COMPARISION OF FLOW STRIATIONS OF VARIOUS SSE MIXERS TO THE RECIRCULATOR AND ELONGATOR MIXERS

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Abstract

The Stratablend (trademark Newcastle), Energy Transfer, Variable Energy Transfer, and DM2 with Eagle mixer are well known single screw extruder (SSE) mixers. They have been diligently compared by mixing black ABS color concentrate pellets into a bright opaque ABS. This contrast reveals color striations and unmelts. The comparison is readily seen by eye.

This paper compares a Recirculator screw and an Elongator screw using the same technique. Since no striations could be seen by eye, the extrudate was sectioned and examined by microscope at 100 and 200 times magnification showing no striations with the Elongator screw.

Introduction

Mixing is an integral part of extrusion. Good quality extrusion requires polymer and thermal mixing. Often mixing of particulate, additives and so on is crucial to the quality of an extrudate.

Historically single screw extruders (SSE) have placed mixers towards the end of the extruder screw and relied primarily on shear mixing. The results have not always been very satisfactory. Twin screw extruders, by contrast, have placed multiple mixers along the screw and relied primarily on elongational flows for mixing.

Several studies have measured mixing on a highly instrumented single screw extruder (SSE) by looking at the color distribution of black color concentrate pellets in a bright, opaque ABS extrudate. This provides good contrast between the black concentrate and the bright, opaque ABS. A control screw is then compared to a mixing screw. The improvement in mixing is apparent and readily judged eye. The fineness of the color stria and the intervening bright material are visible.

Very consistent mixer studies include the Maddock [1, 6], Stratablend (trademark New Castle) [2], Energy Transfer [3], Variable Barrier Energy Transfer [4], and the DM2 with Eagle Mixing Tip [5]—generally referred to as high performance screws. One study even includes the more complex Twente mixing ring, the Barr sleeve mixer and a Barr ring mixer [6]. These papers describe a spiraling pattern in the extrudate. The spiraling pattern is completely obvious in the control screw. But once the mixers are employed, sometimes, the mixing pattern is difficult to see. However, anyone can readily find the patterns referred to if the images are copied and brightened. For example, see Fig. 1. The original is copied in Adobe Acrobat at 400% magnification from the Antec technical library from [4]. Fig. 1 shows the 90 rpm control on the left and the improvement from the mixer in the middle picture. The spiral pattern, often referred to in the cited papers, is difficult to see however. To see the pattern more clearly, once it is imported into Powerpoint, click the “brighten” picture command 5 times. The spiraling pattern becomes readily apparent and is shown on the right. This is necessary because, while the improvement of the mixer is very good, when one sees the spiral pattern that remains, there is clearly room for improvement.

In this study, two newer mixers are tested using the same basic technique as the cited studies. These are the Recirculator (hereafter AFEM for axial fluted elongation mixer) and the Elongator (hereafter SFEM for spiral fluted elongational mixer). The study uses ABS black color concentrate pellets mixed with precompounded bright color concentrate for a contrasting background.

It would not be good science to say that because the technique used in this paper is the same, that the results are then necessarily comparable to the prior studies. For example, the cited studies use only a 21/1 L/D extruder. Longer screws, such as the 24/1 and 36/1 used in this study, are well known to mix a little bit better—but not much better. Otherwise, we would just make longer screws and there would be no need for mixers. The cited studies also use a 63 mm screw. This study used smaller screws at 16 and 25 mm diameter. It is well known, that small screws do not mix as well as large screws owing in part to the much lower shear rates.

All this aside, what we are interested in showing in this paper is to compare the fineness of the stria in an absolute sense. If, while using this technique, the mixers show very much finer stria, then the difference in machinery and the purity of the scientific method are less important than showing the mechanism of mixing that can generate such fine stria.

It seems logical that multiple mixers are more likely to mix better than one mixer. In this study, multiple AFEM and SFEM mixers are placed along the extruder screw, Fig.3, just as twins screws place multiple mixers along their axis. This can be done because the AFEM and SFEM’s C1 channel is non-compressing and open ended so that material does not jam as is common for barrier screws. As in the graphics, the AFEM and SFEM and mixers can then be placed far upstream allowing for 2 to 4 mixers. Because melting begins within the first AFEM and SFEM mixer, there is no reason to place them after melting as in the conventional SSE.

These mixers have shown surprising mixing. As in the cited studies, most extrusion mixing is simply judged by eye. Yet, the AFEM and SFEM mixers have shown a much finer degree of mixing judging by the scale of the pictures in the studies. These mixers also show surprising flexibility.

For examples of scale, the well studied immiscible polymer blends show the minor phase at 2 microns where 2 AFEM mixers were used [7] and 1 micron where 3 AFEM mixers are used—the same as twin screws [8]. In terms of particulate mixing, 45 nm ceramic particles are well mixed at the 500 nm scale [8].

For examples of flexibility, when 35% talc powder was mixed polypropylene (PP) pellets using 3 AFEM mixers, a strand nearly as smooth as unfilled PP was produced [7]. The SFEM screw is known to process rigid polyvinyl chloride (RPVC) pellets at 90 and low temperatures [9]. It can even process RPVC powder at up to 180 rpm [10] at low temperatures both previously unknown. Thin film vents can be placed over each SFEM mixer [11] for increased degassing and efficiency. PP foam has been demonstrated [12]. Finally, while PP is well known to process at about 30% lower rates than PE, the SFEM mixer demonstrated a 100% increased rate [13].

Materials

Acrylonitrile-butadiene-styrene (ABS) was used for the background resin. It was compounded with color concentrate (Colorcon 44562 neon yellow 25:1) pellets at 12% to form the bright, opaque background for the black color concentrate. The black color concentrate was mixed at 0.5, 1.5 and 3%.

Equipment

Two extruders were used for this trial. The first was a vertical, discharge driven, 16 mm diameter by 24/1 L/D with a 1.1 kilowatt (1.5 HP) drive and 15:1 transmission. It was equipped with a conventional control screw with equal parts feed, compression and meter, feed channel depth 4.6 mm and 1.52 mm meter depth. A second screw was equipped with two AFEM and the same feed and meter channel depths. Referring to Fig. 2, pump 1 (P1) and P2 clearances of the screw were 1 mm.

A second extruder was also used, horizontal type, 25 mm diameter, 36/1 L/D with three SFEM mixers, three vents and a 3.73 kilowatt (5 HP) drive. The screw had a 4.6 mm feed depth. The screw had a removable tip. For the compounding, a 1.5 mm channel depth was used. For the mixing study, a 2.3 mm meter depth. The mixers had a P clearances of 1 mm.

The horizontal extruder was used to do the compounding of the bright background material with the first two vents open to atmosphere to insure degassing of the ABS and color concentrate. The vents were of the thin film degassing type [11] and were located over the mixers themselves. The first vent location was 8 L/D beyond the water cooled feed section; the second vent location was 16 L/D beyond the water cooled feed section. For the compounding of the ABS and pigment, the extruder was starve fed but flood fed for the mixing experiments.

For the mixing experiments, the compounded ABS was dried using dessicant type driers for 6 hours at 82C and the extruder vents were plugged.

A single strand die, 3 mm diameter, was used to make the 2.54 mm diameter extrudate for examination. It is not clear from the previous studies what diameter die was used nor the extrudate dimensions.

Experiments

For the trials, no breaker plate or screens were used so as not to mix the extrudate beyond what the screw achieved.

For the 16 mm extruder, the rpm was 30 for all carbon black pellet blends.

For the 25 mm trials, all blends and blending were processed at 90 rpm.

Temperatures were 193C for all zones, all trials on both extruders. Some previous studies [2, 3, 4, 5, 6] were carried out using much higher barrel temperatures at 200 (feed), 230, 250C. It is not clear why the temperatures were set so high for ABS. Our experience is that normal ABS processing temperatures are lower so we elected to do our study at lower temperatures.

Output for the 25 mm extruder at 90 rpm was 10.2 kg/hr. which would be considered high for this size extruder.

A simple optical microscope was used with 100 and 200 magnification. Sections were done by hand using a razor blade.

Results

In the experiments, the conventional screw without mixer showed very poor quality mixing for all the color loading, figures 3 to 5. It is well known that small screws mix more poorly than large ones and a 16 mm is a very small extruder.

It is also well known that, especially with small extruders, machine direction color variation will occur. Since there is only one concentrate pellet for every 200 pellets in a 200:1 let down—and since there the extruders used are so small—it is likely that there are times when there is no color pellet in the extruder! So, one may reasonably expect machine direction variation with the variation in concentrate pellets entering the screw.

For the two mixer AFEM screw, at 200:1 let down, machine direction color variation could be seen in the strand while watching it exit the die. This decreased for the 67:1 let down. It again decreased again for the 33:1 let down to the point that the observer wasn't sure whether he was seeing variation or not. However, when you took a coil of strand and looked at a side by side comparison of strands, there was machine direction variation. For the figures, average color strands were chosen to section.

For the SFEM, at 200:1 let down, it was difficult to see machine direction variation while watching. Again, a coil of extrudate allowed side to side comparison and variation over time was seen. At the 67:1 and 33:1 let downs, machine direction variation in the coils were not seen.

Discussion And Conclusion

The two mixer AFEM [14] screw shows a very significant improvement in the fineness of the stria compared to the control for all let downs. Since these experiments were done at 30 rpm, the yellow material probably is fully melted and the yellow interleaving simply represents poor mixing.

The three mixer SFEM [14] screw shows much better mixing. It should not be surprising that a three mixer SFEM performed much better than the two mixers AFEM—much as a twin would be expected to have better mixing if it had three sets of kneading blocks instead of two.

None of the three mixer SFEM display the spiral pattern that occurs in the other studies [1 to 6] at any let down ratio. There are no pronounced color stria with intervening white material. In Fig. 6, the 200:1 let down of Fig. 3 was brightened to look for undispersed pigment. Only very small darkened areas of pigment are visible.

Most of the "variation" in the SFEM pictures are an artifact of our razor blade sectioning rather than extrudate flaws.

It should be noted that all of these trials were done at low temperature which will likely prevent degradation.

It should be noted that the output of 10.2 kg/hr at 90 rpm is a very respectable rate for a 25 mm extruder.

We believe that the reason for the success of the mixer is that the SFEM generates multiple extensional flow fields. Greater explanation of the elongational mechanism is found in the references [7 to 15].

Overall, it is difficult to say how much better the three mixer SFEM is over the control. If you look at the improvement of the AFEM, though, we can make a very crude measurement of the improvement. Looking at Fig. 5, 200X, control, there are two major bands clearly visible. Looking at AFEM picture to the right, there are about 20 striations or about an order of magnitude improvement over the control. We cannot see any striations in the three mixer SFEM so we can assume, at least, that the mixing improvement is very significant. In the future, perhaps better microscopy and higher magnification can reveal striations or a spiral pattern so that a true measurement of the improvement will be possible.

References

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Figure 1

Center and left, M. Spalding et al, *"Performance of a Distributive Melt Mixing Screw with An Advanced Tip," Antec 2004.* Right, center picture brightened by author.

Figure 2: Three AFEM And SFEM Mixers And Cross Section Of Both

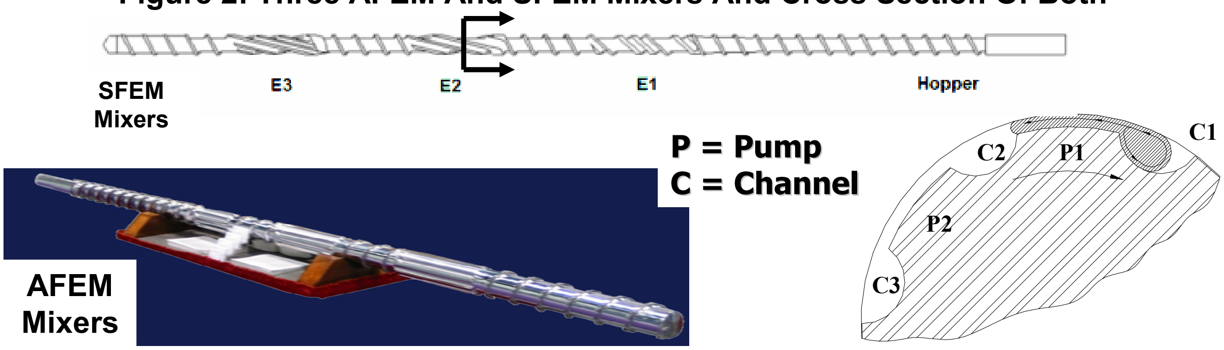

Figure 3: 200 to 1 Let Down

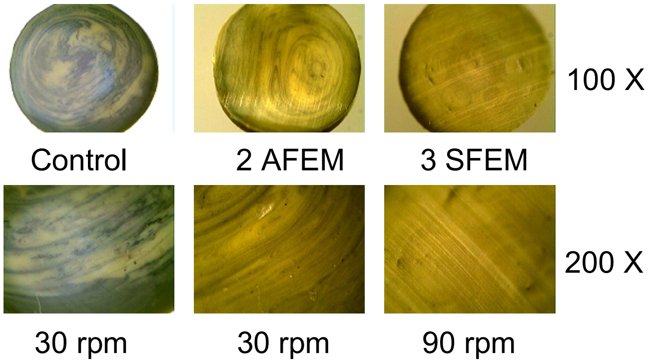

Figure 4: 67 to 1 Let Down

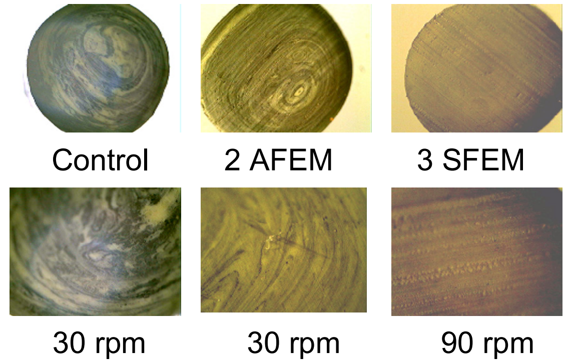

Figure 5: 33 to 1 Let Down

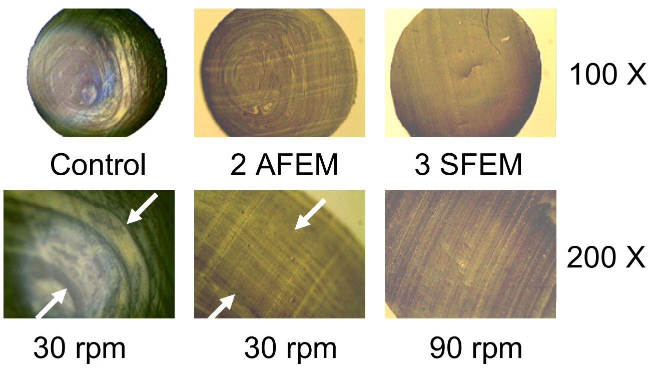

Figure 6: 200 to1 Let Down- 3 SFEM

Brightened In Powerpoint 5 clicks