



EXTRUSION **PROCESSING GUIDE**

Lubrizol

Engineered Polymers

EXTRUSION PROCESSING GUIDE

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INTRODUCTION

Demand is continuously expanding for specialty materials that have a combination of outstanding mechanical properties together with the capability of being converted on conventional thermoplastic processing equipment. Lubrizol's family of thermoplastic polyurethanes (TPUs) occupies a unique position of meeting this demand by providing a versatile range of grades from 70A Durometer to 77D Durometer that are being extruded commercially as wire and cable jacketing, hose jacketing, profiles, tubing, film & sheet, and fabric coatings. Lubrizol's portfolio of extrusion grade TPU includes Estane® TPU, Pearlthane™ TPU, and Pearlcoat™ TPU.

This bulletin is intended to provide general guidelines for equipment, procedures, and extrusion conditions that will help the customer obtain the best possible performance from Lubrizol's portfolio of extrusion grade TPUs. Additional information can be obtained by contacting your Lubrizol technical service or sales representative.

MATERIALS

Polyether-based polyurethanes are normally selected over polyester-based polyurethanes where end-use applications need hydrolytic stability, low temperature flexibility or fungal resistance. Although the polyether-based polyurethanes are inherently better in these characteristics, the hydrolytic stability and fungal resistance properties of polyester-based polyurethanes can be significantly improved by additive compounding.

BASIC GUIDELINES

Lubrizol TPUs must be properly dried before processing. Inadequate drying results in a loss of properties and may give a poor appearance. Extruder barrel and die temperatures must be set properly for each product. Deviation from Lubrizol's recommendations may result in poor extrusion quality. These recommendations can be found on the technical data sheet. The rate of extrusion has a large impact on the quality of the product and should be adjusted accordingly.

TPUs in general can be tacky during processing, so rollers should be coated with suitable nonstick materials. Many Lubrizol TPUs are already formulated to reduce blocking and tackiness. However, the addition of a lubricant masterbatch may be necessary to assure good processing. If a masterbatch or regrind/recycle are added to Lubrizol TPU, then these materials must also be properly dried and may have a significant impact on the quality of the product. Lubrizol TPUs do not draw down well compared to other thermoplastics like polyethylene, therefore, drawdown should be minimized in the process. It is not recommended to shut a line down on Lubrizol TPUs. Even during short breaks, material should be kept moving at slow rates through the system.

EQUIPMENT

Dehumidifying Hopper Dryer

It is imperative to dry the material immediately prior to extrusion. This includes all raw materials containing Lubrizol TPU. Best results are obtained with 0.02% or less moisture content.

Because of the relatively high consumption rate of an extruder, a good dehumidifying hopper drier is a preferred method for delivering consistently pre-dried and pre-heated material to the feed screw. The inlet air to the hopper should be checked at intervals for both dryness and temperature. For most extrusion grade TPU products, the hopper should be sized so that all of the feed has been subjected to a minimum of two hours of dehumidified, dried air at 220°F (105°C) for 2-3 hours. A device to measure actual moisture content of the resin is recommended since dryer malfunctions can occur. Refer to individual technical data sheets for specific drying recommendations.

Extruder

Most extruders are electrically heated with either band-type resistance heaters, cast-in block heaters or tubular resistance heaters wrapped around the barrel as seen in Figure 1. An efficient barrel cooling system is important to control the tendency for mechanical shear heat developed in the melt to override the electrical heater controls.

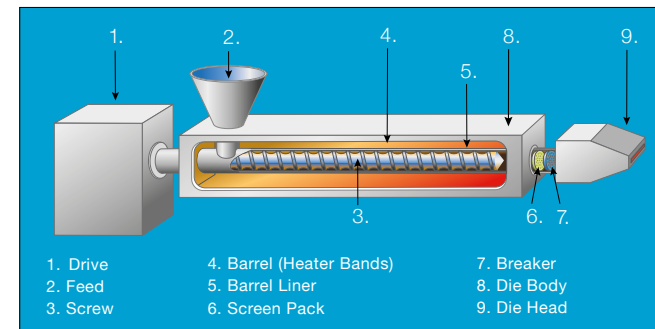


Figure 1: Extruder

The optimal extruder barrel length for Lubrizol TPUs is 30-32 times its internal diameter (30:1 L/D, 32:1 L/D). Although shorter barrels can be used, mixing efficiency and melt uniformity are not optimal. Cooling to the extruder feed throat is critical to prevent surging or bridging. Internal cooling to the screw is not needed.

Screw Design

Excellent quality product has been obtained consistently with screws having the following characteristics:

- Barrier screw construction
- Compression ratio of 3:1
- Long transition section (30-45% of screw length)
- Long metering section (30-45% of screw length)
- Hard-chrome, pinhole free, highly polished surface
- Clearance between screw and barrel liner of 0.003"-0.005"

A properly designed screw should melt and homogenize the Lubrizol TPU material completely and develop a melt temperature about 10°F below the recommended melt temperature. Barrier type screws will give the best quality output and several designs have been used successfully. A mixing section is also recommended at the end of the screw. The best performance seen has been with Saxton type mixers.

The design recommendations for a series of 30:1 screws are listed in **Table 1**. Proper maintenance of the screw will pay off in higher quality output, quicker start-ups, better output rates, and more reliable run-to-run performance consistency.

Breaker Plate & Screen

The primary function of the screen pack is to filter contaminants out of the plastic melt (e.g. paper, wood, metal, undispersed fillers, etc.). Screens should be constructed from stainless steel wire for strength and corrosion resistance. Normally a screen pack makeup of 20-40-80-20 mesh screens is optimal. However, some processes have used up to 200 mesh with good results. The breaker plate not only supports the screen pack, but also serves as a mechanical seal between the barrel and the adapter to the die. The holes in the breaker plate are normally 1/8" to 1/4" with a chamfer designed to give minimal obstruction to material flow.

Table 1

Suggested Screw Design for Extrusion of Lubrizol TPUs				
Extruder Size	1 1/2"	2 1/2"	3 1/2"	4 1/2"
Recommended Horse Power	25	50	100	200
L/D Ratio	30/1	30/1	30/1	30/1
Feed Section - number of flights	8	8	8	8
Feed Section - flight depth	0.270"	0.360"	0.450"	0.525"
Transition Section - number of flights	10	10	10	10
Metering Section - number of flights	9	9	9	9
Metering Section - flight depth	0.090"	0.120"	0.150"	0.175"
Mixer - number of flights	3	3	3	3
Compression Ratio	3.0:1	3.0:1	3.0:1	3.0:1
Cored for Temperature Control	No	No	No	No
Hard Chrome; Pinhole - Free; Polished	Yes	Yes	Yes	Yes

Dies & Take-Off Equipment

Die and take-up considerations are so specific to the type of processing that they will be discussed separately within the respective process sections of this bulletin. A few general guidelines are provided to minimize the drawdown and keep all flow channels streamlined with no dead spots.

COMMON EXTRUSION ISSUES

Bubbles or off gassing: Check the moisture level of the resin. If moisture is acceptable (less than 0.02%), then the melt may be too hot, so lower the temperatures.

Surging (pressure and power widely fluctuating):

Surging is rarely caused by the resin. Check the feed throat cooling and focus on extruder zone 1 for resolution. Slowing the rate down may help. The screw design may need to be modified to insure continuous feed.

Gels or contaminants: Make sure you are at the proper process conditions. Run hotter and slower if you can. Remove any additional components you are adding (regrind, masterbatch, etc.). Try a different lot of resin and if the problem is solved, contact your Lubrizol representative. Save a sample of the problem lot and a lot that worked on your process. Note that cloudy contaminants are a separate issue that should be reviewed with a Lubrizol representative.

Streaks or die lines: These are generally caused by build-up in the die or damage to the die. You will likely need to clean your die. Best results are obtained by shutting down on a non-TPU resin like polyethylene.

Sticking or blocking: Lubrizol TPUs are generally tacky. Insure that the proper formulation is being fed to the extruder. Check the coating on your rollers. A non-stick coating is required and can be damaged over time.

Non-uniform thickness in the machine direction: Check the extruder output for surging. If the output is stable, you may be experiencing draw resonance. Reduce the drawdown. If this is not possible, attempt to heat up the melt and die. It may be necessary to switch to a lower molecular weight lot.

Non-uniform thickness in the transverse direction: This is seldom a resin issue. Insure that the adjusting bolts are properly set. Check your system for build-up. Check for non-uniformity in cooling.

There is a detailed troubleshooting guide at the end of this Processing Guide.

CAST FILM AND SHEET EXTRUSION

Procedure: The process for extruding film and sheeting is illustrated in *Figure 2*. Lubrizol TPU pellets are compacted and melted in the extruder barrel. The high viscosity melted material is forced through a properly designed horizontal coat hanger die, cooled as the web is wrapped around the temperature-controlled polishing rolls and then rolled up as needed on storage reels.

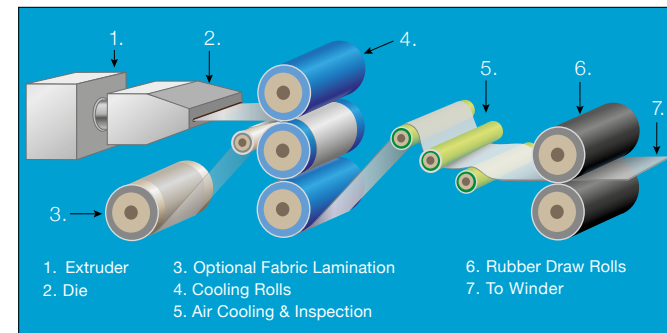


Figure 2: Film and Sheet Extrusion Line

By convention, all gauges of thermoplastic webs under 0.010" are called 'film', whereas gauges in excess of this thickness are called 'sheet'. Some grades of Lubrizol TPU will require the use of a release liner or the addition of lubricants to the formulation to insure blocking does not occur. Most grades can be converted into cast film or sheet.

Equipment

Dies: Generally, successful extrusion of film of is done through a flexible lip film die as in Figure 3, whereas heavier gauges up to 0.90" are extruded through a flexible lip sheet die with an adjustable restrictor bar as shown in *Figure 4*.

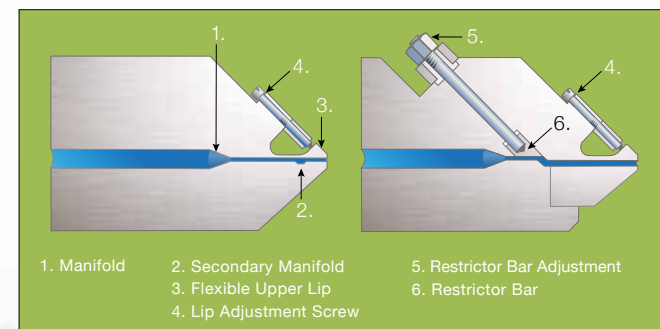


Figure 3: Flexible Lip Flat Film or Die Sheet

Figure 4: Flexible Lip Flat Film Sheet Die with Adjustable Restrictor Bar

Flat sheet dies are heated with electrical resistance cartridge heaters placed in holes drilled in areas carefully selected so as to avoid localized hot spots which would affect melt flow uniformity. It is important to keep the drawdown to a minimum. This should be 20 to 1 or less. If deckles are used, the internal flow channels should be streamlined so there is no stagnant TPU that would result in degradation.

EXTRUSION COATING

Procedure: The extrusion-coating process is illustrated in *Figure 5*. TPU pellets are compacted and fluxed in the extruder barrel (not shown but perpendicular to the place of the paper). The molten material is forced through a slit due downward between two rolls. The substrate is fed into the system between the molten plastic and the rubber pressure roll where the two materials are joined by controlled pressure between the rolls. The product is cooled by passing around the temperature-controlled metal rolls and then trimmed and wound on film wind-up equipment.

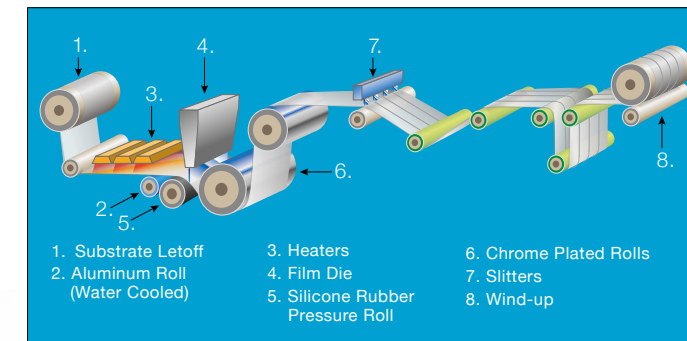


Figure 5: Extrusion Coating Line

Equipment

Dies: The die design that has been found to be most suitable for the flow characteristics of Lubrizol TPUs has a coat hanger flow pattern and tear drop cross-section as illustrated in *Figure 3*. A heated adapter tube carries the melted plastic from the extruded head to the opening in the center-fed die. For best results, the adapter tube and die should be carefully maintained at the same temperature.

The die is heated with electrical resistance cartridge heaters placed in holes drilled in placement areas selected to avoid localized hot spots, which would affect melt flow uniformity. The die lips are V-contoured to minimize the air gap between the die and the roll nip whenever necessary.

Pressure Roll: The uncoated substrate is led over the pressure roll where it meets the hot melt cascade flowing downward from the die. The pressure roll, activated by a pair of pneumatic or hydraulically loaded air cylinders, forces the substrate and the hot melt together in the roll nip as in *Figure 5*.

Adhesion and appearance can be controlled to a degree by using rubber pressure rolls of varying hardness. The pressure roll is usually cooled both by internal circulating high velocity water and by placing a water-cooled aluminum roll against the trailing edge of the pressure roll as a heat sink.

Chill Roll: The chill roll freezes the molten plastic to the substrate almost instantaneously, therefore it must have an adequate water cooling system. The controlled speed determines film thickness and overall coating efficiency, and its surface finish determines the texture of the coating. Commercial controllable line speeds can range from 30 feet/minute to 120 feet/minute.

Unwind & Rewind: Sophisticated tensioning, positioning and aligning devices are normally installed between the unwind and wind-up stations to ensure flat, smooth edged rolls at high production speeds. Flying splice equipment makes it possible to have long, continuous runs at high speeds.

Pre-heat: Preheating of the substrate is one of the methods of controlling adhesion of the coating. The preheating can be done with open flame, cal-rod heating banks, or preferably by passing the substrate over metal heating drums that can be controlled by internal electrical or pressure steam systems to temperatures approaching 350°F (177°C).

Adhesive Bonding: Many types of specialty urethane adhesives may be considered for bonding Lubrizol TPUs to various substrates. Specifically, Lubrizol offers its industry leading Pearlstick™ TPU for adhesives and Pearlbond™ TPUs for hot melt adhesives and adhesive films. For more information, check our web page: <https://go.lubrizol.com/AdhesiveSolutions>

Start-Up Conditions: With the extruder moved away from the threaded substrate coating line, the extrusion conditions are lined out and the die lip adjustments made to give a uniform melt at the desired output rate, die-lip opening and melt temperature. With chill roll temperatures of 80°F-100°F (27°C-38°C), preheating systems of 160°F-200°F (71°C-93°C) and the substrate moving at minimum speed, move the extrusion line into place and bring the coating line up to the predetermined line speed to deposit the required coating weight. Adjustments in preheated control, die-to-roll distance, and roll pressure can be made to modify substrate adhesion. Coating weight is usually controlled by adjusting line speed. Generally substrates are preheated to 160°F to 200°F for improved bonding.

BLOWN FILM

Procedure: The importance of drying has been covered in the preceding text on drying (see Equipment on page 2). Improper or insufficient drying can adversely affect both material properties and the extrusion process.

Blown TPU film can be made using most standard side and bottom-fed die types, **Figures 6 and 7**, both rotating and stationary. Rotating dies are preferable because of their ability to minimize gauge bands. In addition, conventional bubble-cooling methods and takeoff equipment used for other resins are suitable.

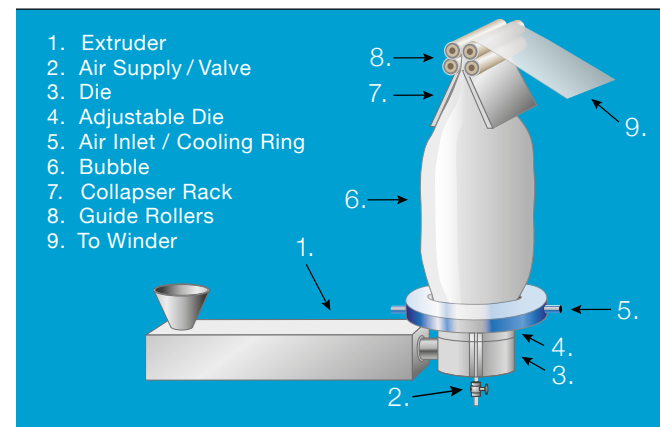


Figure 6: Extrusion of Blown Film

Polyurethane polymer containing no additives has a high coefficient of friction. Depending on the hardness, the film may be tacky and sticky. To avoid problems stemming from tackiness, use TPUs tailored to provide good release. Also, contact between the film and processing equipment should be kept to a minimum. It may be necessary to devise a technique for maintaining the separation between individual plies once the bubble is collapsed and the film trimmed. These might include the use of A-frames with TFE-coated slots and rubber coated rolls.

Depending on the product and thickness, it may be necessary to add a lubricant masterbatch to prevent blocking. Commercially available polyurethane masterbatches lend themselves well to blown TPU film. Polyurethane-based concentrates are preferable to vinyl or polyethylene based products. Not all Lubrizol TPU grades are suitable for blown film processing. Some grades lack suitable melt strength and some crystallize too fast. Refer to the technical data sheet or contact your Lubrizol representative to discuss the best process for a given grade.

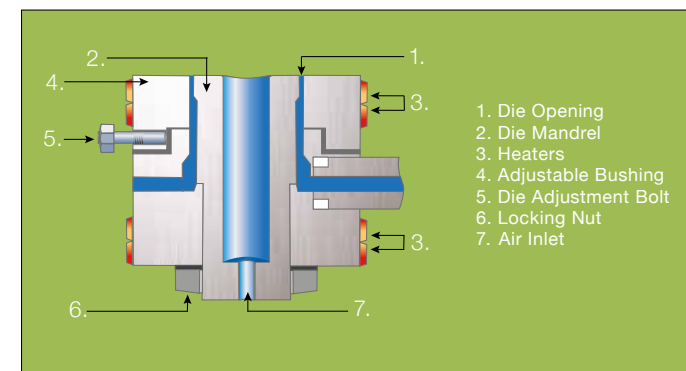


Figure 7: Blown Film Die

WIRE AND CABLE COATING, HOSE JACKETING

Procedure: The process of coating wire and cable by extrusion is diagrammed in **Figure 8**. TPU pellets are compacted and fluxed in the extruder barrel. The molten material is extruded in the crosshead at which point the direction of flow is changed 90°. It is in the crosshead that the wire, coming from the unwind and pre-heater, comes in contact with the molten TPU. The crosshead also holds the guide-tip and the wire die. The guide-tip keeps the wire centrally located in the molten insulation and the properly selected die controls the wall thickness of the final construction.

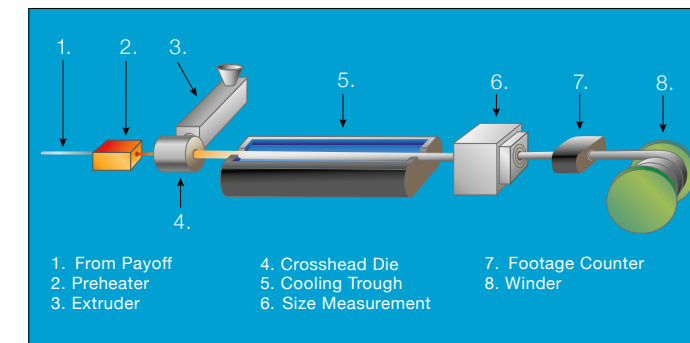


Figure 8: General Wire Coating Set-up

The driven capstan pulls the hot-coated wire through the water cooling trough and the high voltage spark tester. The choice of die opening, capstan speed, and screw RPM are all variables that determine the dimensions of the coated wire.

Equipment

Unwind: Very small single conductor running at high lineal velocities (4,000+ feet/minute) are paid off from stationary reels similar in action to that of a spinning reel used for fishing. Larger wires and multi-strand wires where even slight twisting during the unwind cannot be tolerated are normally paid-off from rotating reels. The payoff reels are usually installed in pairs so that as one reel is emptied the other can be hooked in by splicing on the fly without the need for lengthy shutdowns.

Pre-heater: Pre-heating of the conductor prevents stresses that may occur in the jacket due to premature chilling of hot plastic from the relatively cold conductor. In the case of small conductors, this can be accomplished by using a low voltage resistance applied between two properly insulated metallic rolls placed just before the bare wire goes into the crosshead. In larger diameter conductors, and for secondary jacketing operations, the pre-heating can be done with either a gas flame or water-cooled quartz pre-heater tunnels.

Dies: The two basic types of dies are 'pressure' dies and 'tubing' dies. In both types, the wire is led into the die opening through a guide-tip. In order to maintain concentricity, the clearance between the wire and the tip is minimal. In order to minimize the abrasion that occurs between the wire and the inside of the guide, the guide-tip is made from a very hard metal such as Carbaloy.

In the pressure die, **Figure 9**, the plastic is still under some pressure inside the die when it contacts the conductor. As the conductor emerges from the die, it is coated. The tubing die, **Figure 10**, extrudes plastic tubing concentrically around the emerging conductor.

The tubing is collapsed onto the conductor just after the die face by controlled vacuum drawn from behind the crosshead and through the same passage in which the conductor travels.

For best results, dies should be hard chrome plated.

Cooling Trough: All TPU covered wire is cooled by passing through a water trough. Sufficient immersion time is needed to allow cooling of the coated product without distortion of the jacketing.

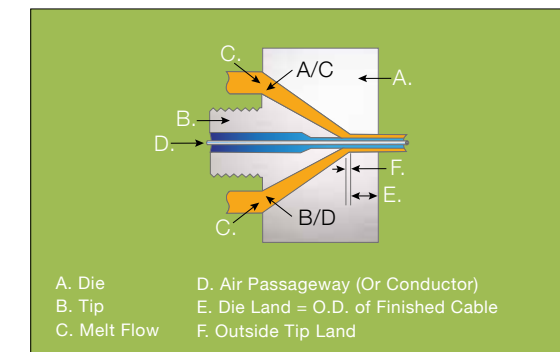


Figure 9: Tip and Die - Pressure Extrusion Over Water (Not to Scale)

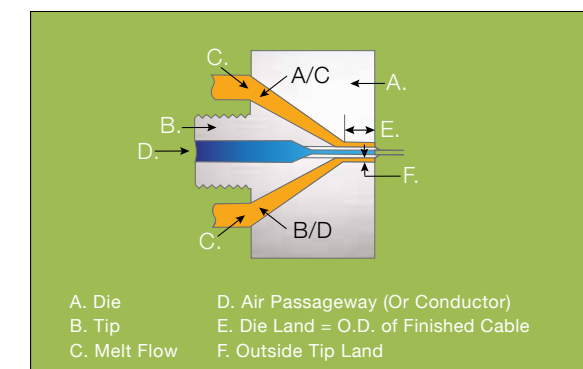


Figure 10: Tip and Die (Not to Scale)

Take-Up: The wire or small cable is pulled through the line by a capstan puller or, for large diameter cables, caterpillar capstans that are basically the same type of haul-off as rigid PVC pipe pullers. From the pulling capstan, the wire is then taken up on reels for storage.

TUBING AND PROFILE EXTRUSION

Procedure: The process for extruding profiles is shown schematically in *Figure 11*. Lubrizol TPUs with high melt strength are best suited for tubing and unsupported profile extrusions. TPU pellets are compacted and fluxed in the extruder barrel. The molten material is extruded in-line under pressure through a die opening designed to yield the required profile. The hot extrudate is immediately passed through a cold water trough where it develops sufficient strength to be pulled away from the die by a suitable take-up. After the take-up, the dimensioned profile is either cut to length or reeled as required.

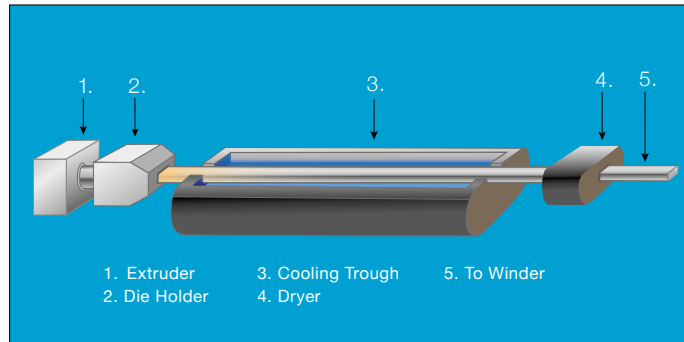


Figure 11: Profile Extrusion Line (Plain View)

Equipment

Dies: For best results, dies should be highly streamlined and well polished to prevent hang-up. Narrow flow channels minimize residence time and promote melt temperature homogeneity. Normally, a restrictor opening of 5/8" in the adapter will be satisfactory for 2 1/2" through 4 1/2" extruders. *Figure 12* represents a typical die for extruding tubing.

Dies should be made from fine grained tool steel, which will accept hardening without changing dimension. It is important to select a steel that will take and hold a good polish and one which is free from gas pockets.

The die should also be finished off with high quality, hard-chrome, pinhole-free plating.

Dies should be heated by electrical band heaters specifically shaped to give complete and close conformation to the outside die dimension. The die, adapter, breaker plate and front zone of the extruder should be maintained at the same temperature, preferably 10°F lower than the melt temperature. Die lands should be 3 - 5 times the dimension of the die opening; entrance angles to the land should be as small as practical for the special profile being considered, however, 30° - 60° is common. The die opening should be cut 20 - 30% oversize to accommodate the drawdown caused by the constant tension necessary to draw the molten material away from the hot die.

Cooling Trough & Take-Up: Profiles of Lubrizol TPUs are normally cooled by immersion in water, water-spray or a combination of the two. They are pulled through the cooling zones by means of pull rolls or a caterpillar take-off. Because of the soft nature of the polyurethane melt, mechanical sizing equipment such as a vacuum sizer or internally cooled mandrel are not normally used. In several instances, modified vacuum sizing systems, together with pre-cooling of the melt prior to entering the vacuum tank, have been used successfully to size tubing.

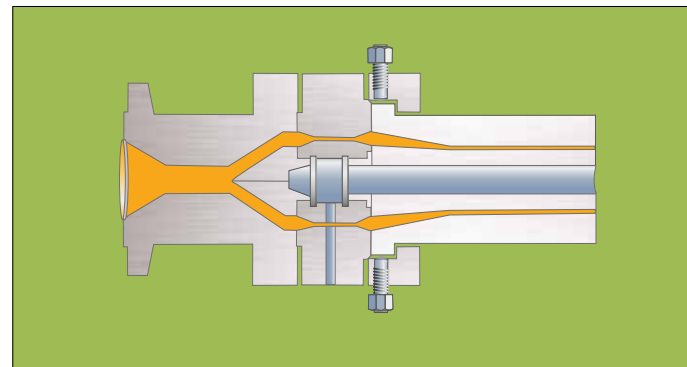


Figure 12: Tubing Die for Single Screw Extruder



TROUBLE SHOOTING GUIDE

Trouble Shooting Specific Extrusion Issues	
PROBLEM	POSSIBLE CAUSES
Tubing:	
1. Tubing dragging on sizing rings causing erratic size	Do not use sizing rings to control O.D. of TPU tubing on materials softer than 50-55D; tubing should be via 'free' extrusion with a vacuum chamber to maintain a roundness (using low vacuum or via internal air pressure)
2. "Droplets" or lumps appearing on O.D. (outside diameter) of tubing	Mandrel and/or die temperature too high Contamination
3. Tube is sagging between die and cooling trough	Melt temperature too high
4. Tubing is out of round	Melt temperature too high / internal air pressure may be needed / vacuum trough with low vacuum can be used Cooling bath too short Use non-blocking rolls to keep extrudate submerged in cooling bath.
Blown Film:	
1. Poor bubble strength	Melt temperature too high Line speed too fast Inadequate cooling Moisture content too high
2. Blocking	Nip rolls too low; nip roll pressure too high Melt temperature too high Line speed too fast Inadequate cooling Material requires additional slip agent Moisture content too high
Sheet Extrusion Cast Film:	
1. Lines perpendicular to flow direction	Material sticking to roll - decrease melt temperature, decrease roll temperature, slow down roller speed
2. Plate out on roll	Poor or non-uniform contact on chill roll Insufficient roll pressure Non-uniform gauge
3. Poor gloss or transparency	Increase melt temperature Increase cooling
4. Blocking	Line speed too high Melt temperature too high Material requires slip additive Top roll temperature too high

Extrusion Trouble Shooting Guide	
PROBLEM	POSSIBLE CAUSES
1. Surging	<ul style="list-style-type: none"> • High-moisture content • Die pressure too low • Rear barrel temperature too low/too high • Screw speed too fast • Die land too short • Die opening too large • Extruder drive belt slipping • Improper screw design • Voltage fluctuation • Temperature controller malfunction • Metering depth too deep or shallow • Warm-hot feed throat • Material bridging in feed throat
2. Bubbles (localized in sections, appearing sporadically)	<ul style="list-style-type: none"> • Localized hot spot in die • Material build-up in die • Improper screw design • Contamination in material
3. Bubbles uniformly distributed through extrudate	<ul style="list-style-type: none"> • High-moisture content • Melt temperature too high • Improper screw design (excessive shear) • Incompatible additive • Die temperature too high
4. Rough surface	<ul style="list-style-type: none"> • Improper screw design • Incompatible additive • Die temperature too low • Die not streamlined • Die land too long • High-moisture content • Melt temperature too low • Contamination • Excessive output • Regrind is not melt-compatible with virgin resin
5. Melt fracture	<ul style="list-style-type: none"> • Metering depth too shallow • Metering depth too deep • Feed insufficient • Die land too short

Extrusion Trouble Shooting Guide	
PROBLEM	POSSIBLE CAUSES
6. Blocking or tacky surface	<ul style="list-style-type: none"> • Melt temperature too high • Die temperature too high • Cooling take up too short • Output excessive • Cooling water or air too cold (polyether-type)
7. Flow lines	<ul style="list-style-type: none"> • Melt temperature too low • Improper screw design • Extruder output excessive • Die temperature too low • Poor mixing • Back pressure too low • Dirty extruder or die • Extruder surging
8. Die lines	<ul style="list-style-type: none"> • High-moisture content • Die temperature too hot, cold, or not uniform • Melt temperature too low • Material build-up in die
9. Bridging in feed zone	<ul style="list-style-type: none"> • Screw overheated • Rear zone temperature too high • Screw speed too low • Poor shut down procedure • Hopper dryer temperature too high
10. Carbon specks	<ul style="list-style-type: none"> • Dirty equipment • Improper resin handling • Extruder run dry at shut down and not cooled promptly
11. Poor gauge control	<ul style="list-style-type: none"> • Extruder surging • Takeoff variable • Temperature control inadequate • High-moisture content





LUBRIZOL GLOBAL PRESENCE

Our global presence means we have the application and development laboratories (with technical service ability) already in place, as well as worldwide production capabilities and renowned customer service. We are also a specialty producer of performance coatings and other unique products for apparel. Teaming with Lubrizol simplifies a complex global supply chain.

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