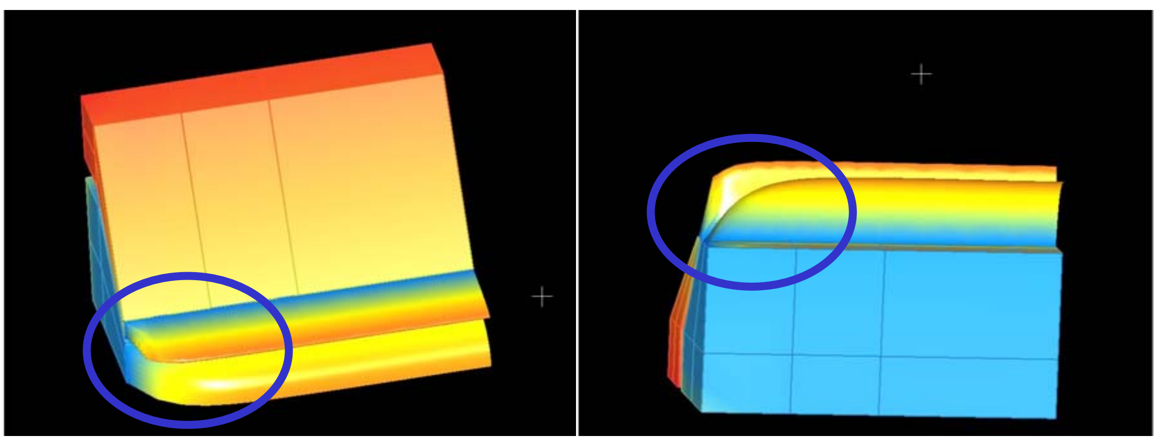

Figure 7 3D FEM simulation of merge region velocity; upper view (left) and lower view (right)

flow field is relatively uniform, the velocity begins to taper off to zero as you approach the wall. It can be seen from figure 7, that this effect is different for each channel. The upper channel in the Figure 7 left has a more uniform velocity for a wider section of the channel and tapers off to zero velocity over shorter distance than the lower (bigger) channel. The circled area, in the right image of figure 7, shows this difference quite clearly.

This difference in velocity affects the relative layer thickness in this area which affects the layer thickness uniformity of the final product. This also determines how much edge trim (scrap) must be taken off of the production sheet.

Figure 8 shows the velocity contours in a feed-block that uses vanes (lamellas) to divide the flow in each channel into more channels. In this case the upper channel is divided into two channels and the lower layer is divided into 4 channels.

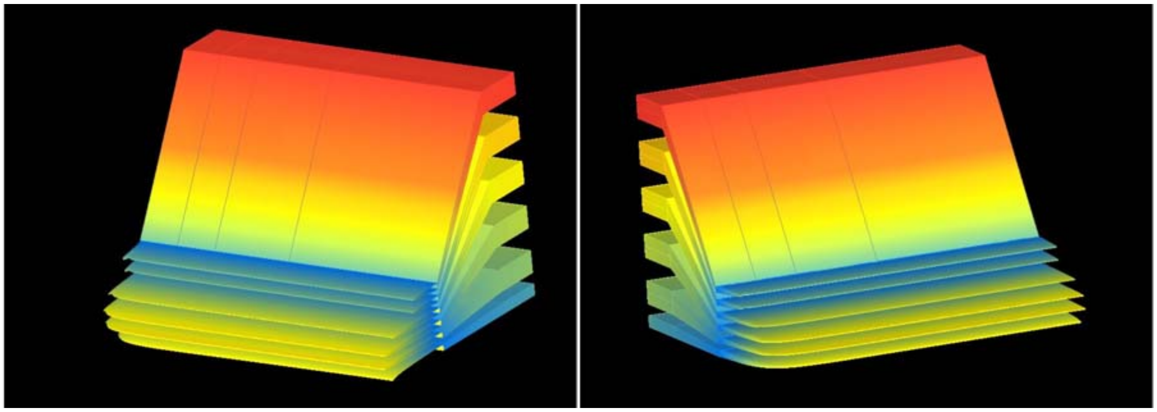

Figure 8 3D FEM simulation of feed-block with vanes

The addition of the vanes makes the aspect ratio of the channels larger which, minimizes the edge effects near the wall. This way, more of the material combines with a more uniform velocity across the width of the feed-block which can result less edge trim and more saleable product.

FEED-BLOCK PROFILING AND GEOMETRIC ENCAPSULATION

The previous example demonstrated how improvements could be made to the feed-block coextrusion process with the aide of vanes in the feed-block to "reshape" the material flow in the merge region. In fact, this is generally taken one step further to help offset the layer encapsulation phenomenon that occurs in feed-block coextrusion. As shown in figure 9, the encapsulation phenomenon causes a relatively uniform input into the die (from the feed-block) to result in a non-uniform layer distribution at the die exit.

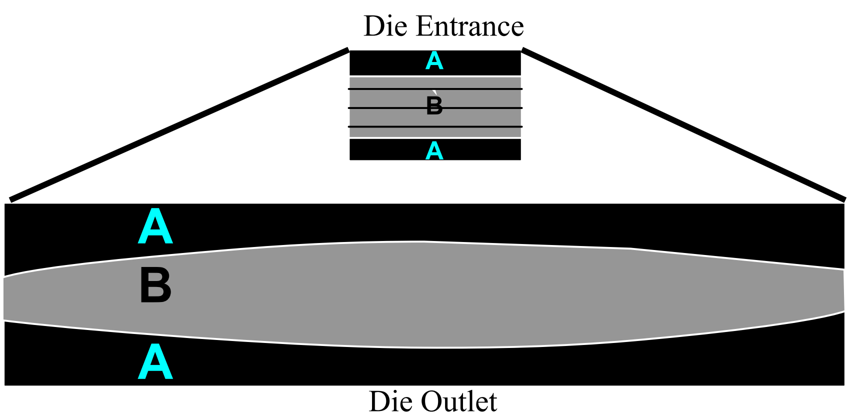

Figure 9 Representation of the encapsulation phenomenon

While many believe that the main reason for the encapsulation is due to viscosity differences between the materials, but this does not explain why the encapsulation phenomenon is observed when coextruding the same polymer (with different colours) in all layers. It has also been postulated that visco-elastic effects and secondary flows can be the cause of the encapsulation and while this can have an affect; it is not believed to be the major driving factor.

The feed-block coextrusion process was investigated using a fully 3D Finite Element Method simulation. A three-layer structure, as shown in figure 9, was assumed. It was further assumed that all 3 layers had the same material (same viscosity) and visco-elastics effects were neglected, in order to see if there was some other reason for the encapsulation. A uniform inlet interface was specified by defining particles in a straight line at the die entrance. The particles where then tracked to the die exit where, once connected, would define the shape of the interface at the exit. The results showed that there was a tendency for the outer layers to encapsulate the middle layer even when the overall flow distribution across the width of the die was very uniform. This result was originally quite surprising. However after more analysis, it was determined that the encapsulation phenomenon was significantly influenced by the shape of the flat die manifold and the natural flow patterns that occur as the material leaks out of the manifold towards the die exit. Figure 10 shows an extrusion direction, velocity profile superimpose on a cross section of the flat die manifold and restrictor.

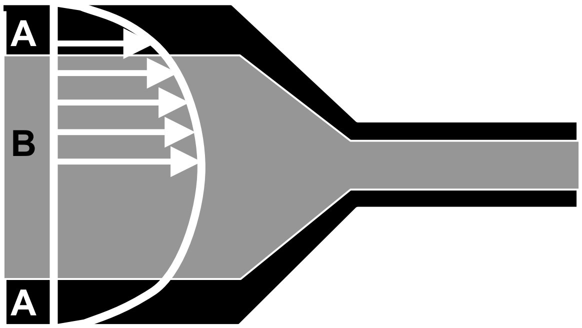

Figure 10 Cross section through the manifold and restrictor

Basically, the center layer has a higher average velocity than the layers that flow near the wall so that the material that flows in the center ends up leaving the manifold faster than the material near the walls. As more and more of the middle layer material leaks out of the manifold near the center of the die, there is proportionately less of the middle material at the die edges. This results in the materials near the appearing to become thicker as it proceeds toward the edge of the die. The net effect is that the materials near the wall end up having more relative presence at the edges than in the center which appears as an encapsulation effect. Once this is understood, the manifold design can be optimized to minimize the “geometric encapsulation” effect.

However, another solution would be to reverse engineer the shape of the interface that is required at the die entrance (feed-block exit) to obtain a more uniform interface at the die exit. In fact, one of benefits of simulation is that particle tracking can be performed either forward or backwards. Particles placed at the die exit to define a uniform layer layer thickeness (flat interface) can be tracked backwards to see how the layers should be arrange in the feed block to achieve the desired result. This is referred to as “feed-block profiling”. This is a powerful technique that can be used to reduce the time it takes to profile the feedblock. This is discussed in more detail in a paper by Perdikoulias and Svabik [5].

LAYER THICKNESS LIMITS

In another study it was determined that there was a limit to the layer ratio that could be used in the production of a two layer product. An experiment was performed in which the layer ratios were systematically altered from a thin top layer to a thick top layer while maintaining a constant total throughput. Figure 11 represent three conditions run in the experiment; unstable (thin top layer), stable, unstable (thick top layer). In an effort to understand the reason for this observation, 2D FEM, flow simulations were performed but in this case, the visco-elastic material properties were considered [6]. The maximum stresses calculated for this experiment are also included in figure 11.

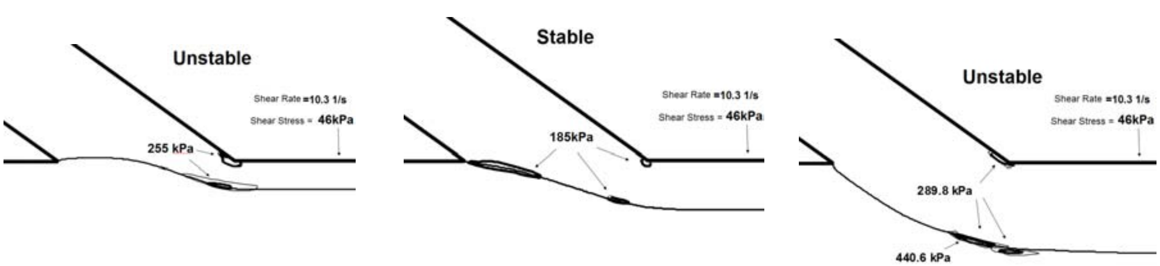

Figure 11 2D FEM flow simulations at 3 layer ratios; unstable (left), stable(middle) unstable (right)

The results of the simulation show that the maxim stress level is higher in the case of the unstable flow field which suggests that a critical stress level results in the instability. The simulation helps to quantify this stress level so that the unstable conditions can be avoided in future experiments or product development. Furthermore, the information can be used to help design new equipment that results in a larger, stable, processing window.

CONCLUDING REMARKS

This paper has shown how flow simulation can be used to help explain some flow phenomena that are unique to the coextrusion process. Coupled with experimental observations, flow simulation helps to better understand the phenomena that occur and to quantify them so that they can be avoided in the future.

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