THE EFFECT OF MATERIAL SELECTION IN FEED-BLOCK COEXTRUSION OF A THREE LAYER FILM

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Abstract

This paper describes a case study dealing with the development of a three-layer product on a feed-block coextrusion system. The problems or phenomena that occurred during the product development experiments are explained via flow simulation and the rheological properties of the materials used. The results of the study are compared with real film samples produced during the development

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 cannot be obtained from a monolayer product or blend. However, coextrusion also brings along some unique problems [1,2,3].

This paper will describe a case study, in which simulation was used to help understand and ultimately solve a problem related specifically to coextrusion. The simulations in this paper were performed with the Compuplast® Virtual Extrusion Laboratory Software™ (FLOW 2000) [4]. The problem occurred during the development of a 3-layer feed-block coextrusion where the top layer was a PETG material, the central layer was an LDPE based adhesive and the bottom layer was originally an LDPE material. The layer percentage was 20% of PETG, 10% of the adhesive and 70% of the LDPE material. The experiments were performed on a lab line with a 250 mm wide die. Initially, a great deal of experimental work was performed in an effort to get an acceptable product but this often resulted in a product like that show in Fig. 1. The sample suffered from surface distortion (waviness) and had also some microscopic cracks. Since the experimentation with process conditions did not lead to any positive solution the focus was put on changing the LDPE layer material. However, even this did not bring any acceptable results. When this attempt failed the company finally decided to try and take a more scientific approach to the development through the use of flow simulation. This paper describes the results of the simulations performed. It is also worth mentioning the time frames of both approaches. The experimentation was performed over about a four-month period and did not lead to any acceptable solution. The simulations were performed in about six hours and led to a solution.

Experiments and Simulations

Many attempts were performed to determine stable operating conditions with no success. The reason for the initial failure can be easily explained through some analysis of the rheology and the flow fields. Fig. 2 shows a comparison of the viscosities of the PETG material and the adhesive and LDPE material. It is clear that there is a big difference in the viscosities of both layers, the PETG material is much more viscous. Therefore we can expect a lot of problems in feed-block extrusion when theses materials flow together for a long time.

Fig 3. shows the flow domain for a 2D study of the flow behavior. Even if the problem is in reality a fully 3D problem we will see that we can get a lot of information and the solution from the 2D simulation. As it is now, there is no 3D solution available for solution of such a problem. The flow domain in Fig. 3 shows the shape of the cross-section on the plane of die symmetry (centerline). Since we are focusing on the effects of the 3 layers within the die, the exact die dimensions were used but the feed block was neglected and the simple inlets shown in fig 3 were used to simply combine the 3 layers.

Fig. 4 shows the extrusion direction velocity profile, in the deep manifold channel and at the die lips. It can be seen that in both cases the LDPE material flows with a higher velocity than the PETG. This is because of the very different shear viscosities [3]. After the material leaves the die the velocities must be balanced to one pull-off velocity (take up speed). This means that the LDPE material is going to be decelerated and the PETG material will be stretched. The deceleration is somewhat compensated by swelling but the swelling can happen up to certain limits. From experience we have found that if the material is expected to swell more than 50% it prefers to corrugate. Corrugation is nothing more that compensating the continuity equation by length instead of thickness (waving). This is the reason why the sample in Fig. 1 has the waves. On the other hand, the PETG material is stretched. If the stretching is very high and the material cannot handle the deformation then it breaks (tears). It should be mentioned that the wall shear rate in the manifold channel is around 101/s and in the die lips around 300 1/s. The sample from Fig. 1 also suffered by small cracks in the PETG layer. This film sample also did not show much layer encapsulation because the feed block was "profiled" to compensate for this effect.

The next attempt was to use another material for the LDPE layer. The comparison of the viscosities is shown in Fig. 5. It can be seen that in this the viscosity curves cross and this selection of the materials has several interesting consequences. The velocity profiles are shown in Fig. 6. The first consequence is that because of the low wall shear rates in the manifold, the PETG material now has a lower viscosity than the LDPE and therefore it will tend to encapsulate the less viscous material as they flow in the manifold channel. Since the feed block was originally "profiled" for the reverse condition, encapsulation can be seen on the edges of the film on a sample from this experiment shown in Fig. 7. Another interesting thing is how the velocity profile changes when the material flows in different sections of the die. This is because of the different wall shear rates in each section which correspond to different positions on the viscosity curves. It can be seen that despite the material change, the viscosity of PETG is again higher at the die lips, so the conditions (velocity profile) at the die exit were not changed very much. Therefore the film sample suffers from similar cracks and waving as before. Overall we can say that the second case was even worse than the starting one because beside the waving and cracks also the observable encapsulation was generated.

Solving the Problem

It is clear that there are mainly two problems to be solved. One is to avoid the encapsulation at the manifold channel and the other one is related to the velocity rearrangement at the exit. Then the velocity rearrangement can be solved if we find a PE material with a very similar or identical viscosity curve as PETG. Unfortunately, such a high viscosity LDPE with little shear thinning behavior could not be found. An alternative to this is to find a material, which has as close viscosity as possible to the PETG curve in the region of low shear rates (around 10 1/s - manifold) and high shear rates (around 300 1/s - die lips). If a material becomes a potential candidate, the simulation can be used to evaluate the velocity profiles influenced by the differences in the viscosities and whether the deviation is acceptable. A suitable LDPE material, which would be close enough, could not be found. The reason being that LDPE materials are generally quite shear thinning. However, a search of some LLDPE materials, which are generally less shear thinning, resulted in a material that had closer shear thinning behavour as shown in Fig. 8. Fig. 9 shows that the velocity profiles at the manifold and die lips are much closer to the parabolic profile, which is needed for good material performance. Subsequent experiments confirmed that this material did indeed produce a much more acceptable product without the waves and distortions that were previously observed.

At this point, it is worth mentioning the time frame for the experiments versus the simulation work. The experiments were performed over about a four-month period and did not lead to any acceptable solutions. The simulation work was performed in about six hours and ultimately led to a solution

Finally, the reader is reminded that the product development was initially performed on a lab line which will most likely not have the exact same geometry as the production line. The added advantage of using simulation is that it will be easier to evaluate the potential success of scaling up to the production line geometry as the critical conditions are understood from the lab line.

Conclusions

The case study presented shows the usefulness of simulation during product development and for better understanding some extrusion problems that can occur. The solution of the problem seems to be relatively easy and straightforward. "Find a material with close enough viscosity". In fact, this was a big part of the simulation to quantify this simple verbal statement and find, among the many potential materials, one which deforms the velocity profiles in the critical sections the least.

References

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4) Compuplast International Inc., Zlin, Czech Republic, 2004

Figure 1: A three-layer sheet sample with distortion

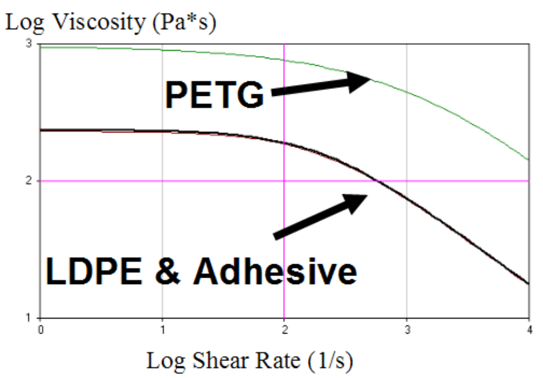

Figure 2: A comparison of the shear viscosity of the 3 materials that were used in the initial experiments.

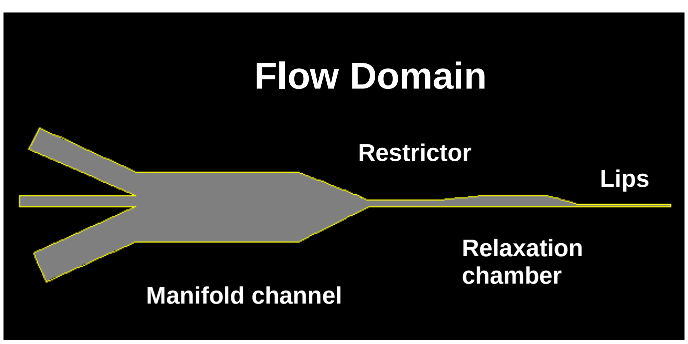

Figure 3: Cross section of flat die flow field

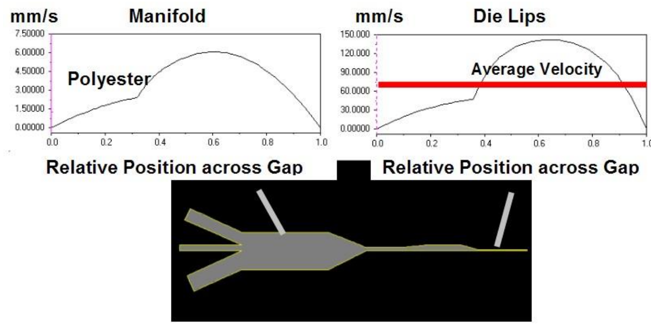

Figure 4: Velocity profile in Manifold (left) and Die Lips (right)

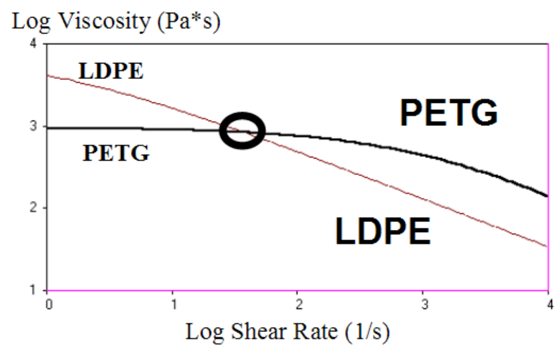

Figure 5: A comparison of the shear viscosity of the PETG material and newly selected material showing the cross over point.

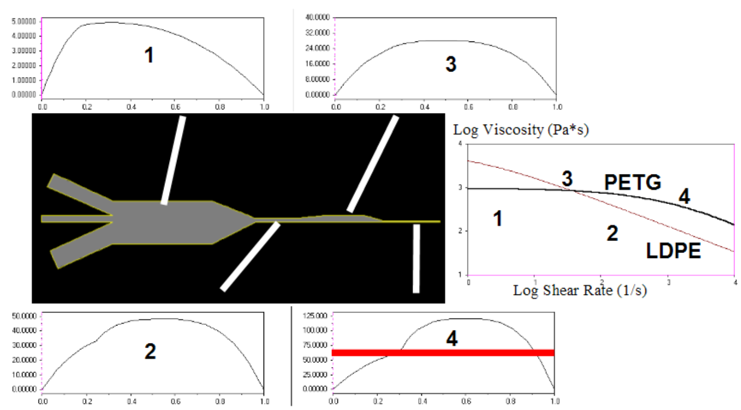

Figure 6: Velocity profiles (mm/s) in different parts of the die in relation to shear viscosity

Figure 7: A three-layer sheet sample with poor layer distribution and distortion

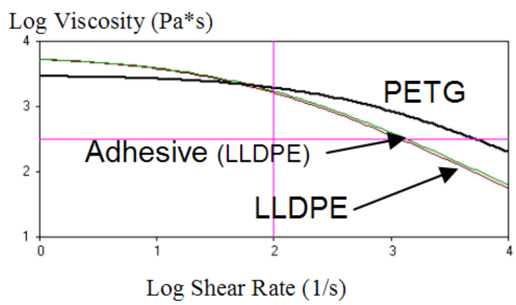

Figure 8: A comparison of the PETG material viscosity with the selected LLDPE material.

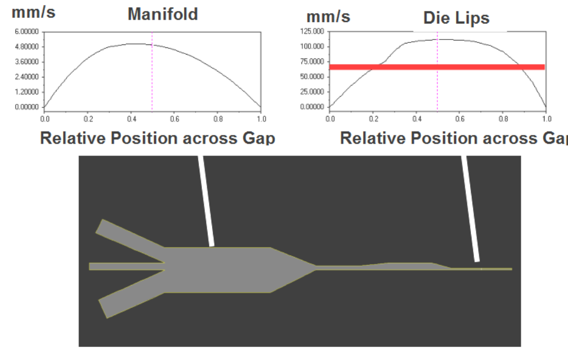

Figure 9: Velocity profiles (mm/s) for closer matched materials in the manifold and lips section.