11.4

Extrusion Problems and Troubleshooting

11.4.1. Melt Fracture

When the extrudate has a rough surface, especially with short cracks or ridges that are oriented in the machine direction or helically around the extrudate, the phenomenon of **melt fracture** has likely occurred. This material defect occurs because the tensile forces on the extrudate exceed the critical shear stress and shear rate of the melt. Hence, the material experiences random fractures. The fractures generally extend through-out the extrudate, not just on the surface. Turbulent flow in the die is one of the principal causes of melt fracture. This turbulence (flow that has eddies and convolutions rather than being smoothly layered) is most often present when the die is not properly streamlined. Examples of non-streamlined and streamlined dies and the differences in extrudates are shown in Figure 11.10. Melt fracture can also occur with streamlined dies, especially when the diameter of the part is small. Low temperatures of the melt and high molecular weights also contribute to melt fracture.

Melt fracture can be reduced by the obvious steps of streamlining the die, raising the melt temperature, and selecting a resin with a lower molecular weight. A long land length will also help to reduce melt fracture because the long land forces the material into laminar flow (smoothly layered flow) and provides sufficient time to relieve stresses that might have been introduced in the melt. Low molecular weight fractions or other processing aids that facilitate melting and reduce shear can also help in reducing melt fracture, as can lowering the extruder speed.

11.4.2. Sharkskin or Alligator Hide

If the surface of the extrudate is rough but with lines running perpendicular to the flow direction, the phenomenon is likely due to a tearing of the surface of the melt. This phenomenon is called **sharkskin** or **alligator hide**. This defect is different from melt fracture stresses because the stresses that give rise to sharkskin arise from laminar flow. As the material is flowing, it will develop a flow profile, with the center of the material flowing faster than the edges due to the friction of the material against the edges of the die. The material in the center of the flow column slides against itself easier than it can slide against the die walls. As the material leaves the die, the outside material has to accelerate to the velocity at which the extrudate is leaving the die. This generates tensile stress and, if the stress exceeds the tensile strength, the surface ruptures, causing the defect. In some cases, the outer surface will "snap back" to relieve the tensile stresses and the part will take on the appearance of a sectioned rod, somewhat like bamboo. **Bambooing** is the term for this severe state of the defect. When the differences between the applied stresses and the tensile strength are small, the material may simply form surface dimples, a phenomenon called **orange peel**. Sharkskin, alligator hide, bamboo, and orange peel are worse if the resin is stiff (high modulus) and if the pressure in the extruder (high extrusion speed) is excessive. Lower temperatures in the die also exaggerate the problem.

These defects can be reduced by heating the resin, especially at the die, and by reducing pressure and the speed of the extruder. A broad molecular weight distribution will also reduce the defects. A larger gap in the die would reduce the stresses, but more drawdown would be required to maintain the same part size. Processing aids to lower overall viscosity and running slower will help.

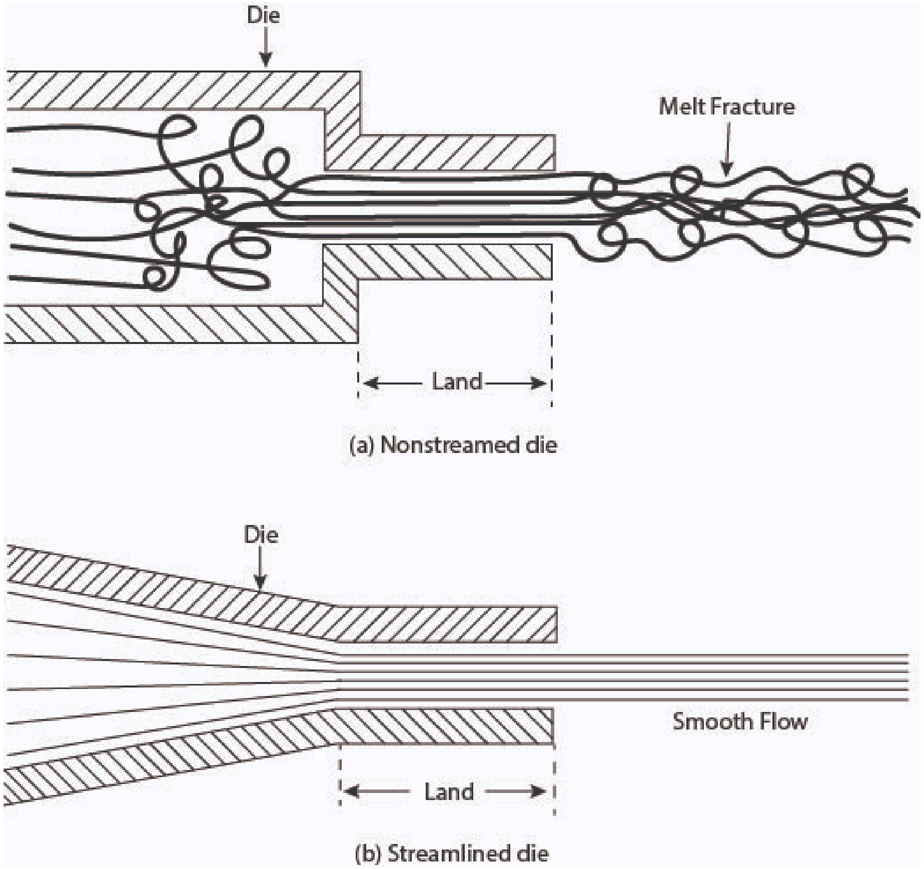

Figure 11.10 The effect of streamlining in a die to prevent melt fracture.

11.4.3. Uneven Flow and Surging

A cyclical variation in the extrudate thickness with a cycle time of from 3 seconds to 3 minutes is called uneven flow, or **surging**. The ammeter on the extruder will often reflect this surging pattern by cycling over a wide amperage range. Pressure ranges could also reflect the same pattern. Several different problems in the extruder could cause this uneven flow. One could be inadequate screw speed control. The motor could be undersized or the speed control inadequate for the size of the screw or the type of material. If surging is caused by this problem, the cure is to move to another machine with greater capacity or, perhaps, raise the temperatures so that the load on the extruder will be less. A major contaminant, such as a piece of metal, could also cause surging as it is pushed against the barrel by the flights of the screw. If the contaminant is large, the screw may have to be pulled and cleaned to cure the problem.

Another possible cause is associated with a mismatch between the screw dimensions and the bulk density of the material being extruded. If the screw was designed for pellets and a less dense, fluffy material is being extruded, the depth of the flights in the feed section may not be sufficient to move enough material to keep the extruder flowing smoothly, resulting in a surging of the extrudate. The problem can be solved by changing to a deeper-flighted screw or by densifying the incoming fluffy material. Densification can be done by several methods, including (1) extruding the fluffy material into pellets using a machine with a more appropriate screw, (2) compressing the material in the hopper with an auger (called a **cram feeder**), (3) spinning the fluff at high speed so that it shrinks and balls up into little particles, or (4) if the fluff is made by chopping filaments or film, eliminating the chopping of the material by feeding the scrap directly into the extruder. Another method for getting poorly flowing material into the extruder is **starve feeding**. In starve feeding the screw runs so fast that whatever material drops from the hopper is immediately carried forward. Then by limiting the flow of material through the hopper, all material is transferred evenly and the flow is controlled.

Partial bridging could also cause surging. In this case, the resin could be clinging to the screw in the feed zone. Traditional bridging would be solved by lowering the heat in the feed zone of the extruder, but partial bridging could arise from on/off heating cycles that are too long, which could be detected by comparing the frequency of the surging with the heating cycle. If the heating cycle is the problem, changes in the heater control cycle will solve the problem. Similarly, the feed from the hopper could be uneven, perhaps dropping as clumps into the feed throat and then moving in an uneven flow through the extruder. A feed auger could solve this problem. An investigation into the cause of the clumps should also be made.

Surging could also be caused by a locking up of the solid mass of resin in the decreasing flight depths of the compression zone and subsequent irregular melting. Sometimes raising the temperature of the feed zone or the compression to get better melting will alleviate this problem. A downstream cause of surging could be slippage in the puller. This can be solved by tightening the grip on the part or by changing to different puller belts or a different type of puller.

If none of these solutions work, simply lowering the speed of the extruder may help, as could increasing the back pressure by using more or finer screens in the screen pack. If these do not solve the problem, the ultimate solution to surging is to install a gear pump.

Note that noncyclical thickness changes might be mistaken for surging. These changes are more likely due to gradual drifts in the extrusion line, as from slow plugging of the screen packs or from long-term temperature drifts, perhaps even day/night cycles.

11.4.4. Degradation

Discolorations and lower physical or mechanical properties of the part indicate degradation. A strong odor may also occur. If the degradation is general—that is, the entire extrudate is affected as shown by discoloration throughout, although darker streaks may also be present—the most likely cause is that the heat is too high for the speed of extrusion. The obvious solutions are to reduce the heat or to increase the extrusion speed. Some combination of these two is likely, since the speed of the extruder affects mechanical heating of the material.

Nonuniform degradation could show up as specks of dark material in the extrudate. This type of degradation could come from material that is trapped or adhering to the surfaces inside the extruder and are therefore degraded by the long residence times at high temperatures. The remedy for this problem is to improve the flow pattern of the material through the extruder. These changes may be difficult to make because they require equipment modifications. However, the most likely region for problems is in the die, which can be modified more easily than other parts of the extruder. Problems upstream from the screen pack will usually show on the screens and probably will not show up in the extrudate. If resin changes are made frequently, the degraded material may be a past resin that is not fully purged. In this case, a better purging material or procedure is indicated.

11.4.5. Poor Mixing

Streaks or particles in the extrudate could also result from poor mixing, usually from running the extruder faster than it can mix the materials. Slowing the extruder speed is the most obvious remedy. Increasing the back pressure will also improve mixing and may be advantageous because output will not be reduced as much. The back pressure could be increased by using more or finer screens and by cooling the metering section and die. Heating farther back in the extruder could also improve mixing.

Some mixing problems are so difficult that a separate step in a special mixer should be done before the material is introduced into the extruder. Another solution is to extrude the materials separately and then add these premixed materials as a pellet that can be mixed with the resin more effectively. Such materials are called **concentrates**. Materials that are often concentrated in this fashion are carbon black, colorants, antioxidant, and thermal stabilizers.

Changing the screw or adding special mixing devices inside the extruder barrel are other methods of improving mixing. Some examples include increasing the *L/D*, using a static mixer at the end of the screw, and using a screw that is optimized for the particular resin and extrusion conditions, but these are difficult and costly changes to make.

11.4.6. Contamination

Contamination could be yet another cause of streaks or spots in the extrudate. Small dimples or discolorations on an otherwise uniform surface are sometimes called **fish eyes**. The contaminants can be distinguished by examining the part under a microscope, with solvents, or by some chemical analysis technique. Examination of the screen pack will often confirm the existence of contaminants. Contamination may be difficult to distinguish from incomplete mixing, as might be the case with incompletely mixed carbon black or other pigments. Contamination is a common problem, especially when the extruder is used with many resins. One source of contamination is, therefore, material from a previous run that is not fully purged.

The most common way for contamination to enter the extruder is through an open hopper. Contaminants could include dust, other resins that might have been in the conveying lines, incompatible materials introduced with regrind, paper or other resin packaging materials, or sim ply materials that fall into the hopper or other parts of the resin conveying system. The solutions include keeping the hopper covered, putting filters in the conveying system, inspecting incoming material, and isolating regrind operations by resin type. Decreasing the opening size of the screens can also stop contamination, although this will result in faster plugging of the screens, less even flow, and more frequent screen pack changes.

11.4.7. Bubbles in the Extrudate

Excessive moisture or volatiles can be absorbed by the resin and then vaporize when the melt exits the die and the external pressure is reduced, resulting in bubbles within the extrudate. Surface defects can also result. Some resins, such as PET, nylon, and polycarbonate, degrade severely when heated in the presence of moisture. Moisture levels of less than 0.1% are recommended for these resins.

Several methods are available to reduce the amount of moisture and volatiles. The most effective is to pass all of the resin through a dehumidifying dryer and to pneumatically con- vey the resin through the drying system and into the hopper. Other drying methods include blowing dry air through the resin while it is in the hopper, using the resin directly from the bag (if bagged resin is used), and storing the resin in a low-humidity location, usually at or below the extruder ambient temperature. Venting the extruder will also re- move moisture and volatiles.

Air entrapment will also cause bubbles in the extrudate. These bubbles tend to be less regular and less numerous than the bubbles from moisture and volatiles. The air entrapment is usually the result of an improper match between resin and screw. The usual remedial actions are to increase the back pressure by using more or finer screens and to lower the barrel heats. Because of the screw-dependent nature of air entrapment, another remedy is to lower the screw speed, which will allow the air to flow backwards in the extruder and will permit the screw to act more effectively.

11.4.8. Troubleshooting

The extrusion problems are very complex and any attempt to reduce them all to one table or guide with some possible solutions is a gross over-simplification. However, there is some value to presenting some of the most typical problems so that the thought process involved in solving the problems might be facilitated by seeing many different solution steps for a single problem. Therefore, some typical problems and some suggested solutions are given in Table 11.2.